

TRANSFORMING THE NATION'S ELECTRICITY SYSTEM

THE SECOND INSTALLMENT OF THE QUADRENNIAL ENERGY REVIEW

January 2017

QUADRENNIAL ENERGY REVIEW

TRANSFORMING THE NATION'S ELECTRICITY SYSTEM: THE SECOND INSTALLMENT OF THE QER

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Preface

LY Wdzy$ нлмо∑ úK№2dz∃K úK$ t№$ăλŘ$yúΩă á/fλY l·ú$!Ŏúλ2Y tfl·y£ l·yŘ λY№$ăLJ2y~ã$ û2 l· нлмм №$Ŏ2YY$yŘl·ûλ2Y ōè úK$ t№$ăλŘ$yúΩă /2dzyŎλf 2Ŧ !ŘØλă2№ă 2Y {Ŏλ$yŎ$ l·yŘ ¢$ŎKy2f2∃è∑ t№$ăλŘ$yú hōl·Yl· λyλûλl·û$Ř l·ljdzl·Ř№$yYλl·f Ŏè$ôt$ 2Ŧ $yŎ$№∃è №$Ø$ă ûž LJ№2ØλŘ$ l· Ydzfûλπè$l·№ №2l·ŘYl·LJ Ŧ2№ ¦φ{φ $yŎ$№∃è LJ2fλŎèφ LY l· t№$ăλŘ$yûλl·f a$Y2№l·yŘdzY №$f$l·ă$Ř 2Y Wl·ydzl·№è φ∑ нлмп óă$$ LJl·∃$ λλλ Ŧ2№ Ŧdzff û$È$úû∑ t№$ăλŘ$yú hōl·Yl· Ř№$Ŏû$Ř Kλă !ŘYλyλăú№l·ûλ2Yû2 Ŏ2yŘdzŎû l· vdzl·Ř№$yYλl·f 9y$№∃è w$ØλŠø óv9wú,ᴹl·yŘ l·yY2dzyŎ$Ř ûK$ Ŧ2№Yl·ûλ2Y 2Ŧ l· ² KλûŠ l2dzăŠ ¢l·ă] C2№Ŏ$ τ Ŏ2πŎKl·№$Ř ōè ûK$ 5λ№$Ŏû2№ 2Ŧ ûK$ hŦŦλŎ$ 2Ŧ {Ŏλ$yŎ$ l·yŘ ¢$ŎKy2f2∃è t2fλŎè l·yŘ ûK$ {LJ$Ŏλl·f !ăăλăúl·yû û2 ûK$ t№$ăλŘ$yú Ŧ2№ 9y$№∃è l·yŘ /fλYl·û$ /Kl·y∃$ Ŧ№2Y ûK$ 52Y$ăúλŎ t2fλŎè /2dzyŎλf l·yŘ Ŏ2YLJ№ăλy∃ нн C$Ř$№l·f l·∃$yŎλ$à øλúK $ljdzλûλ$à λy yy№∃è τ û2 Ř$Ø$f2LJ ûK$ v9wφ ¢K$ ¢l·ă] C2№Ŏ$ λă Ř№$Ŏû$Ř û2 Ř$fλØ$№ l· №$LJ2№ú û2 ûK$ t№$ăλŘ$yú ûKl·ú Ř2$à ûK$ Ŧ2ff2øλy∃Y

- t№2ØλŘ$ă l·yλyú$∃№l·û$Ř ØλSø 2Ŧ∑ l·yŘ №$Ŏ2YY$yŘl·ûλ2yã Ŧ2№∑ C$Ř$№l·f y№∃è LJ2fλŎè λy ûK$ Ŏ2yú$È$ú 2Ŧ $Ŏ2y2YλŎ∑ $yØλ№2yYy$yúl·f∑ 2ŎŎdzLJl·ûλ2yl·f∑ ă$Ŏdz№λûè∑ l·yŘ K$l·fûK l·yŘ ăl·Ŧ$ûè LJ№λ2№λûλ$ă∑ øλúK l·ûú$yûλ2y λy ûK$ Ŧ∧№ăú №$LJ2№ú ∃λØ$y ûž ûK$ ŎKl·ffŝy∃$ă Ŧl·ŎλY∃ ûK$ bl·ûλ2yΩă y№∃è λyŦ№l·ăû№dzŎûdz№$ă
- w$ØλSøă ûK$ l·Ř$ljdzl·Ŏè 2Ŧ $ÈλăúλY∃ $È$Ŏdzúλ$ØŝS l·yŘ f$∃λătfl·ûλØ$ l·Ŏûλ2yã l·yŘ №$Ŏ2YY$yŘă l·ŘŘλûλ2yl·f $È$Ŏdzúλ$ØŝS l·yŘ f$∃λătfl·ûλØ$ l·Ŏûλ2yã l·ă l·LJL№2LJ№λl·û$
- !ăă$ăă$ă l·yŘ №$Ŏ2YY$yŘă LJ№λ2№λûλ$ă Ŧ2№ №$ă$l·№ŎK∑ Ř$Ø$f2LJY$yú∑ l·yŘ Ř$Y2yãû№l·ûλ2Y LJ№2∃№l·Yă û2 ădzLJLJ2№ú]$è y№∃è λyy2Øl·ûλ2Y∃2l·fă
- LŘ$yúλŦλ$ă l·yl·fèûλŎl·f û22fă l·yŘ Řl·úl· y$$Ř$Ř û2 ădzLJLJ2№ú Ŧdz№ûK$№ LJ2fλŎè Ř$Ø$f2LJY$yú l·yŘ λYLJf$Y$yúl·ûλ2yφ

¢K$ t№$ăλŘ$yú Ŧdz№ûK$№ Ř№$ŎûŝŘ ûK$ 5$LJl·№úY$yú 2Ŧ 9y$№∃è ó5h9ú û2 LJ№2ØλŘ$ l·yl·fèûλŎl·f ădzLJLJ2№ú Ŧ2№ ûK$ v9w l·yŘ û2 K$fLJ Yl·yl·∃$ ûK$ λyú$№l·∃$yŎè LJ№2Ô$ää ûK№2dz∃K l· ă$Ŏ№$ûl·№λl·ú l·ú 5h9φ ¢Kλă λă Ŏ2yãλăú$yú øλúK 5h9Ωă Yλăăλ2yã l·yŘ ăûl·ûdzú2№è №$ăLJ2yãλōλfûλ$ăφ 5h9 Kl·ă dzyŘ$№úl·ĵ$yLJ$№2ŘλŎ №$Ø$ø$ă l·yŘ l·yl·fèă$ă 2Ŧ ûK$ y№∃è ă$Ŏû2№ óλyŎfdzRλy∃ λyûK$ ábl·ûλ2yl·f 9y$№∃è {ú№l·û$∃èé 2Ŧ мффм l·yŘ ûK$ á/2YLJ№Ky$ăλØ$ 9y$№∃è {ú№l·û$∃èé 2Ŧ мффyú l·yŘ Ŏ2yú№λōdzú$Ř û2 ûK$ øž№] 2Ŧ ûK$ bl·ûλ2yl·f 9y$№∃è t2fλŎè 5$Ø$f2LJY$yú D№2dzLJ f$Ř ōè ûK$ ±λŎ$ t№$ăλŘ$yú λy нллм∑ ōdzú ûK$ fl·ăú yl·ûλ2yl·f y№∃è LJ2fλŎè №$LJ2№ú øl·ă LJdzōfλăK$Ř y$l·№fè мп è$l·№ă l·∃2∑ l·yŘ ûK$ ¦φ{φ y№∃è ăèăú$Y Kl·ă ŎKl·y∃$Ř Ø$№è ăλ∃yλŦλŎl·yúfè 2Ø$№ ûKl·ú LJ$№λ2Řφ ¢K$ t№$ăλŘ$yúλl·f a$Y2№l·yŘdzY 2y~ûK$ v9w l·Ŏ]y2øf$Ř∃$ă ûKl·ú ădzŎK l· №$Ø$ø$ă λă 2Ø$№Ř dz$ l·yŘ №$Ŏ2∃yλÎ$ă ûK$ Kλ∃K Øl·fdz$ 2Ŧ ûK$ ² Kλû$ l2dză$ l·ă ûK$ Ŏ2yØy№ 2Ŧ ădzŎK l·y~ $ŦŦ2№úφ Lú l·fã2 №$λy~Ŧ2№Ŏ$ă ûK$ $ljdzλûλ$à ûKl·ú Ydzfûλ LJf$ l·∃$yŎλ$ă Kl·Ø$ λy~C$Ř$№l·f y№∃è LJ2fλŎèφ

! ă Ř№$Ŏû$Ř ōè ûK$ t№$ăλŘ$yú∑ ûK$ v9w λă $yØλăλ2y$Ř l·ă l· Ŧ2ŎdzăŠŘ∑ l·Ŏûλ2yl·ōf$ Ř2ŎdzY$yú Ř$ăλ∃y$Ř û2 LJ№2ØλŘ$ LJ2fλŎèYl·]$№ă∑ λyŘdzăúλ№è∑ λyØ$ăú2№ă∑ l·yŘ 2ûK$№ ăûl·]$K2fŘ$№ă øλúK dzyōλl·ă$Ř Řl·úl· l·yŘ l·yl·fèăλă 2y~ y№∃è ŎKl·ffŝy∃$ă∑ y$$Řă∑ №$ljdz№$Y$yúă∑ l·yŘ ōl·№λ$№ă ûKl·ú øλff λyŦ2№Y l· №l·y$ 2Ŧ LJ2fλŎè 2LJúλ2yã∑ λyŎfdzŘλy∃ f$∃λătfl·ûλ2yφ 9l·ŎK λyãûl·ffY$yú 2Ŧ ûK$ v9w øλff l·yl·fèÎ$ l·yŘ Yl·]$ №$Ŏ2YY$yŘl·ûλ2yã Ŧ2№ l·]$è Ŏ2YLJ2y$yú 2Ŧ ûK$ y№∃è Øl·fdz$ ŎKl·λyφ

hy~ C$ō№dzl·№è π∑ нлмc∑ úK$ ¢l·ă] C2№Ŏ$ Ŏ2yØyŘ l· LJdzōfλŎ Y$$ûλy∃ û2 λyú№2Řdzŏ$ ûK$ û2LJλŎ 2Ŧ ûK$ ă$Ŏ2yŘ λyãûl·ffY$yú 2Ŧ ûK$ v9w óv9w мφнú∑ !y~ Ly û$∃№l·û$Ř {ûdzŘè 2Ŧ ûK$ ¦φ{φ 9f$Ŏúλ№Ŏλúè {èăû$Y$ᴴ ¢Kλă λyãûl·ffY$yú l·yl·fèÎ$ ű№$yŘă l·yŘ λăădz$ă Ŏ2yŦ№2yúλy∃ ûK$ bl·ûλ2yΩă fŎúλ№Ŏλúè ă$Ŏû2№ 2dzú û2 нлплπ∑ $ÈI·Yλyλy∃ ûK$ $yúλ№$ fŎúλ№Ŏλúè ădzLJLJfè ŎKl·λy~Ŧ№2Y ∃y№∃l·ûλ2y~û2 $yŘ dză$∑ l·yŘ øλúKλy~ûK$ Ŏ2yú$Èû 2Ŧ ûK№$Ŝ 2Ø$№∃l·№ŎKλy∃ yl·ûλ2yl·f ∃2l·fă û2Y óмú $yKl·yŎ$ $Ŏ2y2YλŎ Ŏ2YLJ$ûλûØyăăT óнú LJ№2Y2ű$ $yØλ№2yY$yúl·f №$ăLJ2yãλōλfûèT l·yŘ óoú LJ№2ØλŘ$ Ŧ2№ ûK$ bl·ûλ2yΩă ă$Ŏdz№λûèφ

[M] ¢KŜ ² KλΰŜ I ƻdzăŜΣ ϧ tNŜŜăλŘŜyΰλI·f a ŜY ƻNI·yŘdzY ππ 9ăΰI·ōfλăKλyƎ I· vdzI·ŘNŜyΎλI·f 9yŜNƎè wŜØλŜøΣϧ ¢KŜ ² KλΰŜ I ƻdzăŜΣ hŦŦλŎŜ ƻŦ ΰKŜ tNŜăă {ŜŎNŜΰI·NèΣ WI·yƀzI·Nè фΣ нлмпΣ KΰΰLJăYккøøøφøKλΰŜK ƻdzăŜφƎƻØκΰKŜπLJNŜăăπƻŦŦλŎŜкнлмпклмклфкLJNŜăλŘŜyΰλI·fπYŜY ƻNI·yŘdzYπ ŜăΰI·ōfλăKλyƎπIjdzI·ŘNŜyΎλI·fπŜyŜNƎèπNŜØλŜøφ

[H] vdzI·ŘNŜyΎλI·f 9yŜNƎè wŜØλŜøT bƻΰλŎŜ ƻŦ tdzōfλŎ a ŜŜΰλyƎΣ ум CŜŘφ wŜƎφ плнр óWI·yƀzI·Nè нрΣ нлмсύΣ KΰΰLJăYккøøøφŦŜŘŜNI·fNŜƎλăΰŜNφƎƻØκŘƻŎdzYŜyΰăкнлмсклмкнркнлмсплмотнкIjdzI·ŘNŜyΎλI·fπŜyŜNƎèπNŜØλŜøπyƻΰλŎŜπƻŦπLJdzōfλŎπ YŜŜΰλyƎKdzΰYψŎƻyΰŜyΰΓϧdzΰYψYŜŘλdzYΓŜYI·λfϧdzΰYψyI·YŜΓϧdzΰYψăƻdzNŎŜΓƎƻØŘŜfλØŜNèϧdzΰYψΰŜNYΓφ

Presidential Memorandum

The White House

WI·yƱzI·NŴè лфΣ нлмп

Presidential Memorandum -- Establishing a Quadrennial Energy Review

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!ŦŦ2NŘI·ōfŜΣ ŎfŜI·yΣ I·yŘ ăŜŎdzNŜ ŜyŜNƎè I·yŘ ŜyŜNƎè ăŜNØλŎŜă I·NŜ ŜăăŜyΰλI·f Ŧ2N λYLJN2ØλyƎ ¦φ{φ ŜŎ2y2YλŎ LJN2ŘdzŎΰΰλØλΰèΣ ŜyƘI·yŎλyƎ 2dzN IjdzI·fλΰè 2Ŧ fλŦŜΣ LJN2ΰŜŎΰΰλyƎ 2dzN ŜyØNN2yYˇŜyΰΣ I·yŘ Ŝyădz NλyƎ 2dzN bI·ΰλ2yΩă ăŜŎdzNλΰèφ !ŎKλŜØλyƎ ΰKŜăŜ Ǝ2I·fă NŜIjdzNNŜă I· Ŏ2YLJNŜKŜyăλØŜ I·yŘ λyΰŜƎNI·ΰŜŘ ŜyŜNƎè ăΰNI·ΰŜƎè NŜădzfΰλyƎ ŦN2Y λyΰŜNI·ƎŜyŎè ŘλI·f2ƎdzŜ I·yŘ I·ŎΰλØŜ ŜyƎI·ƎŜYˇŜyΰ 2Ŧ ŜÈΰŜNyI·f ăΰ!·ʅŜK2fŘŜNăφ ¢2 KŜfLJ ΰKŜ CŜŘŜNI·f D2ØŜNyYˇŜyΰ ōŜΰΰŜN YˇŜŜΰ ΰKλă NŜăLJ2yãλōλfλΰèΣ L I·Yˇ ŘNNŜŎΰλyƎ ΰKŜ dzyŘŜNΰI·ʅλyƎ 2Ŧ I· vdzI·ŘNŜyŷλI·f 9yŜNƎè wŜØλŜø øλff ōŜ 2dzN bI·ΰλ2yΩă λyŦNI·ăΰNdzŎΰdzNŜ Ŧ2N ΰNI·yãLJ2NΰλyƎΣ ΰNI·yãYˇλΰΰλyƎΣ I·yŘ ŘŜfλØŜNλyƎ ŜyŜNƎè φ hdzN ŎdzNNŜyΰ λyŦNI·ăΰNdzŎΰdzNŜ λă λyŎNŜI·ăλyƎfè ŎKI·ffŜyƎŜŘ ōè ΰNI·yãŦ2NYˇI·ΰλ2yã λyˇŜyŜNƎè ădzLJLJfèΣ YˇI·NʅŜΰăΣ I·yŘ LJI·ΰΰŜNyã 2Ŧ ŜyŘ dzăŜT λăădzŜă 2Ŧ I·ƎλyƎ I·yŘ ŎI·LJI·ŎλΰèT λYˇLJI·ŎΰăΣ 2Ŧ ŎfλYˇI·ΰŜ ŎKI·yƎŜT I·yŘ Ŏèōŝ I·yŘ LJKèăλŎI·f ΰKNŜI·ΰăφ !yè ØdzfyŜNI·ōλfλΰè λyˇ ΰKλă λyŦNI·ăΰNdzŎΰdzNŜ YˇI·è ōŜ ŜÈI·ŎŜNōI·ΰŜŘ ōè ΰKŜ λyŎNŜI·ăλyƎ λyΰŜNŘŜLJŜyŘŜyŎλŜă 2Ŧ ŜyŜNƎè ăèăΰŜYˇă øλΰK øI·ΰŜNΣ ΰŜfŜŎ2YˇYˇdzyλŎI·ΰλ2yãΣ ΰNI·yãLJ2NΰI·ΰλ2yΣ I·yŘ ŜYˇŜNƎŜyŎè NŜăLJ2yãŜ ăèăΰŜYˇăφ ¢KŜ ŦNNăΰ vdzI·ŘNŜyŷλI·f 9yŜNƎè wŜØλŜø wŜLJ2Nΰ øλff ăŜNØŜ I·ă I· N2I·ŘYˇI·LJ ΰ2 KŜfLJ I·ŘŘNŜăă ΰKŜăŜ ŎKI·ffŜyƎŜăφ

¢KŜ 5ŜLJI·NΰYˇŜyΰ 2Ŧ 9yŜNƎè KI·ă I· ōN2I·Ř N2fŜ λyˇ ŜyŜNƎè LJ2fλŎè ŘŜØŜf2LJYˇŜyΰ I·yŘ ΰKŜ fI·NƎŜăΰ N2fŜ λyˇ λYˇLJfŜYˇŜyΰλyƎ ΰKŜ CŜŘŜNI·f D2ØŜNyYˇŜyΰΩă ŜyŜNƎè NŜăŜI·NŎK I·yŘ ŘŜØŜf2LJYˇŜyΰ LJ2NΰŦ2fλ2φ a I·yè 2ΰKŜN ŜÈŜŎdzΰλØŜ ŘŜLJI·NΰYˇŜyΰă I·yŘ I·ƎŜyŎλŜă I·fă2 LJfI·è ʅŜè N2fŜă λyˇ ŘŜØŜf2LJλyƎ I·yŘ λYˇLJfŜYˇŜyΰλyƎ LJ2fλŎλŜă Ǝ2ØŜNyλyƎ ŜyŜNƎè NŜă2dzNŎŜă I·yŘ Ŏ2yãdzYˇLJΰλ2yΣ I·ă øŜff I·ă I·ăă2ŎλI·ΰŜŘ ŜyØNN2yYˇŜyΰI·f λYˇLJI·Ŏΰăφ LyˇI·ŘŘλΰλ2yΣ y2yπCŜŘŜNI·f I·Ŏΰ2Nă I·NŜ ŎNdzŎλI·f Ŏ2yΰNλōdzΰ2Nă ΰ2 ŜyŜNƎè LJ2fλŎλŜăφ .ŜŎI·dzăŜ Y2ăΰ ŜyŜNƎè I·yŘ NŜfI·ΰŜŘ λyFNI·ăΰNdzŎΰdzNŜ λă 2øyŜŘ ōè LJNλØI·ΰŜ ŜyΰλΰλŜăΣ λyØŜăΰYˇŜyΰ ōè I·yŘ ŜyƎI·ƎŜYˇŜyΰ 2Ŧ ΰKŜ LJNλØI·ΰŜ âŜŎΰ2N λă ySŎŜăăI·Nè ΰ2 ŘŜØŜf2LJ I·yŘ λYˇLJfŜYˇŜyΰ ŜŦŦŜŎΰλØŜ LJ2fλŎλŜăφ {ΰI·ΰŜ I·yŘ f2ŎI·f LJ2fλŎλŜăT ΰKŜ ØλŜøă 2Ŧ y2yƎ2ØŜNyYˇŜyΰI·fΣ ŜyØλN2yYˇŜyΰI·fΣ ŦI·λΰKπōI·ăŜŘΣ fI·ō2NΣ I·yŘ 2ΰKŜN ă2ŎλI·f 2N3I·yλÎI·ΰλ2yãT I·yŘ Ŏ2yΰNλōdzΰλ2yã FN2Y ΰKŜ I·ŎI·ŘŜYλŎ I·yŘ y2yπLJN2ŦλΰăŜŎΰ2Nă I·NŜ I·fă2 ŎNλΰλŎI·f ΰ2 ΰKŜ ŘŜØŜf2LJYˇŜyΰ I·yŘ λYˇLJfŜYˇŜyΰI·ΰλ2yˇ 2Ŧ ŜŦŦŜŎΰλØŜ ŜyŜNƎè LJ2fλŎλŜăφ

!yˇ λyΰŜNI·ƎŜyŎè vdzI·ŘNŜyŷλI·f 9yŜNƎè wŜØλŜø ¢I·ăʅ C2NŎŜΣ øKλŎK λyŎftdzŘŜă YŜYōŜNă FN2Y I·ff NŜfŜØI·yΰ ŜÈŜŎdzΰλØŜ ŘŜLJI·NΰYˇŜyΰă I·yŘ I·ƎŜyŎλŜă óI·ƎŜyŎλŜăΰΣ øλff ŘŜØŜf2LJ I·yˇλyΰŜƎNI·ΰŜŘ NŜØλŜø 2Ŧ ŜyŜNƎè LJ2fλŎè ΰKI·ΰ λyΰŜƎNI·ΰŜă I·ff 2Ŧ ΰKŜăŜ LJŜNăLJŜŎΰλØŜăφ Lΰ øλff ōdzλfŘ 2yˇ ΰKŜ Ŧ2dzyŘI·ΰλ2yˇ LJN2ØλŘŜŘ λyˇ Yè !ŘYˇλyλăΰNI·ΰλ2yΩă .fdzŜLJNλyΰ Ŧ2N I· {ŜŎdzNŜ 9yŜNƎè CdzΰdzNŜ 2Ŧ aI·NŎK olΣ нлммΣ I·yŘ /fλYˇI·ΰŜ !Ŏΰλ2yˇ tfI·yˇNŜfŜI·ăŜŘ 2yˇWdzyŜ нpΣ нлмоφ ¢KŜ ¢I·ăʅ C2NŎŜ øλff 2ŦŦŜN NŜŎ2YˇYˇŜyŘI·ΰλ2yã 2yˇ øKI·ΰ I·ŘŘλΰλ2yI·f I·Ŏΰλ2yã λΰ ōŜfλŜØŜă ø2dzfŘ ōŜ I·LJLJN2LJNλI·ΰŜφ ¢KŜăŜ YˇI·è λyŎfdzŘŜ NŜŎ2YˇYˇŜyŘI·ΰλ2yã 2yˇI·ŘŘλΰλ2yI·f ŜÈŜŎdzΰλØŜ 2N fŜƎλăfI·ΰλØŜ I·Ŏΰλ2yã ΰ2 I·ŘŘNŜăă ΰKŜ ŜyŜNƎè ŎKI·ffŜyƎŜă I·yŘ 2LJLJ2NΰdzyλΰλŜă ŦI·ŎλyƎ ΰKŜ bI·ΰλ2yφ

¢KŜNŜŦ2NŜΣ ōè ΰKŜ I·dzΰK2NλΰèØŜăΰŜŘ λyˇYˇŜ I·ă tNŜăλŘŜyΰ ōè ΰKŜ /2yãΰλΰdzΰλ2yˇI·yŘ ΰKŜ fI·øă 2Ŧ ΰKŜ ¦yΰŜŘ {ΰI·ΰŜă 2Ŧ !YˇŜNλŎI·Σ L KŜNŜōè ŘNNŜŎΰ ΰKŜ Ŧ2ff2øλyƎY

Section 1. Establishing the Quadrennial Energy Review Task Force.

ó Ù ¢ KS W Ã Ša Ù Ø f Ã K Ř Ú K v dz Ø Ř W Š y Y Ã Ø f 9y Š W Ã è wŠØ Ã Š ø ¢ Ø ă] C2 W Ö Š ó ¢ Ø ă] C2 W Ö Š ú 2 ō Š Ö2 π Õ K Ø · Ã W Š Ř ō è ú K Š 5 Ã W Š Ö ú 2 W 2 ŧ ú K Š h ŦŦ Ã Ö Š 2 ŧ { Ö Ã Š y Ö Š Ø · y Ř ¢ Š Ö K y 2 f 2 Ǝ è t 2 f Ã Ô è Ø · y Ř ú K Š 5 Ã W Š Ö ú 2 W 2 ŧ ú K Š 5 2 Y Š ă ú Ã Ô t 2 f Ã Ô è / 2 dz y Ö Ã f Σ ø K Ã Ö K ă K Ø · ff Ã y Ö f dz Ř Š ú K Š K Š Ø · Ř ă 2 ŧ Š Ø · Ö K 2 ŧ ú K Š Ŧ 2 ff 2 ø Ã y Ǝ Σ 2 W ű K Š Ã W ŘŠ ă Ã Ǝ y Ø · ú Š Ř W Š L J W Š ă Š y ú Ø · ú Ã Ø Š ă Y

ó Ã ú ű K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ { ű Ø · ú Š T

ó Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ ú K Š ¢ W Š Ø · ă dz W è T

ó Ã Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ 5 Š Ŧ Š y ã Š T

ó Ã Ø ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ ú K Š L y ú Š W Ã 2 W T

ó Ø ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ ! Ǝ W Ã Ö dz f ú dz W Š T

ó Ø Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ / 2 Y Y Š W Ö Š T

ó Ø Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ [Ø · ō 2 W T

ó Ø Ã Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ Ø Š Ø · f ú K Ø · y Ř Ø dz Y Ø · y ´ { Š W Ø Ã Ö Š ă T

ó Ã È ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ Ø 2 dz ă Ã y Ǝ Ø · y Ř ¦ W ō Ø · y ´ 5 Š Ø Š f 2 L J Y Š y ú T

ó È ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ ¢ W Ø · y ã L J 2 W ú Ø · ú Ã 2 y T

ó È Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ 9y Š W Ǝ è T

ó È Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ ± Š ú Š W Ø · y ã ! ŦŦ Ø · Ã W ă T

ó È Ã Ã Ã ú ú K Š 5 Š L J Ø · W ú Y Š y ú 2 ŧ Ø 2 Y Š f Ø · y Ř { Š Ö dz W Ã ú è T

ó È Ã Ø ú ú K Š h ŦŦ Ã Ö Š 2 ŧ a Ø · y Ø · Ǝ Š Y Š y ú Ø · y Ř . dz Ř Ǝ Š ú T

ó È Ø ú ú K Š b Ø · ú Ã 2 y Ø · f 9 Ö 2 y 2 Y ´ Ã Ô / 2 dz y Ö Ã f T

ó È Ø Ã ú ú K Š b Ø · ú Ã 2 y Ø · f { Š Ö dz W Ã ú è { ű Ø · Ŧ Ŧ T

ó È Ø Ã Ã ú ú K Š / 2 dz y Ö Ã f 2 y ´ 9y Ø Ã W 2 y Y ´ Š y ú Ø · f v dz Ø · f Ã ú è T

ó È Ø Ã Ã Ã ú ú K Š / 2 dz y Ö Ã f 2 ŧ 9 Ö 2 y 2 Y ´ Ã Ô ! Ř Ø Ã ă Š W Ã T

ó È Ã È ú ú K Š 9y Ø Ã W 2 y Y ´ Š y ú Ø · f t W 2 ú Š Ö ú Ã 2 y ´ ! Ǝ Š y Ö è T

ó È È ú ú K Š { Y Ø · ff . dz ă Ã y Š ă ă ! Ř Y ´ Ã y Ã ă ú W Ø · ú Ã 2 y T

ó È È Ã ú ú K Š ! W Y ´ è / 2 W L J ă 2 ŧ 9y Ǝ Ã y Š Š W Ã T

ó È È Ã Ã ú ú K Š b Ø · ú Ã 2 y Ø · f { Ö Ã Š y Ö Š C2 dz y Ř Ø · ú Ã 2 y T Ø · y Ř

ó È È Ã Ã Ã ú ú ă dz Ö K Ø · Ǝ Š y Ö Ã Š ă Ø · y Ř 2 ŦŦ Ã Ö Š ă Ø · ă ú K Š t W Š ă Ã Ř Š y ú Y Ø · è Ř Š ă Ã Ǝ y Ø · ú Š ø

ó ō ú ¢ K Š / 2 π / K Ø · Ã W ă Y Ø · è Ã y Ø Ã ú Š Ã y Ř Š L J Š y Ř Š y ú W Š Ǝ dz f Ø · ú 2 W è Ø · Ǝ Š y Ö Ã Š ă ø Ã ú K Š y Š W Ǝ è π W Š f Ø · ú Š Ř W Š ă L J 2 y ã Ã ō Ã f ú Ã Š ă Σ Ã y Ö f dz Ř Ã y Ǝ ú K Š C Š Ř Š W Ø · f 9y Š W Ǝ è w Š Ǝ dz f Ø · ú 2 W è / 2 Y Y ´ Ã ă Ã 2 y ´ Ø · y Ř ú K Š b dz Ö f Š Ø · W w Š Ǝ dz f Ø · ú 2 W è / 2 Y Y ´ Ã ă Ã 2 y Σ ú 2 L J Ø · W ú Ã Ö Ã L J Ø · ú Š Ã y ´ ú K Š ¢ Ø · ă] C2 W Ö Š Σ Ø · ă Ř Š ú Š W Y ´ Ã y Š Ř ú 2 ō Š Ø · L J L J W N 2 L J W Ã Ø · ú Š ō è ú K 2 ă Š Ø · Ǝ Š y Ö Ã Š ă ø

ó Ö ú ¢ K Š / 2 π / K Ø · Ã W ă ă K Ø · ff W Š Ǝ dz f Ø · W f è Ö 2 y Ø Š y Š Ø · y Ř L J W Š Ã Ř Š Ø · ú Y Š Š ú Ã y Ǝ ă 2 ŧ ú K Š ¢ Ø · ă] C2 W Ö Š Ø · y Ř ă K Ø · ff Ř Š ú Š W Y ´ Ã y Š Ã ú ă Ø · Ǝ Š y Ř Ø · ø ¦ y Ř Š W ú K Š Ř Ã W Š Ö ú Ã 2 y ´ 2 ŧ ú K Š / 2 π / K Ø · Ã W ă Σ ú K Š ¢ Ø · ă] C2 W Ö Š ă K Ø · ff Y

ó Ã ú Ǝ Ø · ú K Š W Ã Ř Š Ø · ă Ø · y Ř Ø · Ř Ø Ã Ö Š Ŧ W 2 Y ´ {ú Ø · ú Š Ø · y Ř f 2 Ö Ø · f Ǝ 2 Ø Š W y Y ´ Š y ú ă Σ ú W Ã ō Š ă Σ f Ø · W Ǝ Š Ø · y Ř ă Y ´ Ø · ff ō dz ă Ã y Š ă ă Š ă Σ dz y Ã Ø Š W ă Ã ú Ã Š ă Σ y Ø · ú Ã 2 y Ø · f f Ø · ō 2 W Ø · ú 2 W Ã Š ă Σ y 2 y Ǝ 2 Ø Š W y Y ´ Š y ú Ø · f Ø · y Ř f Ø · ō 2 W 2 W Ǝ Ø · y Î Ø · ú Ã 2 y ã Σ Ö 2 y ã dz Y ´ Š W ă Σ Ø · y Ř 2 ú K Š W ă ú Ø ·] Š K 2 f Ř Š W ä Ø · y Ř Ã y ú Š W Š ă ú Š Ř L J Ø · W ú Ã Š ă T Ø · y Ř

óλλú Ò22ℕŘλy1·ΰŜ ΰKŜ ŜŦŦ2ℕΰă 2Ŧ I·ƎŜyÒλŜă I·yŘ 2ŦŦλÒŜă ℕŜfI·ΰŜŘ ΰ2 ΰKŜ ŘŜØŜf2LJY^Ŝyΰ 2Ŧ ΰKŜ vdzI·ŘℕŜyŷλI·f 9yŜℕƎè wŜØλŜø wŜLJ2ℕΰΣ I·ă ŘŜăÒℕλōŜŘ λy^ăŜÒΰλ2yã м I·yŘ н 2Ŧ ΰKλă Y^ŜY^2ℕJI·yŘdzY^Φ

óŘú ¢KŜ {ŜÒℕΩŜΰI·ℕè 2Ŧ 9yŜℕΩƎè ăKI·ff LJℕ2ØλŘŜ ădzLJLJ2ℕΰ ΰ2 ΰKŜ ¢I·ă] C2ℕÒŜΣ λyÒfdzŘλyƎ ădzLJLJ2ℕΰ Ŧ2ℕ Ò22ℕŘλy1·ΰλ2y^ I·ÒΰλØλΰλŜă ℕŜfI·ΰŜŘ ΰ2 ΰKŜ LJℕŜLJI·ℕJI·ΰλ2y^ 2Ŧ ΰKŜ vdzI·ŘℕŜyŷλI·f 9yŜℕƎè wŜØλŜø wŜLJ2ℕΰΣ LJ2fλÒè I·yI·fèăλă I·yŘ Y^2ŘŜfλyƎΣ I·yŘ ăúI·]ŜK2fŘŜℕ ŜyƎI·ƎŜY^Ŝyΰ Φ

óŜú ¢KŜ ¢I·ă] C2ℕÒŜ ăKI·ff ădzŌY^λΰ I· vdzI·ŘℕŜyŷλI·f 9yŜℕƎè wŜØλŜø wŜLJ2ℕΰ ΰ2 ΰKŜ tℕŜăλŘŜyΰ ŜØŜℕè π èŜI·ℕă ŌŜƎλyŷλyƎ øλΰK I· ℕŜLJ2ℕΰ ŘŜfλØŜℕŜŘ ōè WI·ydzI·ℕè oмΣ нлмрΦ LyΰŜℕY^ŜŘλI·ΰŜ ℕŜLJ2ℕΰă I·yŘ 2ΰKŜℕ Y^I·ΰŜℕλI·f Y^I·è ŌŜ LJℕŜLJI·ℕŜŘ ōè ΰKŜ ¢I·ă] C2ℕÒŜ I·ă ℕŜIjdzλℕŜŘ ōè ΰKŜ tℕŜăλŘŜyΰΦ

Sec. 2. The Quadrennial Energy Review Report.

¢KŜ ¢I·ă] C2ℕÒŜ ăKI·ff Ŝăΰ I·ōfλăK λyΰŜƎℕI·ΰŜŘ ƎdzλŘI·yÒŜ ΰ2 ăΰℕŜyƎΰKŜy^ ¦Φ{Φ ŜyŜℕƎè LJ2fλÒèΦ .dzλfŘλyƎ 2y^ ΰKŜ .fdzŜLJℕλyΰ Ŧ2ℕ I· {ŜÒdzℕŜ 9yŜℕƎè Cdzΰdzℕ Ŝ I·yŘ ΰKŜ /fλY^I·ΰŜ !Òΰλ2y^ tfI·yΣ I·yŘ ΰI·]λyƎ λyΰ2 Ò2yãλŘŜℕI·ΰλ2y^I·LJLJfλÒI·ōfŜ fI·øă I·yŘ ℕŜƎdzfI·ΰλ2yãΣ ΰKŜ ¢I·ă] C2ℕÒŜ ăKI·ff LJℕŜLJI·ℕŜ I· vdzI·ŘℕŜyŷλI·f 9yŜℕƎè wŜØλŜø wŜLJ2ℕΰ ΰKI·ΰY

óI·ú LJℕ2ØλŘŜă I·y^ λyΰŜƎℕI·ΰŜŘ ØλŜø 2ŦΣ I·yŘ ℕŜÒ2Y^Y^ŜyŘI·ΰλ2yã Ŧ2ℕΣ CŜŘŜℕI·f ŜyŜℕƎè LJ2fλÒè λy^ ΰKŜ Ò2yΰŜ̈ΰ 2Ŧ ŜÒ2y2Y^λÒΣ ŜyØλℕ2yY^Ŝyΰ I·fΣ 2ÒÒdzLJI·ΰλ2y1·fΣ ăŜÒdzℕλΰ̈èΣ I·yŘ KŜI·fΰK I·yŘ ăI·ŦŜΰè LJℕλ2ℕλΰλŜăΣ øλΰK I·ΰΰŜyΰλ2y^ λy^ ΰKŜ Ŧλℕăΰ ℕŜLJ2ℕΰ ƎλØŜy^ΰ2 ΰKŜ ÒKI·ffŜyƎŜă ŦI·ÒλyƎ ΰKŜ bI·ΰλ2yΩă ŜyŜℕƎè λyŦℕI·ăΰℕdzÒΰdzℕŜăT

óŌú ℕŜØλŜøă ΰKŜ I·ŘŜIjdzI·ÒèΣ øλΰK ℕŜăLJŜÒΰ ΰ2 ŜyŜℕƎè LJ2fλÒèΣ 2Ŧ ŜÈλăΰλy3 ŜÈŜÒdzΰλØŜ I·yŘ fŜƎλăfI·ΰλØŜ I·Òΰλ2yãΣ I·yŘ ℕŜÒ2Y^Y^ŜyŘă I·ŘŘλΰλ2y1·f ŜÈŜÒdzΰλØŜ I·yŘ fŜƎλăfI·ΰλØŜ I·Òΰλ2yã I·ă I·LJLJℕ2LJℕλI·ΰŜT

óÒú I·ăăŜăăŜă I·yŘ ℕŜÒ2Y^Y^ŜyŘă LJℕλ2ℕλΰλŜă Ŧ2ℕ ℕŜăŜI·ℕÒKΣ ŘŜØŜf2LJY^ŜyΰΣ I·yŘ ŘŜY^2yãΰℕI·ΰλ2y^ LJℕ2ƎℕI·Yă ΰ2 ădzLJLJ2ℕΰ]Ŝè ŜyŜℕƎèπλyŷ2ØI·ΰλ2y^Ǝ2I·făT I·yŘ

óŘú λŘŜyΰλŦλŜă I·y1·fèΰλÒI·f ΰ22fă I·yŘ ŘI·ΰI· yŜŜŘŜŘ ΰ2 ădzLJLJ2ℕΰ ŦdzℕΰKŜℕ LJ2fλÒè ŘŜØŜf2LJY^ŜyΰΣ I·yŘ λY^LJfŜY^ŜyΰI·ΰλ2yΦ

Sec. 3. Outreach.

Ly^ 2ℕŘŜℕ ΰ2 ƎI·ΰKŜℕ λyŦ2ℕY^I·ΰλ2y^ I·yŘ ℕŜÒ2Y^Y^ŜyŘI·ΰλ2yã I·yŘ ΰ2 LJℕ2ØλŘŜ Ŧ2ℕ I· ΰℕI·yãLJI·ℕŜyΰ LJℕ2ÒŜăă λy^ ŘŜØŜf2LJλyƎ ΰKŜ vdzI·ŘℕŜyŷλI·f 9yŜℕƎè wŜØλŜø wŜLJ2ℕΰΣ ΰKŜ ¢I·ă] C2ℕÒŜ ăKI·ff ŜyƎI·ƎŜ øλΰK {ΰI·ΰŜ I·yŘ f2ÒI·f Ǝ2ØŜℕyY^ŜyΰΣ ΰℕλōŜΣ fI·ℕƎŜ I·yŘ ăY^I·ff ōdzλyŜăăŜΣ dzyλØŜℕăλΰλŜΣ y1·ΰλ2y1·f fI·ō2ℕI·ΰ2ℕλŜΣ y2y3Ǝ2ØŜℕyY^ŜyΰI·f I·yŘ fI·ō2ℕ 2ℕƎI·yλÎI·ΰλ2yãΣ I·yŘ 2ΰKŜℕ ăΰI·]ŜK2fŘŜℕă I·yŘ λyΰŜℕΩŜΰŜŘ LJI·ℕΰλŜă¢KŜ ¢I·ă] C2ℕÒŜ ăKI·ff ŘŜØŜf2LJ I·y^ λyΰŜƎℕI·ΰŜŘ 2dzΰℕΩŜI·ÒK ăΰℕI·ΰŜƎè ΰKI·ΰ ℕŜfλŜă 2y^ ō2ΰK ΰℕI·Řλΰλ2y1·f Y^ŜŜΰλyƎă I·yŘ ΰKŜ dzăŜ 2Ŧ λyŦ2ℕY^I·ΰλ2y^ ΰŜÒKy2f2Ǝè Φ

Sec. 4. General Provisions.

óI·ú ¢Kλă Y^ŜY^2ℕJI·yŘdzY^ ăKI·ff ōŜ λY^LJfŜY^ŜyΰŜŘ Ò2yãλăΰŜyΰ øλΰK I·LJLJfλÒI·ōfŜ fI·ø I·yŘ ădzō?ŜÒΰ ΰ2 ΰKŜ I·ØI·λfI·ōλfλΰûè 2Ŧ I·LJLJℕ2LJℕλI·ΰλ2yãΦ

óŌú b2ΰKλyƎ λy^ ΰKλă Y^ŜY^2ℕJI·yŘdzY^ ăKI·ff ōŜ Ò2yãΰℕdzŜŘ ΰ2 λY^LJI·λℕ 2ℕ 2ΰKŜℕØλăŜ I·ŦŦŜÒΰY

óλú ΰKŜ I·dzΰK2ℕλΰè ƎℕI·yΰŜŘ ōè fI·ø ΰ2 I·yê I·ƎŜyÒèΣ 2ℕ ΰKŜ KŜI·Ř ΰKŜℕΩŜ2ŦT 2ℕ

óλú ΰKŜ Ŧdzyÿΰλ2yã 2Ŧ ΰKŜ 5λℕŜÒΰ2ℕ 2Ŧ ΰKŜ hŦŦλÒŜ 2Ŧ a I·y1·ƎŜY^Ŝyΰ I·yŘ .dzŘƎŜΰ ℕŜfI·ΰλyƎ ΰ2 ōdzŘƎŜΰI·ℕèΣ I·ŘY^λyλăΰℕI·ΰλØŜΣ 2ℕ fŜƎλăfI·ΰλØŜ LJℕ2LJ2ăI·fãΦ

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Transforming the Nation's Electricity System:

The Second Installment of the Quadrennial Energy Review

Summary for Policymakers

The second installment of the Quadrennial Energy Review (QER 1.2) focuses on the electricity system and its role as the enabler for accomplishing three key national goals: improving the economy, protecting the environment, and increasing national security. As a critical and essential national asset, it is a strategic imperative to protect and enhance the value of the electricity system through modernization and transformation. Reliable and affordable electricity provides essential energy services for consumers, business, and national defense.

The electricity system we have today was developed over more than a century and includes thousands of generating plants, hundreds of thousands of miles of transmission lines, distribution systems serving hundreds of millions of customers, a growing number of distributed energy resources, and billions of end-use devices and appliances. These elements are connected together to form a complex system of systems. The electricity sector is, however, confronting a complex set of changes and challenges, including: aging infrastructure; a changing generation mix; growing penetration of variable generation; low and in some cases negative load growth; climate change; increased physical and cybersecurity risks; and in some regions widespread adoption of distributed energy resources (DER). How these changes are managed is critical and could fundamentally transform the electricity system's structure, operations, customer base, and jurisdictional framework.

QER 1.2 analyzes trends and issues confronting the Nation's electricity sector out to 2040, examining the entire electricity supply chain from generation to end use, and within the context of three overarching national goals to: (1) enhance economic competitiveness; (2) promote environmental responsibility; and (3) provide for the nation's security. The report builds on analysis and recommendations in the first installment of the QER (QER 1.1) on improving energy transmission, distribution, and storage infrastructures, and provides recommendations that must be implemented to optimize and modernize the electricity sector.

Scope and Structure of the Second Installment of the QER

In 2013, President Obama directed the Administration to conduct an interagency QER in order to "establish integrated guidance to strengthen U.S. energy policy". The first installment of the QER (QER 1.1), published in April 2015, focused "on infrastructure challenges, and identified the threats, risks, and opportunities for U.S. energy and climate security, enabling the Federal Government to translate policy goals into a set of analytically based, clearly articulated, sequenced and integrated actions, and proposed investments."

QER 1.2 analyzes trends and issues confronting the Nation's electricity sector, examining the entire electricity supply chain from generation to end use. It builds on analysis and recommendations in QER 1.1, which included electricity as part of an examination of energy transmission, distribution, and storage infrastructures. The scope of QER 1.2 includes generation, transmission, distribution, and end-use application in the electricity sector. It does not explore other energy-related sectors, except where they directly affect the electricity system, such as the critical role of natural gas supply in generation and reliability.

Figure S-1. Organization/Areas of Focus in QER. 1.2

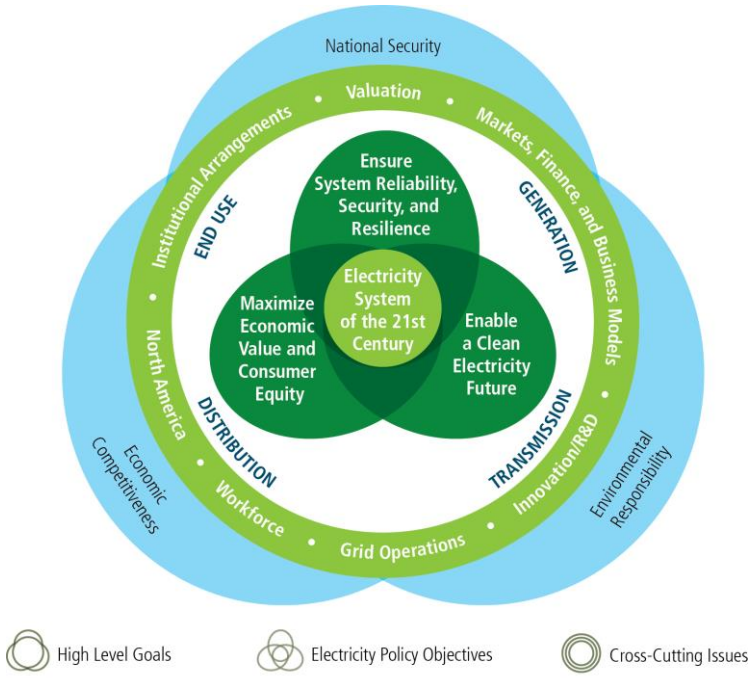


Figure S-1. A comprehensive set of interactions and overlapping objectives and goals must be analyzed to inform policies that will enable the electricity sector of the 21st century. Analysis in QER 1.2 is organized around a set of national goals, integrated objectives, and cross-cutting issues.

This summary follows the organization of the main report, starting with an introduction to electricity generation issues and the changing context, corresponding to the first chapter of the main report. The summary then highlights key findings based on deep analysis from several sections on the integrated objectives of the report.

This summary also includes brief summaries of select recommendations to modernize and transform the electricity sector. Specific descriptions of and rationale for the 76 QER recommendations are in the 21st Century Electricity System chapter. The QER also includes an Appendix with an Electricity System Overview.

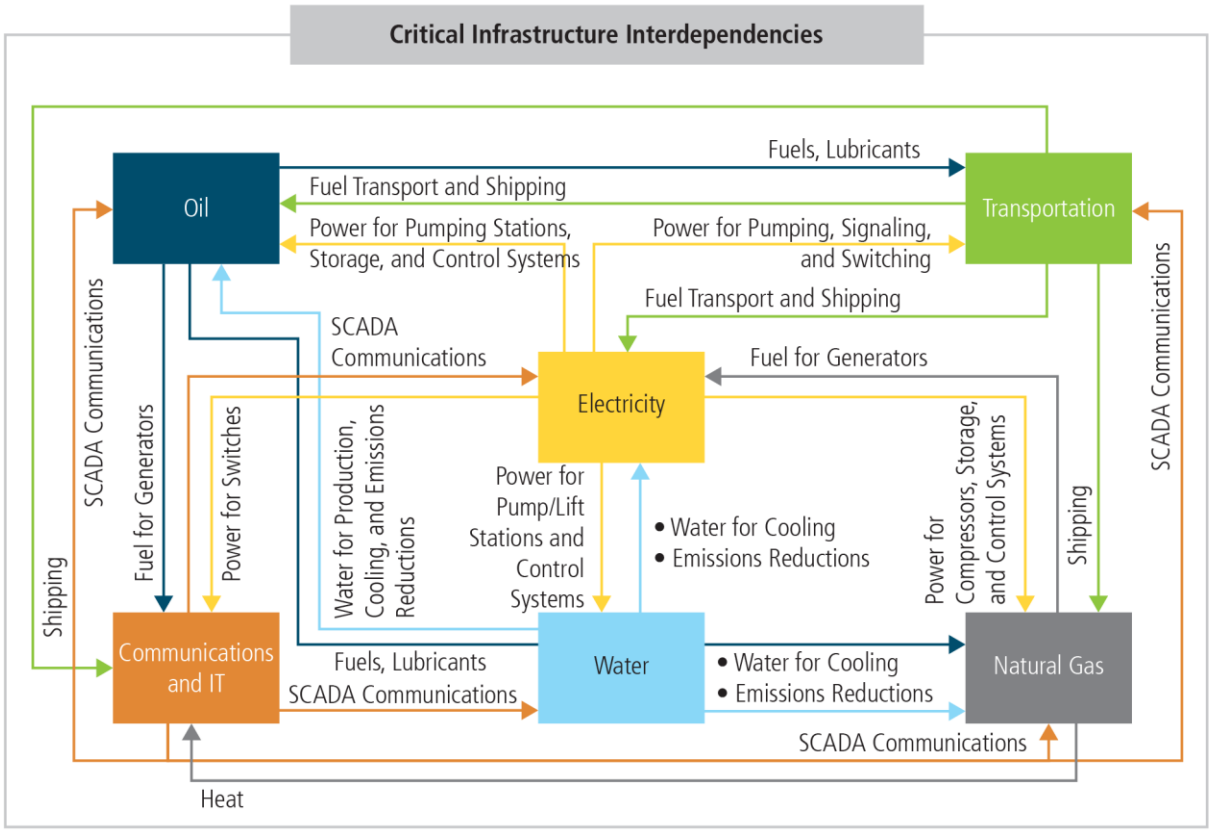
The Electricity Sector and National Goals

While respecting state, regional, and tribal prerogatives, the QER 1.2 supports development of consistent Federal strategy that accounts for the complex electricity sector context. The analysis conducted for the QER 1.2 identified three major *integrated objectives* that address the needs and challenges to enable the electricity sector of the 21st century. These objectives—discussed in detail in several QER 1.2 chapters—include (1) Maximizing Economic Value and Consumer Equity, (2) Enabling a Clean Electricity Future, and (3) Ensuring System Reliability, Security and Resilience. In addition to these objectives, QER 1.2 also explores several cross-cutting issues and includes in-depth chapters on two of these: workforce issues and North American electricity system integration.

The nation's critical infrastructures depend on electricity. Electricity is at the center of key infrastructure systems that support these sectors, including transportation, oil and gas production, water,

communications and information, and finance. These electricity-dependent critical infrastructures represent core lifeline networks that supports the American economy and society. These critical networks are increasingly converging, sharing resources and synergistic interactions via common architectures (see Figure S-2).

Figure S-2. Critical Infrastructure Interdependencies



Key critical infrastructure interdependencies represent the core underlying framework that supports the American economy and society. The financial services sector (not pictured) is also a critical infrastructure with interdependencies across other major sectors supporting the U.S. economy.

Rapidly Evolving Context

The QER 1.2 identifies a number of key trends that will shape the future electricity sector, including: the changing generation mix; low load growth; increasing vulnerabilities to severe weather/climate change; the proliferation of new technologies, services, and market entrants; increasing consumer choice; emerging cyber/physical threats; aging infrastructure and workforce; and the growing interdependence of regulatory jurisdictions. Each topic is introduced here and discussed in more detail in Chapter 1, Transforming the Nation's Electricity Sector: The Second Installment of the QER.

Increasing Importance of "Internet of Things" (IoT) and Digitization. IoT is *"sensors and actuators embedded in physical objects—from roadways to pacemakers—[that] are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet."* The rapid growth of IoT is both a manifestation and key enabler of this major change in the economy. Electricity enables this information-intense economy, while at the same time gaining new value through digitization and interconnectedness.

Increased Productivity, Lower Load Growth. Since the 1950s, growth in U.S. electric consumption has gradually slowed each decade due to a number of factors, including moderating population growth, improvements in the energy efficiency of buildings and industry, market saturation of certain major appliances, and a shift in the broader economy to less energy-intensive industries. Looking forward to 2040, electricity use is projected to grow slowly.

Decarbonizing the Electricity System. U.S. electricity system emissions declined since 2005 by 20 percent, largely due to a slowing of electricity demand growth and the accelerated deployment of lower-carbon generation. Low natural gas prices have led to substantial substitutions of lower-emitting gas for high-emitting coal. The electricity sector has been and—depending on the interplay of technology innovation, market forces, and policy—is likely to continue to be the first mover in economy-wide GHG emissions reductions. This is in part because the electricity sector has the broadest and most cost-effective abatement opportunities of any sector, including multiple zero-carbon and low-carbon generation options—such as nuclear, hydropower, solar, wind, geothermal, biomass, and fossil generation with carbon capture and storage—as well as many operational and end-use efficiency opportunities. It will also play a major role in the levels of decarbonization needed from other sectors such as transportation.

National Security Vulnerability. Without access to reliable electricity, much of the economy and all electricity-enabled critical infrastructures are at risk. These include our national security and homeland defense networks, which depend on electricity to carry out their missions to ensure the safety and prosperity of the American people. As U.S. policies establish new pathways to enhance economic competitiveness and environmental objectives, it is also essential that these policies work in concert with national security objectives.

Growing Importance of Back-up Generation. The loss of significant economic value from even short power outages places a very high premium on *customer as opposed to system reliability* and has helped to create a growing market for back-up generation to meet individual customer needs. Such back-up solutions sometimes have multiple components to ensure necessary redundancy.

Information Technology and the Electricity System. Information and Communications Technology (ICT) as well as grid control technologies for electricity systems—both large and small scale—have evolved, enabling increased interconnection and capture of economies of scale and scope. The electricity industry's early adoption of analytical and computer techniques to coordinate the generation and transmission of power facilitated increased interconnection and inter-utility power transfers.

A Smarter Grid. The "smart grid" refers to an intelligent electricity grid—one that uses digital communications technology, information systems, and automation to detect and react to local changes in usage, improve system operating efficiency, and in turn reduce operating costs while maintaining high system reliability. Smart meter infrastructure, sensors, and communication-enabled devices and controls give electricity consumers and utilities new abilities to monitor electricity consumption and potentially lower usage in response to time, local distribution, or price constraints. Smart meters also provide a number of other benefits, including enhanced outage management and restoration, improved distribution system monitoring, and utility operational savings.

Changing Generation Profile. The national generation mix has realigned over the past few decades and is likely to continue changing. The U.S. generation fleet is transitioning from one dominated by centralized generators with high inertia and dispatchability to one that is more "hybridized," relying on a mixture of traditional, centralized generation, and variable utility-scale and distributed renewable generation.

Aging Infrastructure. Like any infrastructure, the physical components of the electricity system are constantly aging. The continual maintenance and replacement of electricity system infrastructure components provides an important opportunity to modernize the electricity system.

Two-way Flows. For over 100 years, the electricity system has been operated through one-way flows of electricity and information. The generation and smart grid technology innovations described earlier can reduce grid costs and improve efficiency, as well as save time and effort. These technologies have also enabled an electricity system where two-way flows are possible and more common, and where digitization is a key enabler of a new range of services, including increased flexibility, higher system efficiency, reduced energy consumption, and increased consumer options and value.

Customer Engagement, New Business Models, and the Emerging Role of Aggregators. Throughout the electricity industry's development, the electricity customer was viewed as "load"—the aggregate accumulation of demand that utilities served, supported by a "ratepayer." This view of customers as load and ratepayer, largely passive because there were no real alternative options to utility service, was operative through the early 1980s. Changes in the electricity sector starting in the mid-1980s, however, have prompted utilities and emerging competitors to slowly shift their "customer as load" views to a point of view that is more customer-centric.

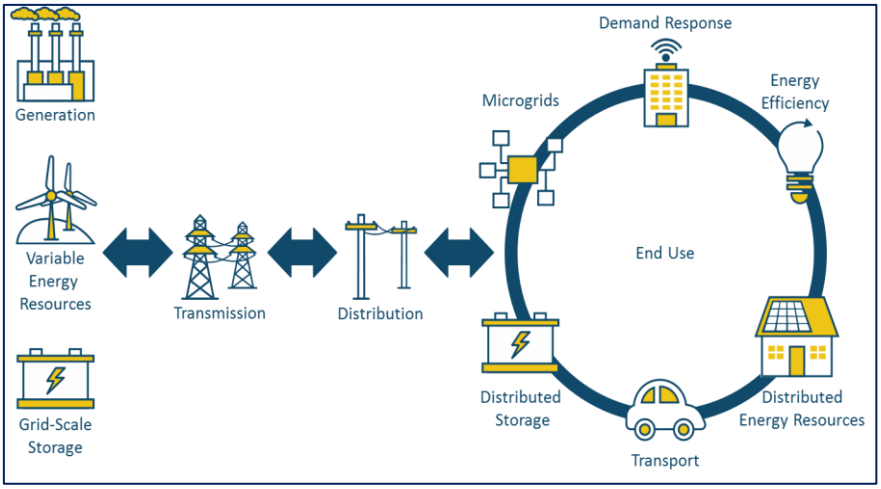
Workforce Challenges. Realizing the full potential of shifts in generation technologies, operations tools, and industry structure will require an electricity industry workforce capable of adapting and evolving to meet the needs of the 21st century electricity sector. A skilled workforce that can build, operate, and manage a modernized grid infrastructure is an essential component for realizing the full value of a modernized electricity sector.

Extreme Weather. The increased severity of extreme weather events over time has been a principal contributor to an observed increase in the frequency and duration of U.S. power outages between 2000 and 2012. Many weather-related threats to the electricity system are increasing in frequency and intensity and are also projected to worsen in the future due to climate change.

The Electricity Sector: Maximizing Economic Value and Consumer Equity

This chapter discusses the role of the electricity sector in creating economic value. The electricity sector has been an economic engine for the United States for over a century, providing reliable and competitively priced electricity that is critical for the United States' productivity. The vast majority of American consumers—encompassing households, businesses, and institutions—enjoy reliable and affordable electricity that enables a modern economy and a high standard of living. Consumers can now both produce and consume power and increase efficiency through advanced distribution infrastructure, and increasingly can provide energy, capacity, and ancillary services. This changing relationship between consumers and the grid is further

Figure S-3. Emerging 21st Century Electricity Two-Way Flow Supply Chain



driving the convergence of systems, business models, services, policies, and new technologies in a development feedback loop.

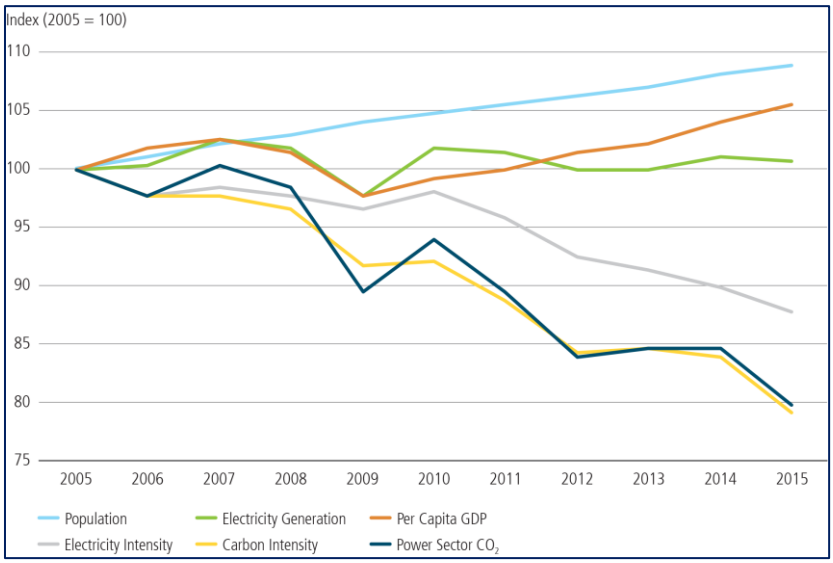
Key Findings

- Advanced metering infrastructure has had a significant impact on the nature of interactions between the electricity consumer and the electric system, allowing two-way flow of both electricity and information and enabling the integration of assets behind the meter into the larger electric grid.
- Interconnection standards and interoperability are critical requirements for seamless integration of grid-connected devices, appliances, and building energy management systems, without which grid modernization and further energy efficiency gains may be hindered.
- Evolving consumer preferences for electricity services are creating new opportunities.
- The convergence of the electric grid with information and communications technology creates a platform for value creation and the provision of new services beyond energy.
- There is enormous potential for electric end-use efficiency improvement based on (1) technical analyses, and (2) the differences in energy efficiency performance between states and utilities with and without ambitious electric end-use efficiency policies and programs.
- Tribal lands and American territories have the highest rates of un-electrified homes—more than half of a million homes. The extreme rurality of some tribal communities coupled with high levels of poverty present an economic challenge for the electric utilities trying to serve them.
- Optimization of behind-the-meter assets will require the design of coordination, communication, and control frameworks that can manage the dispatch of these devices in a way that is both economical and secure, while maintaining system reliability.
- Mobile, internet-connected devices foster new ways of consumer engagement, as well as enable consumers to have more efficient and real-time management of their behind-the-meter assets.
- Consumers and third party merchants that produce electricity can provide economic, environmental, and operational benefits.
- New grid services, modern technologies, and evolving system topologies and requirements are straining traditional methods of valuation. Appropriate valuation of the grid services by various technologies is technically and administratively challenging and may depend on spatial and temporal variables unique to different utilities, states, and regions.
- Currently, about 90 percent of the residential electricity consumption, 60 percent of commercial, and 30 percent of industrial is used in appliances and equipment that are subject to Federal minimum efficiency standards implemented, and periodically updated by, the Department of Energy. Between 2009 and 2030, these cost-effective standards are projected to save consumers more than $545 billion in utility costs, reduce energy consumption by 40.8 quads, and reduce carbon dioxide emissions by over 2.26 billion metric tons.
- Miscellaneous electric loads (MELs), devices that are often inadequately addressed by minimum standards, labeling and other initiatives, are expected to represent an increasing share of total electricity demand, particularly for the residential and commercial sectors.
- Connected devices and energy management control systems are decreasing in cost and improving in functionality, although their market penetration is still low, particularly in residences and small–to-medium-sized commercial buildings. These new technologies and systems, and the broader ‘Internet of Things’ provide a wide range of options for consumers to manage their energy use, either passively using automated controls, or through active monitoring and adjustment of key systems.
- Energy management control systems with communication capabilities are increasing opportunities for demand response services in support of grid operations. Third-party aggregators and other business models are facilitating the expanded use of demand response, but the regulatory environment remains unsettled in many states.
- Lower-income households use less energy, but pay a considerably higher fraction of their after-tax income for electricity services.
- Insufficient broadband access in rural areas could inhibit the deployment of grid modernization technologies and the economic value these technologies can create.

Building a Clean Electricity Future

A clean electricity system reduces air and water pollution, lowers GHG emissions and limits the impacts to the ecosystem in areas such as water and land use. Addressing climate change will require the United States to greatly reduce our carbon emissions, while simultaneously addressing new grid management challenges that have arisen due to recent trends in electricity generation and demand, the changing climate, and the national security implications of grid dependency. Keeping this context in mind, this Chapter explores the essential elements of a clean electricity system, and identifies the policy, market and technology innovations needed to achieve it. In short, we have made substantial progress in reducing the environmental impact of the electricity system, but much work remains.

Figure S-4. Trendlines in CO_2 Emissions Drivers, 2005–2015



Key Findings

- A clean electricity system reduces air and water pollution, lowers GHG emissions and limits the impacts to the ecosystem in areas such as water and land use.
- Deep decarbonization of the electricity system is essential for meeting climate goals; this has multiple economic benefits beyond those of environmental responsibility.
- The United States is the largest producer and consumer of environmental technologies. In 2015, the U.S. environmental technology and services industry employed 1.6 million people, had revenues of $320 billion, and exported $51 billion worth of goods and services.
- Though the U.S. population and economy have grown, between 1970 and 2014, aggregate emissions of common air pollutants from the electric power sector dropped 74 percent even as electricity generation grew by 167 percent.
- U.S. carbon dioxide (CO_2) emissions from the power sector have substantially declined. Between 2006 and 2014, 61 percent of these reductions are attributed to switching from coal- to gas-fired power generation and 39 percent to increases in zero-emissions generation.
- The increasing penetration of zero-carbon variable energy resources (VERs) and deployment of clean distributed energy resources (DERs) (including energy efficiency) are critical components of a U.S. decarbonization strategy.
- It is beneficial to a clean electricity system to have many options available as many of the characteristics of clean electricity technologies complement each other.
- Currently, 29 states and D.C., have a Renewable Portfolio Standard and 23 states have active and binding Energy Efficiency Resource Standards (EERSs) for electricity. States that have actively created and implemented such electricity resource standards and other supporting regulatory policies have seen the greatest growth in renewables and efficiency.
- The integration of variable renewables increases the need for system flexibility as the grid transitions from controllable generation and variable load to more variable generation and the need and potential for controllable load. There are a number of flexibility options such as demand response (DR), fast ramping natural gas generation, and storage.

- Energy efficiency is a cost-effective component of a clean electricity sector. The average levelized cost of saved electricity from energy efficiency programs in the United States is estimated at $46/MWh, versus the levelized cost of electricity for natural gas combined-cycle generation, with its sensitivity to fuel prices, at $52 to $78/MWh.
- Electricity will likely play a significant role in the decarbonization of other sectors of the U.S. economy as electrification of transportation, heating, cooling, and industrial applications continues. In the context of the Quadrennial Energy Review (QER), electrification includes both direct use of electricity in end use applications as well as indirect use whereby electricity is used to make intermediate fuels such as hydrogen.
- Realizing GHG emissions reductions and other environmental improvements from the electricity system to achieve national goals will require additional policies combined with accelerated technology innovation
- Improving understanding of the electricity system and its dynamics through enhancements in data, modeling, and analysis is needed to provide information to help meet clean objectives most cost-effectively.
- Decades of federal, state, and industry innovation investments have significantly contributed to recent cost reductions in renewable energy and energy efficiency technologies.
- Innovation in generation, distribution, efficiency, and demand response technologies is essential to a low carbon future. Innovation combined with supportive policies can provide the signal needed to accelerate deployment of clean energy technologies, providing a policy pull to complement technology push.
- Nuclear power currently provides 60 percent of U.S. zero-carbon electricity, but existing nuclear merchant plants are having difficulty competing in restructured electricity markets due to low natural gas prices and flat or declining electricity demand. Since 2013, six nuclear power reactors have shut down earlier than their licensed lifetime, and eleven[1] others have announced plans to close in the next decade. In 2016, two states, Illinois and New York, put policies in place to incentivize the continued operation of existing nuclear plants.
- Enhanced oil recovery (EOR) operations in the United States are commercially demonstrated geologic storage, and could provide a market pull for the deployment of carbon capture, utilization, and storage (CCUS).
- Federal laws currently limit the ability of regulated utilities to utilize federal tax credits in the same manner as private and unregulated developers. Publicly owned clean energy projects cannot benefit from the clean energy tax credits because tax equity investors cannot partner directly with tax exempt entities to monetize tax credits.
- Low-income and minority communities are disproportionately exposed to air quality and water quality issues associated with electric power generation. Compared to the U.S. population overall, there is a greater concentration of minorities living within a three-mile radius of coal- and oil-fired power plants. In these same areas, the percentage of the population below the poverty line is also higher than the national average.
- Some energy technologies that reduce greenhouse gas emissions, such as carbon capture, utilization, and storage (CCUS), concentrated solar power, and geothermal generation, have the potential to increase energy's water intensity; others, such as wind and photovoltaic (PV) solar power, can lower it. Dry cooling can reduce water intensity but may increase overall GHG emissions by decreasing generation efficiency. Though there can be a strong link between energy and water efficiency in energy technologies, many research, development, demonstration, and deployment (RDD&D) funding criteria do not incorporate water use or water performance metrics. Designing technologies and optimizing operations for improved water performance can have both energy and water benefits.
- There is currently no centralized permanent-disposal facility for used nuclear fuel in the United States, so this radioactive material is stored at reactor sites in 35 states awaiting development of consolidated storage facilities and/or geologic repositories.
- Coal combustion residues, such as coal ash and scrubber slurry, are the second most abundant waste material in the United States, after household waste.

[1] Note that six of these reactors (the New York and Illinois reactors) are expected to remain open with the passage of Clean Energy Standards (CESs) in those states.

- There is a range of decommissioning needs for different types of power generation facilities.

Ensuring Electricity System Reliability, Security, and Resilience

This chapter addresses a range of possible risks to the electricity system and the broader economy and suggests options to mitigate and prepare for these risks. Traditional electricity system operations are evolving in ways that could enable a more dynamic and integrated grid. The growing interconnectedness of the grid's energy, communications and data flows creates enormous opportunities; at the same time, it creates the potential for a new set of risks and vulnerabilities. Also, the emerging threat environment, particularly with respect to cybersecurity and increases in the severity of extreme weather events, poses challenges for the reliability, security, and resilience of the electricity sector, as well as to its traditional governance and regulatory regimes.

Figure S-5a. Time Scales of Traditional Grid Operations

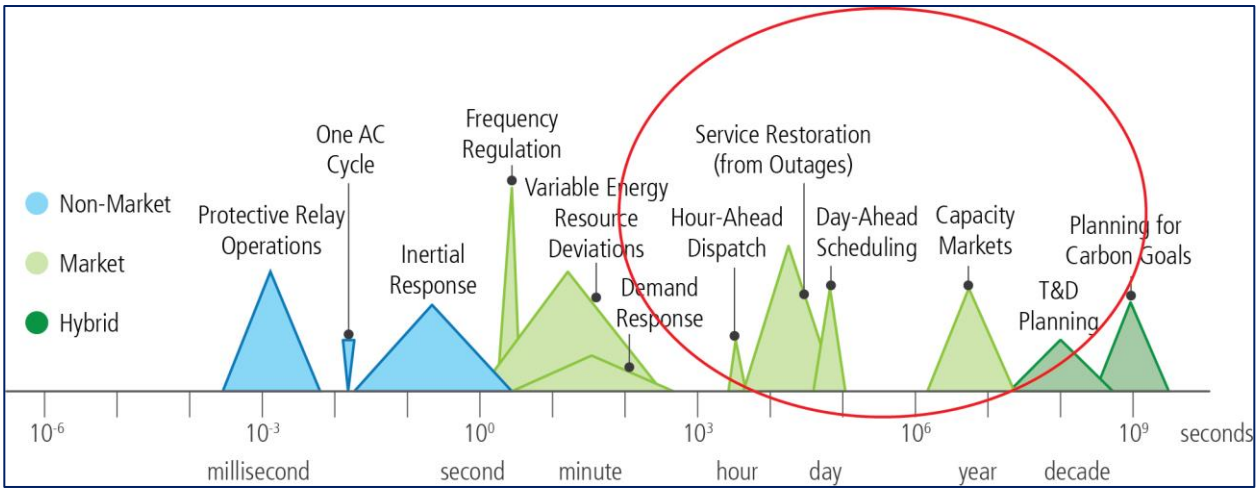
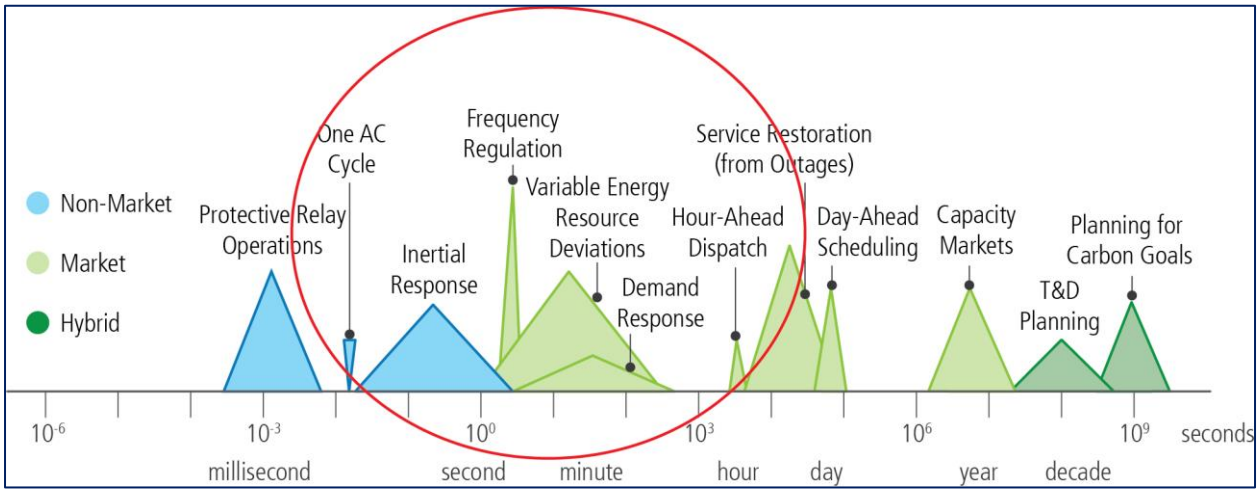


Figure S-5b. Changing Time Scales for Grid Operators Managing Two Way Electricity Flows



Key Findings

- The reliability of the electric system underpins virtually every sector of the modern U.S. economy. Reliability of the grid is a growing and essential component of national security. Standard definitions of reliability have focused on the frequency, duration, and extent of power outages. With the advent of more two-way flows of information and electricity, communication across the entire system from generation to end use, controllable loads, more variable generation, and new technologies such as storage and advanced meters, reliability needs are changing, and reliability definitions and metrics must evolve accordingly.
- The time scales of power balancing have shifted from daily to hourly, minute, or second-to-second to millisecond to millisecond at the distribution end of the supply chain; with the potential to impact system frequency and inertia and/or transmission congestion. The demands of the modern electricity system has required, and will increasingly require, innovation in technologies (e.g., inverters), markets (e.g., capacity markets), and system operations (e.g., balancing authorities).
- Electricity outages disproportionately stem from disruptions on the distribution system (over 90 percent of electric power interruptions), both in terms of the duration and frequency of outages; this is largely due to weather-related events. Damage to the transmission system, while infrequent, can result in more widespread major power outages that affect large numbers of customers with significant economic consequences.
- As transmission and distribution system design and operations become more data-intensive, complex, and interconnected, the demand for visibility across the continuum of electricity delivery has expanded across temporal variations, price signals, new technology costs and performance characteristics, socio-economic impacts, and others. However, deployment and dissemination of innovative visibility technologies face multiple barriers that can differ by the technology and the role each plays in the electricity delivery system.
- Data analysis is an important aspect of today's grid management, but the granularity, speed, and sophistication of operator analytics will need to increase, and distribution- and transmission-level planning will need to be integrated.
- The leading cause of power outages in the United States is extreme weather, including heat waves, blizzards, thunderstorms, and hurricanes. Events with severe consequences are becoming more frequent and intense, due to climate change, and have been the principal contributors to an observed increase in the frequency and duration of power outages in the United States.
- Grid owners and operators are required to manage risks from a broad and growing range of threats. These threats can impact almost any part of the grid (e.g., physical attacks), but some vary by geographic location and time of year. Near-term and long-term risk management is increasingly critical to the ongoing reliability of the electricity system.
- The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities, juxtaposed against the slower-moving deployment of defense measures. Mitigation and response to cyber threats are hampered by inadequate information-sharing processes between government and industry, the lack of security-specific technological and workforce resources, and challenges associated with multi-jurisdictional threats and consequences. System planning must evolve to meet the need for rapid response to system disturbances.
- Other risk factors stem from the increasing interdependency of electric and natural gas systems as natural gas–fired generation provides an increasing share of electricity. However, coordinated long-term planning across natural gas and electricity can be challenging since the two industries are organized and regulated differently.
- As distributed energy resources (DERs) become more prevalent and sophisticated—from rooftop solar installations to applications for managing building electricity usage—planners, system operators, and regulators must adapt to the need for an order of magnitude increase in the quantity and frequency of data to ensure the continuous balance of generation and load.
- Demand response technologies and programs offer a particularly flexible grid resource that is capable of improving system reliability, reducing the need for capital investments to meet peak demand, reducing electricity market prices, and improving the integration of variable renewable energy resources. It can be used for load reduction, load shaping, and management of consumption to help grid operators mitigate the impact of variable and distributed generation on the transmission and distribution systems.

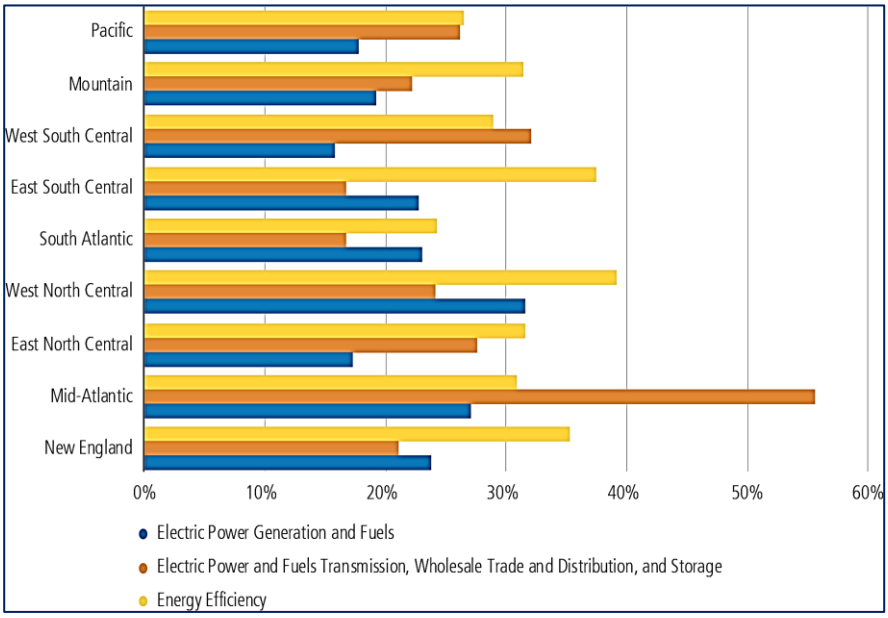
- Information and communications technologies are increasingly utilized throughout the electric system and behind the meter. These technologies offer advantages in terms of efficient and resilient grid operations and opportunities for consumers to interact with the electricity system in new ways. They also expand the grid's vulnerability to cyber attacks by offering new vectors for intrusions and attacks, making cybersecurity a system-wide concern.
- There are no commonly used metrics for measuring grid resilience. Several resilience metrics and measures have been proposed; however, there has been no coordinated industry or government initiative to develop a consensus on or implement standardized resilience metrics.
- Low-income and minority communities are disproportionately impacted by disaster-related damage to critical infrastructure. These communities with fewer resources may not have the means to mitigate or adapt to natural disasters and disproportionately rely on public services, including community shelters, during disasters.

This chapter was developed in conjunction with the closely-related and recently-published "Joint United States-Canada Electric Grid Security and Resilience Strategy."

The Electricity Workforce: Changing Needs, New Opportunities

This chapter provides an overview of current and projected employment in and related to the electricity sector, and it discusses options to assist workers and develop a workforce that has the skills to build, maintain, and operate the electricity system of the future. The broader changes in the electricity industry have created both new opportunities and new challenges for the electricity industry workforce, including new workforce opportunities in the renewable energy industry and information and communications technologies, and the challenges of the skills gap for deploying and operating new technologies, the shift in the geographic location of jobs, and the need to recruit and retain an inclusive workforce. The electricity industry is the dominant consumer of coal, natural gas, and renewable energy technologies, so changes in electricity industry demand for these resources can cause regional and sectoral dislocations in these industries. Each industry has distinctive workforce skills requirements and geographic concentrations, so employment gains in one industry do not always translate to opportunities for those workers affected by employment loss in other industries that may be geographically distant and require different skills.

Figure S-6. Percentage of Employers Reporting Very High Hiring Difficulty by Census Region and Subsector (Q4 2015)



Key Findings

- Over 1.9 million people are employed in jobs related to electric power generation and fuels, while 2.2 million people are working in industries directly or partially related to energy efficiency.
- Job growth in renewable energy is particularly strong. Employment in the solar industry has grown over 20 percent annually from 2013 to 2015. From 2010 to 2015, the solar industry created 115,000 new jobs. In 2016, approximately 374,000 individuals worked, in whole or in part, for solar firms, with more than 260,000 of those employees spending most of their time on solar. There were an additional 102,000 workers employed at wind firms across the Nation. The solar workforce increased by 25 percent in 2016, while wind employment increased by 32 percent.
- The oil and natural gas industry experienced a large net increase in jobs over the last several years, adding 80,000 jobs from 2004 to 2014. Unlike coal production, natural gas production is projected to increase over the coming decades under a business-as-usual scenario, sustaining natural gas industry employment.
- Employment in the natural gas industry is regionally and temporally volatile; 28,000 jobs were lost between January 2015 and August 2016. Shifts in locations pose challenges for employees and the economies of the areas where they live and work.
- Between 1985 and 2001, coal production increased 28 percent as industry employment fell by 59 percent due to efficiencies gained by shifting production from Appalachia to the West. In 2015, annual coal production was at its lowest level since 1986, and it is forecast to continue declining over the coming decades.
- Aside from a minor employment increase from 2000 to 2011, 141,500 domestic coal jobs were lost between 1985 and 2016, and the industry shrank by 60 percent. Today, the coal mining industry employs about 53,000 people.
- Despite ongoing economic challenges in the Appalachian region, the non-highway appropriated budget for the Appalachian Regional Commission (ARC), a federally-funded regional economic development agency, has fallen from roughly $600 million in the early 1970s to around $100 million in the 1980s and remained roughly constant until 2016. The ARC budget recently increased from $90 million in fiscal year 2015 to nearly $150 million in fiscal year 2016.
- The Abandoned Mine Lands Reclamation Fund's (AML Fund's) inability to fully support the reclamation of lands disrupted by the coal mining industry has the potential to leave communities in regions with declining local revenues with polluted and unsafe lands and few means to repair the damage. The AML Fund's increased ability to support coal mine reclamation would provide local employment opportunities and help coal communities transition to new industries.
- The continued fiscal difficulties of coal miner pensions threaten the solvency of the Pension Benefit Guaranty Corporation, a Federal agency that insures private-sector pension funds and is funded out of insurance premiums paid by member funds.
- Proliferation of information and communications technology and new technologies like distributed generation, smart home devices, and electric battery storage have led to new businesses and employment opportunities, which will require a wide array of new skills.
- The electricity industry will need a cross-disciplinary power grid workforce that can comprehend, design, and mange cyber-physical systems; the industry will increasingly require a workforce adept in risk assessment, behavioral science, and familiarity with cyber hygiene.
- A dip in the number of electricity industry workforce training programs in the 1980s contributed a shortage of middle and upper management positions in the sector today, creating a workforce gap as the large number of baby boomers retire.
- Workforce retirements are a pressing challenge. Industry hiring managers often report that lack of candidate training, experience, or technical skills are major reasons why replacement personnel can be challenging to find—especially in electric power generation.
- Electricity and related industries employ fewer women and minorities than the national average, but have a higher proportion of veterans. Only 5 percent of the boards of utilities in the United States in

2015 include women, and approximately 13 percent of board members among the top 10 publicly owned utilities were African American or Latino. Underrepresentation in or lack of access to science, technology, engineering, and mathematics educational opportunities and programs contribute to the underrepresentation of minorities and women within the electricity industry.

- From 1995 to 2013, the number of injuries per 100 employee-years in the electricity utility industry decreased from 4.7 to 1.3. However, line workers continue to experience hazardous working conditions. In 2014, electrical power line installers and repairers suffered 25 fatal work injuries—a rate of 19 per 100,000 full-time equivalent workers, which is over five times the national work fatality rate.
- While data on energy sector workforce are improving, there are still major shortcomings in the data availability, precision, and categorization of energy sector jobs.

Enhancing Electricity Integration in North America

This chapter details the interconnectivity of the United States, Canada, and Mexican electric systems and opportunities for enhancing integration. The potential for electricity integration to provide economic benefits and support the development of more modern and resilient energy infrastructure has been a longstanding theme for North American diplomacy. Earlier this year at the North American Leaders' Summit, President Barack Obama, President Enrique Peña Nieto and Prime Minister Justin Trudeau signed a statement agreeing to collaborate on cross-border transmission projects in order to achieve the mutual goal of advancing clean and secure power. The extensive electricity integration that already exists between the United States and Canada, and the potential to increase existing integration between the United States and Mexico, suggests that North America has much to gain from collaborative planning, strategy, and cooperation in the power sector.

Figure S-7. Border Crossings of Electric Transmission Lines



Key Findings

- Integration of the power systems of Canada, Mexico, and the United States historically occurred by gradual, ad hoc, and regional adjustments implemented by an array of regional public and private stakeholders, reflecting the complex and fragmented jurisdictions in all countries. Many opportunities for enhanced integration have included a collection of stakeholders and were pursued on a sub-regional basis.
- One model for shared power sector governance is demonstrated by the reliability planning under the North American Electric Reliability Corporation (NERC); however, this engagement has been limited to Canada, the United States, and the Baja California region of Mexico.
- Canada, Mexico, and the United States governments have all made significant climate commitments and indicated a desire to shift towards greater renewable energy penetration. Greater cross-border integration could be a tool to maximize gains from the deployment of clean energy generation, but the complexity and current asymmetry of national and subnational policy frameworks may impede implementation.
- The design of domestic U.S. clean energy policies, both at the federal and state level, have implications for cross-border trade and continental emissions reductions. Currently, there are significant disparities between U.S. states' policies for recognition or exclusion of international clean energy imports.
- Continued study of the context and levels of integration of each subregional cross-border interconnection will allow for a deeper understanding of which policies have shaped current levels of cross-border trade (Table 7-1).
- Canada has additional hydropower resources which could be exported to the United States to provide a reliable source of firm, low-carbon energy. There are concerns among stakeholders that increased imports of Canadian hydropower could reduce U.S. renewable energy competitiveness; however, there are examples of arrangements where Canadian hydropower decreases curtailments of U.S. renewable resources.
- Trade has been increasing across the North American bulk power system, but cross border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.
- Under a low carbon future scenario, current modeling results show that transmission with Canada becomes increasingly important for sustaining emissions reductions, and has a significant impact on the generation mix in border regions.
- While many electricity system models exist for the United States (and in some cases, the United States and Canada), detailed modeling tools to explore the economic, social, and/or reliability impacts of electricity trade across all of North America are currently insufficient to inform opportunities for enhancing integration.
- While extensive integration between the United States and Canada can inform the potential for increased future U.S.-Mexico integration, these situations are fundamentally dissimilar in four main ways: lack of a dominant exporting country on the U.S.-Mexican border, the different regional approaches to integration on the U.S. side, the nascent regulatory framework in Mexico, and the lack of parity in open access transmission agreements and reliability coordination between the United States and Mexico. The United States and Mexico agreed to a set of principles for electricity integration in early January 2017.
- Mexico's ongoing electricity utility industry reforms could have significant impacts on the future of cross-border integration. The reforms are focused on the overall goal of competitiveness, with the twin objectives of reducing electricity costs and developing more clean energy. A transition in Mexico from oil to natural gas in electricity generation could have significant impacts in the manufacturing sector, reducing electricity prices, boosting manufacturing output and increasing overall GDP for Mexico.
- Mexico's increasing importation of U.S. natural gas could be an economic and environmental opportunity for both sides, by offsetting expensive and high-GHG-emitting diesel generation in Mexico and creating economic opportunities for U.S. exporters. The resulting reduction in electricity costs in Mexico could also boost overall North American competitiveness.
- The Electric Reliability Council of Texas (ERCOT) could benefit from greater integration with Mexico, through access to enhanced imports or as a business opportunity for power exporters.

- California's ambitious clean energy policy provides an opportunity for energy exporters in Mexico, especially in the Baja California region, to supply clean energy, dispatchable power, or ancillary services.

A 21st-Century Electricity System: Conclusions and Recommendations

This chapter highlights many recommendations that are enablers of the modernization and transformation necessary. The recommendations build on the analysis and findings in earlier chapters. Many of the recommendations will provide the incremental building blocks for longer-term, planned changes and activities, undertaken in conjunction with state and local governments, policy-makers, industry and other stakeholders. The policy, research and investment choices made today will establish critical pathways for decades.

Recommendations in Brief

QER 1.2 provides 76 recommendations divided into six sections. The first section addresses recommendations that are crosscutting, addressing all three high level goals national security, economic competitiveness and environmental responsibility. Following this section in the QER, three sections make more specific recommendations that will help meet the strategic objectives: maximizing economic value and consumer equity; building a clean electricity future; and ensuring grid reliability, security, and resilience. There are also recommendation sections on the electricity sector workforce and on enhancing electricity integration in North America. These recommendations are summarized here, with full details in Chapter 7.

Key Crosscutting Recommendations to Support the Security and Reliability of the Electricity System

Protect the Electricity System as a National Security Asset. The Federal Power Act provides a statutory foundation for an electricity reliability organization to develop reliability standards for the bulk power system. Pursuant to this authority, FERC has certified NERC as the Electric Reliability Organization. Under this arrangement, NERC and FERC have put into place a comprehensive set of binding reliability standards for the bulk power system over the past decade, including standards on cybersecurity and physical security. However, the Federal oversight authority is limited: FERC can approve or reject NERC-proposed reliability standards, but it cannot author or modify reliability standards.

The nature of a national security threat, however, as articulated in the FAST Act, stands in stark contrast to other major reliability events that have caused regional blackouts and reliability failures in the past. In the current environment, the U.S. grid faces imminent danger from cyber attacks. Widespread disruption of electric service because of a transmission failure initiated by a cyber attack at various points of entry could undermine U.S. lifeline networks, critical defense infrastructure, and much of the economy; it could also endanger the health and safety of millions of citizens. Also, natural gas plays an increasingly important role as fuel for the Nation's electricity system; a gas pipeline outage or malfunction due to a cyber attack could affect not only pipeline and related infrastructures, but also the reliability of the Nation's electricity system.

- **Amend Federal Power Act authorities to reflect the national security importance of the Nation's electric grid**. Grid security is a national security concern—the clear and exclusive purview of the Federal Government. The Federal Power Act, as amended by the FAST Act, should be further amended by Congress to clarify and affirm the Department of Energy's (DOE's) authority to

develop preparation and response capabilities that will ensure it is able to issue a grid-security emergency order to protect critical electric infrastructure from cyber attacks, physical incidents, EMPs, or geomagnetic storms. In this regard, Federal authorities should include the ability to address two-way flows that create vulnerabilities across the entire system. DOE should be supported in its development of exercises and its facilitation of the penetration testing necessary to fulfill FAST Act emergency authorities. In the area of cybersecurity, Congress should provide FERC with authority to modify NERC-proposed reliability standards—or to promulgate new standards directly—if it finds that expeditious action is needed to protect national security in the face of fast-developing new threats to the grid. This narrow expansion of FERC's authority would complement DOE's national security authorities related to grid-security emergencies affecting critical electric infrastructure and defense-critical electricity infrastructure. This approach would maintain the productive NERC-FERC structure for developing and enforcing reliability standards, but would ensure that the Federal Government could act directly if necessary to address national security issues.

- **Collect information on security events to inform the President about emergency actions as well as imminent dangers**. DOE should collect targeted data on critical cyber, physical, EMP, and geomagnetic disturbance events and threats to the electric grid to inform decision making in the event of an emergency or to inform the anticipatory authorities in the FAST Act. DOE should concurrently develop appropriate criteria, processes, and definitions for collecting these targeted data using a dedicated information protection program to safeguard utility data consistent with FERC rules. Reporting will be done on a confidential basis. Updating will be required to address evolving threats. DOE will coordinate the development of analytical data-surveillance and data-protection tools with the National Labs, states, universities, industry, Federal agencies, and other organizations as appropriate.

- **Adopt integrated electricity security planning and standards**. FERC should, by rule, adopt standards requiring integrated electricity security planning on a regional basis to the extent consistent with its statutory authority. Such requirements would enhance DOE's effectiveness in carrying out its responsibilities and authorities to address national security imperatives and new vulnerabilities created by (1) two-way flows of information and electricity and (2) the transactive role of customers and key suppliers (such as those providing stored fuel for strategic generators). Important national security considerations warrant careful consideration of how generation, transmission, distribution, and end-user assets are protected from cybersecurity risks. Vulnerabilities of distribution and behind-the-meter assets, which may provide an increasing number of potential entry points for access to utility control systems, are threats that can adversely affect the operation of the transmission system; for these vulnerabilities, a careful review of protections is required. To adequately address and support the security requirements of the FAST Act and DOE's implementation of the FAST Act, this review should be performed on an integrated basis, rather than separating the review into bulk power system and other assets.

  To ensure that there are no unnecessary vulnerabilities associated with state-to-state or utility-to-utility variations in protections, integrated electricity security planning should be undertaken to cover the entire United States, including Alaska, Hawaii, and U.S. territories. FERC should consider having existing regional organizations undertake such planning, as it deems appropriate. FERC should evaluate whether the costs of implementing security measures identified in the integrated electricity security plan are appropriate for regional cost allocation, where such measures are found to enhance the security of the regional transmission electric system.

To the extent necessary, appropriate statutes should be amended to clearly authorize FERC to adopt such integrated electricity security planning requirements. However, FERC should immediately begin to advance this initiative to the maximum extent possible under its current authority by initiating a dialogue, including discussions with DOE and state authorities, and driving consensus on Integrated Electricity Security Plans.

- **Assess natural gas/electricity system infrastructure interdependencies for cybersecurity protections**. DOE, pursuant to FAST Act authorities and in coordination with FERC, should assess current cybersecurity protections for U.S. natural gas pipelines and associated infrastructure to determine whether additional or mandatory measures are needed to protect the electricity system. If the assessment concludes that additional cybersecurity protections—including mandatory cybersecurity protocols—for natural gas pipelines and associated infrastructure are necessary to protect the electricity system, such measures and protocols should be developed and implemented. This work should build on existing assessments, including those underway at the Transportation Security Administration.

Increase Financing Options for Grid Modernization Estimates of total investment requirements necessary for grid modernization range from a low of about $350 billion to a high of about $500 billion. Grid modernization is the platform for the 21st-century electricity system, bringing significant value associated with lower electricity bills due to fuel and efficiency savings, more electricity choices, and fewer and shorter outages. The Federal Government currently plays a role in providing tax incentives for deployment of clean energy technologies, as well as Federal credit assistance to facilitate early deployment of innovative technologies.

- **Expand DOE's loan guarantee program and make it more flexible to assist in the initial deployment of innovative grid technologies and systems**. The design of the current DOE loan guarantee program is focused primarily on financing deployment of innovative generation technologies. Most DOE loan guarantee recipients, for example, are structured as special project entities that can raise equity outside of regulated business structures and can provide credit security in the form of power purchase agreements. This financing model is not amenable to grid modernization financing by regulated entities, especially in cases of some technological uncertainty associated with initial commercial deployments. In addition, there will an ongoing need for innovation in grid technologies beyond the likely availability of current DOE loan guarantee authority. Also, the limitations of the loan program restrict the program to a very small and ever-changing portion of new transmission capacity; more projects and innovation are necessary to transform the grid.

  Modifications to the current DOE Title XVII loan guarantee program are needed to (1) reduce restrictions on numbers/types of projects and timeframes, e.g. in order to adequately address innovative transmission capacity needs, and (2) provide clear statutory authority for lending to other public or public/private entities that support transmission and other grid modernization projects (e.g., state agencies, regional power pools) through on-lending or equity investing. By their nature, transmission projects, especially big projects, involve many entities and jurisdictions. Statutory clarification is needed on indirect lending authorities to such entities for multi-jurisdictional projects.

  Some of the benefits of grid modernization are realized over time, as the electricity system itself is changed by technology and market innovations. Additional funding resources would bridge the gap between investment costs and realization of benefits and would enable utilities to invest in

grid modernization. A relatively low-cost permanent Federal financing system could be established by setting up a revolving loan fund with one-time seed capital.

Increase Technology Demonstrations and Utility/Investor Confidence. The future electric grid will require that utilities deploy a wide range of new, capital-intensive technologies. Primary technologies are needed to support increased reliability, security, value creation, consumer preferences, and system optimization and integration at the distribution level. Demonstrating the technical readiness and economic viability of advanced technologies is needed to inspire the confidence of utilities and investors.

- **Significantly expand existing programs to demonstrate the integration and optimization of distribution system technologies.** The complexity of the issues facing distribution systems—including new technologies, the need for systems approaches, and geographical differences in markets and regulatory structures—points to a significant need for multiple "solution sets" to enable two-way electricity flows on distribution systems, enhance value, maximize clean energy opportunities, optimize grid operations, and provide secure communications. Building on existing demonstration programs and reflecting the Administration's commitment to the doubling of Federal clean energy innovation over 5 years as part of its Mission Innovation initiative, DOE should develop a focused, cost-shared program for qualifying utilities to demonstrate advanced distribution system technologies at the community scale, including advanced voltage control/optimization systems; dynamic protection schemes to manage reverse power flows, communications, sensors, storage, switching and smart-inverter networks; and advanced distribution management systems, including automated substations.

  Demonstrations supported by the cost-shared, cooperative agreement program would be specifically designed to inform standards and regulations and increase regulatory and utility confidence in key technologies or technology systems. Under this program, utilities would have to make a positive business case for projects and obtain regulatory approvals for their proposed demonstrations. Preference would be given to multi-utility partnerships with diverse customer profiles and to projects that promote education and training in key academic disciplines that are essential for distribution system transformation. Cybersecurity plans for all projects would be required and supported by programmatic review of plans and deployments.

  Existing DOE programs, including advanced distribution management systems, microgrids, communications and sensors, storage, and cybersecurity, should be leveraged to provide technical assistance regarding technological issues, planning and performance evaluation, and institutional needs. A percentage of funding could be dedicated to small, publicly-owned utilities. The program should be of sufficient size to have a material impact; it should start in fiscal year (FY) 2018 and be ramped up over the time period identified in the Mission Innovation initiative.

Build Capacity at the Federal, State, and Local Levels. The 21st-century electricity system is becoming increasingly transactive, and properly valuing attributes is key to an efficient system. Application of lessons learned that pair economic and system analysis will lead to a power system that cost-effectively serves customers while providing nationally valued public goods, e.g., reliability, resilience, and acceptable environmental performance.

Advances in electricity technologies (i.e., smart grid processes and solutions) require enhanced capabilities in human resources to ensure the cost-effective selection, deployment, and operations of key technologies.

- **Provide funding assistance to enhance analytical capabilities in state Public Utility Commissions and improve access to training and expertise for small and municipal utilities.** Federal support should be provided to states and small utilities to enable them to better manage the increasing

complexities in the electricity system, such as integrating variable energy resources; incorporating energy efficiency, demand response (DR), and storage into planning; developing competencies in various technologies; and making investment and security decisions within uncertain parameters. These issues are highly technical and require a new knowledge base and skillset often within the domain of computer sciences, economics, and cybernetics. At the same time, these entities are dealing with the workforce issues of outside recruitment or retirement across the electricity industry, which are referenced in the QER. DOE should build and cultivate much-needed analytical capacity at the state level over a limited period of time by allocating funding to state public utility commissions to allow them to hire new or train existing analysts with more sophisticated and advanced skills and build institutional knowledge. Eligibility for state and local funding should be contingent upon demonstration of consideration for Integrated System Planning, which is outlined in this chapter. DOE should support these analysts through an online interactive education and training platform with access to nationally recognized experts. This platform would also be available and tailored to the needs of small utilities. On a national scale, these actions will serve to sustain system reliability and security and bolster resilience.

- **Create a Center for Advanced Electric Power System Economics**. DOE should provide two years of seed funding for the formation of a center designed to provide social science advice and economic analysis on an increasingly transactive and dynamic 21st-century electricity system. The center should be modeled after the National Bureau of Economic Research and be managed by a university consortium. The consortium will establish and maintain a network of experts in economics, the social sciences, and the electricity system; these experts should be from academia, industry, nonprofit institutions, and the National Laboratories. The center will develop new methods where appropriate, serve as advisor and consultant to stakeholders preparing germane analyses, and foster the advancement of students and professionals who are developing expertise in these disciplines. The focus of the center will include power systems evaluation (e.g., valuation, benefit-cost, and competition analysis).

Inform Electricity System Governance in a Rapidly Changing Environment. The rapid rate of change in the electricity sector today often exceeds the ability of institutions and governance structures to respond in a manner sufficient to meet critical national goals and objectives. This is particularly true in the resolution of jurisdictional disputes over responsible price formation and valuation. Clarification and harmonization of roles and responsibilities for developing pricing can reduce market uncertainty, facilitate the achievement of policy goals, and reduce costs to ratepayers.

- **Establish a Federal Advisory Committee on Alignment of Responsibilities for Rates and Resource Adequacy.** DOE, in collaboration with the National Association of Regulatory Utility Commissioners, should convene a Federal advisory committee that reports to the Secretary or the Secretary's designee to examine potential jurisdictional concerns and issues associated with harmonizing wholesale and retail rates and tariffs. This advisory committee will evaluate and make recommendations (where appropriate) on the way in which the organized markets reflect state policy; pricing mechanisms for maintaining resource adequacy; state and Federal roles in pricing and operation of distributed energy resources (DERs), storage, and microgrids; the role of aggregators; and mechanisms for implementing consumer protection across the various markets and jurisdictions. The advisory committee will represent a broad cross-section of industry and stakeholders. An annual report will be prepared by this advisory committee for the Secretary that identifies the impact of governance issues and recommends solutions.

In the remainder of this Summary, we highlight a few recommendations from a much more extensive set in the full report.

Maximize Economic Value and Consumer Equity

Tailor and Increase Tools and Resources for States and Utilities to Effectively Address Transitions Underway in the Electricity System. States and electric utilities are responsible for making critical decisions regarding how to improve the reliability, affordability and sustainability of the electric grid, and officials from state agencies and utilities provided comments as part of the QER Stakeholder process on the federal role in informing these decisions. Technical assistance, improved regional consideration in program offerings, and new analysis for decision-making, will allow the federal government to respond to the needs of states and utilities in ensuring consumer value and equity in the electricity system of the 21st Century. Recommendations include:

- Improve energy management and demand response in buildings and industry
- Increase Federal support for state efforts to quantitatively value and incorporate energy efficiency, demand response, distributed storage, and distributed generation into resource planning.

Expand Federal and State Financial Assistance to Ensure Electricity Access for Low-income and Under-served Americans. Analysis indicates that electricity costs represent a disproportionate share of total income for low-income Americans. Increased funding for proven, state-administered programs and enhanced data and tools for targeting assistance can reduce this "electricity burden." Ensuring that the costs of the rapid transition of the electricity system are not disproportionately borne by low-income Americans is a top priority; low-income Americans should also be able to share in the benefits from an electricity system transition. Recommendations include:

- Encourage public-private partnerships to underwrite and support clean energy access for low and moderate income households.
- Provide assistance to address rural, islanded, and tribal community electricity needs.

Increase Electricity Access and Improve Electricity-related Economic Development on Tribal Lands. The interdependencies of electricity access, health, economic wellbeing and quality of life underscore the importance of universal access to electricity. While recent data on electricity access on Tribal Lands is limited, there are still areas that lack adequate access to electricity despite the nation's commitment to full electrification dating back to the Rural Electrification Act of 1936. More recent anecdotal evidence suggests that the problem broadly persists. It is a moral imperative that the Federal Government support Tribal leadership and utility authorities to provide basic electricity service for the tens of thousands of Native Americans who currently lack access to electricity and to foster the associated economic development on tribal lands. Federal agencies should also support renewable energy acceleration and economic development opportunities through renewable energy incentives, workforce development, financing program improvements, and improved consultation with Tribes. Recommendations include:

- Support the achievement of full tribal land electrification.
- Support advanced technology acceleration and economic development opportunities for tribal lands.

Strengthen Rural Electricity and Broadband Infrastructure. The Federal government has historically supported the expansion of access to affordable electricity and communications service in rural America, with major initiatives continuing today mainly through the USDA. The lack of access to broadband in rural areas means that these consumers lack access to demand response technologies, such as smart meters, smart thermostats, and other technologies can reduce pollution, help consumers save electricity, improve overall grid resilience and reliability, and enhance economic development. Broadband expansion into these regions would significantly advance grid modernization goals, while providing significant

communications, connectivity, and educational benefits to numerous regions of the country. Supporting broadband access in sparsely-populated rural areas, many of which are low-income, is not, however, profitable for the private sector. Federal support would help enhance security, environmental and economic development goals. Recommendations include:

- Leverage utility broadband build-out to expand public broadband access in rural areas.
- Increase opportunities for small and rural utilities to utilize USDA's electricity financing programs

Enable a Clean Electricity Future

Transform the Electricity System through Leadership in National Clean Electricity Technology Innovation. Private sector investment in clean energy technology faces many barriers, e.g. prices do not reflect the costs and benefits of clean energy, investments are made in a highly-regulated environment, and there are high capital costs and the long time horizons for R&D and capital stock turnover in comparison to many other sectors (e.g. IT). Increased investments in electricity technology innovation is essential for transformation of the electricity system. Federal investments have a history of success and have been leveraged by the private sector to create significant economic value; case studies on nuclear energy, shale gas, and solar PV, among many other electricity-related technologies, demonstrate the instrumental role of federal investment in early-stage R&D. Recommendations include:

- Significantly increase federal investment in clean electricity RD&D.
- Implement Regional Clean Energy Innovation Partnerships.

Address Challenges to Large-scale, Centralized Clean Generation. Regardless of the energy source, there are a number of challenges to deploying large centralized power generation facilities. Lower electricity prices, largely related to low-cost natural gas, are reducing the economic viability of other clean generation resources, especially nuclear energy. Nuclear power currently provides 60 percent of zero-carbon generation in the United States. Hydropower is one of the oldest and most established forms of electricity generation, contributing 6 percent of the electricity generated in the U.S. in 2015 and 19 percent of zero-carbon generation. Non-hydropower renewables – including wind, solar, geothermal, and biomass – accounted for about 7 percent of electricity generated in the U.S. in 2015. Each of these technologies face a range of siting constraints, licensing and permitting processes, or environmental concerns, which can be broad and extensive; this can make new, large-scale deployments difficult, in some cases, taking a decade or more to build. A combination of federal coordination, licensing support, analysis of financing opportunities, and RD&D can help address these barriers. Recommendations include:

- Increase funding for the life-extension R&D program to ensure maximum benefits from existing nuclear generation.
- Increase support for advanced nuclear technology licensing at NRC.
- Develop environmental mitigation technologies for hydropower.

Address Significant Energy-water Nexus Issues Affecting – and Affected by – the Electricity Sector. Electricity systems and water systems are in many cases interconnected. Water is a critical requirement for many electricity generation technologies. Two-thirds of total U.S. electricity generation—including many coal, natural gas, nuclear, concentrated solar power (CSP), and geothermal plants—requires water for cooling. In addition, carbon capture, utilization, and storage (CCUS) technologies have significant water demands. Electricity is also required for water and wastewater conveyance, treatment, and distribution. From a full-system perspective, the joint reliance of electricity and water systems can create vulnerabilities (e.g., drought impacts on thermoelectric generation and hydropower), but it can also create opportunities for each system to benefit from well-designed integration. Such challenges and

opportunities can be addressed through improved policy integration, data collection, modeling, analysis, RDD&D, and engagement with stakeholders. Recommendations include:

- Launch an electricity-related Energy-Water Nexus Policy Partnership with Federal, state and local partners.

Provide Federal Incentives for a Range of Electricity-related Technologies and Systems. A package of tax incentives targeted at specific market segments can support an all-of-the-above energy strategy by helping to reduce the costs of deploying and using innovative, commercially available energy technologies. The economies of scale and "learning by doing" promoted by such deployments support continued technology cost reductions and greater market competition. Recommendations include:

- Expand the timeframe and the total capacity allowed under the PTC for nuclear generation.
- Provide tax credits for Carbon Capture, Utilization and Storage.
- Increase power purchasing authorities for the Federal Government from 10 to 20 years.

Address a Range of Power Plant Siting Issues. The land use requirements for different types of power generation reflect significant differences between the various types of infrastructure and their operational requirements. Recommendations include:

- Evaluate and develop generation siting best practices.
- Modernize electricity transmission permitting procedures.

Grid Operations and Planning for Electricity System Reliability, Security and Resilience

Support Industry, State, Local, and Federal Efforts to Enhance Grid Security and Resilience. Some types of extreme weather events are projected to increase in frequency and intensity due to climate change. Cyber threats to the electricity system are increasing in sophistication, magnitude, and frequency. Physical threats remain a concern for industry. These challenges could be mitigated through a combination of cost-benefit analyses, standards, and collaboration across industry, state, local, and federal stakeholders. The recommendations build upon and extend current initiatives, such as DOE's Grid Modernization Initiative and Partnership for Energy Sector Climate Resilience. Recommendations include:

- Develop uniform methods for cost-benefit analysis of security and resilience investments for the electricity system.
- Provide incentives for energy storage.
- Support grants for small utilities facing cyber, physical, and climate threats.
- Support mutual assistance for recovering from disruptions caused by cyber threats.
- Support the timely development of standards for grid-connected devices.
- Require states to consider the value of DER, funding for public purpose programs, energy and efficiency resource standards, and emerging risks in integrated resource or reliability planning under PURPA.

Improve Data for Grid Security and Resilience. As the nation increasingly relies on electricity to power the economy and support consumer options and choices, the consequences of electricity outages are rising. The U.S. currently lacks sufficient data on all-hazard events and losses. Such data would help utility regulators, planners, and communities analyze and prioritize security and resilience investments. Recommendations include:

- Enhance coordination between Energy Sector Information Sharing and Analysis Centers (ES-ISACs) and the intelligence communities to synthesize threat analysis and disseminate it to industry in a timely and useful manner.

Encourage Cost-effective Use of Advanced Technologies that Improve Transmission Operations. Permitting and planning are necessary, but complex processes that can slow transmission development and increase costs. Other barriers restrain the use of new technologies that can increase transmission system capacity utilization and improve reliability and security, and other planning priorities. Recommendations include:

- Promote deployment of advanced technologies for new and existing transmission.

Improve EIA's Electricity Data, Modeling, and Analysis Capabilities. EIA provides all levels of stakeholders--government, companies and customers--with data to inform the evaluation and development of policies that affect the electricity grid. More timely and publicly accessible data on how system operations are changing and how efficiency and renewable energy are specifically affecting them would facilitate the development of federal and state policies and investments needed to ensure the reliability, resilience, and security of the grid. Substantially improved electricity transmission data and related analyses by EIA would support significant improvements in the effectiveness of a broad range of government policies and programs, including market design and transmission planning. Recommendations include:

- Expand economic modeling capability for electricity.
- Expand EIA data collection on energy end-use.
- Support EIA's collection of additional data on electricity and water flow for water and wastewater.

Electric Workforce of the 21st Century

Support the Electricity Sector Workforce. The electricity sector is undergoing a number of significant shifts in structure, energy sources, and applications as the industry modernizes and evolves. The full potential of these shifts will, however, only be realized if the electricity sector workforce appropriately adapts and grows to meet the needs of the 21st century electricity system. The federal government has both an interest in development of this workforce. Recommendations include:

- Support Cyber Physical Systems (CPS) curriculum, training, and education for grid modernization and cybersecurity.
- Support Federal and regional approaches to electricity workforce development and transition assistance.

Meet Federal Commitments to Communities Affected by the Transformation of the Electricity Sector. To achieve the transition to the electricity sector of the 21st century smoothly, quickly, and fairly, the Federal government should offer a synthesized package of incentives that address the needs of the most important stakeholders both within and outside of the electricity sector. Many of these needs are addressed through other recommendations on this list, including incentives to reduce the cost of flexible and clean assets, encourage the deployment of new and improved technologies throughout the electricity supply chain, and train workers for 21st century electricity jobs. Recognizing that the shift to the 21st century electricity system can impact communities dependent on 20th century resources, the following recommendations provide transition assistance for communities affected by the multi-decadal decline in coal production. Recommendations include:

- Meet the Federal commitment to appropriate sufficient funding to accomplish the mission of the Abandoned Mine Lands Fund.

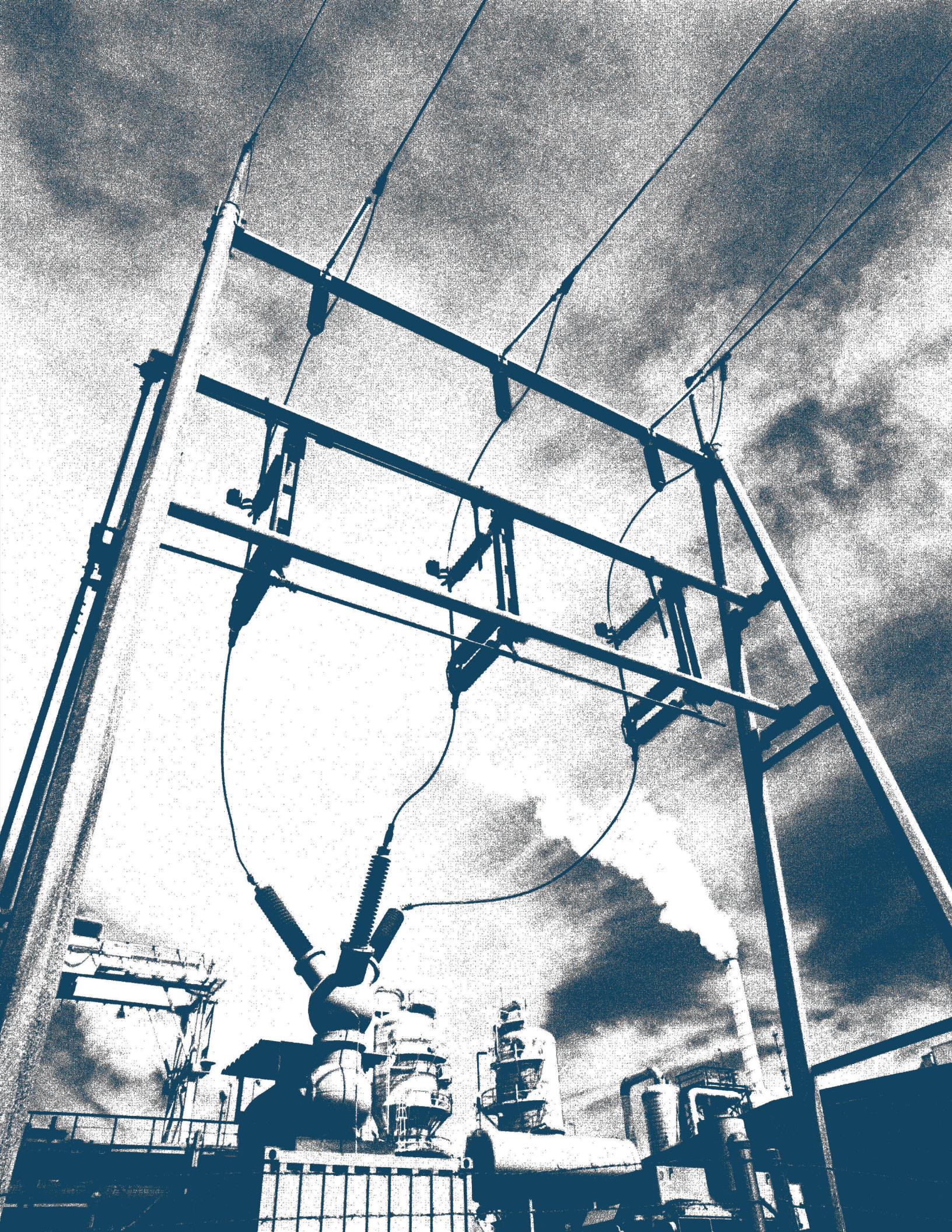
Enhance Electricity Integration in North America

Increase North American Cooperation on Electric Grid and Clean Energy Issues: Electric reliability cooperation is needed to strengthen the security and resilience of an increasingly integrated cross-border electricity grid. A clear understanding of the regulatory requirements at the federal and state levels for the permitting of cross-border transmission facilities, sharing of best practices, and exploration of potential future cooperation on grid security issues, will limit uncertainties and improve policy coordination at the multilateral and international levels. Recommendations include:

- Increase U.S. and Mexican cooperation on reliability.
- Advance North American grid security.
- Modernize international cross-border transmission permitting processes.

Conclusion

The electricity sector has been, and will continue to be, an indispensable tool to enable the United States to meet its linked National goals. Thanks to technology innovation and more than a century of development, the electricity system is already an extraordinary national asset. It has supported significant progress towards economic prosperity, equity, environmental responsibility, and security and resilience. The QER identifies many approaches that can build on this success to advance – and accelerate – the electricity system's role in meeting these goals.



I Transforming the Nationôs Electricity System: The Second Installment of the QER

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Conceptual Framework for Electricity Sector Policy Considerations

Thomas Edisonôs observation that electricity had the potential to ñreorganize the life of the worldò was prescient. Electricity is now foundational to modern life and has enabled enormous value creation over the last 130 yearsð from Edisonôs Pearl Street Station, to Insullôs grid, to the electrification of rural America, to the build-out of the Nationôs grid after World War II, to todayôs vast and complex interconnected power grid.[1]

9fŜŎúNλÔλúě λă ŜăăŜyűλI·f ₮2NJ úKŜ bI·úλ2yQă Ô2yãdzY ŜNJăΣ Ô2Y ŸŜNJÔλI·f I·yŘ λyŘdzăúNλI·f ăŜÔű2NJăΣ ă2ÔλI·f ₮I·ōNJλÔΣ I·yŘ yI·űλ2yI·f ŘŜ₮ŜyãŜΦ ¢KŜ ŜfŜÔúNλÔλúě ăŜÔű2NJ λăΣ K2ǿŜØŜNJΣ Ô2yFNJ2yűλyE I· Ô2Y LJfŜÈ ăŜű 2₮ ÔKI·yESă I·yŘ ÔKI·ffŜyESăΣ λyÔfdzŘλyE I·EλyE λyFNJI·ăúNJdzŎűdzNJŜT I· ÔKI·yEλyE EŜyŜNJI·űλ2Y Y λÈT ENJ2ǿλyE LJŜySűNJI·űλ2Y 2₮ ØI·NJλI·ōtŜ ESySNJI·űλ2yT f2ǿ I·yŘ λy ă2YŜ ÔI·ăŜă ySEI·úλØŜ f2I·Ř ENJ2ǿűKT ÔfλY I·ûŜ ÔKI·yESŜT λyÔNJŜI·ăŜŘ LJKèăλÔI·f I·yŘ Ôèō ŜNJăŜÔdzNJúě NJλă]ăT I·yŘ λy ă2YŜ NJŜEλ2ya ǿλŘŜăLJNJŜI·Ř I·Ř2LJűλ2y 2₮ ŘλăúNJλōdzúŜŘ ŜySNJEè NJŜă2dzNJÔŜă ó59wúΦ I2ǿ úKŜăŜ ÔKI·yESă I·NJŜ YI·yI·EŜŘ λă ÔNJλúλÔI·f I·yŘ Ô2dzfŘ ₮dzyŘI·YŜyűI·ffè úNJI·yã₮2NJY úKŜ ŜfŜÔúNJλÔλúě ăèăúŜY Qă áúNJdzÔűdzNJŜΣ 2LJŜNJI·úλ2yãΣ Ödzăű2YŜNJ ōI·ăŜΣ I·yŘ ?dzNJăŘλÔűλ2yI·f FNJI·YŜǿ2NJ]Φ *The electricity system is the enabler for accomplishing three key national goals: improving the economy, protecting the environment, and increasing national security. As a critical and essential national asset, it is a strategic imperative to protect and enhance the value of the electricity system through modernization and transformation.*

¢KλăÔKI·LJűŜNJ ǿλff ŜÈLJf2NJŜ úKŜ Ô2yűŜÈű ădzNJN2dzyŘλyE úKŜ úNJI·yã₮2NJY I·úλ2y 2₮ úKŜ bI·úλ2yQă ŜfŜÔúNJλÔλúě ăèăúŜYΣ λyÔfdzŘλyE úKŜ ÔNJλúλÔI·f N2fŜ úKI·ú ŜfŜÔúNJλÔλúě LJfI·èă λy úKŜ bI·úλ2yQă λyFNJI·ăúNJdzÔűdzNJŜΣ 2LJLJ2NJúdzyűλŜă úKI·ú úKŜ ŜfŜÔúNJλÔλúě ăèăúŜY I·yŘ ǿλŘŜăLJNJŜI·Ř ŜfŜÔúNJλ₮λÔI·úλ2y I·yŘ ŘλEλúλÎI·úλ2y KI·ØŜ ÔNJŜI·úŜŘ û2 ŜyKI·yÔŜ ŜÔ2y2YλÔ ØI·fdzŜΣ úKŜ λYLJŜNJI·úλØŜ û2 NJŜŘdzÔŜ ÔI·N2y ŜYλăăλ2yã û2 YλúλEI·úŜ ÔfλYI·úŜ ÔKI·yESΣ ySǿ YI·yI·EŜYŜyű ÔKI·ffŜyESă ₮2NJ ENJλŘ 2LJŜNJI·ú2NJă úKI·ú KI·ØŜ I·NJλăŜy ŘdzŜ û2 NJŜÔŜyű úNJŜyŘă λy ŜfŜÔúNJλÔλúě ESySNJI·úλ2y I·yŘ ŘŜYI·yRΣ I·yŘ úKŜ yI·űλ2yI·f ăŜÔdzNJλúě λYLJfλÔI·úλ2yã 2₮ ENJλŘ ŘŜLJŜyŘŜyÔè¢ ¢K2dzEK úKŜ ?dzNJλăŘλÔűλ2yI·f ăúNJdzÔűdzNJŜ 2₮ úKŜ ŜfŜÔúNJλÔλúě ăèăúŜY λă Ô2YLJfŜÈΣ úKŜ CŜŘŜNJI·f D2ØŜNJyY Ŝyű ǿλff LJfI·è I· Y I·?2NJ N2fŜ λy Y I·yI·EλyE úKŜ ÔKI·ffŜyESă I·yŘ úI·]λyE I·ŘØI·yűI·ES 2₮ úKŜ 2LJLJ2NJúdzyűλŜă úKI·ú úKŜ нмăú ÔŜyűdzNJè ENJλŘ LJNJŜăŜyűă¢

The U.S. Electricity System: Operating and Economic Statistics

In the United States, there are around 7,700 operating power plants[2] that generate electricity from a variety of primary energy sources; 707,000 miles of high-voltage transmission lines;[3] more than 1 million rooftop solar installations;[4] 55,800 substations;[5] 6.5 million miles of local distribution lines;[6] and 3,354 distribution utilities[7] delivering electricity to 147 million customers.[a, 8] The total amount of money paid by end users for electricity in 2015 was about $400 billion.[9] This drives an $18.6 trillion U.S. gross domestic product and significantly influences global economic activity totaling roughly $80 trillion.[10]

1.1 Electricity from Generation to End Use: Quadrennial Energy Review 1.2

¢KŜ ăŜÔ2yŘ λyăúI·ffYŜyű 2₮ úKŜ vdzI·ŘNJŜyyλI·f 9ySNJEè wŜØλŜǿ óv9w м¢нú I·yI·fêÎŜă úNJŜyŘă I·yŘ λăădzŜă Ô2y₮NJ2yűλyE úKŜ bI·úλ2yQă ŜfŜÔúNJλÔλúě ăŜÔű2NJΣ ŜÈI·YλyλyE úKŜ ŜyűλNJŜ ŜfŜÔúNJλÔλúě ădzLJLJfè ÔKI·λy ₮NJ2Y EŜySNJI·úλ2y űž ŜyŘ dzăŜ¢ lú ōdzλfŘă 2y I·yI·fèăλă I·yŘ NJŜÔ2YYŜyŘI·úλ2yã λy úKŜ ₮ANJăú λyăúI·ffYŜyű 2₮ úKŜ vdzI·ŘNJŜyyλI·f 9ySNJEè wŜØλŜǿ óv9w м¢мúΣ ǿKλÔK λyÔfdzŘŜŘ ŜfŜÔúNJλÔλúě I·ă LJI·NJű 2₮ I· ōN2I·ŘŜNJ ŜÈI·YλyI·úλ2y 2₮ ŜySNJEè úNJI·yãYλăăλ2yΣ ŘλăúNJλōdzűλ2yΣ I·yŘ ăű2NJI·EŜ λyFNJI·ăúNJdzÔűdzNJŜă¢

v9w м¢м λŘŜyűλ₮λŜŘ]Ŝè úNJŜyŘă úKI·ú ădzE3ŜăúŜŘ úKŜ ySŜŘ ₮2NJ ENJŜI·úŜNJ I·yI·fèăλă û2 λy₮2NJY I· ăŜű 2₮ NJŜÔ2YYŜyŘI·úλ2yã úKI·ú ǿλff KŜfLJ ăŜű I· LJI·úKǿI·è ₮2NJ Y2ŘŜNJyλÎŜŘ ŜfŜÔúNJλÔλúě ăèăúŜYă ÔI·LJI·ōfŜ 2₮ YŜŜűλyE úKŜ

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[a] ! áÔdzăű2YŜN£ λă ŘŜ₮λySŘ I·ă I·y Ŝyűúě úKI·ú λă Ô2yãdzYλyE ŜfŜÔúNJλÔλúě I·ú 2yŜ ŜfŜÔúNJλÔ YŜűŜN¢ ¢KdzăΣ I· Ôdzăű2YŜN YI·è ōŜ I· fI·NJEŜ ₮I·ÔűλNJèΣ I· Ô2YYŜNJÔλI·f ŜăűI·ōfλăKYŜyűΣ 2N I· NJŜăŘŜyÔŜ¢ ! N2dzE3K NdzfŜ 2₮ űKdzYō λă úKI·ú ŜI·ÔK NJŜăŘŜyűλI·f ŜfŜÔúNJλÔ YŜűŜN ăŜNJØŜă н¢p LJŜ2LJfŜ¢ h₮ úKŜ bI·úλ2yQă мпт YλffQ2yÖdzăű2YŜN£ мо YλffQ2y y2ǿ LJdzNJÔKI·ăŜ ŜfŜÔúNJλÔλúě FN2Y y2yπdzűλfQúě NJŜűI·λf ăŜNJØλÔŜ LJN2ØλŘŜN£ Ô2YLJNJăλyE нл LJŜNJÔŜyű 2₮ I·ff ¦¢{¢ NJŜűI·λf ŜfŜÔúNJλÔ ăI·fŜă óYŜ3I·ǿI·úűπK2dzNJăú I·yŘ ŘŜfQØŜNJŜŘ Y2ăűfè ōè λyØŜăú2NJπ2ǿySŘ ŘλăúNJλōdzűλ2y dzűλfQűλŜă£ λy úKŜ мф ăűI·úŜă I·yŘ 5λăúNJλÔű 2₮ /2fdzYōλI· úKI·ú I·ff2ǿ NJŜűI·λf Ô2YLJŜűλúλ2y¢

bl·ûλ2yΩă ySŜŘă λy˝l· нмăΰ ŎŜyΰdzNè ŜŎ2y22Y˙è◊ ¢NŜyŘă ₮2N v9w м◊н λyŎfdzŘŜ ûKŜ ŎKl·yΞλyΞ ΞŜySNl·ûλ2y˝Y˙λÈT f2ø f2l·Ř ΞN2øûK˙T λyŎNŜl·ăλyΞ Ødzfy$Nl·ōλfλûλŜă ú2 ăŜØŜNŜ øŜl·ûKŜNkŎfλY˙l·ûŜ ŎKl·yΞŜ˙ ûKŜ LJN2fλ˙ŜNl·ûλ2y˝ 2₮ ySø ûŜŎKy2f2ΞλŜăΣ ăŜNØλŎŜăΣ l·yŘ Y˙l·N˙ʃŜΰ Ŝyΰ$Nl·yΰă˙ λyŎNŜl·ăλyΞ Ŏ2yãdzY˙ŜN ŎK2λÖŜ˙ ŜY˙ŜN2λyΞ ŎèōŜNkLJKèăλŎl·f ûKNŜl·ûă˙ l·ΞλyΞ λy₮Nl·ăúNdzŎΰdzNŜ l·yŘ ø2N˙ʃ₮2NŎŜ˙ l·yŘ ûKŜ ΞN2øλyΞ λyΰŜNŘŜLJŜyŘŜyŎŜ 2₮ NŜΞdzfl·û2Nè ∂dzNλăŘλŎûλ2yã◊ wŜŎ2Y˙Y˙ŜyŘl·ûλ2yã ₮2Ödză 2y˝ NŜăŜl·NŎK l·yŘ ŘŜØŜf2LJY˙Syΰ ówɔ5úΣ ăΰ2Nl·ΞŜΣ úNl·yãY˙λăăλ2y˝ LJfl·yγλyΞΣ {ΰl·ûŜ ₮λyl·yŎλl·f l·ăăλăΰl·yŎŜΣ Øl·fdzl·ûλ2y˝ 2₮ ySø ăŜNØλŎŜă l·yŘ ûŜŎKy2f2ΞλŜăΣ l·yŘ λyΰŜN2LJŜNl·ōλfλûè 2₮ ûŜŎKy2f2ΞλŜă◊ !ŘŘŜŘ û2 ûKλă Y˙λÈ˙ λă ûKŜ ΞN2øλyΞ l·yŘ ySl·NπŎ2Y˙LJfŜΰŜ ŘŜLJŜyŘŜyŎŜ 2₮ 2ΰKŜN ŎNλΰλŎl·f λy₮Nl·ăΰNdzŎΰdzNŜă 2y˝ ŜfŜŎΰNλŎλΰèΣ λyŎNŜl·ăλyΞ Ŏ2yãdzY˙ŜN ŎK2λÔŜ 2LJûλ2yã ₮2N ŘλăΰNλōdzΰŜŘ ΞŜySNl·ûλ2yΣ l·yŘ ySø KλΞKπØl·fdzŜ λy₮2NY˙l·ûλ2yκŎ2Y˙Y˙dzyλŎl·ûλ2yã λyŘdzăΰNλŜă l·yŘ ōdzăλySăăŜă◊

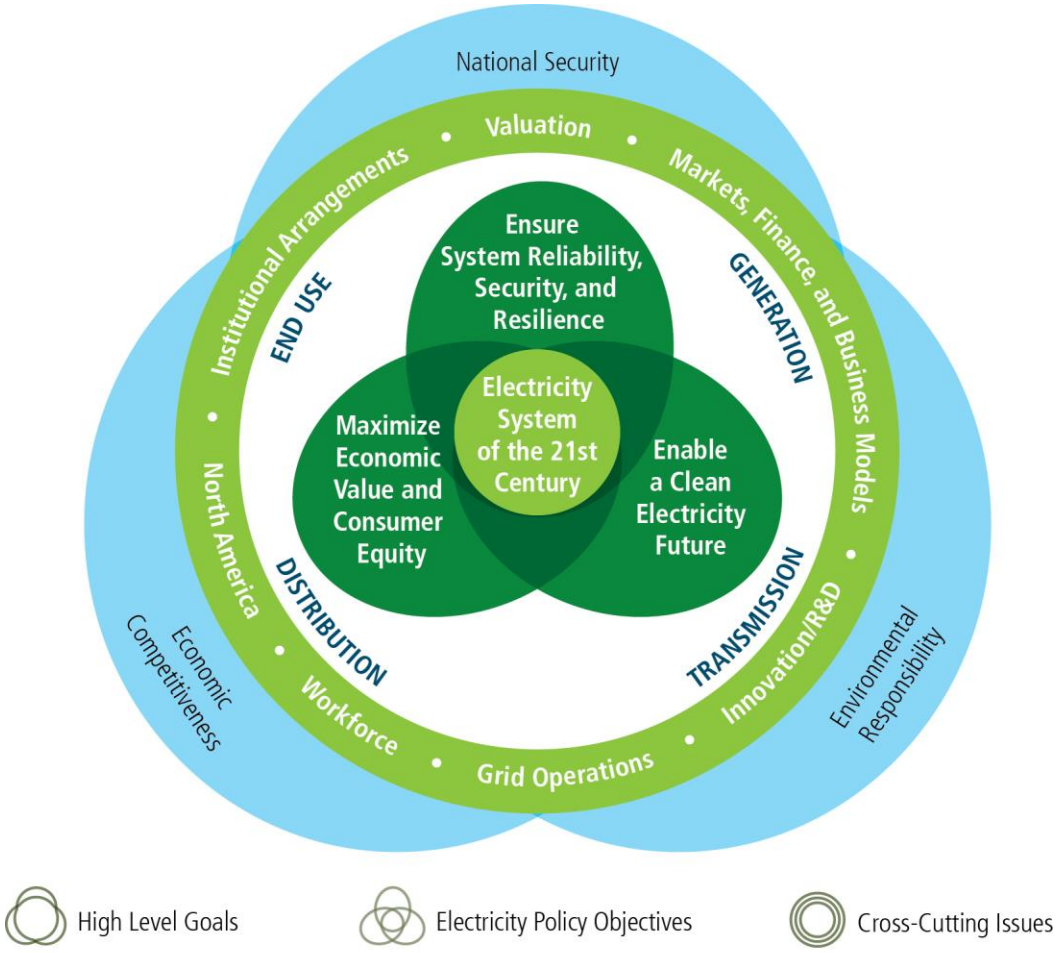
¦ yŘŜNfèλyΞ ûKλă λă ûKŜ ySŜŘ ₮2N ŜØŜNπΞNŜl·ûŜN ăèăΰŜY˙ ăŜŎdzNλΰèΣ ŘNλØŜy˝ōè ΞN2øλyΞ ŎèōŜN l·yŘ LJKèăλŎl·f ûKNŜl·ûăΣ ŜÈLJl·yŘλyΞ λyΰŜNŎ2yγŜŎΰŜŘySăăΣ l·yŘ ûKŜ λyŎNŜl·ăŜ λy˝ŜÈΰNŜY˙Ŝ øŜl·ûKŜN ŜØŜyΰă ōŜŎl·dzăŜ 2₮ ŎfλY˙l·ûŜ ŎKl·yΞŜ◊ ¢Kλă ŜØ2fdzΰλ2y˝ λă l·yŘ øλff ōŜ áōdzY˙LJè€ τ ûKŜ Ŏ2ăΰăkōŜyŜ₮λΰă l·yŘ λyØŜăΰY˙Syΰ NŜljdzλNŜY˙Syΰă ySŜŘŜŘ û2 l·ŎŎ2Y˙Y˙2Řl·ûŜ ŘŜLJf2èY˙Syΰ 2₮ ySø ûŜŎKy2f2ΞλŜă l·yŘ ΞNλŘ Y˙2ŘŜNyλÎl·ûλ2y˝ l·NŜ ŎKl·ftŜyΞλyΞ ûKŜ ŜfŜŎΰNλŎλΰè λyŘdzăΰNè l·yŘ NŜΞdzfl·û2Nă l·fλ˙ʃŜ û2 dzyŘŜNăΰl·yŘ ăŎl·fŜΣ ăŎ2LJŜΣ l·yŘ 2LJŜNl·ûλyΞ ŎKl·yΞŜă NŜljdzλNŜŘ l·ă ûKŜ ΞNλŘ ΞŜΰă ăY˙l·NΰŜNΣ øλΰK ûKŜ {dzLJNŜY˙Ŝ /2dzNΰ y2ø λy˝ΰKŜ LJ2ăλûλ2y˝2₮ NŜă2fØλyΞ ˙ŜèdzNλăŘλŎûλ2yl·f λăădzŜă◊

1.1.1 National Goals for a 21st Century Electricity Sector

² KλfŜ NŜăLJŜŎûλyΞ {ûl·ûŜΣ NŜΞλ2yl·fΣ l·yŘ úNλōl·f LJNŜN23l·ûλØŜăΣ v9w м◊н ădzLJLJ2Nΰă ŘŜØŜf2LJY˙Syΰ 2₮ Ŏ2yãλăΰŜyΰ CŜŘŜNl·f ăΰNl·ΰŜΞè û2 ădzLJLJ2Nΰΰ l· нмăΰ ŎŜyΰdzNè ŜyŜNΞè ăèăΰŜY˙◊

v9w м◊н øλff l·yl·fèÎŜ ûKŜăŜ λăădzŜă λy˝ ûKŜ Ŏ2yΰŜÈΰ 2₮ ûKNŜŜ 2ØŜNl·NŎKλyΞ yl·ûλ2yl·f Ξ2l·fă û2 óMú ŜyKl·yŎŜ ŜŎ2y2Y˙λŎ Ŏ2Y˙LJŜΰλûλØŜyŜăăΣ óHú LJN2Y˙2ΰŜ ŜyØλN2yY˙Syΰl·f NŜăLJ2yãλōλfλûèΣ l·yŘ óoú LJN2ØλŘŜ ₮2N ûKŜ bl·ûλ2yΩă ăŜŎdzNλúè◊ ¢KŜ 2ØŜNl·ff ăΰNdzŎΰdzNŜ 2₮ ûKŜ ăΰdzŘè l·yŘ λûă NŜŎ2Y˙Y˙SyŘl·ûλ2yã λă ŘŜLJλŎΰŜŘ λy˝ CλΞdzNŜ MTM◊ {ŜŎdzNλúèΣ ŜŎ2y2Y˙èΣ l·yŘ ŜyØλN2yY˙Syΰl·f NŜăLJ2yãλōλfλûè l·NŜ l·ff λyΰŜNŎ2yγŜŎΰŜŘ l·yŘ ŎN2ăăŎdzΰΰλyΞ◊ ¢Nl·yãŧ2NY˙l·ûλ2y˝ 2₮ ûKŜ ŜfŜŎΰNλŎλΰè ăŜŎΰ2N Y˙dzăΰ l·ŘŘNŜăă l·ff ûKNŜŜ yl·ûλ2yl·f Ξ2l·fă◊

Figure 1-1. Goals, Objectives, and Organization of QER 1.2



The organization of QER 1.2 reflects the comprehensive set of interactions and overlapping goals and objectives for enabling the electricity system of the 21st century.

!yl·fèäŜă ǿŜNŜ Ò2yŘdzŎűŜŘ ǿλűK KλƎKπfŜØŜf yl·űλ2yl·f Ǝ2l·fă l·ă ƎdzλŘŜLJ2ăűăϒ óMú yl·űλ2yl·f ăŜŎdzNλűèΣ óHú ŜyØλN2yϒŜyűl·f NŜăLJ2yãλōłfλűèΣ l·yŘ óoú ŜŎ2y22ϒλŎ Ò2ϒLJŜűλűλØŜyŜăă℗ /ŜyűNl·f ű2 űKŜ v9w M℗H λă l· ăŜű 2ŦűKNŜŜ l·yl·fèűλÔl·ffè ŘŜNλØŜŘ 2ō2ŜŎűλØŜă ŭKl·ú NŜLJNŜăŜyű l·yϒλyűŜƎNl·ŭŜŘ l·LJLJN2l·ÔK ű2 Ŝyl·ōfłyƎ ŭKŜ ŜfŜŎűNλŎλűè ăèăűŜϒ 2Ł ŭKŜ нмăű ÔŜyűdzNè ŭKN2dzƎK ŭKŜăŜ KλƎKπfŜØŜf Ǝ2l·fã℗ ¢KŜăŜ 2ō2ŜŎűλØŜă l·NŜ óMú ŜyãdzNλyƎ ăŜŎdzNλűèΣ ăèăűŜϒ NŜăłfłŜyŎŜΣ l·yŘ NŜfłl·ōłfłűèŤ óHú Ŝyl·ōfłyƎ l· ŎfŜl·yϒŜfŜŎűNλŎλűè ŦdzűdzNŜŤ l·yŘ óoú λyŎNŜl·ăλyƎ ŜŎ2y22ϒλŎ Øl·fdzŜ l·yŘ Ŝyãdz NλyƎ Ò2yãdzϒŜN Ŝljdzλűè℗ v9w M℗H l·fã2 LJN2ØλŘŜă l· Ò2ϒLJNŜKŜyãλØŜ NŜØλŜØ 2Ł ŭKŜ bl·űλ2yΩă ŜfŜŎűNλŎλűè ăèăűŜϒ l·yŘ Ò2ØŜNă ŭKŜ Kλăű2Nè l·yŘ]Ŝè űNŜyŘă NŜfl·ŭŜŘ ű2 ŭKŜ ŜfŜŎűNλŎλűè ăèăűŜϒΣ λyŎfdzŘλyƎ óMú ƎŜyŜNl·ŭλ2yΣ óHú űNl·yãϒλăăλ2yΣ óoú Řλăűλdzűλ2yΣ l·yŘ óMú ŜyŘ dzăŜ℗

1.1.1.1 Economic Competitiveness and the Electricity System

!]Ŝè ŘNλØŜN Ł2N ¦℗{℗ ŜŎ2y22ϒλŎ Ò2ϒLJŜűλűλØŜyŜăă Kl·ă ōŜŜyϒ ŭKŜ ădzLJLJfè l·yŘ ŘŜfłØŜNè 2Ł ŜfŜŎűNλŎλűè ŭKl·ú λă l·ŦŦ2NŘl·ōfŜΣ l·ŎŎŜăăλōfŜΣ l·yŘ NŜfłl·ōfŜ℗ ¢KŜ NŜfłl·ōłfλűè 2Ł ŜfŜŎűNλŎλűè ŘλNŜŎűfè l·ŦŦŜŎűă ŭKŜ ŜŦŦλŎλŜyŎè 2Ł LJN2ŘdzŎűλ2yϒ LJN2ŎŜăăŜăΣ Syl·ōfłyƎ ŭKŜ ŜŦŦλŎλŜyűκŎ2ăűπŜŦŦŜŎűλØŜ Ò22NŘλyl·ûλ2yϒ2Ł ŜŎ2y22ϒλŎ l·ŎűλØλűè ǿλűK2dzú ŘλăNdzLJûλ2y℗ ² λűK ă2ϒŜ 2Ł ŭKŜ f2ǿŜăű ŜfŜŎűNλŎλűè LJNλŎŜă λyϒ ŭKŜ ŘŜØŜf2LJŜŘ ǿ2NfŘ²ᴹᴹ ŭKŜ ¦℗{℗ ŜfŜŎűNλŎλűè ăŜŎű2N ădzLJLJ2NűăŜŎ2y22ϒλŎ Ò2ϒLJŜűλűλØŜyŜăă 2Ł ¦℗{℗ Ǝ22Řă l·yŘ ăŜNØλŎŜă λyϒ ō2űK Ř2ϒŜăűλŎ l·yŘ Ǝf2ōl·f ϒl·N]ŜűăϒŜyŎèΣ yŜǿ l·ŜŎKλűŜŎűdzNŜă ăK2dzfŘ Syl·ōfŜ yŜǿ l·NŎKλűŜŎűdzNŜă ű2 ăűλϒdzfl·ûŜ SyŜNƎè ŜŦŦλŎλŜyŎèΣ yŜǿ ŜŎ2y22ϒλŎ ûNl·yãl·ÔûλyãΣ l·yŘ yŜǿ Ò2yãdzϒŜN ăŜNØλŎŜă℗ ¢KŜ ϒ2ŘŜNyλÎl·ûλ2yϒ2Ł ŭKŜ ¦℗{℗ ŜfŜŎűNλŎλűè ăèăűŜϒ τ ŭKN2dzƎK ŭKŜ

∃№2ǿűK 2ŦŏfŜI·y΢ăY·I·№ŰΣ I·yŘ №ŜăƛfΩŜyű ăëăűŜY˙ă I·yŘ ăŜ№ØΛŏŜă τ ǿλtf ŏ№ŜI·ŰŜ ŘŜY˙I·yŘ Ŧ2№ I·y˙ŜyKI·yŏŜŘ ǿ2№ϽŦ2№ŏŜ ű2 Ŝy1·ōfŜ ŰKλă Ú№I·yãλŰλ2yΦ

1.1.1.2 Environmental Responsibility and the Electricity System

¢KŜ ŜfŜŏŰ№ΛŏλŰè ăëăűŜY˙ ăK2dzfŘ ōŜ ŘŜØŜf2LJŜŘ I·yŘ Y˙I·y1·∃ŜŘ λy˙I·y˙ŜyØΛ№2yY˙Ŝyű I·ffè №ŜăLJ2yãλōfŜ Y˙I·yȳŜ№ ōëΣ λy˙LJI·№ΰΣ I·ŘŘ№ŜăăλyΞ ŰKŜ ŏŜyŰ№I·f ŏKI·ffŜyΞŜ 2Ŧ ŏfΩY˙I·ŰŜ ŏKI·yΞŜ I·yŘ Y˙λŰλ∃I·ŰλyΞ λŰă λY˙LJI·ŏŰă¢ ¢KŜ y1·ûλ2y1·f 2ō?ŜŏŰλØŜ 2Ŧ áŘŜŜLJ ŘŜŏI·№ō2yΛÎ I·Űλ2y£ ōè Y˙λŘπŏŜyűdz№è ǿλtf ŏKI·ffŜyΞŜ ŰKŜ ŜfŜŏŰ№ΛŏλŰè ăŜŏŰ2№ λy˙Y˙I·yȅ ǿI·ëă¢ !ŏKΛŜØλyΞ ŰKλă]Sè 2ō?ŜŏŰλØŜ ǿλtf λY˙LJ№2ØŜ ŰKŜ KŜI·fŰK 2Ŧ !Y˙Ŝ№ŏI·yã I·yŘ ŰKŜ ŜyØΛ№2yY˙Syű 2Ŧ ŰKŜ Ŏ2dzyŰ№ëΣ ō2ŰK 2Ŧ ǿKΛŏK I·№Ŝ LJ2ăλŰλØŜ Ŏ2yŰ№ŏdzŰλ2yã ű2 Y˙I·ŰŰŜ№ă 2Ŧ Ŝŏ2y2Y˙λŏ Ŏ2Y˙LJŜŰλŰλØŜyŜăă I·yŘ y1·ûλ2y1·f ăŜŏdz№ΛŰè¢ !ű ŰKŜ ăI·Y˙Ŝ ŰλY˙Ŝ LJ2fΛŏëY˙I·]Ŝ№ăΣ λyØŜăŰ2№ăΣ I·yŘ λyŘdzăŰ№è Y˙dzăŰ Ŏ2yãλŘŜ№ I·yŘ I·ŘŘ№ŜăăŰKŜ f2y∃ăŰI·yŘλy∃ ySŜŘă 2Ŧ ŰKŜ Ødzfy Ŝ№I·ōfŜ ăŜ∃Y˙Syűă 2Ŧ ŰKŜ LJ2LJdzfI·ûλ2y˙ I·yŘ I·LJLJ№2LJ№ΛI·ŰŜfè I·ŘŘ№ŜăăŰKŜăŜ λăădzŜă I·ă ŰKŜ ŜfŜŏŰ№ΛŏλŰè ăëăűŜY˙ λă Ú№I·yãŦ2№Y˙ŜŘ¢

hŰKŜ№ Ŏ№ΛŰλŏI·f ŜyØΛ№2yY˙Syű I·f Ŏ2yŏŜ№yã λyŏfdzŘŜ ŏfΛY˙I·ŰŜ I·ŘI·LJŰI·ûλ2yT ŦdzNŰKŜ№ №ŜŘdzŏŰλ2yã λy˙Ŏ2yØŜyűλ2y1·f LJ2ffdzűI·yŰăT I·ŘŜIjdzI·ŰŜfè I·y1·fèÎλyΞ I·ŘŘ№ŜăăλyΞΣ I·yŘ Y˙I·y1·∃λyΞ ŰKŜ ŜyŜ№∃èπǿI·ŰŜ№ ySÈdzăT №ŜŘdzŏλyΞ fI·yŘπdzăŜ I·yŘ 2ŰKŜ№ λY˙LJI·ŏŰă 2Ŧ ŜfŜŏŰ№ΛŏλŰè ∃ŜySŜ№I·ûλ2yΣ Ú№I·yãY˙λăăλ2yΣ I·yŘ ŘλáŰ№ΛōdzŰλ2yT I·yŘ λyŦ№I·ăŰ№dzŏŰűdz№Ŝ fΛŦŜŏëŏfŜ Y˙I·y1·∃ŜY˙Ŝyű¢

1.1.1.3 National Security and the Electricity System

9fŜŏŰ№ΛŏλŰè λă ŜăăŜyűλI·f Ŧ2№ ădzLJLJ2№ŰλyΞ I·yŘ ădzăŰI·λyλyΞ λyŘdzăŰ№ΛI·f 2dzŰLJdzŰΣ ∃2ØŜ№yY˙Syű Σ ŜY˙Ŝ№∃Ŝyŏè ăŜ№ØΛŏŜăΣ λyűŜ№ŘŜLJŜyŘŜyű fΛŦŜfΛyŜ ySűǿ2№ϽăΣ I·yŘ ŰKŜ ¦¢{¢ y1·ûλ2y1·f ăŜŏdz№ΛŰè I·LJLJI·№I·ŰdzăΦ [λŦŜfΛyŜ ySűǿ2№ϽăΣ λyŏfdzŘŜ LJKèăλŏI·f I·yŘ λyŦ2№Y˙I·ûλ2y˙λyŦ№I·ăŰ№dzŏŰűdz№Ŝ ŰKI·ű I·№Ŝ №ŜIjdz№ŜŘ Ŧ2№ Ŏ2Y˙Y˙dzyλŏI·ûλ2yãΣ Ú№I·yãLJ2№ŰI·ûλ2yΣ I·yŘ I·fY˙ăűŜØŜ№è 2ŰKŜ№ ŜfŜY˙Syű 2Ŧ Ŝŏǿy2Y˙λŏ I·yŘ ă2ŏλI·f I·ŏŰλØλŰè¢ 9ØŜy˙ŰK2dz∃K ϽŰ λă ŜăăŜyűλI·f ű2 ŰKŜ Ŝŏǿy2Y˙èΣ fΛŦŜfΛyŜ ySűǿ2№ϽăΣ ŜY˙Ŝ№∃ŜyŏλŜăΣ I·yŘ ŰKŜ y1·ûλ2y1·f ăŜŏdz№ΛŰè I·LJLJI·№I·ŰdzăΣ ŜfŜŏŰ№ΛŏλŰè τ dzyfΛ]Ŝ 2λf τ ŏI·yȳ2ű ōŜ ăŰ2№ŜŘ I·ŰăŏI·fŜ¢ ¢KŜ ŜfŜŏŰ№ΛŏλŰè ăëăűŜY˙ ăK2dzfŘ ōŜ I· Ŏ2yãλŘŜ№I·ûλ2y˙ I·yŘ λyŏfdzŘŜŘ λy˙ŰKŜ ŘŜØŜf2LJY˙Syű 2Ŧ y1·ûλ2y1·f ăŜŏdz№ΛŰè Ř2ŏŰ№ΛyŜΣ LJ2fΛŏλŜăΣ I·yŘ LJfI·yã¢ ! Ŏ2yűλyűz2dză ŜŦŦ2№Ű ű2 Y˙I·λyűI·λy˙№ŜfΛI·ŏfŜ ŜfŜŏŰ№ΛŏλŰè ădzLJLJfΛŜă λy˙ŰKŜ ŦI·ŏŜ 2Ŧ I· ∃№2ǿλyΞ yűzY˙ōŜ№ 2Ŧ LJ2ŰŜyűλI·f ŰK№ŜI·ŰăóŏèōŜ№Σ ŜfŜŏŰ№2Y˙I·∃yŜŰλŏ LJdzfăŜΣ ŰŜ№№2№ăŰ I·ŰűI·Ŏ]ăΣ I·yŘ yI·ŰdzNJI·f ŘλăI·ăűŜ№ăÚ λă №ŜIjdzλ№ŜŘ Ŧ2№ ŰKŜ y1·ûλ2y1·f ŘŜŦSyãŜΣ Ŏ2yűλyűzλŰè 2Ŧ ∃2ØŜ№yY˙Syű Σ Ŝŏǿy2Y˙λŏ LJ№2ăLJŜ№ΛŰè∃ I·yŘ Ijdz I·fŰŰè 2Ŧ fΛŦŜ yI·ûλ2yǿλŘŜ¢

1.1.2 Turning National Goals into Actionable Priorities for Electricity System Transformation: Integrated Objectives for QER 1.2

¢KŜ I·y1·fèăλă Ŏ2yŘdzŏŰŜŘ Ŧ2№ ŰKŜ v9w м¢н λŘŜyűλŦΛŜŘ ŰK№ŜŜ Y˙I·?2№ *integrated objectives* ŰKI·ű I·ŘŘ№ŜăăŰKŜ ySŜŘă I·yŘ ŏKI·ffŜyΞŜă ű2 Ŝy1·ōfŜ ŰKŜ ŜfŜŏŰ№ΛŏλŰè ăŜŏŰ2№ 2Ŧ ŰKŜ нмăű ŏŜyűdz№è¢ ¢KŜăŜ 2ō?ŜŏŰλØŜă τ ŘλăŏdzăăŜŘ λy˙ŘŜű I·λf λy˙ăŜØŜ№I·f v9w м¢н ŏKI·LJŰŜ№ă¢

1.1.2.1 Maximize Economic Value and Consumer Equity

¢KŜ ¦yλűŜŘ {ű I·ûŜă KI·ă №ŜfI·ŰλØŜfè f2ǿπŏ2ăű ŜfŜŏŰ№ΛŏλŰè I·yŘ I· KΛ∃Kfè №ŜfΛI·ōfŜ ŜfŜŏŰ№ΛŏλŰè ŘŜfØŜ№è ăëăűŜY˙ óŰ№I·yãY˙λăăλ2y˙ I·yŘ ŘλăŰ№ΛōdzŰλ2yű¢ t2ǿŜ№ λă ∃ŜySŜ№I·ûŜŘ F№2Y˙ ō2ŰK ŏŜyŰ№I·f I·yŘ 2yãλŰŜ ă2dz№ŏŜăΣ ădzŏK I·ă ŘλăŰ№ΛōdzűŜŘ ă2fI·№ I·yŘ Ŏ2Y˙ōΛySŘ KŜI·ű I·yŘ LJ2ǿŜ№ λyãűI·ffI·ûλ2yã¢ ¢KŜ ădzY˙ 2Ŧ ŰKŜăŜ ŏI·LJI·ŏΛfΛûλŜă λă I· LJfI·ûŦ2№Y˙ 2y˙ǿKΛŏK I· ØλōNJI·yű ∃f2ōI·ffè Ŏ2Y˙LJŜŰλŰλØŜ Ŝŏǿy2Y˙è ŰK№ΛØŜă¢

!fűK2dz∃K ŜfŜŏŰ№ΛŏλŰè λă I·y˙ ŜySŜ№∃è ŏI·№ΛŜ№ I·yŘ y2ű I· LJ№ΛY˙I·№è ŜySŜ№∃è ă2dz№ŏŜΣ ŜfŜŏŰ№ΛŏλŰè ŜÈKλōΛûă ŰKŜ λyűŜ№ŏKI·y∃ŜI·ōfŜ ŏKI·№I·ŏŰŜ№ăûŰλŏă Ŧ I· Ŏ2Y˙Y˙2ŘλûèΤ I·]λf2ǿI·ûŰπK2dz№ ∃ŜySŜ№I·ûŜŘ ōè I·yè №Ŝă2dz№ŏŜ ŏI·y˙ōŜ ŜI·ăΛfè dzăŜŘ ōè I·yè ûèLJŜ 2Ŧ Ödzăű2Y˙Ŝ№¢ 9fŜŏŰ№ΛŏλŰè λă dzyΛIjdzŜ I·ă I· Ŏ2Y˙Y˙2ŘλûèΣ K2ǿŜØŜ№Σ ōŜŏI·dzăŜ λű №ŜIjdz№ŜăŜ №ŜI·fπ ûλY˙Ŝ ōI·fI·yŏλy∃ I·Ŏ№2ăă Y˙dzfŰλLJfŜ ăLJI·ûλI·f I·yŘ ŰŜY˙LJ2№I·f ăŏI·fŜă óf2ŏI·ûλ2yπăLJŜŏΛŦΛŏ LJdzY˙LJŜŘ KëŘ№2 λă I·y˙

ŜÈŎŜLJűλ2yűΦ ¢Kλă ₪ŜIjdzλ₪ŜYŜyű ₮2₪ λYYŜŘλI·űŜ YI·űŎKλyΞ 2₮ ŘŜYI·yŘ I·yŘ ădzLJLJfè ŎI·y′₪Ŝădztű λy′LJ₪λŎŜă űKI·ű ØI·₪è ăλΞyλ₮λŎI·yűtè ₮₪2Y Yλydzű$ ű2 Yλydzű$ 2₪ ăŜI·ă2y′ű2 ăŜI·ă2yΦ

. ŜŎI·dzăŜ YI·yè I·ăLJŜŎűă 2₮ űKŜ ŜfŜŎű₪λŎλűè ăèăűŜY τ λyŎftdzŘλyΞ w ɔ 5 λy′yŜó űŜŎKy2f2ΞλŜăΣ ŜYλăăλ2yã YλűλΞI·űλ2yΣ I·yŘ Ξ₪λŘ ₪ŜfλI·ōλftűè τ I·₪Ŝ LJdzōftŎ ΞŦ2Řă I·yŘ ólff ōŜ dzyŘŜ₪LJ₪2ØλŘŜŘ ōè LJ₪λØI·ûŜ λyŘdzăű₪èΣ ûKŜ ¦Φ{Φ Ξ2ØŜ₪yYŜyű KI·ă LJftI·èŜŘ I· Ŏ₪λűλŎI·f ₪2fŜ λy′ŘŜØŜf2LJλyΞ I· ŎfŜI·y′ŜfŜŎű₪λŎλűè ŜŎ2y2Yè I·yŘ YI·ˆλyΞ ădz₪Ŝ ûKI·ű ûKŜ ŜfŜŎű₪λŎλűè ădzLJLJfè KI·ă Ŏ2yűλydzŜŘ ű2 ōŜ I·Ø I·λftI·ōfŜΣ I·₮₮2₪ŘI·ōfŜΣ I·yŘ ₪ŜfλI·ōfŜ ű2 ¦Φ{Φ λyŘdzăű₪è I·yŘ ŎλűλÎŜyãΦ

I λăű2₪λŎI·ftèΣ ŜfŜŎű₪λŎλűè Ŏ2yãdzY′LJűλ2y′I·yŘ Ξ₪2ăă Ř2YŜăűλŎ LJ₪2ŘdzŎű óD5 t ú KI·ØŜ ûŜyŘŜŘ ű2 Y′2ØŜ λy′űI·yŘŜY τ ŜfŜŎű₪λŎλűè Ŏ2yãdzY′LJűλ2y′ KI·ă ûŜyŘŜŘ ű2 ₪λăŜ ŘdzNλyΞ ŜŎ2y2YλŎ ŜÈLJI·yãλ2yã I·yŘ ₮I·ff ŘdzNλyΞ ₪ŜŎŜăăλ2yã óōŜűØŜŜy′мфрл I·yŘ нлмоΣ ûKŜ₪Ŝ ØI·ă I· cc LJŜ₪ŎŜyű Ŏ2₪NŜfI·ûλ2y′ōŜűØŜŜy′D5 t I·yŘ ŜfŜŎű₪λŎλűè dzăŜúΦᴹᴴ hØŜ₪ ûKŜ fI·ăű ăŜØŜ₪I·f ŘŜŎI·ŘŜăΣ K2ØŜØŜ₪Σ Ξ₪2ØűK λy′ŜfŜŎű₪λŎλűè dzăŜ KI·ă ōŜŜy′f2ØŜ₪ ûKI·y′Ξ₪2ØűK λy′D5 tΦ ¢Kλă λă ŘdzŜ λy′LJI·₪ű ű2 I· ₪ŜăűNdzŎűdz₪λyΞ 2₮ ûKŜ ŜŎ2y2Y′èT I·fă2Σ I·Ŏ₪2ăă I·ff ŜŎ2y2YλŎ ăŜŎű2₪ăΣ ŜyŜ₪Ξè Ŝ₮₮λŎλŜyŎè KI·ă ōŜŜy′ ₪ŜY′I·₪ˆI·ōfè ădzŎŎŜăă₮dzf 2ØŜ₪ ăŜØŜ₪I·f ŘŜŎI·ŘŜă λy′ KŜfLJλyΞ Ŏ2yű₪2f Ŏ2ăűă I·yŘ λY′LJ₪2ØλyΞ LJŜ₪₮2₪YI·yŎŜ I·yŘ LJ₪2ŘdzŎűλØλűèΦ

1.1.2.2 Enable a Clean Electricity Future

adzŎK 2₮ ûKŜ ¦Φ{Φ ŜfŜŎű₪λŎ ăèăűŜY ólă ōdzλftű 2dzű ōŜ₮2₪Ŝ ûKŜ ¦ yλűŜŘ {ű I·ûŜă KI·Ř I· ăλΞyλ₮λŎI·yű Ŏ2Y′LJtŜY′Ŝyű 2₮ Y′2ŘŜ₪y′ ŜyØλ₪2yYŜyűI·f fI·ólăΣ I·yŘ ólűK2dzű ûKŜ ₪I·yΞŜ 2₮ ûŜŎKy2f2ΞλŜă ûKI·ű KI·ØŜ ōŜŜy′ ŘŜØŜf2LJŜŘ I·yŘ ŘŜLJf2èŜŘ ű2 ₪ŜŘdzŎŜ I·λ₪ ŜY′λăăλ2yã I·yŘ 2űKŜ₪ ŜyØλ₪2yYŜyűI·f λY′LJI·Ŏűă 2₮ LJ2ólŜ₪ ΞŜySŜ₪I·ûλ2yΣ ű₪I·yãY′λăăλ2yΣ I·yŘ dzăŜΦ

¢KŜ ŜfŜŎű₪λŎλűè ăŜŎű2₪ ú2ŘI·è λă ûKŜ fI·₪ΞŜăű ă2dz₪ŎŜ 2₮ ¦Φ{Φ Ξ₪ŜŜyK2dzăŜ ΞI·ă óD I Dú ŜY′λăăλ2yãΣ LJI·₪ű λŎdztI·ûŜ Y′I·ûűŜ₪Σ I·yŘ I·ŎλŘ LJ₪ŜŎλLJλűI·ûλ2yT 2yŜ 2₮ ûKŜ fI·₪ΞŜăű dzăŜ₪ă 2₮ ₮₪ŜăK ólI·ûŜ₪T I· Y′I·2₪ ŎI·dzăŜ 2₮ fI·yŘ I·yŘ ŜŎ2ăèăűŜY′ă λY′LJI·ŎűT I·yŘ ûKŜ LJ₪λyŎλLJI·f ă2dz₪ŎŜ 2₮ ₪I·Ř2I·ŎűλØŜ ólăűŜΦ !ŘŘ₪ŜăăλyΞ ûKŜăŜ ŜyØλ₪2yYŜyűI·f Ŏ2yŎŜ₪yă Y′I·è ₪ŜIjdzλ₪Ŝ I· ₪I·yΞŜ 2₮ yŜó LJ2tλŎλŜăΣ I·ŎŎŜfŜ₪I·ûλ2y′ 2₮ ûŜŎKy2f2Ξè λyy2ØI·ûλ2yΣ I·yŘ I·ŘŘλûλ2yI·f λyŎŜyűλØŜă ₮2₪ ûKŜ ŘŜLJf2èY′Ŝyű 2₮ yŜó ûŜŎKy2f2ΞλŜăΦ !ă y2ûŜŘΣ ûKŜ ¦Φ{Φ ŜfŜŎű₪λŎλűè ăèăűŜY ăă ŘŜŜLJfè tλy′ˆŜŘ ű2 ŜyØλ₪2yYŜyűI·f Ijdzl·tλűèT ŜyØλ₪2yYŜyűI·f LJ2tλŎλŜă Y′dzăű ōŜ ŎI·₪Ŝ₮dztfè I·yŘ LJdz₪LJ2ăŜ₮dztfè ōl·fI·yŎŜŘ ólûK 2ûKŜ₪ 2ō2ŜŎűλØŜăΦ Ly′I·ŘŘ₪ŜăăλyΞ I·ăă2ŎλI·ûŜŘ λăădzŜăΣ ûKŜ ¦ yλűŜŘ {ű I·ûŜă ăK2dztfŘ ōdzλtfŘ 2y′LJI·ăű ădzŎŎŜăăŜă λy′₪ŜŘdzŎλyΞ ûKŜ LJdzōftŎ KŜI·fûK I·yŘ ŜyØλ₪2yYŜyűI·f λY′LJI·Ŏűă ₮₪2Y ûKŜ ŜfŜŎű₪λŎλűè ăèăűŜY ōI·ăŜŘ 2y′I· Y′dzűdzI·ffè ₪ŜλyF2₪ŎλyΞ ŎèŎfŜ 2₮ ûŜŎKy2f2ΞλŎI·f λY′LJ₪2ØŜYŜyűă I·yŘ LJ2tλŎλŜăΦ

9IjdzλűèλăI·LJI·₪ûλŎdztI·₪ Ŏ2yŎŜ₪y′ ólKŜy′I·ŘŘ₪ŜăăλyΞ LJ2ffdzűλ2y′₮₪2Y′ ŜfŜŎű₪λŎλűè ΞŜySŜ₪I·ûλ2yΣ ű₪I·yãY′λăăλ2yΣ I·yŘ ŘλăűNλŏdzűλ2yΦ t2ólŜ₪ LJfI·yűă I·yŘ 2ûKŜ₪ ŜfŜŎű₪λŎλűè π₪ŜfI·ûŜŘ λy₮NI·ăű₪dzŎűdz₪Ŝ I·₪Ŝ 2₮ûŜy′f2Ŏ I·ûŜŘ λy′2₪ yŜI·₪ f2ólπ λyŎ2YŜ I·yŘ Y′λy2₪λűè Ŏ2Y′Ydzyλű$ăΣ Ŏ₪ŜI·ûλyΞ ŘλăLJ₪2LJ2₪ű$λ2yl·ûŜ λY′LJI·Ŏűă 2y′ûKŜăŜ LJ2LJdzfI·ûλ2yãΦ !fă2Σ ŎftλY′I·ûŜ ŎKI·yΞŜ λY′LJI·Ŏűă τ ădzŎK I·ă KŜI·ű ólØŜăΣ ŘŜΞ₪I·ŘŜŘ I·λ₪Σ I·yŘ ŜÈú₪ŜY′Ŝ óŜI·ûKŜ₪ τ ólftf I·ŘŘ I·ŘŘλûλ2yl·f ăú₪Ŝăă2₪ă ûKI·ű ólftf ŘλăLJ₪2LJ2₪ű$λ2yl·ûŜfè I·₮₮ŜŎű f2ólπλyŎ2YŜ Ŏ2Y′Ydzyλű$ăΦ

1.1.2.3 Ensure Electricity Reliability, Security, and System Resilience

¢KŜ ¦ yλűŜŘ {ű I·ûŜă ₮I·ŎŜă Ŏ2Y′LJftŎI·ûŜŘ I·yŘ ŜØ2tØλyΞ ŎKI·ffŜySΞŜă ûKI·ű I·₮₮ŜŎű ûKŜ ₪ŜfλI·ōλftűèΣ ăŜŎdz₪λűèΣ I·yŘ ₪ŜăλftλŜyŎŜ 2₮ ûKŜ ŜfŜŎű₪λŎλűè ăèăűŜYΦ hLJŜ₪I·ű2₪ă 2₮ ûKŜ Ξ₪λŘ Y′dzăű ăλY′dztűI·yŜ2dzăfè Y′ŜŜű ŜÈλăűλyΞ LJŜ₪₮2₪YI·yŎŜ ăű′I·yŘI·₪Řă I·yŘ ăèăűŜY ₪ŜIjdzλ₪ŜYŜyűăΣ I·ă ólŜft I·ă I·ŘŘ₪ŜăăI· ₪I·LJλŘfè ŜØ2tØλyΞ ăèăűŜYΦ ¢KŜăŜ ŎKI·yΞŜă ăű₪Ŝăă ûKŜ LJdzōftŎ I·yŘ LJ₪λØI·ûŜ λyăűλűdzűλ2yã Ŏ₪ŜI·ûŜŘ ű2 ădzLJLJ2₪ű I· tŜΞI·Ŏè LJI·₪I·ŘλΞY′ ŜăűI·ōtλăKŜŘ 2ØŜ₪ ûKŜ fI·ăű млл èŜI·₪ă 2₪ Y′2₪ŜΦ ¢KŜ ûK₪ŜI·ű ŜyØλ₪2yYŜyű λă I·tă2 ŎKI·yΞλyΞ τ ŘŜŎλăλ2y′Y′I·ˆŜ₪ă Y′dzăű Y′I·ˆŜ ûKŜ ŎI·ăŜ ₮2₪ λyØŜăűY′ŜyűăûKI·ű Y′λűλΞI·ûŜ ŎI·ûI·ăű₪2LJKλŎΣ KλΞKπλY′LJI·ŎűΣ f2ólπLJ₪2ōI·ōλftűè ŜØŜyűăΦᴹᴼ !fă2Σ y2ű I·ff KI·ÎI·₪Ră ŎI·y′ōŜ LJ₪ŜØŜyűŜŘTλY′LJ₪2ØŜY′Ŝyűă I·₪Ŝ yŜŜŘŜŘ λy′ ûŜŎKy2f2ΞλŜă I·yŘ LJ₪2ŎŜăăŜă ōè ólKλŎK ûKŜ Ξ₪λŘ ŎI·y′₮I·λf ŜfŜΞI·yűfèΣ ₪ŜŎ2ØŜ₪ IjdzλŎˆfèΣ I·yŘ ōŜŎ2YŜ Y′2₪Ŝ ₪ŜăλftŜyű 2ØŜ₪ ûλY′ŜΦ

Ly′I·ŘŘλûλ2yΣ ûKŜ ŜfŜŎű₪λŎλűè ăèăűŜY λă ØλűI·f ű2 ûKŜ bI·ûλ2yűă λyŎ₪ŜI·ăλyΞfè λyűŜ₪ŎŽyŷŜŎűŜŘΣ ŘλΞλűI·ffè ŘŜLJŜyŘŜyű ŜŎ2y2Y′è I·yŘ ă2ŎλŜűè ² λűK2dzű I·ŎŎŜăă ű2 ₪ŜftλI·ōfŜ ŜfŜŎű₪λŎλűèΣ ăλΞyλ₮λŎI·yű ŜŎ2y2YλŎ ØI·fdzŜ I·yŘ I·ff ŜfŜŎű₪λŎλűèπ

ŝyl·ōfŝŘ ŎNƛűƛŎl·f ƛyŦNJl·ăúNdzŎűdzNŴŝă l·NJŜ LJdzű l·ú Nƛăʅ℗ ¢Kŝăŝ ƛyŎftdzŘŝ yl·űƛ2yl·f ăŜŎdzNƛúè l·yŘ K2Yˆŝfl·yŘ ŘŝŦŝyãŝ yŝűø2NJʅă úKl·ú ŘŜLJŝyŘ 2yˆŝfŜŎűNƛŎƛúè ú2 KŝfLJ ŝyãdzNŴŜ űKŝ ăl·Ŧŝúè l·yŘ LJNJ2ăLJŜNƛúè 2Ŧ űKŝ ! YˆŜNƛŎl·yˆLJŜ2LJfŜ℗

Addressing Climate Change Is an Environmental, Economic, and National Security Imperative

The accumulated evidence of decades of climate science clearly shows that humans are impacting the climate system in new and damaging ways, primarily through the emissions of greenhouse gases (GHGs). Since the widespread adoption of fossil fuels during the Industrial Revolution, human activities have been emitting carbon dioxide (CO_2) faster than the Earth has been removing and storing it. The 17 warmest years on record have occurred in the last 18 years,[14] with 2015 being the warmest year on record and 2016 will likely set yet another record.[15, 16]

Humans experience the climate system not as global, annual averages, but through the climate effects on local weather. Localized impacts can make dry places dryer; wet places wetter; and areas exposed to tropical storms more at risk for high winds, heavy rain, and flooding. What were once rare extreme heat events are already becoming commonplace. Sea-level rise and coastal erosion, coupled with more powerful storms, have destroyed infrastructure and damaged tourism along the East Coast of the United States. Flooding of inland rivers has damaged Midwestern and Northeastern cities. Also, the Arctic, which has been warming at more than twice the rate of lower latitudes,[17] is experiencing infrastructure damage from thawing permafrost; shrinking sea ice (with impacts on coastal erosion and subsistence hunting); and a longer, more destructive wildfire season.

The electricity supply system is a major contributor to U.S. GHG emissions and creates other stresses on the environment as well. Minimizing impacts on the climate, air, water, land, ecosystems, and worker and public safety must be priorities for the electric system, including power plant construction, operation, and decommissioning, as well as transmission and distribution of the electricity, no matter its source. These topics are covered in Chapter III, *Building a Clean Electricity Future*.

The long residence time of CO_2 in the atmosphere establishes an urgent need to act to mitigate the impacts of climate change; even if all CO_2 emissions stopped immediately, the global mean surface temperature would continue to rise and the associated impacts would be felt around the globe for decades to come. In the electric sector, increasing temperatures can increase demand for cooling and warmer water supplies can challenge water-cooled electric generation facilities. Resilience and adaptation are the means by which the United States can reduce these harms, and the electric sector will need to become more resilient and adapt to a changing climate. A discussion of adaptation and resilience are further discussed in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

1.1.3 Crosscutting Issues Important to Achieving National Goals and 21st Century Grid Modernization

DNƛŘ Yˆ2ŘŜNJyƛÎl·úƛ2yˆ NJŜIjdzNJŜă l·ŎűƛŎ2yl·ōfŜ LJ2ftŎƛŜăŻ LJNJl·ŎűƛŎŎŜăŻ l·yŘ ƛyØŜăűYˆŜyűă úKl·ú KŝfLJ ŝyãdzNJŜ ăèăúŜYˆ ăŜŎdzNƛúèŻ NJŜfƛl·ōƛftƛúèŻ NJŜăƛftƛŜyŎŜŻ l·yŘ l· ŎfŜl·yˆ ŝfŜŎűNƛŎƛúè ŦdzűdzNJŜ℗ ¢KŜăŝ 2ō?ŜŎűƛØŜă Kl·ØŜ 2ØŜNJfl·LJLJƛyƎ l·yŘ ŎNJ2ăăŎdzúűƛyƎ Ŏ2yãƛŘŜNJl·úƛ2yã úKl·ú Yˆdzăű ōŜ NJŜŎ2ƎyƛÎŜŘ l·yŘ Yˆl·yl·ƎŜŘ℗ ¢KŜ ŎNJ2ăăŎdzúűƛyƎ ƛăădzŜă ŜÈl·Yˆƛy̆ŜŘ ƛyˆ v9w м℗н ƛyŎftdzŘŜ Øl·fdzl·úƛ2yŤ Yˆl·NJʅŜűăŻ ŦƛyŤ·yŎŜŻ l·yŘ ōdzăƛy̆ŜăăŻ Yˆ2ŘŜftăŤ ƛyy2Øl·úƛ2yˆ l·yŘ wℑ5Ť ƎNƛŘ 2LJŜNJl·úƛ2yãŤ ø2NJʅŦ2NJŎŜŤ b2NJúK ! YˆŜNƛŎl·π ø ƛŘŜ l·yŘ ƛyãűƛúdzűƛ2yl·f l·NJNJl·yƎŜYˆŜyűă úKl·ú l·NJŜ Ŧ2dzyŘl·úƛ2yl·f ú2 úKŝ ăŜŎű2NJ℗ ¢NJŜl·úYˆŜyű 2Ŧ Yˆ2ăű 2Ŧ úKŜăŜ Ŏ2Yˆ LJfŜÈ ű2LJƛŎă ƛă ŜYˆōŜŘŘŜŘ ƛyű2 Ŝl·ŎK v9w м℗н ŎKl·LJJŜNJ℗

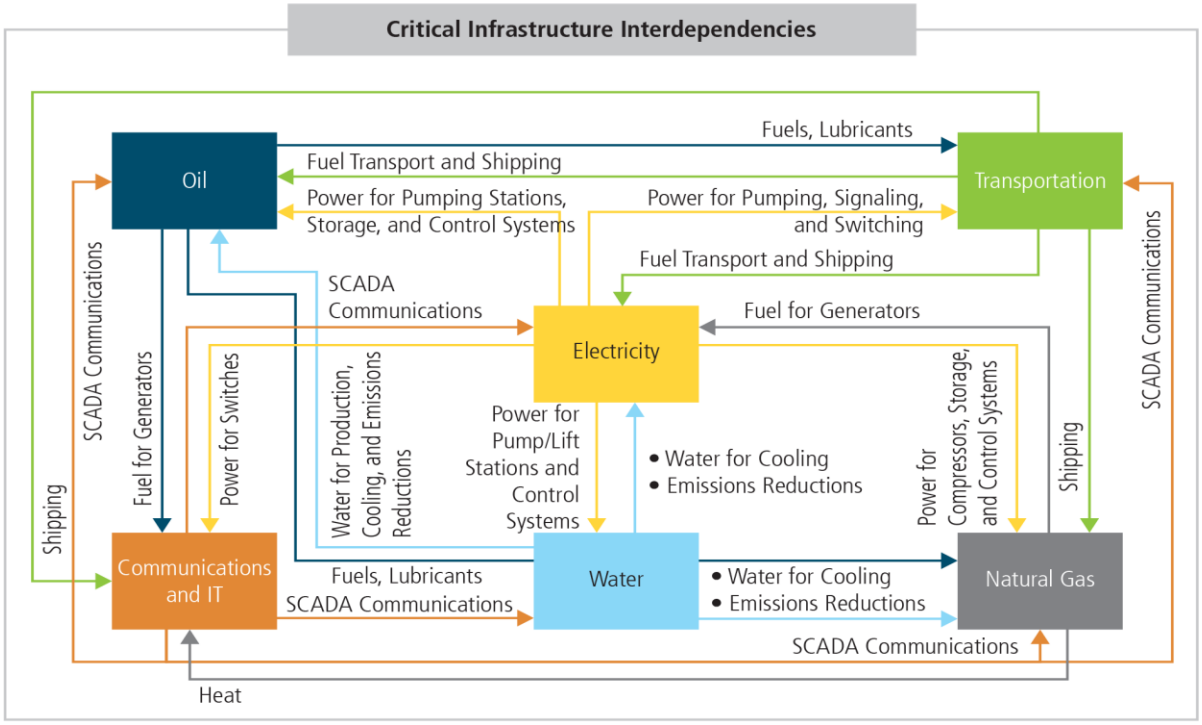
1.2 The Nation's Critical Infrastructures Depend on Electricity

v9w м℗нΩă ŜÈl·Yˆƛyl·úƛ2yˆ 2Ŧ úKŝ ŜfŜŎűNƛŎƛúè ăèăúŜYˆ ŦNJ2Yˆ ƎŜySyŜNJl·úƛ2yˆ ú2 ŜyŘ dzăŜ ySŎŜăăl·NJƛfè ăúl·NJúă øƛúK l·ŘƛăŎdzăăƛ2yˆ 2Ŧ úKŝ ŘŜLJŜyŘŜyŎŜ 2Ŧ úKŝ bl·úƛ2yΩă ŎNƛűƛŎl·f ƛyŦNJl·ăúNdzŎűdzNŴŜă 2yˆŜfŜŎűNƛŎƛúè℗ /NƛűƛŎl·f ƛyŦNJl·ăúNdzŎűdzNŴŜ ŘŜLJŜyŘŜyŎƛŜă l·yŘ ƛyűŜNJŘŜLJŜyŘŜyŎƛŜă NJŜLJNJŜăŜyű úKŝ Ŏ2NJŜ dzyŘŜNJfèƛyƎ ŦNJl·YˆŜø2NJʅ úKl·ú ădzLJLJ2NJúă úKŝ

! Y Ŝ№ΛÔI·y ŜÕ2y2Yè I·yŘ ă2ÔλŜűè¢ 9fŜÕú№ΛÔλúè λă I·ú úKŜ ÔŜyűŜ№ 2Ŧ]Ŝè Ô№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝ ySűǿ2№]ă ûKI·ú ădzLJLJ2№ú úKŜăŜ ăŜÕú2№ăΣ λyÕfdzŘλyЭ ú№I·yãLJ2№úI·úΛ2yΣ 2λf I·yŘ ∃I·ă LJ№2ŘdzÕűΛ2yΣ ǿI·úŜ№Σ I·yŘ ûŜfŜÕ2YY dzyΛÔI·úΛ2yã¢ ¢KŜăŜ ŜfŜÕú№ΛÔλúè¤ŘŜLJŜyŘŜyű Ô№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝă №ŜLJ№ŜăŜyű Õ2№Ŝ fλҒŜfλyŜ ySűǿ2№]ă úKI·ú ădzLJLJ2№ú úKŜ ! Y Ŝ№ΛÔI·y ŜÕ2y2Yè I·yŘ ă2ÔλŜűè¢

¢KŜăŜ Ô№ΛúΛÔI·f ySűǿ2№]ă I·№Ŝ λyÕ№ŜI·ăλyЭfè Õ2yØŜ№ЭλyЭΣ ăKI·№λyЭ №Ŝă2dz№ÕŜă I·yŘ ăèyŜ№ЭλăúΛÔ λyűŜ№I·ÕúΛ2yã ØλI· Õ2YY2y I·№ÕKΛúŜÕűdz№Ŝă óăŜŜ CλЭdz№Ŝ мπн0¢ ¢KŜ 2λf I·yŘ ∃I·ă ăŜÕú2№ă №Ŝfè KŜI·Øλfè 2y ŜfŜÕú№ΛÔλúè¢ ¢№I·yãLJ2№úI·úΛ2y λă Ô№ΛúΛÔI·f ûž LJ2ǿŜ№ LJ№2ŘdzÕűΛ2y ōŜÕI·dzăŜ λú ŜyI·ōfŜă úKŜ ăKΛLJLJλyЭ 2Ŧ ŦdzŜfăT ûKŜ ăŜÕú2№ I·fă2 ŘŜLJŜyŘă 2y ŜfŜÕú№ΛÔλúè ŦŽ№]Ŝè ySŜŘăΣ ădzÕK I·ă LJ2ǿŜ№ ŦŽ№ ăλ∃yI·fλyЭ I·yŘ ăǿλûÕKλyЭ I·yŘ ǿλff ōŜÕ2YŜ Y2№Ŝ ă2 I·ă Y2№Ŝ ŜfŜÕú№ΛÔ ØŜKλÕfŜă I·№Ŝ ŘŜLJf2èŜŘ¢ ² I·úŜ№ ăèăúŜYă I·№Ŝ I·fă2 άÔ№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝ¢ε ² I·úŜ№ LJdz№ΛҒΛÔI·úΛ2yΣ Y2ØŜYŜyűΣ I·yŘ ú№ŜI·úYŜyű ÕdzN№ŜyűfŝÕ2yãdzYŜ №2dz∃Kfè п LJŜ№ÕŜyű 2Ŧ úKŜ bI·úΛ2yΩă I·yӯdzI·f ŜfŜÕú№ΛÔλúè ∃ŜyŜ№I·úΛ2y™ λy /I·fλҒ2№yλI·Σ úKλă I·Y2dzyű ÔI·y ōŜ dzLJ û2 нл LJŜ№ÕŜyű 2Ŧ ŜfŜÕú№ΛÔλúè ∃ŜyŜ№I·úΛ2y℗ᴹᶜᵠ a I·yè ǿI·úŜ№ ŦI·ÔλfλúΛŜă fI·Ô] ădzŦŦΛÕΛŜyű LJ2ǿŜ№ ōI·Ô]πdzLJ ÕI·LJI·ōΛfλúΛŜăT I·ú úKŜ ăI·YŜ úΛYŜΣ úKŜè YŜŜű]Ŝè Ô22fλy∃ №ŜIjdz№ŜYŜyűă Ŧ2№ LJ2ǿŜ№ ∃ŜyŜ№I·úΛ2y℗ ² I·úŜ№ I·ØI·λfI·ōλfλúè λă I·fλŜI·Řè I· Õ2yÕŜ№y λy YI·yè LJI·№úă 2Ŧ úKŜ Õ2dzyű№èΣ I·yŘ ÔfλYI·úŜ ÕKI·y∃Ŝ λă ŜÈLJŜÕúŜŘ û2 ŜÈI·ÕŜ№ōI·úŜ úKλă LJ№2ōfŜY λy]Ŝè №Ŝ∃λ2yã 2Ŧ úKŜ ¦ yλúŜŘ {úI·úŠă¢нл

Figure 1-2. Critical Infrastructure Interdependencies[21]



Key critical infrastructure interdependencies represent the core underlying framework that supports the American economy and society. The financial services sector (not pictured) is also a critical infrastructure with interdependencies across other major sectors supporting the U.S. economy.

¢KŜ№Ŝ λă I·fă2 I· Ř№ŜÕű I·yŘ Ô№ΛúΛÔI·f fλy] ōSűǿŜŜy úKŜ ŜfŜÕú№ΛÔλúè ăèăúŜY I·yŘ úKŜ Õ2YYdzyΛÔI·úΛ2yã ySűǿ2№]ă¢нн ¢KŜ 5ŜLJI·№úYŜyű 2Ŧ I2YŜfI·yŘ {ŜÕdz№ΛúèóЭ5 I {ú λŘŜyűλҒΛŜă úKŜ λyҒ2№YI·úΛ2y I·yŘ Õ2YYdzyΛÔI·úΛ2yã ûŜÕKy2f2∃è óL/¢ú λyҒ№I·ăú№dzÕűdz№Ŝ I·ă I· Ô№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝ ōŜÕI·dzăŜ λú LJ№2ǿλŘŜă I·y ΰŜyI·ōfλy∃ ŦdzyÕûΛ2yε I·Ô№2ăă I·ff Ô№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝ ăŜÕú2№ăΦ L/¢ λyҒ№I·ăú№dzÕűdz№Ŝ ăă Ô№ΛúΛÔI·f û2 ŜI·ÕK ăúI·∃Ŝ λy úKŜ ŜfŜÕú№ΛÔλúè ădzLJLJfè ÕKI·λy I·yŘ û2 I·ff 2ûKŜ№ Ô№ΛúΛÔI·f λyҒ№I·ăú№dzÕűdz№Ŝă ăŜŜy λy CλЭdz№Ŝ мπн0¢ ² λúKλy úKŜ ŜfŜÕú№ΛÔλúè ăŜÕú2№Σ L/¢ λyҒ№I·ăú№dzÕűdz№Ŝ ăă λyÕ№ŜI·ăλy∃fè λY LJ2№úI·yű Ŧ2№ ∃№ΛŘ YI·yI·∃ŜYŜyűΣ I·ă ǿŜff I·ă Ŧ2№ Õ2YYdzyΛÔI·úΛ2yã ǿλúK Ôdzăû2YŜ№ă I·yŘ ØI·№Λ2dză

ŘλăúŃλōdzúŜŘ l·ăăŜúă℗ LУ l·ŘŘλúλ2yΣ ŝtŜŎúŃλŎλúê LJ2ǿŜŃă L / ¢ ăèăúŜY ă ŜIjdzλLJY ŜyúT λúă ŎŜyúŃl·f Ŏ2yúŃ2f l·yŘ 2LJŜŃl·úλyƎ ăèăúŜY ăT l·yŘ ŜØŜy λúă KŜl·úλyƎΣ ØŜyúλfl·úλ2yΣ l·yŘ l·λŃ Ŏ2yŘλúλ2yλyƎ ăèăúŜY ă℗

¢KŜ ŦλyΊ·yŎλl·f ăŜŎúΣ2Ń λă l·yƵúKŜŃ fλŦŜfλyŜ ySúǿ2ŃΊ úKl·ú ŘŜLJŜyŘă 2У ŝtŜŎúŃλŎλúê óúKŃ2dzƎK λúă Ń2fŜ λУ Ŝyl·ōfλyƎ úŜtŜŎ2YY dzyλŎl·úλ2yăú l·yŘ 2úKŜŃ Ŏ2YY dzyλŎl·úλ2yã ySúǿ2ŃΊă℗ 5 l {Ωă нлмр άCλyl·yŎλl·f {ŜŃØλŎŜă {ŜŎúΣŃπ{LJŜŎλŦλŎ tfl·yɛ yΣúŜŘ úKl·úΣ ά a 2ăú 2Ŧ úKŜ ăŜŎúΣ2ŃΩă ΊŜè ăŜŃØλŎŜă l·ŃŜ LJŃ2ØλŘŜŘ úKŃ2dzƎK 2Ń Ŏ2yŘdzŎúŜŘ 2У λyŦ2ŃYl·úλ2У l·yŘ Ŏ2YY dzyλŎl·úλ2yã úŜŎKyΣf2Ǝè LJfl·úŦ2ŃYăΣ Yl·ΊλyƎ ÕèōŜŃăŜŎdzŃλúê ŜăLJŜŎλl·ffê λYLJ2ŃúÍl·yú ú2 úKŜ ăŜŎúΣ2Ń℗ LУ l·ŘŘλúλ2yΣ úKŜ ăŜŎúΣ2Ń Ŧl·ŎŜă 2yƎ2λyƎ ŃλăΊă l·ăă2ŎλÍ·úŜŘ ǿλúK yl·údzŃl·f ŘλăI·ăúŜŃăΣ l·ă ǿŜff l·ă úKŜ LJ2ůŜyúλl·f Ŧ2Ń LJKèăλŎl·f l·úúÍ·Ŏ℗ㅤ l dzŃŃλŎl·ySăΣ ů2ŃyΊ·Ř2ŜăΣ ff22ŘăΣ l·yŘ ůŜŃŃ2Ńλăúㅤl·úúÍ·Ŏ℗ă l·ff KI·ØŜ úKŜ LJ2ůŜyúλl·f ů2 Ŏl·dzăŜ LJKèăλŎl·f ŘλăŃdzLJúλ2yã úKl·ú KI·ØŜ ăλƎyλŦλŎl·yú λYLJl·Ŏúă 2yCλyl·yŎλl·f {ŜŃØλŎŜă {ŜŎúΣ2Ń 2LJŜŃl·úλ2yã℗ɛᴴᴼ

bl·údzŃl·f Ǝl·ă l·yŘ ŝtŜŎúŃλŎλúê λyúŜŃŘŜLJŜyŘŜyŎλŜă l·ŃŜ l·fă2 ƎŃ2ǿλyƎ℗ ¢KŜ ŦλŃăúㅤKI·fŦ 2Ŧ нлмс ǿl·ă úKŜ ŦλŃăúㅤLJŜŃλ2Ř ǿKŜŃŜ yl·údzŃl·f Ǝl·ă ǿl·ă úKŜ fl·ŃƎŜăúㅤă2dzŃŎŜ 2Ŧ LJŃλYl·Ńè ŦdzŜf Ŧ2Ń LJ2ǿŜŃ ƎŜyŜŃl·úλ2yλyúKŜ ¦yλúŜŘ {ůl·úŜă℗ ¢KŜ λyŎŃŜl·ăŜŘ dzăŜ 2Ŧ yl·údzŃl·f Ǝl·ă Ŧ2Ń LJ2ǿŜŃ ƎŜyŜŃl·úλ2y λyúŃ2ŘdzŎŜă úKŜ LJ2ůŜyúλl·f Ŧ2Ń Ŏ2YLJfλŎl·úλ2yã l·yŘ ŘλăŃdzLJúλ2yãΣ l·yŘ λúl Kl·ăΣ λyŦl·ŎúΣ ŃŜădztúŜŘ λУl· Ŧdzůdz℗Ńă Yl·Ń℗ΊŜúă l·ō2dzú úKŜ Ǝl·ăkŜtŜŎúŃλŎλúê Yl·Ń℗ΊŜú ŃŜtl·úλ2yãKλLJ℗ ¢KŜ Ǝl·ă ăŜŎúΣ2Ń l·tă2 ŃŜfλŜă 2У ŝtŜŎúŃλŎλúê λУ ăŜƎYŜyúă 2Ŧ úKŜ LJŃ2ŘdzŎúλ2У ŎKl·λyΣ λyŎfdzŘλyƎ dzăŜ Ŧ2Ń ŦλŜfŘπƎl·úKŜŃλyƎ LJdzYLJăΣ ăŜtŜŎúŜŘ úŃl·yăYλăăλ2yLJλLJŜfλySăΣ l·yŘ Ǝl·ăπ LJŃ2ŎŜăăλyƎ ăúl·úλ2yã℗

¢KŜ λyúŜŃŘŜLJŜyŘŜyŎλŜă 2Ŧ Ί·Ŝè λyŦŃl·ăúŃdzŎúdzŃŜă l·yŘ úKŜ ŜăăŜyúλl·f Ń2fŜ 2Ŧ ŜfŜŎúŃλŎλúê l·ŃŜ λffdzăúŃl·ŜŘ ōè ŃŜŎŜyú ǿŜl·úKŜŃ ŜY ŜŃƎŜyŎλŜă℗ 9ĒúŃŜYŜfè Ŏ2fŘ ǿŜl·úKŜŃ λУ bŜǿ a ŜĒλŎ2 λУ нлмм ŃŜădztúŜŘ λУ ō2úK yl·údzŃl·f Ǝl·ă l·yŘ ŜfŜŎúŃλŎλúê 2dzúl·ƎŜăT f2ăă 2Ŧ ŜfŜŎúŃλŎλúê ŦdzŃúKŜŃ ŃŜŘdzŎŜŘ Ǝl·ă LJŃ2ŘdzŎúλ2У l·ă ŦλŜfŘπƎl·úKŜŃλyƎ LJdzYLJă f2ăú LJ2ǿŜŃ℗ᴴᴳ ! yƵúKŜŃ ŜĒl·YLJfŜ λă l·ŦúŜŃ {dzLJŜŃăúΣ2ŃY {l·yŘè λУ нлмн ǿKŜУ dzúλfλúλŜă l·yŘ úKŜ LJdzōfλŎ ŜĒLJŜŃλŜyŎŜŘ Yl·ăăλØŜ LJ2ǿŜŃ 2dzúl·ƎŜă λУ úKŜ b2ŃúKŜl·ăúǿ wŜŎ2ØŜŃè ŎŃŜǿă ǿŜŃŜ Kl·YLJŜŃŜŘ ōè ăλYdzfúl·yŜ2dză Ŧl·λfdzŃŜă 2Ŧ Ŏ2YYdzyλŎl·úλ2yã ăèăúŜY ă úKl·ú l·ŃŜ l·fY2ăú ŜyúλŃŜfè ŘŜLJŜyŘŜyú 2У ŝtŜŎúŃλŎλúê óōl·Ŏ Ίπdzl·J ăèăúŜY ă ƎŜyŜŃl·ffê LJŃ2ØλŘŜ тнçфc K2dzŃă 2Ŧ LJ2ǿŜŃú℗

1.3 Electricity-Connected Systems and Digitization Create Significant Economic Value

¢KŜ ŜfŜŎúŃλŎλúê ăèăúŜY ădzLJLJ2ŃúㅤúKŜ λyŎŃŜl·ăŜŘ ŜfŜŎúŃλŦλŎl·úλ2Y2Ŧ l·ffăŜŎúΣ2Ńă 2Ŧ úKŜ ¦℗{℗ ŜŎ2y2YèΦ ! ú úKŜ ăl·YŜ úλYŜΣ l·fY2ăú ŜØŜŃè ŜŎ2y2YλŎ ăŜŎúΣ2Ń yǿ ŃŜfλŜăΣ λУØl·ŃèλyƎ ŘŜƎŃŜŜăΣ 2У KλƎKfê λyúŜŃŎ2yyŜŎúŜŘΣ Řl·úÍ·πŘŃλØŜyΣ l·yŘ ŜfŜŎúŃλŎλúêπŘŜLJŜyŘŜyú ăèăúŜY ă ú2 Yl·yl·ƎŜ 2LJŜŃl·úλ2yã l·yŘ LJŃ2ØλŘŜ ăŜŃØλŎŜă℗ ¢KŜ ŜØ2fØλyƎ *electricity-information nexus* ădzLJLJ2Ńúㅤăl· ǿλŘŜ Ńl·yƎŜ 2Ŧ LJŃ2ŘdzŎúㅤl·yŘ ăŜŃØλŎŜă l·yŘ Kl·ă úKŜ LJ2ůŜyúλl·f Ŧ2Ń ŜØŜУƎŃŜl·úŜŃ Øl·fdzŜ ŎŃŜl·úλ2y℗ Lú ădzLJLJ2ŃúㅤyŜǿ λyŦ2ŃYl·úλ2yπŘŃλØŜУ ŜyúŜŃŁJŃλăŜăΣ KŜfŁJă fźǿŜŃ λyλúλl·f l·yŘ 2yƎ2λyƎ Ŏ2ăúăΣ λYLJŃ2ØŜă Ŏ2yúŃ2f 2Ŧ Ńλă΍ăΣ ăl·ØŜă úλYŜ l·yŘ ŜŦŦ2ŃúΣ ŜyKl·yŎŜă LJŃ2ŘdzŎúλØλúèΣ l·yŘ Ŏl·У ŎŃŜl·ůŜ ySǿ Yl·Ń℗ΊŜú Ŏl·úŜƎ2ŃλŜă℗ ¢KŜ λYLJ2ŃúÍl·yŎŜ 2Ŧ úKŜ ŜfŜŎúŃλŎλúê ăèăúŜY yƵǿ l·yŘ λУúKŜ ŦdzúdzŃŜ τ ŘŜăŎŃλōŜŘ λУ l· ŃŜŎŜyú ăúdzŘè l·ă úKŜ áŎŜyúŃl·f ySŃØ2dză ăèăúŜY 2Ŧ l· Řl·úÍ·πŘŃλØŜУ ŜŎ2y2Yèɛ τ Ŏl·yy2ú ōŜ Ŧdzftfè l·LJLJŃŜŎλl·úŜŘ ǿλúK2dzú l· ŘλăŎdzăăλ2У l·ō2dzú K2ǿ ŘλƎλúλÎ l·úλ2yΣ Kl·ă Ŝyl·ōfŜŘ úKŜ LyúŜŃyŜú 2Ŧ ¢KλyƎă óL2¢ú℗ᴴᴾ

1.3.1 Value of the Electricity-Dependent “Internet of Things”

¢KŜ L2¢ λă ŘŜŦλyŜŘ l·ă “ăŜyă2Ńăㅤl·yŘ l·ŎúdzÍ·ú2ŃăㅤŜYōŜŘŘŜŘ λУ LJKèăλŎl·f 2ō?ŜŎúă τ ŦŃ2Y Ń2l·Řǿl·ëà ů2 LJl·ŎŜYl·Ί·ŜŃă τ ωúKl·úß l·ŃŜ fλyΊŜŘ úKŃ2dzƎK ǿλŃŜŘ l·yŘ ǿλŃŜŦŜăă ySúǿ2ŃΊăΣ 2ŦúŜУ dzăλyƎ úKŜ ăl·YŜ LyúŜŃyŜú tŃ2ů2Ŏ2f óLtú úKl·ú Ŏ2yyŜŎúă úKŜ LyúŜŃyŜú℗ɛᴴᶜ ¢KŜ Ńl·LJλŘ ƎŃ2ǿúK 2Ŧ úKŜ L2¢ λă ō2úK l· Yl·yλŦŜăúÍ·úλ2У l·yŘ Ί·Ŝè Ŝyl·ōfŜŃ 2Ŧ úKλă Yl·ΣŃ ŎKl·yƎŜ λУúKŜ ŜŎ2y2Yè℗ 9fŜŎúŃλŎλúê LJŃ2ØλŘŜă Ŧ2dzyŘl·úλ2yl·f ădzLJLJ2ŃúΣ ů2 úKŜ λyŎŃŜl·ăλyƎfê λyŦ2ŃYl·úλ2yπλyúŜyãŜ ¦℗{℗ ŜŎ2y2Yè℗

5λƎλúλÎ l·úλ2У l·yŘ L / ¢ Kl·ØŜ Ŝyl·ōfŜŘ ØλŃúdzl·ffê λyãúÍ·yúl·yŜ2dzăㅤƎf2ōl·f Ŏ2YYdzyλŎl·úλ2y℗ ¢KŜăŜ ySúǿ2ŃΊă l·yŘ úKŜŃ l·ăă2ŎλÍ·úŜŘ ŘŜØλŎŜă l·ŃŜ fl·ŃƎŜ l·yŘ ƎŃ2ǿλyƎ℗ ! ŎŎ2ŃŘλyƎ ů2 l· CŜŘŜŃl·f ¢Ńl·ŘŜ /2YYλăăλ2У ŃŜLJ2ŃúㅤλăădzŜŘ λУ

WI·yŒzI·NŵèнлмpΣ ά{ʎÈ èŜI·NŵăI·∃2Σ₮2NJ úKŜ ₮ʎNŵăΰ ΰʎYŜΣ úKŜ yŒzY¯ōŜN 2₮ ΨΰKʎy∃ăΩ Ò2yŷŜÒΰŜR ΰ2 ΰKŜ ώ∃f2ōI·fß LyΰŜNŷŜΰ ădzNŵJI·ăăŜR ΰKŜ yŒzY¯ōŜN 2₮ LJŜ2LJ₮ŜX9ÈLJŜNŵΰă ŜăΰʎY¯I·ΰŜ ΰKI·ΰΣ I·ă 2₮ ΰKʎă èŜI·NΣ ΰKŜNŵŜ ǿʎ₮f ōŜ нр ōʎ₮fΛ2y¯Ò2ŷŷŜÒΰŜR ŘŜØʎÒŜăΣ I·yŘ ōè нлнлΣ рл ōʎ₮fΛ2yΦ€ᴴᵀ ¢KŜ Y¯I·yΛ₮Ŝăΰ I·ΰʎ2yã 2₮ ΰKŜ ∃NJ2ǿʎy∃ Řʎ∃ʎΰʎÎ I·ΰʎ2y¯2₮ ΰKŜ ¦Φ{Φ ŜÒ2y2Y¯è ʎă ăΰdzyŷʎy∃Y уф LJŜNŵÒŜyΰ 2₮ ! Y¯ŜNŵÒI·yã KI·ØŜ I·ÒÒŜăă ΰ2 Kʎ∃KπăLJŜŜŘ ōN2I·ŘōI·yŘ ăŜNØʎÒŜă 2₮ нр Y¯Ŝ∃I·ōʎΰă LJŜNJ ăŜÒ2yŘ ₮2NJ Ř2ǿyƒ2I·Řă I·yŘ o Y¯Ŝ∃I·ōʎΰă LJŜNJ ăŜÒ2yŘ ₮2NJ dzLJƒ2I·ŘăTᴴʸ то LJŜNŵÔŜyΰ 2₮ ! Y¯ŜNŵÒI·y¯K2dzăŜK2fŘă dzăŜ I· Ò2Y¯LJdzΰŜN ǿʎΰK Kʎ∃KπăLJŜŜŘ LyΰŜNŷŜΰ I·ΰ K2Y¯ŜTᴴᶲ фр LJŜNŵÔŜyΰ 2₮ Ò2ffŜ∃Ŝ ŜRdzÒI·ΰŜR I·Řdzfΰă dzăŜ ΰKŜ LyΰŜNŷŜΰT ут LJŜNŵÔŜyΰ 2₮ ΰI·È NŜΰdzNŷã I·NŵŜ ŜπƑʎfŜŘTᵒʌ I·yŘ сп LJŜNŵÔŜyΰ 2₮ I·Řdzfΰă dzăŜ ăY¯I·NŵΰLJK2yŜăΦᵒᴹ

b2ΰ ădzNŵLJNŵăʎy∃fèΣ ŘI·ΰI·πΣ ʎy₮2NJY¯I·ΰʎ2yπΣ I·yŘ Ò2Y¯Y¯dzyʎÒI·ΰʎ2yãπÔŜyΰNŵʎÒ ʎyŘdzăΰNŵʎŜă I·NŵŜ ʎyŘNJŜI·ăʎy∃ ΰKŜʎNJ ØI·fdzŜ ΰ2 ΰKŜ ¦Φ{Φ ŜÒ2y2Y¯è ΰKN2dz∃K Řʎ∃ʎΰʎÎ I·ΰʎ2yΦ Ly₮2NJY¯I·ΰʎ2y¯I·yŘ Ò2Y¯Y¯dzyʎÒI·ΰʎ2yã ΰŜÒKy2f2∃ʎŜă Ò2Y¯LJNŵăŜŘ N2dz∃KfÈ p LJŜNŵÔŜyΰ 2₮ D5tΣ ōI·ăŜŘ 2y¯ нлмп Y¯ŜΰNŵÒăΣᴼᴴ I·yŘ ΰŜÒKy2f2∃èπŘNŵØŜy¯LJNŵʎÒŜ ŘŜÒƑʎySă I·NŵŜ Y¯I·ʅʎy∃ L/¢ ŜØŜy¯ Y¯2NJŜ I·ΰΰNJI·ÒΰʎØŜ ₮2NJ ōdzăʎyŜăăŜăΦ lΰ ʎă ŜăΰʎY¯I·ΰŜŘ ΰKI·ΰ ΰKNJŜŜ I·NJŜI·ă 2₮ ΰKŜ ŜÒ2y2Y¯è I·f2yŜ τ 2yƑʎyŜ ΰI·fŜyΰ LJfI·ΰ₮2NJY¯ăΣ ōʎ∃πŘI·ΰI· I·yI·fèΰʎÒăΣ I·yŘ ΰKŜ L2¢ τ Ò2dzfŘ ʎyÒNŵŜI·ăŜ D5t ōè I·ă Y¯dzÒK I·ă Þн⊕н ΰNŵʎƑʎ2y¯ʎy¯нлнрΦᵒᵒ

¢KŜ L2¢ ʎă ʎyÒNŵŜI·ăʎy∃fèΣ dzăŜŘ ōè ÒNŵʎΰʎÒI·f ăŜÒΰ2NJă 2₮ ΰKŜ ¦Φ{Φ ŜÒ2y2Y¯è⊕ ¢KŜ KŜI·fΰKÒI·NŵŜ ʎyŘdzăΰNŵèΣ ₮2NJ ŜÈI·Y¯LJfŜΣ ʎă NŵŜØ2fdzΰʎ2yʎÎʎy∃ ÒI·NŵŜ 2LJŜNJI·ΰʎ2yã ΰKN2dz∃K Řʎ∃ʎΰʎÎ I·f NŵŜÒ2NJŘăΣ ʎY¯LJNJ2Øʎy∃ LJI·ΰʎŜyΰ ΰNŵŜI·ΰY¯Ŝyΰ I·yŘ ÒI·NŵŜ ōè ăKI·Nŵʎy∃ LJI·ΰʎŜyΰ ʎy₮2NJY¯I·ΰʎ2y¯ōŜΰǿŜŜy¯K2ăLJʎΰI·fă⊕ ¢KŜ I·dzΰ2Y¯2ΰʎØŜ ʎyŘdzăΰNŵè ʎă LJʎ2yŜŜNŵʎy∃ ŜfŜÒΰNŵʎÒ ØŜKʎÒ₮Ŝ ΰŜÒKy2f2∃è ₮2NJ dzăŜ ʎy¯KŜI·Øè ŜIjdzʎLJY¯Syΰ£ f2y∃πKI·dzf I·dzÈʎƑʎI·Nŵè LJ2ǿŜNJ dzyʎΰă I·yŘ ΰNŵdzÕ¦ ăΰ2LJăΣ f2ÒI·fʎÎŜŘ ăŜNŵØʎÒŜ ₮fŜŜΰăΣ I·yŘ LJŜNŵă2yI·f ØŜKʎÒfŜăΦ /ʎΰʎŜă I·NŵŜ ʎyΰŜ∃NJI·ΰʎy∃ ΨăY¯I·NŵΰŜNΩ τ ʎyKŜNŵŜyΰfè Y¯2NJŜ ŜfŜÒΰNŵʎÒʎΰè⊓ʎyΰŜyăʎØŜ τ ÒI·Nŵă ΰ2 ʎY¯LJNJ2ØŜ LJI·ăăŜy∃ŜNJ ăI·₮ŜΰèΦ ¦NJōI·y¯I·NŵŜI·ă ǿʎΰK ∃NJŜI·ΰŜNJ I·LJLJfʎÒI·ΰʎ2y¯2₮ L2¢ ΰŜÒKy2f2∃è I·yŘ L/¢ KI·ØŜ ΰKŜ LJ2ΰŜyΰʎI·f ΰ2 NŵdzY¯Y2NJŜ Ŝ₮₮ʎÒʎŜyΰΰfè I·yŘ ădzăΰʎI·ʎyI·ōfè⊕ ! ăΰdzŘè ōè ¢ŜÈI·ă ! ɔ a ¦yØŜNŵăʎΰè ₮2dzyŘ ΰKI·ΰ ΰNJI·₮₮ʎÒ LJNJ2ōfŜY¯ă I·yŘ Ò2y∃Ŝăΰʎ2y¯ ʎy¯ ΰKŜ ¦yʎΰŜŘ {ΰI·ΰŜă I·f2yŜ Ò2ăΰă Y¯2NJŜ ΰKI·y¯ Þмнл ÒʎƑʎ2y¯ I·yŷŒzI·ffè⁰ᵐ ǿʎΰK2dzΰ Ò2yăʎŘŜNʎy∃ I·ŘŘʎΰʎ2yI·f Ŝ₮₮ŜÒΰă ₮N2Y¯ ʎyÒNŵŜI·ăŜŘ LJ2ffdzΰʎ2yΣ ŘŜÒNŵŜI·ăŜŘ ǿ2NJ¦ LJN2ŘdzÒΰʎØʎΰèΣ 2NJ ŘŜfI·èŜŘ ŘŜfʎØŜNŵè Ŝ₮₮ŜÒΰă⊕ ¢KŜ I·ōʎƑΰΰè ΰ2 Ò2Ż2NJŘʎyI·ΰŜ ØI·NJΛ2dză dzNŵÒI·y¯ ʎy₮NJI·ăΰNŵdzÒΰdzNŵŜă óŜΦ∃⊕Σ ΰNJI·yăLJ2NJΰI·ΰʎ2yΣ ōdzʎƑŘʎy∃ăΣ I·yŘ ΰKŜ ŜfŜÒΰNŵʎÒʎΰè ŘʎăΰNŵʎōdzΰʎ2y¯ăèăΰŜY¯ú ΰKI·ΰ ÒI·y¯I·LJLJfè ŘI·ΰI· ʎyΰŜ₮fʎ∃Syΰfè ǿ2dzfŘ KŜfLJ ʎY¯LJNJ2ØŜ 2LJŜNJI·ΰʎ2yI·f Ŝ₮₮ʎÒʎŜyÒèΣ ʎyÒNŵŜI·ăŜ ăI·₮ŜΰèΣ f2ǿŜNJ Ò2ăΰăΣ I·yŘ Ò2yΰNŵʎōdzΰŜ ΰ2 ăèăΰŜY¯ ăΰI·ōʎƑΰè⊕

¢KŜ L2¢ y2ΰ 2yƒè I·₮₮ŜÒΰă ʎy₮2NJY¯I·ΰʎ2y¯₮f2ǿă 2y¯fI·NJ∃Ŝ ăèăΰŜY¯ăΣ ʎΰ ʎă I·fă2 I·₮₮ŜÒΰʎy∃ K2ǿ ŜyŜNJ∃è Ò2yãdzY¯ŜNJă ʎyΰŜNJI·Ò΅ I·yŘ Ò2yΰNJ2f ΰKŜʎNJ K2Y¯Ŝ ŜyØʎNJ2yY¯Syΰă⊕ ! ŘØI·yÒŜŘ ΰKŜNJY¯2ăΰI·ΰ ŘŜØʎÒŜăΣ ₮2NJ ŜÈI·Y¯LJfŜΣ I·dzΰ2Y¯I·ΰŜ ΰŜY¯LJŜNJI·ΰdzNŵŜ Ò2yΰNJ2fΣ ǿKʎfŜ fŜI·NJyʎy∃ ă2₮ΰǿI·NJŜ ŜY¯ōŜŘŘŜŘ ʎy¯ΰKŜ ΰŜÒKy2f2∃è ʎyΰŜ∃NJI·ΰŜă LJNJŜLJNJ2∃NJI·Y¯Y¯ŜŘ ăŜΰΰʎy∃ōè ΰKŜ dzăŜNJ ǿʎΰK ÎʎLJ Ò2ŘŜ f2ÒI·ΰʎ2y¯ΰ2 ʎŘŜyΰʎ₮è ΰKŜ NŜI·fπΰʎY¯Ŝ ǿŜI·ΰKŜNJ τ ΰǿ2 ʎyLJdzΰă ΰKI·ΰ ΰKŜ ŘŜØʎÒŜă dzăŜ ΰ2 ăŜƑπI·Ř2dzăΰΦ ¢Kʎă I·yŘ 2ΰKŜNJ K2Y¯Ŝ ΰŜÒKy2f2∃ʎŜăΣ ădzÒK I·ă ÒK2NJŜ I·dzΰ2Y¯I·ΰʎ2y¯I·yŘ NJŜY¯2ΰŜfè Ò2yΰNJ2ffŜŘ ăŜÒdzNŵʎΰè ăèăΰŜY¯ăΣ I·NJŜ I·ff LJI·NJΰ 2₮ I· ySǿ ŜNJI· ʎy¯ǿKʎÒK ΰKŜ L2¢ ʎă dzΰʎƑʎÎŜŘ ΰ2 LJNJ2ØʎŘŜ ∃NJŜI·ΰŜNJ Ò2Y¯₮2NJΰΣ Ŝ₮₮ʎÒʎŜyÒèΣ ăŜÒdzNŵʎΰè ăèăΰŜY¯ăΣ I·NJŜ I·ff LJI·NJΰ 2₮ I· ySǿ ŜNJI· ʎy¯ǿKʎÒK ΰKŜ L2¢ ʎă dzΰʎƑʎÎŜŘ ΰ2 LJNJ2ØʎŘŜ ∃NJŜI·ΰŜNJ Ò2Y¯₮2NJΰΣ Ŝ₮₮ʎÒʎŜyÒèΣ ăŜÒdzNŵʎΰè ₣fŜÈʎōʎƑʎΰèΣ I·yŘ ăI·Øʎy∃ăΦ wŜÒŜyΰ I·yI·fèăʎă ădzE∃Ŝăΰăΰ ΰKI·ΰ ΰKŜ ŜÒ2y2Y¯ʎÒ ØI·fdzŜ 2₮ K2Y¯Ŝ I·dzΰ2Y¯I·ΰʎ2y¯ I·yŘ ōŜΰΰŜNJ ʎyΰŜ∃NJI·ΰʎ2y¯2₮ L2¢ ΰŜÒKy2f2∃ʎŜă Ò2dzfŘ ōŜ I·ă Kʎ∃K I·ă Þорл ōʎƑʎ2y¯₮2NJ ΰKŜ ¦Φ{Φ Y¯I·NJʅŜΰ I·f2yŜΦᵒᵖ

!ff ăŜÒΰ2NJă ΰKI·ΰ NJŜfè 2y¯ ʎy₮2NJY¯I·ΰʎ2y¯ I·yŘ 2yƒʎyŜ I·ÒΰʎØʎΰè τ ʎyÒfdzŘʎy∃ ŜY¯I·ʎfΣ ă2ÒʎI·f Y¯ŜŘʎI·Σ I·yŘ LyΰŜNŷŜΰπ Ò2ŷŷŜÒΰŜR ōdzăʎyŜăă τ I·NJŜ ădzLJLJ2NJΰŜR ōè ŘI·ΰI· ÒŜyΰŜNJăΦᵒᶜ ¢KŜăŜ ŘI·ΰI· ÒŜyΰŜNJă KI·ØŜ ōŜŜy¯ÒI·ffŜŘ ΰΰKŜ ōI·Ò ʅō2yŜ 2₮ ΰ2ŘI·è Řʎ∃ʎΰʎÎ I·f ŜÒ2y2Y¯èΣ£ LJ2ǿŜNJʎy∃ ōdzăʎyŜăăŜăΣ Ò2Y¯Y¯dzyʎÒI·ΰʎ2yãΣ I·yŘ 2yƒʎyŜ Ò2yãdz Y¯ŜNJ ăŜNØʎÒŜă I·yŘ KŜfLJʎy∃ ΰ2 Y¯I·ʅŜ ă2ÒʎŜΰè Y¯2NJŜ LJN2ŘdzÒΰʎØŜ I·yŘ Ŝ₮₮ʎÒʎŜyΰ ¢KŜăŜ ÒŜyΰŜNJă I·NJŜ ŘʎΰΰNJʎōdzΰŜŘ I·ÒNJ2ăă ΰKŜ Ò2dzyΰNJèΣ K2dzăŜ N2dz∃KfÈ мп Y¯ʎfΛ2y¯Ò2Y¯LJdzΰŜNJ ăŜNØŜNŵăΣ I·yŘ LJNJ2ØʎŘŜ ō2ΰK Ř2Y¯ŜăΰʎÒ I·yŘ ∃f2ōI·f ăŜNØʎÒŜă⊕ 5I·ΰI· ÒŜyΰŜNJă I·NJŜ 2yŜ 2₮ ΰKŜ ₮I·ăΰŜăΰπ∃NJ2ǿʎy∃ ă2dzNJÒŜă 2₮ ŜfŜÒΰNJʎÒʎΰè ŘŜY¯I·yŘ⊕ a 2NJŜ ΰKI·y¯o Y¯ʎfΛ2y¯ŘI·ΰI· ÒŜyΰŜNJă ʎy¯ΰKŜ ¦yʎΰŜŘ {ΰI·ΰŜă ó2₮ I·ff ăʎÎŜăΰ y2ǿ dzăŜ N2dz∃KfÈ тл ōʎƑʎ2y¯ʅʎf2ǿI·ΰΰπK2dzNJă 2₮ ŜfŜÒΰNJʎÒʎΰè I·yŷŒzI·ffè⊕ᵒᵀ ¢Kʎă ʎă I·ō2dzΰ мΦy LJŜNJÒŜyΰ 2₮ ΰ2ΰI·f yI·ΰʎ2yI·f ŜfŜÒΰNJʎÒʎΰè Ò2yãdzY¯LJΰʎ2yΣᵒʸ ǿKʎÒK ʎă ŜIjdzʎØI·fŜyΰ ΰ2 ΰKŜ ∃ŜyŜNJI·ΰʎ2y¯2₮ нр fINJ∃Ŝ óрлл Y¯Ŝ∃I·ǿI·ΰΰΰ Ò2I·fπ₮ʎNJŜŘ LJ2ǿŜNJ LJfI·yΰăᵒᶲ ¢I·ōfŜ мπм ʎyÒfdzŘŜă ŘI·ΰI· ₮2NJ fINJ∃Ŝ ŘI·ΰI· ÒŜyΰŜNJă óҕнл ΰK2dzăI·yŘ ăIjdzI·NJŜ ₮ŜŜΰΰΣ ǿKʎÒK ÒdzNŵNJŜyΰfè I·ÒÒ2dzyΰ ₮2NJ I·ō2dzΰ KI·f 2₮ ΰ2ΰI·f ŘI·ΰI· ÒŜyΰŜNJ ŜyŜNJ∃è dzăŜΦ

Table 1-1. National Data Centers Are Electricity Dependent[40]

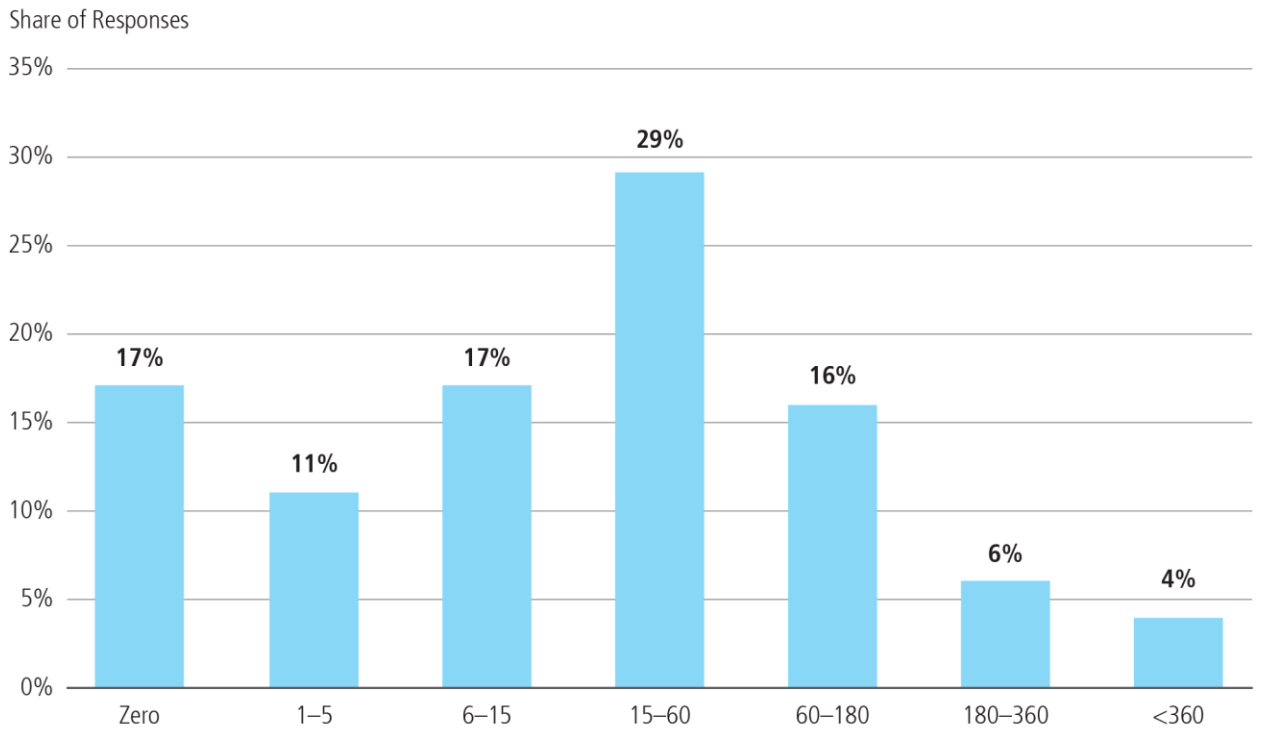
Large Data Centers (>20K square feet)	Nationwide
Number	9,500
Size	~320 million square feet
Server count	8 million
Power load	4 gigawatts
Storage	160 million terabytes
Energy consumption	37 billion kilowatt-hours
Back-up power description (Tier III+ only)	• ñRedundant and maintainableò • Fully redundant power path to all equipment (2N substation to server) • Dual utility power feed • Vendor-owned substation • 10s of back-up gensets (diesel, natural gas) • Generally designed for 72-hour outage

Commercial data centers are an important economic segment that supports much of the internet, business activity, and e-commerce activity. These data centers also require available and reliable electricity service and invest significant money in on-site generation and back-up systems to ensure power availability.

[illegible]

[illegible]

Figure 1-3. Company Survey: Approximately How Many Minutes of IT Downtime Can Occur before Business Is Negatively Impacted?[44]



When the grid goes down, data centers face significant risks as backup power does not always work. The key is to try to minimize the likelihood of grid power outages. Local power grid reliability should be a factor considered when choosing data center locations.

¢Kλă f2ää 2ŦăλƎγλŦλÕΙ·yű ŜÕ2y2YλÕ ØΙ·fdzŜ ŦN2Y ŜØŜy ăK2N΄ű LJ2ØŜN 2dzΰΙ·ƎŜă LJfΙ·ÕŜă Ι· ØŜNè KλƎK LJNŜYλdzY 2y *customer as opposed to system reliability* Ι·yŘ KΙ·ă KŜfŁJŜŘ ΰ2 ÕNΰŜΙ·ΰŜ Ι· ƎN2ØλyƎ YΙ·N΄Şΰ Ŧ2N ōΙ·Õ΄πdzLJ ƎŜyŜNΙ·ΰλ2y ΰ2 YŜŜΰ λyŘλØλŘdzΙ·f Ödzăΰ2YŜN ySŜŘă{ {dzÕK ōΙ·Õ΄πdzLJ ă2fdzΰλ2yã ă2YŜΰλYŜă KΙ·ØŜ Ydzfΰλ LJfŜ Õ2YLJ2ySyΰă ΰ2 Ŝyãdz NŜ ySÕŜăăΙ·N΄è NŜŘdzyŘΙ·yÕè [Ι·NƎŜN ¢λŜN LLLь ŘΙ·ΰΙ· ÔŜyΰŜNă Kl·ØŜ ΰKŜ Y2ăΰ ŜÈΰŜyãλØŜ Ι·fΰŜNyΙ·ΰλØŜ LJ2ØŜN Ι·NNΙ·yƎŜYŜyΰă ØλΰK NŜŘdzyŘΙ·yΰ LJ2ØŜN ăèăΰŜYă Ι·yŘ 2yãλΰŜ ƎŜyŜNΙ·ΰλ2yΤ ΰKŜăŜ Ι·N΄Ŝ fλYλΰŜŘΣ K2ØŜØŜNΣ ōè Ι·ØΙ·λfΙ·ōfŜ ōΙ·ΰΰŜNè ăΰ2NΙ·ƎŜ ÕΙ·LJΙ·ÕλΰèΣ 2yãλΰŜ ŦdzŜf ăΰ2NΙ·ƎŜ óτнçфc K2dzNăúΣπρ Ι·yŘ fλljdzλŘ ŦdzŜf NŜădzLJLJfè Ι·ƎNŜŜYŜyΰă΄ⁿᶜ

LY΄нлмпΣ ¦φ{φ Ödzăΰ2YŜNă ăLJŜyΰ yŜΙ·Nfè Рнφp ōλffλ2y΄λY΄ÕΙ·LJλΰΙ·f Õ2ăΰă ΰ2 LJdzNÕKΙ·ăŜ Ι·yŘ λyăΰΙ·ff ōΙ·Õ΄πdzLJ Ι·fΰŜNyΙ·ΰλyƎ ÖdzNNΰŜyΰ ƎŜyŜNΙ·ΰλ2yᵐᵀ Ι·yŘ Рοφн ōλffλ2y΄Ŧ2N dzyλyΰŜNNdzLJΰλōfŜ LJ2ØŜN ădzLJLJfλŜăᵠⁿʸ Lΰ λă ŜăΰλYΙ·ΰŜŘ ΰKΙ·ΰ ΰKλă ōΙ·Õ΄π dzLJ ƎŜyŜNΙ·ΰλ2y΄ NŜLJNŜăŜyΰă N2dzƎKfè нлл ƎλƎΙ·ØΙ·ΰΰă 2Ŧ ƎŜyŜNΙ·ΰλ2y΄ LJ2ΰŜyΰλΙ·fᵐᵠ óλy΄ Õ2yΰNΙ·ăΰ ΰ2 Ι· LJNλYΙ·N΄è λyăΰΙ·ffŜŘ ÖΙ·LJΙ·ÕλΰèΣ 2Ŧ мΣмлл ƎλƎΙ·ØΙ·ΰΰăΰφ DŜyŜNΙ·ffèΣ ΰKŜăŜ ōΙ·Õ΄πdzLJ ăèăΰŜYă Õ2YŜ Ι·ΰ Ι· ÖΙ·LJΙ·ÕλΰèΣ Õ2ăΰ 2Ŧ Рнллç Рслл LJŜN ΄λf2ØΙ·ΰΰΣ ōdzΰ ΰKλă Õ2ăΰ LJN2ŦλfŜ λă Ŧ2N Ι· yΙ·NN2Ø ăŜΰ 2Ŧ Ι· Y΄dzÕK ØλŘŜN dzyλΰŜNăŜ 2Ŧ Ι·ăăŜΰ ΰèLJŜă ΰKΙ·ΰ λyÕfdzŘŜ Õ2Y΄ōλyŜŘ KŜΙ·ΰ Ι·yŘ LJ2ØŜNΣ yΙ·ΰdzNΙ·f ƎΙ·ăπŦλNŜŘ dzyλΰă 2Ŧ ØΙ·NèλyƎ ăλÎŜăΣ ŦdzŜf ÔŜffăΣ Ι·yŘ ØΙ·NN2dză ăΰ2NΙ·ƎŜ ă2fdzΰλ2yãφᵖʌ

. dzăλyŜăăŜă ōdzλfŘ 2yãλΰŜ ƎŜyŜNΙ·ΰλ2y΄ōŜÕΙ·dzăŜ ΰKŜè ŦΙ·ÔŜ ăλƎγλŦλÕΙ·yΰ ŜÕ2y2YλÕ f2ăăŜă ŦN2Y΄ Ι· Y΄2Y΄ŜyΰΙ·N΄è f2ää 2Ŧ ŜfŜÕΰNλÕλΰè 2N ăfλƎKΰ ØΙ·NλΙ·ΰλ2y΄λy΄ŦNΰSIjdzŜyÕè¢ KλăNŜLJNŜăŜyΰă Ι· ă2dzNÕŜ 2Ŧ f2ăΰ NŜØŜyΰzŜ Ŧ2N dzΰλfΰλŜă τ Ι· Ŧ2NY 2Ŧ άŘŜŦŜÕΰλ2yΤέ λΰ Õ2dzfŘ Ι·fă2 LJNŜăŜyΰ Ι·y΄2LJLJ2Nΰdzyΰè Ŧ2N dzΰλfΰλŜă ΰ2 LJN2ØλŘŜ KλƎKŜNπIjdzΙ·fΰè ăŜNØλÕŜă ΰKΙ·y΄

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[0] 5Ι·ΰΙ· ÔŜyΰŜNă Ι·NŜ ÕfΙ·ăăλŦλŜŘ ōè dzăŜ 2Ŧ Ι· Ŧ2dzN ΰλŜN ăèăΰŜY΄ Ŝăΰ Ι·ōfλăKŜŘ ōè ΰKŜ ¢ŜfŜÕ2YY΄dzyλÕΙ·ΰλ2yã LyŘdzăΰNè ! ăă2ÕλΙ·ΰλ2yφ ¢λŜN L λă ΰKŜ ăλY΄LJfŜăΰ fŜØŜfΣ ØKλfŜ ¢λŜN L± λă ΰKŜ Y2ăΰ ăΰNλyƎSyΰ fŜØŜf ŘŜăλƎySŘ ΰ2 K2ăΰ Yλăăλ2y΄ÕNλΰλÕΙ·f Õ2YLJdzΰŜN ăèăΰŜYăφ ¢λŜN LLLь ŘΙ·ΰΙ· ÔŜyΰŜNă Ι·NŜ Ι·ØΙ·λfΙ·ōfŜ Ι·ΰ fŜΙ·ăΰ φφφфун LJŜNÕŜyΰ 2Ŧ ΰKŜ ΰλYŜφ

ΰΚ2ăŜ ℕŜIjdzλℕŜŘ ōè ΰΚŜ ΰèLJλŎI·f Ŏdzăΰ2ϒŜℕΦ 9ØλŘŜyŎŜ ădzƎƎŜăΰă ΰΚI·ΰ ă2ϒŜ ŜfŜŎΰℕλŎλΰè Ŏdzăΰ2ϒŜℕă I·ℕŜ ǿλffΛyƎ ΰ2 LJI·è ØŜℕè ΚλƎK LJℕλŎŜă ₮2ℕ ΰΚŜ λyŎℕŜϒŜyΰI·f Řλ₮₮ŜℕŜyŎŜ ōŜΰǿŜŜϒΰΚŜ ŎdzℕℕŜyΰ ϒŜI·ădzℕŜ 2₮ ℕŜfΛI·ōλfΛΰè I·yŘ ǿKI·ΰ ΰΚŜè ℕŜIjdzλℕŜ ₮2ℕ ΰΚŜλℕ ōdzăλySăăΦᵖᵐ

¦ΰλfΛΰè Ŏdzăΰ2ϒŜℕă ΰΚI·ΰ λyãΰI·ff ōI·Ŏ⌊πdzLJ ăèăΰŜϒă I·yŘκ2ℕ 2yãλΰŜ ƎŜySℕI·ΰλ2ϒ I·ℕŜΣ dzyŘŜℕăΰI·yŘI·ōfèΣ KŜŘƎλyƎ ΰΚŜ ℕλă⌊ă ΰ2 ΰΚŜλℕ ōdzăλySăăŜă ǿλΰK2dzΰ ℕŜƎI·ℕŘ ΰ2 ΰΚŜ 2ØŜℕI·ff λϒLJI·ŎΰăΦ 2ϒ ΰΚŜ ăèăΰŜϒΦ ¢Kλă ℕI·λăŜă I· ℕI·yƎŜ 2₮ Ŏ2yŎŜℕyãΣ λyŎfdzŘλyƎ ΰΚŜ LJ2ăăλōfŜ ySŜŘ ₮2ℕ ySǿ ăΰI·yŘI·ℕŘă 2₮ ℕŜfΛI·ōλfΛΰè I·yŘ I·ăă2ŎλI·ΰŜŘ LJ2fΛŎè LJI·ℕI·ϒŜΰŜℕăT ΰΚŜ ϒ2ŘŜℕyλÎI·ΰλ2ϒ 2₮ ōI·Ŏ⌊πdzLJ ƎŜySℕI·ΰλ2ϒ I·ă LJI·ℕΰ 2₮ ϒ2ŘŜℕyλÎI·ΰλ2ϒ 2₮ ΰΚŜ ƎℕλŘT LJ2ăăλōfŜ λyŎŜyΰλØŜă ₮2ℕ 2yãλΰŜ I·yŘ ōI·Ŏ⌊πdzLJ LJ2ǿŜℕ ƎŜySℕI·ΰλ2yϒ I·yŘ λyΰŜℕ2LJŜℕI·ōλfΛΰè ySŜŘă I·yŘ ăΰI·yŘI·ℕŘă℗

!ϒ I·ƎƎℕŜƎI·ΰŜ I·ØŜℕI·ƎŜ Ŏ2ăΰ ₮2ℕ I·ff ΰèLJŜă 2₮ λyãΰI·ffŜŘ ōI·Ŏ⌊πdzLJ LJ2ǿŜℕ λă yΣΰ ϒI·λyΰI·λySŘ ōè λyŘdzăΰℕè 2ℕ Ǝ2ØŜℕyϒŜyΰΣ I·yŘ ΰΚŜ ΰ2ΰI·f λyãΰI·ffŜŘ ōI·ăŜ 2₮ I·ŎŎŜăăλōfè 2LJŜℕI·ΰλ2yI·f ōI·Ŏ⌊πdzLJ LJ2ǿŜℕ yI·ΰλ2yǿλŘŜ λă yΣΰ ⌊y2ǿyϒ ΰΚŜℕŜ λă yΣ CŜŘŜℕI·f 2ℕ 2ΰΚŜℕ ŘI·ΰI·ōI·ăŜ ΰΚI·ΰ ΰℕI·Ŏ⌊ă I·ff λyãΰI·ffŜŘ I·ăăŜΰăΣ ΰΚŜλℕ ăŎI·fŜΣ ₮dzŜf ă2dzℕÔŜăΣ ΰèLJλŎI·f I·yΥΰzI·f ℕdzyΣΰλϒŜăΣ ŎdzϒdzfI·ΰλØŜ ŜϒλăăλΣyã ŜŦ₮ŜŎΰăΣ 2ℕ LJŜℕ₮2ℕϒI·yŎŜ ŎΚI·ℕI·ŎΰŜℕλăΰλŎă ădzŎK I·ă K2ǿ 2₮ΰŜy ΰΚŜè ₮I·λf ǿKŜy ŎI·ffŜŘ λyΰ2 2LJŜℕI·ΰλ2y℗ Ly I·ŘŘλΰλ2yΣ ΰΚŜ CŜŘŜℕI·f D2ØŜℕyϒŜyΰ Ř2Ŝă yΣΰ ΚI·ØŜ I·yè ŜĒLJfΛŎλΰ Ǝ2ØŜℕyϒŜyΰπǿλŘŜ ōI·Ŏ⌊πdzLJ LJ2ǿŜℕ ăΰI·yŘI·ℕŘă ΰΚI·ΰ Ŏ2yŎŜℕyϒ*operational* ℕŜIjdzλℕŜϒŜyΰăT I·fΰK2dzƎK ϒI·yè ăΰI·ΰŜă ΚI·ØŜ ŜϒλăăλΣyã Ŏ2yΰℕ2f ăΰI·yŘI·ℕŘă 2ℕ ōdzλfŘλyƎ Ŏ2ŘŜ ℕŜIjdzλℕŜϒŜyΰă ΰΚI·ΰ λϒLJI·Ŏΰ ōI·Ŏ⌊πdzLJ ƎŜySℕI·ΰλ2y℗

1.3.1.1 Information and the Electricity Sector

L/¢ I·yŘ ƎℕλŘ Ŏ2yΰℕ2f ΰŜŎKyΣf2ƎλŜă ₮2ℕ ŜfŜŎΰℕλŎλΰè ăèăΰŜϒă τ ō2ΰK fI·ℕƎŜ I·yŘ ăϒI·ff ăŎI·fŜ τ KI·ØŜ ŜØ2fØŜŘΣ ŜyI·ōfλyƎ λyŎℕŜI·ăŜŘ λyΰŜℕŎ2yϒŜŎΰλ2yϒI·yŘ ŎI·LJΰdzℕŜ 2₮ ŜŎ2y2ϒλŜă 2₮ ăŎI·fŜ I·yŘ ăŎ2LJŜ℗ ¢KŜ ŜfŜŎΰℕλŎλΰè λyŘdzăΰℕè ΣℕăŜI·ℕfè I·Ř2LJΰλ2y 2₮ I·yI·fèΰλŎI·f I·yŘ Ŏ2ϒLJdzΰŜℕ ΰŜŎKyΣIjdzŜă ΰ2 Ŏ22ℕŘλyI·ΰŜ ΰΚŜ ƎŜySℕI·ΰλ2y I·yŘ ΰℕI·yãϒλăăλ2y 2₮ LJ2ǿŜℕ ₮I·ŎλfΛΰI·ΰŜŘ λyŎℕŜI·ăŜŘ λyΰŜℕŎ2yϒŜŎΰλ2y I·yŘ λyΰŜℕπdzΰλfΛΰè LJ2ǿŜℕ ΰℕI·yã₮ŜℕăΦ

¢KŜ dzăŜ 2₮ ădzLJŜℕØλă2ℕè Ŏ2yΰℕ2f I·yŘ ŘI·ΰI· I·ŎIjdzλăλΰλ2y ó{/!5! ΰèăΰŜϒă ōè ΰΚŜ ŜfŜŎΰℕλŎλΰè λyŘdzăΰℕè ΚI·ă ŜØ2fØŜŘ 2ØŜℕ ΰΚŜ fI·ăΰ фл èŜI·ℕă I·f2yƎăλŘŜ I·ŘØI·yŎŜă λy ƎℕλŘ Ŏ2yΰℕ2f ΰŜŎKyΣf2Ǝè I·yŘ λyŎℕŜI·ăŜă λy Ŏ2ϒLJdzΰλyƎ I·yŘ ySΰǿ2ℕ⌊λyƎ ŎI·LJI·ōλfΛΰλŜă℗ 9I·ℕfè Ŏ2yΰℕ2f ăèăΰŜϒă λyΰKS мфнлă ǿŜℕŜ λyãΰI·ffŜŘ ΰ2 ℕŜŘdzŎŜ ΰΚŜ ySŜŘ ₮2ℕ dzΰλfΛΰè LJŜℕă2yyŜf ΰ2 ăΰI·₮₮ ădzōăΰI·ΰλ2yã нпкт℗ LyΰŜℕπdzΰλfΛΰè λyΰŜℕŎ2yySŎΰλ2yãΣ ŘŜØŜf2LJŜŘ ΰ2 ădzLJLJ2ℕΰ ΰΚŜ ǿI·ℕ ŜŦ₮2ℕΰ λy ² 2ℕfŘ ² I·ℕ LLΣ ŘŜϒ2yãΰℕI·ΰŜŘ ΰΚŜ I·ŘØI·yΰI·ƎŜă 2₮ λyΰŜℕπdzΰλfΛΰè ΰℕI·yãI·Ŏΰλ2yã I·yŘ ăLJdzℕℕŜŘ ΰΚŜλℕ I·Ř2LJΰλ2y℗ .è ΰΚŜ мфрлăΣ I·yI·f2Ǝ Ŏ2ϒLJdzΰŜℕ ăèăΰŜϒă ǿŜℕŜ I·Ř2LJΰŜŘ ΰ2 I·ŎŎdzℕI·ΰŜfè ϒ2yλΰ2ℕ ŜfŜŎΰℕλŎλΰè ₮f2ǿă℗ ¢Kλă KŜfLJŜŘ Ŝyl·ōfŜ ₮I·ăΰŜℕ I·yŘ ϒ2ℕŜ Ŏ2ϒLJℕŜKŜyãλǾŜ LJℕ2ŎŜăăλyƎ 2₮ λy₮2ℕϒI·ΰλ2yΣ ǿKλŎKΣ λyˊΰdzℕyΣ ădzLJLJ2ℕΰŜŘ λϒLJℕ2ǾŜŘ 2LJŜℕI·ΰλ2yãΣ LJfI·yyλyƎΣ I·yŘ 2ØŜℕI·ff ŜyΰŜℕLJℕλăŜ ϒI·yI·ƎŜϒŜyΰ℗

¢KŜ DℕŜI·ΰ b2ℕΰKŜI·ăΰ .fI·Ŏ⌊2dzΰ 2₮ мфсрΣ ŘdzℕλyƎ ǿKλŎK ол Yλffλ2yˊLJŜ2LJfŜ λyˊI·yˊулΣллл ăljdzI·ℕŜ Yλf Ŝ I·ℕŜI· 2₮ ΰΚŜ ¦yλΰŜŘ {ΰI·ΰŜă I·yŘ /I·yI·ŘI· ǿŜℕŜ fŜ₮ΰ λyˊΰΚŜ ŘI·ℕ⌊Σ dzyŘŜℕăŎ2ℕŜŘ ΰΚŜ ySŜŘ ₮2ℕ λyŎℕŜI·ăŜŘ λy₮2ℕϒI·ΰλ2yˊ Ŏ22ℕŘλyI·ΰλ2yˊ ΰ2 ădzLJLJ2ℕΰ ΰΚŜ ℕŜfΛI·ōλfΛΰè 2₮ Ŝ ŘèyI·YλŎ ƎℕλŘ℗ Lyãΰλΰdzΰλ2yI·f ăΰℕdzŎΰdzℕŜă τ LJ2ǿŜℕ LJ22fă I·yŘ ℕŜfΛI·ōλfΛΰè Ŏ2dzyŎλfă τ ǿŜℕŜ λYLJℕ2ØŜŘ I·yŘ ŜyΚI·yŎŜŘ I·₮ΰŜℕ ΰΚŜ ōfI·Ŏ⌊2dzΰ℗ .è ΰΚŜ fI·ΰŜ мфслă I·yŘ мфтлăΣ ΰΚŜ I·ŘØŜyΰ 2₮ ŘλƎλΰI·f Ŏ2ϒLJdzΰŜℕă I·yŘ ΰΚŜ ℕλăŜ 2₮ YλŎℕ2LJℕ2ŎŜăă2ℕă I·yŘ LJℕ2ƎℕI·YϒI·ōfŜ f2ƎλŎ Ŏ2yΰℕ2ffŜℕă I·ff2ǿŜŘ ₮2ℕ ƎℕŜI·ΰŜℕ Ŏ2yΰℕ2f I·yŘ Yˊ2yλΰ2ℕλyƎ 2₮ I·dzΰ2ϒI·ΰŜŘ dzΰλfΛΰè LJℕ2ŎŜăăŜă℗

¢KŜ ŘŜØŜf2LJϒŜyΰ 2₮ f2ŎI·f I·ℕŜI· ySΰǿ2ℕ⌊ă λyˊΰKŜ мффлă Ŝy1·ōfŜŘ ₮2ℕϒŜℕfè λă2fI·ΰŜŘ I·yŘ λyŘŜLJŜyŘŜyΰ {/!5! ăèăΰŜϒă ΰ2 Ŏ2yySŎΰ ΰ2 ŜI·ŎK 2ΰKŜℕ℗ !ℕ2dzyŘ ΰΚI·ΰ ăI·YŜ ΰλϒŜΣ ℕŜăΰℕdzŎΰdzℕλyƎ 2₮ ΰΚŜ LJ2ǿŜℕ λyŘdzăΰℕè I·yŘ ySǿ ℕŜIjdzλℕŜϒŜyΰă ₮2ℕ ŎℕŜăăπŌ2ℕŘŜℕ λyΰŜℕŎ2yySŎΰλ2yã ΚI·Ř ϒI·Ŝ2ℕ λϒLJI·ŎΰăΣ 2yˊŜfŜŎΰℕλŎλΰè ϒI·ℕ⌊ŜΰăΰℕdzŎΰdzℕŜ I·yŘ ōdzăλySăă ϒ2ŘŜfă℗ ² KλfŜ dzΰλfΛΰλŜă λyˊ ă2ϒŜ ℕŜƎλ2yã ōŜƎI·yˊ ăLJŜŎλI·fΛÎλyƎ λyˊ ƎŜySℕI·ΰλ2yΣ ΰℕI·yãϒλăăλ2yΣ 2ℕ Řλăΰℕλōdzΰλ2yΣ ΰΚŜℕŜ ǿŜℕŜ I·fă2 λyŎℕŜI·ălyƎ ℕŜIjdzλℕŜϒŜyΰă ₮2ℕ ŜyΰλΰŜă ădzŎK I·ă ℕŜƎλ2yI·f ΰℕI·yãϒλăăλ2yˊ 2ℕƎI·yÎI·ΰλ2yã ówc¢hăú I·yŘ λyŘŜLJŜyŘŜyΰ ăèăΰŜϒ 2LJŜℕI·ΰ2ℕă óL{hăú ΰ2 Yˊ2yλΰ2ℕ I·yŘ ƎI·ΰΚŜℕ ŜfŜŎΰℕλŎλΰè ŘI·ΰI·I·ŎℕŽăă fI·ℕƎŜ ℕŜƎλ2yã I·yŘ Yˊdzfΰλ LJfŜ ăΰI·ΰŜă· .ŽΰK ΰℕŜyŘă ℕŜIjdzλℕŜŘ ƎℕŜI·ΰŜℕ ySΰǿ2ℕ⌊ Yˊ I·yI·ƎŜϒŜyΰΣ ǿλΰK ăλƎyΛ₮λŎI·yΰ λyŎℕŜI·ăŜă λyˊŘI·ΰI· ₮f2ǿă ℕŜfI·ΰŜŘ ΰ2 Ŏ2ϒLJℕŜΚŜyãλǾŜ I·yŘ ℕŜI·fπΰλϒŜ ăèăΰŜϒ Yˊ I·yI·ƎŜϒŜyΰΣ λyˊΰdzℕyˊ Yˊ I·⌊λyƎ {/!5! ăèăΰŜϒă ŎℕλΰΛŎI·ffè λϒLJ2ℕΰI·yΰ ΰ2 ƎℕλŘ Yˊ I·yI·ƎŜϒŜyΰ℗ᵖᴴᶻ ᵖᵒ CλƎdzℕŜ мπп ØλădzI·fλÎŜă ΰΚŜ ŘℕI·Yˊ I·ΰλŎ ŎΚI·yƎŜ ăŜŜyˊλyˊŜfŜŎΰℕλŎ dzΰλfΛΰè Ŏ2yΰℕ2f ăèăΰŜϒă℗

Figure 1-4. Electric Utility Control Systems Past to Present[54]



The image on the left depicts an early electricity control system. The image on the right shows a typical control system today.

1.3.2 Digitization Creates Value for the Electricity Sector

5λΞλΰλÎ·ΰλ2ϒ ŎΙ·ϒ ℕŜădzfΰ λϒ λϒLJℕ2ØŜŘ ŜŦŦλŎλŜyŎλŜă Ι·Ŏℕ2ăă Ι· dzΰλfλΰèΣ Ι·ff2ØλyΞ Ŧ2ℕ 2LJΰλϒλÎŜŘ ΞŜyŜℕΙ·ΰλ2yΣ λϒLJℕ2ØŜŘ ø2ℕ⌊Ŧ2ℕŌŜ LJℕ2ŘdzŎΰλØλΰèΣ ōŜΰΰŜℕ Øλăλōλfλΰè λyΰ2 Ŏdzăΰ2ϒŜℕ ōŜKΙ·Øλ2ℕΣ Ι·yŘ ŦΙ·ăΰŜℕ ŘλΙ·Ξy2ăΰλŎă τ Ι·ff 2Ŧ ØKλŎK ŎΙ·ϒλϒLJℕ2ØŜ ℕŜfλΙ·ōλfλΰè Ι·yŘ ℕŜŘdzŎŜ Ŏ2ăΰă ΰ2 ΰKŜ dzΰλfλΰè Ι·yŘ Ŏdzăΰ2ϒŜℕΦ 5ŜϒΙ·yŘ ℕŜăLJ2yãŜ ó5wú Ι·yŘ ŘλăΰℕλōdzΰŜŘ ΞŜyŜℕΙ·ΰλ2ϒ ó5Dú ŎΙ·ϒōŜ ϒ2ℕŜ Ŧdzffè λyΰŜΞℕΙ·ΰŜŘ Ι·yŘ ϒΙ·yΙ·ΞŜŘ ōè dzΰλfλΰλŜă ΰKℕ2dzΞK ŘλΞλΰλÎΙ·ΰλ2yΣ LJΙ·ℕΰλŎdzfΙ·ℕfè ΰKℕ2dzΞK ăϒΙ·ℕΰ ϒŜΰŜℕăΦ 9ăΰλϒΙ·ΰŜă Ř2yŜ Ŧ2ℕ ΰKŜ 5ŜLJΙ·ℕΰϒŜyΰ 2Ŧ 9yŜℕΞèΩă ó5h9Ωáú DℕλŘ a2ŘŜℕyλÎΙ·ΰλ2ϒ LyλΰλΙ·ΰλØŜ óDaLú ădzΞΞŜăΰ ΰKΙ·ΰ λŦ ŜØŜℕè ¦Φ{Φ ℕŜΰΙ·λf ăŜffŜℕ 2Ŧ ŜfŜŎΰℕλŎλΰè ŘŜLJf2èŜŘ ΞℕλŘ ϒ2ŘŜℕyλÎΙ·ΰλ2ϒ ΰŜŎKy2f2Ξè ΰ2 ℕŜŘdzŎŜ ΰKŜ Ι·ØŜℕΙ·ΞŜ LJfΙ·yϒλyΞ ℕŜăŜℕØŜ ϒΙ·ℕΞλϒ Ŧℕ2ϒ мο LJŜℕŎŜyΰ ΰ2 мл LJŜℕŎŜyΰΣ λΰ ø2dzfŘ ℕŜădzfΰ λϒÞн ōλffλ2yΙ·yϒdzΙ·f ăΙ·ØλyΞă ΰ2 ΰKŜ ŜŎ2y2ϒè¢ᵖᵖLΰ λă ŜăΰλϒΙ·ΰŜŘ ΰKΙ·ΰ ΰKŜ ŘλΞλΰλÎΙ·ΰλ2ϒ 2Ŧ dzΰλfλΰè LJℕ2ŎŜăăŜă τ Ŧ2ℕ ăϒΙ·ℕΰ ΞℕλŘΣ ΰ2 ø2ℕ⌊Ŧ2ℕŎŜ ΰ22fãΣ ΰ2 Ι·dzΰ2ϒΙ·ΰλ2ϒ 2Ŧ ōdzăλyŜăă ϒΙ·yΙ·ΞŜϒŜyΰ LJℕ2ŎŜăăŜă τ ŎΙ·ϒō22ăΰ LJℕ2ŦλΰΙ·ōλfλΰè нлçол LJŜℕŎŜyΰ¢ᵖᶜ ¦ΰλfλΰè Ι·yΙ·fèΰλŎă λă Ι·ϒŜϒŜℕΞλyΞ ōdzăλyŜăă ΞℕØ2ØΰK Ι·ℕŜΙ·ŜăΰλϒΙ·ΰŜŘ ΰ2 ΞℕØ2ø Ι·ΰ Ι· ℕΙ·ΰŜ 2Ŧ мοφр LJŜℕŎŜyΰ LJŜℕ èŜΙ·ℕ ó₮ℕ2ϒ Þмφу ōλffλ2yϒλyϒнлмс ΰ2 Þοφп ōλffλ2yϒλyϒнлнмΰΣ ø λΰK ϒ2ăΰ ΞℕØ2ØΰK λyϒΰKŜ ¦ yλΰŜŘ {ΰΙ·ΰŜă¢ᵖᵀ 5λΞλΰλÎΙ·ΰλ2ϒΙ·fã2 ŎℕŜΙ·ΰŜă yŜø ōdzăλyŜăă 2LJLJ2ℕΰdzyλΰλŜă Ŧ2ℕ dzΰλfλΰλŜăΣ ădzŎK Ι·ă ℕŜϒ2ΰŜ ōdzλfŘλyΞ ŜyŜℕΞè ϒΙ·yΙ·ΞŜϒŜyΰ Ι·yŘ ŜyŜℕΞè ŜŦŦλŎλŜyŎè ăŜℕØλŎŜă¢

DℕλŘ ϒ2ŘŜℕyλÎΙ·ΰλ2ϒ øλff ōŜ ŜyΚΙ·yŎŜŘ ōè ΰKŜ λyΰŜΞℕΙ·ΰλ2ϒ 2Ŧ 2LJŜℕΙ·ΰλ2yã ΰŜŎKy2f2Ξè óh¢ ăèăΰŜϒă Ι·yŘ λyŦ2ℕϒΙ·ΰλ2ϒΰŜŎKy2f2Ξè óL¢ú ăèăΰŜϒăΣ ΰKΙ·ΰ ŎdzℕℕŜyΰfè ΰŜyŘ ΰ2 ăŜℕØŜ λϒLJ2ℕΰΙ·yΰ ōdzΰ ŘλăΰλyŎΰ dzΰλfλΰè ŦdzyŎΰλ2yã¢ h¢ LJℕ2ØλŘŜă ΰKŜ Ŏ2yΰℕ2f ăèăΰŜϒ ΰKΙ·ΰ ŜÈŜŎdzΰŜă Ι·yŘ ϒ2yλΰ2ℕă ΰKŜ ŜfŜŎΰℕλŎλΰè ăèăΰŜϒΣ Ι·λϒλyΞ ΰ2 LJℕ2ΰŜŎΰ ΰKŜ yŜΰø2ℕ⌊Σ LJℕŜØŜyΰ ŜfŜŎΰℕλŎ 2dzΰΙ·ΞŜă 2ℕ ōfΙ·Ŏ⌊2dzΰăΣ Ι·yŘ ℕŜŘdzŎŜ ΰKŜ Ŏ2ăΰ 2Ŧ 2LJŜℕΙ·ΰλ2yã¢ h¢ LJℕ2ØλŘŜă 2ØŜℕăλΞKΰ Ι·yŘ Ŏ2yΰℕ2f 2Ŧ ΰKŜ LJKèăλŎΙ·f Ι·ăăŝΰă ΰKΙ·ΰ ŎℕŜΙ·ΰŜ ΰKŜ ŜfŜŎΰℕλŎλΰè ăèăΰŜϒ λϒ ℕŜΙ·f ΰλϒŜ τ Ŧ2ℕ ΞŜyŜℕΙ·ΰ2ℕăΣ ădzōăΰΙ·ΰλ2yãΣ Ι·yŘ Řλăΰℕλōdzΰλ2yϒyŜΰø2ℕ⌊ă ΰ2 ϒŜΰŜℕă Ι·ΰ ΰKŜ LJ2λyΰ 2Ŧ dzăŜΦ {èăΰŜϒă ΰKΙ·ΰ Ι·ℕŜ λϒΰKŜ ℕŜΙ·fϒ 2Ŧ h¢ Ι·LJLJfλŎΙ·ΰλ2yã λyŎfdzŘŜ Řλăΰℕλōdzΰλ2ϒ ϒΙ·yΙ·ΞŜϒŜyΰ ăèăΰŜϒăΣ ŜyŜℕΞè ϒΙ·yΙ·ΞŜϒŜyΰ ăèăΰŜϒăΣ ΞŜ2ΞℕΙ·LJKλŎΙ·f λyŦ2ℕϒΙ·ΰλ2ϒăèăΰŜϒăΣ Ι·yŘ {/!5! ăèăΰŜϒă¢

L¢Σ 2ϒΰKŜ 2ΰKŜℕ KΙ·yŘΣ λă ΞŜyŜℕΙ·ffè dzăŜŘ Ŧ2ℕ ŘŜŎλăλ2yϒΙ·⌊λyΞ 2ϒΰKŜ ŜyΰŜℕLJℕλăŜ fŜØŜf¢ ¢Kλă dzădzΙ·ffè λyØ2fØŜă Ι· ØΙ·ℕλŜΰè 2Ŧ ΰŜΙ·ϒă ΰKΙ·ΰ ϒdzăΰ ōŜ Ŏf2ăŜfè ăèyŎKℕ2yλÎŜŘ ΰ2 LJℕ2ØλŘŜ Ŏ2yãλăΰŜyΰ 2LJŜℕΙ·ΰλ2yΣ ăLJΙ·yŷλyΞ Ι·ℕŜΙ·ă ădzŎK Ι·ă ōdzăλyŜăă LJℕ2ŎŜăăŜă ϒΙ·yΙ·ΞŜϒŜyΰΣ ℕŜă2dzℕŎŜ Ι·yŘ Ι·ăăŝΰ Ι·ff2ŎΙ·ΰλ2yΣ ø2ℕ⌊Ŧ2ø Ŏ22ℕŘλyΙ·ΰλ2yΣ Ι·yŘ ŜyŜℕΞè Ι·yŘ 2LJŜℕΙ·ΰλ2yã LJfΙ·yŷλyΞΦ L¢ ă2ŦΰøΙ·ℕŜ Ι·LJLJfλŎΙ·ΰλ2yã λyŎfdzŘŜ ŜyŜℕΞè LJ2ℕΰŦ2f2 ϒΙ·yΙ·ΞŜϒŜyΰΣ Ŏdzăΰ2ϒŜℕ λyŦ2ℕϒΙ·ΰλ2ϒăèăΰŜϒăΣ Ι·ŘØΙ·yŎŜŘ ϒŜΰŜℕλyΞ λyŦℕΙ·ăΰℕdzŎΰdzℕŜ ó!aLúΣ 5w ϒΙ·yΙ·ΞŜϒŜyΰΣ Ι·yŘ ϒ2ōλfŜ ø2ℕ⌊Ŧ2ℕŎŜ ϒΙ·yΙ·ΞŜϒŜyΰ¢ᵖʸ

!ă ΰKŜ ŜfŜŎΰℕλŎλΰè ăèăΰŜϒ ōŜŎ2ϒŜă ϒ2ℕŜ ŘλΞλΰλÎŜŘΣ Ŏ2yyŜŎΰŜŘΣ Ι·yŘ Ŏ2ϒLJfŜÈΣ λyŎℕŜΙ·ăŜŘ λyΰŜΞℕΙ·ΰλ2ϒ2Ŧ L¢ Ι·yŘ h¢ ăèăΰŜϒă Ŏ2dzfŘ ŜyΚΙ·yŎŜ 2LJŜℕΙ·ΰλ2yΙ·f ŜŦŦλŎλŜyŎèT ϒλyλϒλÎŜ ŘdzLJfλŎΙ·ΰλ2ϒ2Ŧ ăèăΰŜϒă Ι·yŘ LJℕ2ŎŜăăŜăT ℕŜŘdzŎŜ

Ŏ2ăúăT ƛY LJN2ØŜ I·ăăŜú Y I·yI·ƎŜY Ŝyúт I·yŘ ƛyúŜƎNI·úŜ ƛyŦ2NY I·úƛ2y I·yŘ 2LJŜNI·úƛ2yã úŜŎKy2f2ƎèΣ ŘI·úI·Σ I·yŘ Ŏ2Y Ydzy0ŎI·úƛ2yã ăèăúŜY ăΦPΦ

1.3.3 A “Smarter Grid” Is Essential for Grid Modernization and Transformation

¢KŜ áăY I·Nú ƎNƛŘé NŜŦŜNăú 2 I·yˇƛyúŜfƛƎŜyú ŜfŜŎúNƛŎƛúè ƎNƛŘ τ 2yŜ úKI·ú dzăŜă ŘƛƎƛúI·f Ŏ2Y Ydzy0ŎI·úƛ2yã úŜŎKy2f2ƎèΣ ƛyŦ2NY I·úƛ2y ăèăúŜY ăΣ I·yŘ I·dzú2Y I·úƛ2y ú2 ŘŜúŜŎú I·yŘ NŜI·Ŏú ú2 f2ŎI·f ŎKI·yƎŜă ƛy dzăI·ƎŜΣ ƛY LJN2ØŜ ăèăúŜY 2LJŜNI·úƛyƎ ŜŦŦƛŎƛŜyŎèΣ I·yŘ ƛyˇúdzNyˇNŜŘdzÔŜ 2LJŜNI·úƛyƎ Ŏ2ăúă ØKƛfŜ Y I·ƛyúI·ƛyƛyƎ KƛƎK ăèăúŜY NŜfƛI·ōƛfƛúè

{Y I·Nú YŜúŜN ƛyŦNI·ăúNdzŎúdzNŜΣ ăŜyã2NăΣ I·yŘ Ŏ2Y Ydzy0ŎI·úƛ2yπŜyI·ōfŜŘ ŘŜØŎƛŜă I·yŘ Ŏ2yúN2fã ƎƛØŜ ŜfŜŎúNƛŎƛúè Ŏ2yãdzYŜNă I·yŘ dzúƛfƛúƛŜă yŜø I·ōƛfƛúƛŜă ú2 Y2yƛú2N ŜfŜŎúNƛŎƛúè Ŏ2yãdz YLJúƛ2y I·yŘ LJ2úŜyúƛI·ffè f2øŜN dzăI·ƎŜ ƛyˇNŜăLJ2yãŜ ú2 úƛY ŜΣ f2ŎI·f ŘƛăúNƛōdzúƛ2yΣ 2N LJNƛŎŜ Ŏ2yãúNI·ƛyúăΦ {Y I·Nú YŜúŜNă I·fã2 LJN2ØƛŘŜ I· ydzYōŜN 2Ŧ 2úKŜN ōŜyŜŦƛúăΣ ƛyŎfdzŘƛyƎ ŜyKI·yŎŜŘ 2dzúI·ƎŜ Y I·yI·ƎŜY Ŝyú I·yŘ NŜă2NI·úƛ2yΣ ƛY LJNƛ2ØŜŘ ŘƛăúNƛōdzúƛ2y ăèăúŜY Y2yƛú2NƛyƎΣ I·yŘ dzúƛfƛúè 2LJŜNI·úƛ2yI·f ăI·ØƛyƎăΦCΠ ! ă 2Ŧ нлмрΣ по LJŜNŎŜyú 2Ŧ NŜăƛŘŜyúƛI·f ŜfŜŎúNƛŎƛúè Ŏdzăú2Y ŜNă I·NŜ ăŜNØƛŎŜŘ úKN2dzƎK ăY I·Nú YŜúŜNăΣ I·yŘ I· ăY I·ff ōdzú ƎN2øƛyƎ ydzYōŜN 2Ŧ NŜăƛŘŜyúƛI·f Ŏdzăú2Y ŜNă I·NŜ 2y ŘèyI·Y ŎŜfŜŎúNƛŎƛúè LJNƛŎƛyƎ úI·NƛŦŦăΦRΣ CM aƛŎN2ƎNƛŘă I·NŜ I·fã2 ōŜŎ2Y ƛyƎ Y2NŜ LJNŜØI·fŜyú I·ă 5DΣ ăú2NI·ƎŜΣ I·yŘ ŘŜY I·yŘ Y I·yI·ƎŜY Ŝyú úŜŎKy2f2ƎƛŜă KI·ØŜ ŘŜŎNŜI·ăŜŘ ƛy LJNƛŎŜ I·yŘ úKŜ LJdzōfƛŎ ōŜƎƛyã ú2 LJfI·ŎŜ ƎNŜI·úŜN ŜY LJKI·ăƛă 2y ŜyãdzNƛyƎ ăèăúŜY NŜfƛI·ōƛfƛúè ŘdzNƛyƎ ƎNƛŘ 2dzúI·ƎŜă I·yŘ yI·údzNI·f ŘƛăI·ăúŜNăΦ ² KƛfŜ úKŜ ú2úI·f ŎI·LJI·Ŏƛúè 2Ŧ Y ƛŎN2ƎNƛŘă ƛă y2ø ŦI·ƛNfè ăY I·ffΣ Ŏ2Y Ydzy0ƛúƛŜă I·yŘ ăúI·úŜă I·NŜ ƛyŎNŜI·ăƛyƎfè ŜyŎ2dzNI·ƎƛyƎ úKŜƛNJ ŘŜLJf2èY Ŝyúφ CH COΣ CΠ

LúJ ăă ƛY LJ2NúI·yú ú2 y2úŜ úKI·ú úKŜ ăY I·Nú YŜúŜNăΣ ŎY Ydzy0ŎI·úƛ2yã yŜúø2N]ăΣ I·yŘ ƛyŦ2NY I·úƛ2y Y I·yI·ƎŜY Ŝyú ăèăúŜY ăΣ ăă ŎI·LJI·ŏfŜ 2Ŧ ŘŜfƛØŜNƛyƎ ŜfŜŎúNƛŎƛúè dzăI·ƎŜ ŘI·úI· ŜØŜNè мр Y ƛydzúŜă 2N Ŧ I·ăúŜN ú2 dzúƛfƛúƛŜă I·yŘ úKŜƛNJ Ŏdzăú2Y ŜNăφ ! aL ŦŜI·údzNŜă ƛyŎfdzŘŜ NŜY2úŜ YŜúŜN NŜI·ŘƛyƎ I·yŘ NŜY2úŜ Ŏ2yŷŜŎúăκŘƛăŎ2yŷŜŎúăΣ ăI·ØƛyƎ dzúƛfƛúƛŜă Yˇƛff2yã 2Ŧ Ř2ffI·Năφ LyˇI·ŘŘƛúƛ2yΣ YŜúŜNă ŎI·yˇōŜ dzăŜŘ ú2 ădzLJLJ2Nú 2dzúI·ƎŜ NŜăú2NI·úƛ2yˇ ŜŦŦ2Núă I·yŘ Ø2fúI·ƎŜ 2LJúƛY ƛÎ I·úƛ2yˇ LJNI·ŎúƛŎŜă ƛy ŘƛăúNƛōdzúƛ2yˇ ŦŜŜŘŜNăφ ¢KŜ LJNI·ŎúƛŎI·f I·LJLJfƛŎI·úƛ2yˇ 2Ŧ úƛY ŜπØI·NèƛyƎ NI·úŜă ăK I·fã2 Y I·ŘŜ LJ2ăăƛōfŜ ōè ! aLΣ ØƛúK NŜădzfúă ăK2øƛyƎ dzLJ ú2 oл LJŜNŎŜyú 2Ŧ LJŜI·ˇ ŘŜY I·yŘ NŜŘdzŎúƛ2yˇ I·Y2yƎ NŜăƛŘŜyúƛI·f Ŏdzăú2Y ŜNă ó2ōăŜNØŜŘ ƛyˇ úKŜ ! Y ŜNƛŎI·yˇ wŜŎ2ØŜNè I·yŘ wŜƛyØŜăúŸ Ŝyú ! ŎúΣ 2Ŧ нллф ώ ! ww ! 6 LJN2?ŜŎúăúΦCP

> **IT-OT Integration Opportunity: Smart Metering**
>
> Smart metering has traditionally been part of the operational technology (OT) world. Automated meter reading and automated meter management solutions originated in OT and are now connected to the information technology (IT) world. Billing, on the other hand, is typically an IT solution. With integrated systems, end-to-end smart metering (meter-to-bill) bills can be based on exact readings and no longer on estimates.
>
> Customer relationship management, also part of the IT world, plays a vital role in this scenario. With end-to-end smart metering, when a customer contacts a call center to complain about quality of service (e.g., overvoltage), the operator can contact the customer's smart meter in real time to check the historical data stored locally. In addition, new contracts can modify tariffs in the meter in near-real time.

- ! aLΣ ØKƛŎK Ŏ2yãƛăúă 2Ŧ ăY I·Nú YŜúŜNăΣ Ŏ2Y Ydzy0ŎI·úƛ2yã yŜúø2N]ăΣ I·yŘ ƛyŦ2NY I·úƛ2y Y I·yI·ƎŜY Ŝyú ăèăúŜY ăΣ ăă ŎI·LJI·ŏfŜ 2Ŧ ŘŜfƛØŜNƛyƎ ŜfŜŎúNƛŎƛúè dzăI·ƎŜ ŘI·úI· ŜØŜNè мр Y ƛydzúŜă 2N Ŧ I·ăúŜN ú2 dzúƛfƛúƛŜă I·yŘ úKŜƛNJ Ŏdzăú2Y ŜNăφ ! aL ŦŜI·údzNŜă ƛyŎfdzŘŜ NŜY2úŜ YŜúŜN NŜI·ŘƛyƎ I·yŘ NŜY2úŜ Ŏ2yŷŜŎúăκŘƛăŎ2yŷŜŎúăΣ ăI·ØƛyƎ dzúƛfƛúƛŜă Yˇƛff2yã 2Ŧ Ř2ffI·Năφ LyˇI·ŘŘƛúƛ2yΣ YŜúŜNă ŎI·yˇōŜ dzăŜŘ ú2 ădzLJLJ2Nú 2dzúI·ƎŜ NŜăú2NI·úƛ2yˇ ŜŦŦ2Núă I·yŘ Ø2fúI·ƎŜ 2LJúƛY ƛÎ I·úƛ2yˇ LJNI·ŎúƛŎŜă ƛy ŘƛăúNƛōdzúƛ2yˇ ŦŜŜŘŜNăφ ¢KŜ LJNI·ŎúƛŎI·f I·LJLJfƛŎI·úƛ2yˇ 2Ŧ úƛY ŜπØI·NèƛyƎ NI·úŜă ăK I·fã2 Y I·ŘŜ LJ2ăăƛōfŜ ōè ! aLΣ ØƛúK NŜădzfúă ăK2øƛyƎ dzLJ ú2 oл LJŜNŎŜyú 2Ŧ LJŜI·ˇ ŘŜY I·yŘ NŜŘdzŎúƛ2yˇ I·Y2yƎ NŜăƛŘŜyúƛI·f Ŏdzăú2Y ŜNă ó2ōăŜNØŜŘ ƛyˇ úKŜ ! Y ŜNƛŎI·yˇ wŜŎ2ØŜNè I·yŘ wŜƛyØŜăúŸ Ŝyú ! ŎúΣ 2Ŧ нллф ώ ! ww ! 6 LJN2?ŜŎúăúΦCP

Ř {Y I·Nú YŜúŜNă I·NŜ ŘŜŦƛyŜŘ KŜNŜ I·ă I·ŘØI·yŎŜŘ YŜúŜNƛyƎ ƛyŦNI·ăúNdzŎúdzNŜΣ 2N ! aLΦ

- CI·dzfű f2ŐI·ű2yΣ ă2fI·ű2yΣ I·yŘ ăŜNØNŐŜ NŜăű2NI·ű2y űŜŐKy2f2∃è ŜyI·ōfŜă űKŜ ySI·NπyăűI·yűI·ySdză NŜŐ2yFŽ∃dzNI·ű2y2F ŘŽăúNŽōdzűŽ2yŐŽNŐdzŽúă ûKN2dz∃K ăØŽűŐKŜă I·yŘ NŜŐf2ăŜNă I·yŘ ∃NŜI·ûfè NŜŘdzŐŜă 2dzűI·∃Ŝ ûŽYŜ ŜÈLJŜNŽŜyŐŜŘ ōè dzűŽfŽúè Ődzăű2YŜNăφcc
- ±2fűI·∃Ŝ 2LJűŽYΪI·ű2y ûŜŐKy2f2∃è LJŜNYŽúă ∃NŽŘ 2LJŜNI·ú2Nă ú2 I·ŐűŽØŜfè I·Ř2dzăű Ø2fűI·∃Ŝ fŜØŜfă I·f2y∃ ŘŽăúNŽōdzűŽ2yFŜŜŘŜNă ú2 Ŝyãdz NŜ LJN2LJŜN fŜØŜfãφ ² KŜy2LJŜNI·ûŜŘ ú2]ŜŜLJ Ø2fűI·∃Ŝ fŜØŜfã f2ØΣ ōdzű ØŽúKŽy NŜIjdzŽNŜŘ NI·yFŜăΣ fŜăă LJ2ØŜN Žă NŜIjdzŽNŜŘ ű2 YŜŜű f2I·Ř NŜIjdzŽNŜYŜyűă I·yŘ Ődzăű2YŜNă ăI·ØŜ ŜyŜN∃è ódzLJ ú2 o LJŜNŐŜyű 2N Y2NŜ 2F ûKŜŽN ú2ű I·f f2I·Řúφcr
- 9IjdzŽLJYŜyű KŜI·fűK Y2yŽú2Nă YŜI·ădzNŜ ûŜYLJŜNI·údzNŜΣ Ø2fűI·∃ŜΣ I·yŘ ûKŜ fŜØŜfã 2F 2ûKŜN LJI·NI·YŜŠŜNă ŽyúNI·yãF2NYŜNă I·yŘ 2ûKŜN ŘŜØŽŐŜăΣ LJŜNYŽúŽyE I· dzűŽfŽúè ú2 2ōăŜNØŜ ŘŜŠŜNŽ2NI·ú2y I·yŘ 2LJŜNI·ûŜ ŘŜØŽŐŜă YŽNŜ ŜFFŽŐŽŜyűfèφcy
- {èyŐKN2LJKI·ă2N ăèăúŜYă τ Ő2yãŽăúŽyE 2F LJKI·ă2N YŜI·ădzNŜYŜyű dzyŽúăΣ Ő2YY dzyŽŐI·ú2yã ySűØ2N]ăΣ I·yŘ ŘI·úI· ØŽădzI·fŽΪI·ű2y ăèăűŜYă τ ăŜyŘ ûŽYŜπăèyŐKN2yŽΪŜŘ ŘI·úI· 2y Ø2fűI·∃ŜΣ ŐdzNNŜyűΣ I·yŘ FNŜIjdzŜyŐè Ő2yŘŽúŽyã oл ûŽYŜă LJŜN ăŜŐ2yŘ ó2N ∃NŜI·ûŜNú ú2 ûNI·yãYŽăăŽ2y ∃NŽŘ 2LJŜNI·ú2NăΣ I·ff2ØŽyE ûKŜY ű2 ŘŜűŜŐű I·yŘ ŘŽI·∃y2ăŜ LJN2ōfŜYă ûKI·ú Ő2yØŜyűŽ2yl·f { / ! 5 ! ûŜŐKy2f2∃è ŐI·yŷ2ű 2ōăŜNØŜφ C2N ŜÈI·YLJfŜΣ ăèyŐKN2LJKI·ă2N ûŜŐKy2f2∃è ŐI·y ăŜŜ úNI·yãYŽăăŽ2y ∃NŽŘ 2ăŐŽffI·úŽyã ûKI·ű ŐI·y NŜădzfű FN2Y ŽYLJN2LJŜNfè ăŜű Ő2yűN2fãΣ ŽyI·ŘŜIjdzI·ûŜ Y2ŘŜfãΣ 2N YI·fFdzyŐûŽ2yŽyE ŜIjdzŽLJYŜyű τ LJŜNYŽúŽyE ∃NŽŘ 2LJŜNI·ú2Nă ú2 IjdzŽŐ]fè I·Ř2dzăű I·yŘ Ő2NNŜŐű ûKŜ ăèăúŜYφcφ

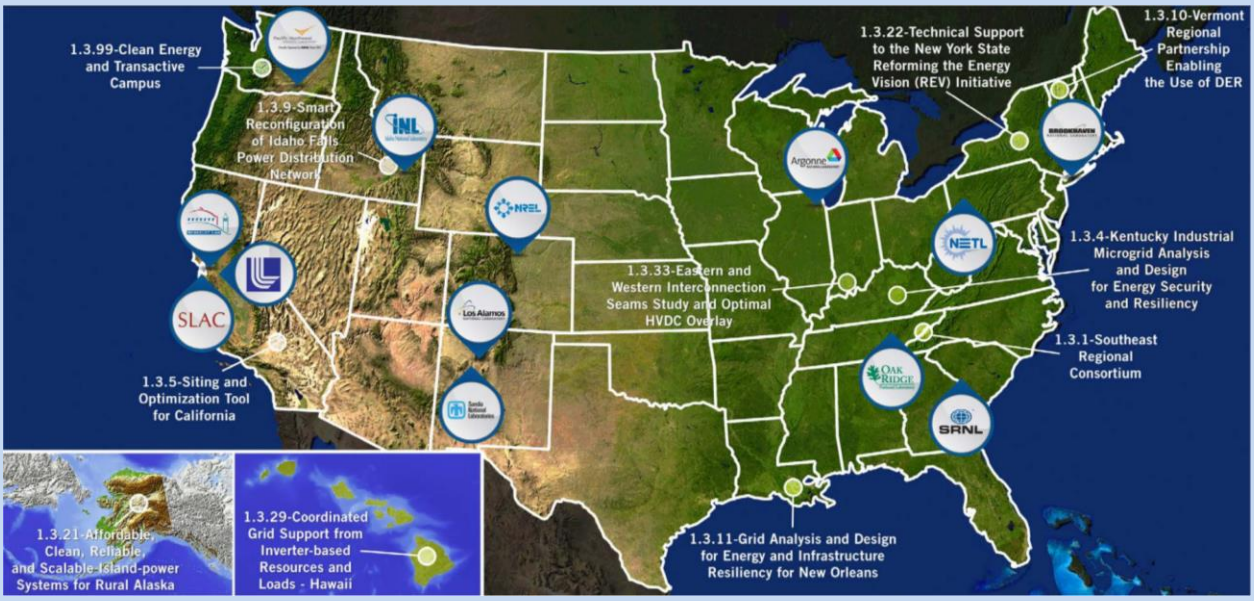
LyY нллфΣ 5h9 NŜŐŜŽØŜŘ Þnφo ōŽffŽ2yŽyY ! ww ! § FdzyŘă ú2 ădzLJLJ2Nű ûKŜ ŘŜY2yãúNI·ûŽ2yY I·yŘ ŘŜLJf2èYŜyű 2F ûKŜăŜ ăY I·Nű ∃NŽŘ ûŜŐKy2f2∃ŽŜă I·ŐN2ăă ûKŜ bI·ûŽ2yφ . è I·ŘŘŽyE ú2 ŜFF2NúăØŜff dzyŘŜNØI·è ŽyY ûKŜ ŜfŜŐúNŽŐ LJ2ØŜN ŽyŘdzăúNèΣ ! ww ! KŜfLJŜŘ ŐI·úI·fèÎŜ ûKŜ I·ŘØI·yŐŜYŜyű 2F ăY I·Nű ∃NŽŘ ûŜŐKy2f2∃ŽŜăΣ ŽyŐfdzŘŽyE ăY I·Nű YŜúŜNăΣ LJN2∃NI·YYI·ōfŜ Ő2YY dzyŽŐI·ûŽyE ûKŜNY2ăúIúăΣ I·dzű2YI·ûŜŘ FŜŜŘŜN ăØŽűŐKŜă I·yŘ ŐI·LJI·ŐŽűŽ2NăΣ ŜIjdzŽLJYŜyű KŜI·fűK ăŜya2NăΣ I·yŘ LJKI·ă2N YŜI·ădzNŜYŜyű dzyŽúă LJfdzăNŜIjdzŽăŽúŜ Ő2YY dzyŽŐI·ûŽyã I·yŘ ŽyF2NYI·ûŽ2y YI·yI·∃ŜYŜyű ăèăúŜYăφ LyăŽ2YŜ ŐI·ăŜăΣ dzűŽfŽúŽŜă ØŜNŜ I·ōfŜ ű2 I·ŐŐŜfŜNI·ûŜ ûKŜNY ăYI·Nű ∃NŽŘ ŘŜLJf2èYŜyű LJfI·yã ōè dzLJ ű2 p èŜI·NăΣ ØKŽfŜ 2ûKŜNă fŜăă FI·YŽfŽI·N ØŽúK ûKŜ ûŜŐKy2f2∃è ØŜNŜ I·ōfŜ ű2 ăűI·Nű ûKŜNY Y2ŘŜNyŽÎI·ű2y ŜFF2NúăØŽúK ! ww ! ădzLJLJ2NúφTN !yŽYLJ2NúI·yű dzŜ 2F ! ww ! ăYI·Nű ∃NŽŘ FdzyŘŽyE ØI·ă ű2 LJN2ØŽŘŜ ûKŜ ŽyŽúŽI·f ădzLJLJ2Nű F2N 5h9Ωă 2y∃2Ž y∃ D a LΣ ØKŽŐK Žă ŘŜăÐNŽōŜŘ ŽyŘŜűI·Žf ŽyûKŜ ō2È ōŜf2Øφ

§ ! ww ! ØI·ă I· ăűŽYdzfdză LJI·Ő]I·∃Ŝ ŜyI·ŐűŜŘ ōè ûKŜ мммúK ¦ yűŜŘ {úI·ûŜă /2y∃NŜăă ŽyCŜōNdzI·Nè нллф I·yŘ ăŽ∃yŜŘ Žyű2 fI·Ø 2yCŜōNdzI·Nè мтΣ нллфΣ ōè tNŜăŽŘŜyű . I·NI·Ő] hōI·YI·φ ! ww ! ădzLJLJ2NúŜŘ YI·yê 2F ûKŜ ŽyűŽI·ûŽØŜă LJNŜăŜyűŜŘ ØŽúKŽy ¢Žúf Ŝ · LLL ó{YI·Nű DNŽŘú 2F ûKŜ 9yŜN∃è LyŘŜLJŜyŘŜyŐŜ I·yŘ {ŜŐdzNŽúê ! Őű 2F нллтφ

Department of Energy Grid Modernization Initiative

The Grid Modernization Initiative (GMI) is a crosscutting Department of Energy (DOE) effort through which the Department works with public and private partners to develop concepts, tools, and technologies needed to modernize the Nationôs grid infrastructure. This work leverages DOEôs core capabilities in modeling, computation, systems integration, cybersecurity, and energy storage to help improve system reliability, integrate diverse sources of electricity, advance energy technologies, and provide a critical platform for U.S. competitiveness and innovation in the global economy. In January 2016, the Grid Modernization Laboratory Consortium (GMLC) started 29 regional projects that foster local approaches to grid modernization while contributing to a diverse and balanced national grid.

Figure 1-5. Grid Modernization Laboratory Consortium Locations and Regional Projects[71]



Thirteen DOE National Laboratories collaborate with regional partners on national grid modernization goals throughout the U.S. Projects vary widely, with some of these projects displayed in the figure above and detailed further in Table 1.2 below.

Table 1-2. Sample Grid Modernization Initiative Projects[72]

Project	Summary	Partners
Kentucky Industrial Microgrid Analysis and Design for Energy Security and Resiliency *Oak Ridge National Laboratories, Sandia National Laboratories*	LyØŜăúλƎl·úλ2yΣ ŘŜØŜƭ2LJYŜyűΣ l·yŘ l·yl·ƭèăλă 2Ŧ úKŜ ŃλăʅăΣ Ŏ2ăúăΣ l·yŘ ōŜyŜŦλúă 2Ŧ l· YλŎŃ2ƎŃλŘ dzúλƭλÎλyƎ ŃŜyŜø l·ōƭŜ ŜyŜŃƎè ăèăúŜYă l·ú úKŜ ¦ t{ ² 2ŃƭŘ t2Ńú l·yŘ /ŜyűŜyyλl·ƭ l dzō Ŧl·ŎλƭλúλŜăφ 5ŜØŜƭ2LJ Ń2l·ŘY l·LJ ú2 KŜƭLJ λyŘdzăúŃλŜă ŜØl·ƭdzl·úŜ YλŎŃ2ƎŃλŘ l·Ř2LJúλ2y¯ōè ŘŜŦλyλyƎ λyăúλúdzúλ2yl·ƭ l·yŘ ŃŜƎdzƭl·ú2Ńè ŎKl·ƭƭŜyƎŜă l·ăă2Ŏλl·úŜŘ øλúK ŘŜØŜƭ2LJYŜyű 2Ŧ λyŘdzăúŃλl·ƭπōl·ăŜŘ ŃŜăλƭλŜyű ăèăúŜYăφ	¦yλúŜŘ t l·ŃŎŜƭ {ŜŃØλŎŜΣ ² l·ăúŜ a l·yl·ƎŜYŜyűΣ .dzŃyă ɘ aŎ52yyŜƭƭΣ l l·ŃăKl·ø ¢Ńl·yŜΣ [2dzλăØλƭƭŜ Dl·ă l·yŘ 9ƭŜŎúŃλŎΣ {úl·úŜ 2Ŧ YŜyűdzŎʅè

Project	Summary	Partners
Midwest Interconnection Seams Study *National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory*	/2yØŠyŠ λyŘdzăúNè I·yŘ I·ÖI·ŘŠYʻλÕ ŠÈLJŠNűă λy˙LJ2ǿŠN ăèăúŠYă ű2 ŠØI·fdzI·úŠ űKŠ KλƎKπØ2fűI·ƎŠΣ ŘNNŠÕű ÕdzNNŠyű I·yŘ I·fűŠNyI·úλyƎ ÕdzNNŠyű úNI·yăYʻλăλ2y˙ăŠI·Yă ōŠúǿŠŠy˙ úKŠ ¦φ{φ λyűŠNÕ2yŷŠÕűλ2yã I·yŘ LJN2LJ2ăŠ dzLJƎNI·ŘŠă ű2 ŠÈλăúλyƎ ŦI·ÖλfűúλŠă úKI·ú NŠŘdzÕŠ űKŠ Õ2ăű 2Ŧ Y˙2ŘŠNyλÎλyƎ úKŠ bI·úλ2yűă LJ2ǿŠN ăèăúŠY˙φ	{2fdzúλ2yăΣ ¦úλfúè ±I·NλI·ōfŠDŠyŠNI·úλ2y˙LyűŠƎNI·úλ2y˙DN2dzLJΣ .NèyŘI·y˙ !ăă2ÕλI·úŠă
Grid Analysis and Design for Resiliency in New Orleans *Sandia National Laboratories, Los Alamos National Laboratories*	/2yŘdzÕű űŠÕKyλÕI·f ŠØI·fdzI·úλ2yã ű2 I·ăăŠăä ŠyŠNƎè I·yŘ ÕNλúλÕI·f λyŦNI·ăúNdzÕűdzNŠ ØdzfyŠNI·ōλfúλŠă I·yŘ ű2 λŘŠyűλŦè Õ2ăúπŠŦŦŠÕűλØŠ 2LJúλ2yã ű2 λY˙LJN2ØŠ űKŠ NŠăλfλŠyÕè 2Ŧ ō2úK úKŠ ŠfŠÕúNλÕI·f ƎNλŘ λyŦNI·ăúNdzÕűdzNŠ I·yŘ úKŠ Õ2Yʻdzyλúèφ	/λúè 2Ŧ bŠø hNŦŠI·yãΣ w2Ö⌊ŠŦŠffŠN Lyãúλúdzúŝ 9yűŠNƎèΣ ¦φ{φ !NYˆè /2NLJă 2Ŧ 9yƎλyŠŠNă

Grid modernization projects vary widely in scope and region. Three of these projects are summarized above.

¢KŠNŠ λă I· yŠø ăŠű 2Ŧ ŘŠYˆI·yŘă 2y˙ƎNλŘ ŦdzyÖűλ2y˙I·yŘ ăúNdzÕűdzNŠ úKI·ú øI·ă y2ű Ŧdzffè I·LJLJNŠÕλI·ûŠŘ τ èŠI·Nă I·Ǝ2 øKŠy˙ !ww! ŦdzyŘă øŠNŠ YˆI·ŘŠ I·ØI·λfI·ōfŠφ !ă úKŠ yűzYʻōŠN 2Ŧ λyűŠƎNI·ûŠŘΣ λyűŠffλƎŠyű I·ăăŠûă λyÖNŠI·ăŠăΣ úKŠ ăLJŠŠŘ 2Ŧ Õ2YʻdzyλÕI·úλ2yΣ Õ22NŘλyI·úλ2yΣ I·yŘ Õ2yűN2f øλff NŠIjdzλNŠ Yˆ2NŠ ŘλăúNλōdzűŠŘΣ I·dzű2YˆI·ûŠŘ óYˆI·ÕKλyŠ ű2 YˆI·ÕKλyŠú λyűŠffλƎŠyÖŠ ŘŠI·fλyƎ øλúK ădzōπăŠÕ2yŘ ŘŠÕλăλ2yã úKI·ú ÕI·yŷ2ű ōŠ YˆI·yI·ƎŠŘ ōè KdzYˆI·y˙2LJŠNI·ú2Nă λy˙ NŠI·f ûλYˆŠφ ¢KŠ ăÕ2LJŠ 2Ŧ áăYˆI·NűΣ Yˆdzăű ŠØ2fØŠ ű2 λyÖfdzŘŠ YˆI·ÕKλyŠ fŠI·NyλyƎ ű2 YˆI·yI·ƎŠ úKŠ Õ2π2LJúλYˆλÎˆûλ2y˙ 2Ŧ àèăúŠYă I·yŘ ădzōăèăúŠYă øKλfŠ YˆI·λyűI·λyλyƎ àèăúŠY˙ NŠfλI·ōfŠúè I·ă Yˆ2NŠ 59w I·NŠ λyűŠƎNI·ûŠŘ λyű2 ƎNλŘ 2LJŠNI·úλ2yãφ

¢KŠ ⌊Šè λyƎNŠŘλŠyű ű2 ŠyI·ōfλyƎ úKλă ÕI·LJI·ōλfúè I·NŠ L/¢ ySűø2N⌊ă űKI·ú y2ű 2yfè ădzLJLJ2Nűú ƎNλŘ 2LJŠNI·úλ2yãΣ ōdzű I·fă2 LJŠNYˆλúΣ øKŠNŠ I·LJLJN2LJNλI·ûŠΣ λűă Õ2yØŠNƎŠyÖŠ øλúK 2űKŠN λyŦNI·ăúNdzÕűdzNŠăΣ λyÖfdzŘλyƎ ōdzλfŘλyƎăΣ úNI·yãLJ2NűI·úλ2yΣ øI·ûŠNΣ I·yŘ yI·údzNI·f ƎI·ă λyŦNI·ăúNdzÕűdzNŠăφ LűλăŠyØλăλ2yŠŘ úKI·ú úKŠ λyűŠƎNI·úλ2y˙2Ŧ λyűŠffλƎŠyű I·ăăŠűă I·ÖN2ăă úKŠăŠ ăèăúŠYă øλff LJN2ØλŘŠ ŠyKI·yÖŠŘ fŠØŠfă 2Ŧ ŠŦŦλÕλŠyÖèΣ I·ăăŠű dzűλfλÎI·úλ2yΣ I·yŘ λyy2ØI·úλ2yφ {LJŠŠŘ I·yŘ LJNŠÕλλ2y˙ øλff ōŠ ŠăăŠyűλI·f ŠfŠYˆŠyűă Ŧ2N ŠyădzNλyƎ I· KλƎKfè NŠfλI·ōfŠ ŠfŠÕűNλÕλúè ăèăúŠYφ ² Šffπ ŘŠăλƎyŠŘ ăYˆI·Nű ƎNλŘă I·NŠ ăúNdzÕűdzNŠŘ ú2 ŠyI·ōfŠ I·ŘI·LJúI·úλ2y˙ ú2 ŠØŠNπÕKI·yƎλyƎ ŘŠØλÕŠ ÕKI·NI·ÕűŠNλăúλÕă I·yŘ NŠIjdzλNŠYˆŠyűăφ !ű úKŠ ăI·YˆŠ ûλYˆŠΣ ySø ŘŠØλÕŠă úKI·ú λYˆLJI·Õű úKŠ ƎNλŘ I·yŘ dzűλfλúλŠă I·NŠ ŦλyŘλyƎ úKI·ú ØŠyŘ2Nă I·NŠ NŠűλNλyƎ úKŠ Yˆ I·yűzŦI·ÖűdzNŠ 2Ŧ I·yI·f2Ǝ YˆŠűŠNăΣ øKλÕK YˆŠI·yã úKI·ú øKŠy˙YˆŠűŠN NŠLJfI·ÕŠYˆŠyű λă NŠIjdzλNŠŘΣ λű øλff fŠI·Ř ű2 úKŠ ySŠŘ Ŧ2N ōdzλfŘλyƎ I·dzű2YˆI·ûŠŘ YˆŠűŠN λyŦNI·ăúNdzÕűdzNŠφ

1.4 Electricity Systems and Grid Management Are Facing New Challenges

² KλfŠ ŠfŠÕűNλŦλÕI·ûλ2y˙I·yŘ ŘλƎλúλÎI·úλ2y˙KI·ØŠ ÕNŠI·ûŠŘ ySø 2LJLJ2NúdzyλúλŠă Ŧ2N dzűλfλúλŠă ű2 λYˆLJNN2ØŠ NŠfλI·ōλfλúè I·yŘ NŠŘdzÕŠ Õ2ăűăΣ 2úKŠN úNŠyŘă λy˙ ŠfŠÕűNλÕλúè ƎŠyŠNI·úλ2y˙KI·ØŠ ÕNŠI·ûŠŘ ySø ÕKI·ffŠyƎŠă Ŧ2N ƎNλŘ YˆI·yI·ƎŠYˆŠyűφ LyÖNŠI·ăλyƎ ŘŠLJf2èYˆŠyű 2Ŧ ØI·NλI·ōfŠ ŠyŠNƎè NŠă2dzNÖŠă ó±9wăú ădzÕK I·ă øλyŘ I·yŘ ă2fI·N LJ2ǿŠNΣ úKŠ λyűŠNI·Öűλ2y˙ 2Ŧ 59w øλúK ōI·ăŠf2I·Ř ƎŠySNI·úλ2yΣ I·yŘ úKŠ ÕKI·yƎλyƎ N2fŠ 2Ŧ ŠfŠÕűNλÕλúè Ödzăű2YˆŠNă KI·ØŠ λyÖNŠI·ăŠŘ úKŠ Õ2YˆLJfŠÈλúè 2Ŧ YˆI·úÕKλyƎ ŠfŠÕűNλÕλúè ădzLJLJfè øλúK ŘŠYˆI·yŘ I·ú I·ffûλYˆŠă φ !ű úKŠ ăI·YˆŠ ûλYˆŠ úKŠè LJ2ăŠ ÕKI·ffŠyƎŠăΣ ŠI·ÕK 2Ŧ úKŠăŠ úNŠyŘă KI·ă ŘλăúλyÖű I·ŘØI·yűI·ƎŠăΣ ădzÕK I·ă KŠfLJλyƎ ű2 Šyl·ōfŠ úKŠ ŘŠÕI·Nō2yλÎI·úλ2y˙2Ŧ ŠfŠÕűNλÕλúè ƎŠyŠNI·úλ2yΣ λyÖNŠI·ăλyƎ Õ2yãdzYˆŠN 2LJúλ2yã I·yŘ âŠNØλÕŠăΣ I·yŘ I·ŘØI·yÖλyƎ ƎNλŘ YˆI·yI·ƎŠYˆŠyű ă2fdzúλ2yãΣ ădzÕK I·ă

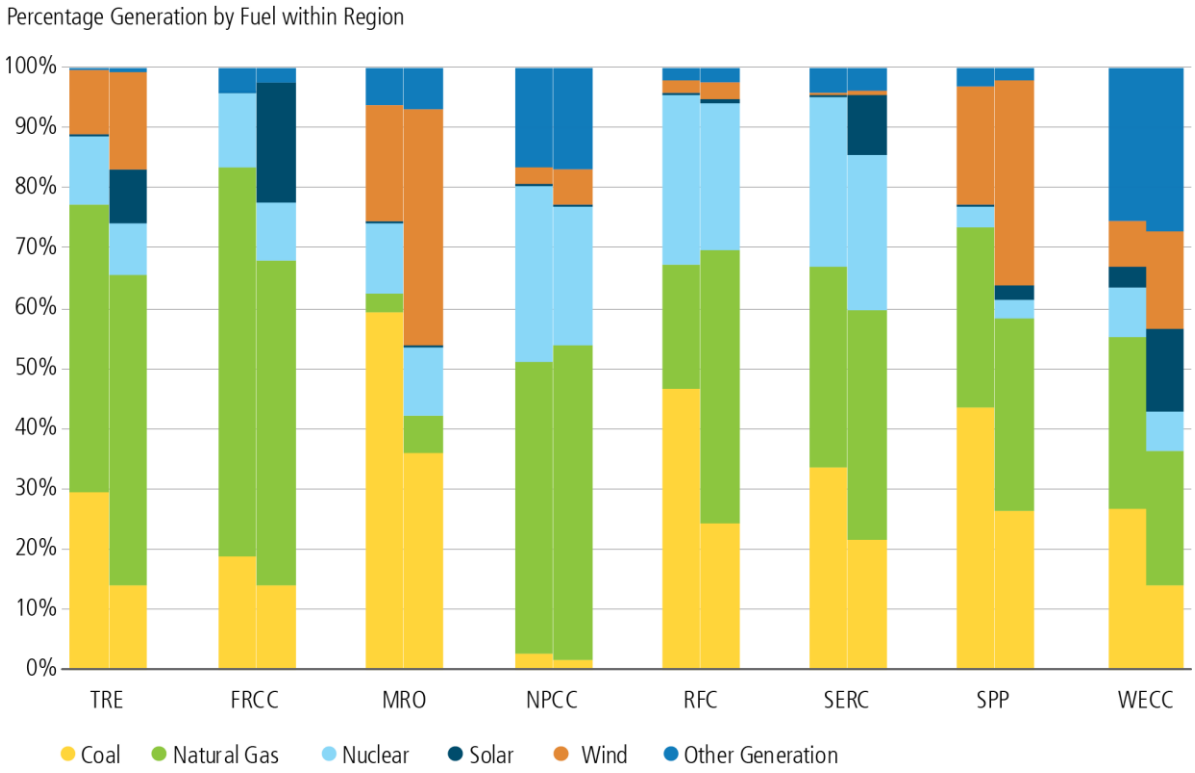
ŦfŜÈλõλfλúêè l·yŘ ∃ℕλŘπăÕl·fŜ ăű2ℕl·∃Ŝ¢ a l·yê 2Ŧ ΰĸKŜăŜ úℕŜyŘă l·ℕŜ ŘλăÕdzăăŜŘ λy ŘŜűl·λf λy /Kl·LJűŜℕ L±Σ *Ensuring Electricity System Reliability, Security, and Resilience.*

1.4.1 The Changing Generation Profile

¢KŜ ¦φ{φ ∃ŜySŜℕl·úλ2y ŦfŜŜű λă ûℕl·yãλúλ2yλy∃ Ŧℕ2Y 2yŜ Ř2Yλyl·úŜŘ õè ÕŜyűℕl·fλÎŜŘ ∃ŜySŜℕl·ű2ℕă ǿλúK Kλ∃K λySℕúλl· l·yŘ ŘλăLJl·úÕKl·õλfλúè ű2 2yŜ úKl·ΰ ăă Y2ℕŜ áKèõℕλŘλÎŜŘΣέ ℕŜfêλy∃ 2y l· Yλ̀ÈűdzℕŜ 2Ŧ úℕl·Řλúλ2yl·fΣ ÕŜyűℕl·fλÎŜŘ ∃ŜySℕl·úλ2y l·yŘ Ø·ℕλl·õfŜ dzűλfλúèπăÕl·fŜ l·yŘ ŘλăúℕλõdzúŜŘ ℕŜySǿl·õfŜ ∃ŜySℕl·úλ2yφᵀº Ly нллpΣ úKŜ ű2LJ ăλÈ ∃ŜySℕl·úλ2y ă2dzℕÕŜă λy ŘŜăÕŜyŘλy∃ 2ℕŘŜℕ ǿŜℕŜ Õ2l·fΣ yűzÕfŜl·ℕΣ ∃l·ăΣ KèŘℕ2Σ LJŜúℕ2fŜdzYΣ l·yŘ ℕŜySǿl·õfŜă¢ .è нлмpΣ ∃l·ă l·yŘ Õ2l·f ǿŜℕŜ úλŜŘ l·ΰ ΰKŜ ű2LJΣ Ŧ2fŦ2ǿŜŘ õè yűzÕfŜl·ℕΣ ℕŜySǿl·õfŜăΣ KèŘℕ2Σ l·yŘ LJŜúℕ2fŜdzY¢

DŜySℕl·úλ2y ÕKl·y∃Ŝă õŜűǿŜŜy нлмc l·yŘ нлпл óăŜŜ Cλ∃dzℕŜ мπcú l·ℕŜ ŜÈLJŜŎúŜŘ ű2 õŜ dzySØŜySΣ õ2úK õè ΰŜÕKy2f2ècè l·yŘ ℕŜ∃λ2y¢ hØŜℕ ΰKλă ΰλYŜ LJŜℕλ2ŘΣ yűzÕfŜl·ℕ l·yŘ KèŘℕ2ŜfŜÕúℕλÕ ∃ŜySℕl·úλ2y λă LJℕλ2ŜÕúŜŘ ű2 õŜ ℕŜfl·úλØŜfè Ŧfl·ú¢ ¢KŜ ăKλŦű ŦℕŸ Õ2l·fπŦλℕŜŘ ű2 yl·údzℕl·f ∃l·ăπŦλℕŜŘ ∃ŜySℕl·úλ2y λă ăúℕ2y∃Ŝăű λy úKŜ Ŝl·ăűŜℕy Kl·fŦ 2Ŧ úKŜ Õ2dzyűℕè óǿKŜℕŜ ∃ℕ2ǿűK λy ℕŜySǿl·õfŜ ŜfŜÕúℕλÕλúè λă Y2ŘŜăúΰΣ ǿKλfŜ úKŜ ǿŜăûŜℕy ¦yλûŜŘ {ûl·ûŜă λă ŜÈLJŜℕλŜyÕλy∃ ℕl·LJλŘ ∃ℕ2ǿűK λy ℕŜySǿl·õfŜă¢™ wŜ∃λ2yl·f ∃ŜySℕl·úλ2y Y λÈŜă Ø·ℕè ăλ∃yλŦλÕl·yűfè ŦℕŸ úKŜ yl·úλ2yl·f ∃ŜySℕl·úλ2y LJℕ2ŦλfŜΣ l·yŘ úKŜℕŜ l·ℕŜ Y l·2ℕ ŘλŦŦŜℕŜyÕŜă l·Y2y∃ úKŜ ℕŜ∃λ2yã λy õ2úK ∃ŜySℕl·úλ2y Y λÈ l·yŘ úKŜ l·ŘŘλúλ2y l·yŘ ℕŜúλℕŜY Ŝyűă 2Ŧ Õl·LJl·ÕλűèΦ

Figure 1-6. Comparison between Generation Fuel Mix in 2016 and 2040 by North American Electric Reliability Corporation Region[75]



Based upon EIA's AEO 2016 business-as-usual modeling results, the regional variations in generation fuel of 2015 are projected to continue through 2040. Solar generation is expected to play a significant part in Texas (TRE), Florida (FRCC) and the Southeastern U.S. (SERC) and the Western States, particularly the Southwest and California (WECC). Wind generation is anticipated to be largely concentrated in the upper Midwest (MRO), New England (NPCC), and the Western States (WECC). The upper Midwest (MRO), Reliability First Corporation (RFC) region, and Southwest Powerpool (SPP) is expected to decrease their coal generation capacities, but will still retain over 20% of their generation capacity from coal. Hydropower accounts for the largest portion of ñOther Generationòin New England and WECC.

±9wă I·NŜ ƛyŎNŜI·ăƛyƎ ƛy˝ō2ΰK ŎI·LJI·ŎƛΰêI·ŘŘƛΰƛ2yã I·yŘ ƎŜyŜNJ·ΰƛ2yΦ ¢KŜăŜ I·ŘŘƛΰƛ2yã KI·ØŜ ōŜŜy˝ŜyI·ōfŜŘ ōè yŜø ΰŜŎKy2f2ƎƛŜăƶ Ŏ2ăΰ NŜŘdzŎΰƛ2yãƶ I·yŘ I· NJI·yƎŜ 2Ŧ LJ2fƛŎƛŜăΦ {LJŜŎƛŦƛŎ LJ2fƛŎƛŜă ΰ2 ădzLJLJ2Nΰ ±9wă óI·yŘ 2ΰKŜNJ ŎfŜI·y˝ ŜyŜNJƎè 2LJΰƛ2yãú ƛyŎfdzŘŜ {ΰI·ΰŜ I·yŘ CŜŘŜNJI·f LJNJ2ŘdzŎΰƛ2y˝ I·yŘ ƛyØŜăΰY˝Ŝyΰ ΰI·È ŎNJŜŘƛΰăƶ NJŜyŜøI·ōfŜ LJ2NΰŦ2fƛ2 ăΰI·yŘI·NJŘă ƛy˝ нт ăΰI·ΰŜăƶ I·yŘ yŜΰ Y˝ŜΰŜNJƛyƎ LJ2fƛŎƛŜă 2NJ 2ΰKŜNJ ƛyŎŜyΰƛØŜă ƛy˝ по ăΰI·ΰŜăΦ /I·fƛŦ2NJyƛI· 2ŦŦŜNJă I·y˝ ŜÈI·Y˝LJfŜ 2Ŧ ±9w LJ2ΰŜyΰƛI·fΦ ¢KŜ /I·fƛŦ2NJyƛI· L{h ŜÈLJŜŎΰă ΰ2 I·ŎKƛŜØŜ I· ол LJŜNJŎŜyΰ LJŜyŜΰNJI·ΰƛ2y˝fŜØŜf 2Ŧ ±9wă ōè нлнл I·yŘ рл LJŜNJŎŜyΰ LJŜyŜΰNJI·ΰƛ2y˝ōè нлолΦTC

1.4.1.1 Information Needs for Load Management Increase with High VER/DER Penetration

¢KŜ ƛyΰNJ2ŘdzŎΰƛ2y˝2Ŧ yŜø ƎNJƛŘ Ŏ2yΰNJ2f I·yŘ 2LJΰƛY˝ƛÎI·ΰƛ2y˝I·fƎ2NJƛΰKY˝ă ΰKI·ΰ ΰI·ˆ]Ŝ I·ŘØI·yΰI·ƎŜ 2Ŧ ±9wă I·yŘ 59wă I·yŘ f2I·Ř ŦfŜÈƛōƛfƛΰêI· Ŏ2dztŘ Ŏ2yΰNJƛōdzΰŜ ΰ2 ¦Φ{Φ ƎNJƛŘ NJŜfƛI·ōƛfƛΰêI· I·yŘ KI·ØŜ I· NJI·yƎŜ 2Ŧ ōŜyŜŦƛΰăƶ ƛyŎfdzŘƛyƎ ΰKŜ NJŜŘdzŎΰƛ2y˝ 2Ŧ NJŜyŜøI·ōfŜă ŎdzNΰI·ƛfY˝ŜyΰT ΰKŜ NJŜŘdzŎΰƛ2y˝ ƛy˝ ΰNJI·yãY˝ăăƛ2y˝ I·yŘ ŘƛăΰNJƛōdzΰƛ2y˝ Ŏ2y3Ŝăΰƛ2yT I·yŘ ƛY˝LJNJ2ØŜY˝Ŝyΰăƛy˝LJ2øŜNJ I·yŘ ƎNJƛŘ ØdzfyŜNJI·ōƛfƛΰêI· IjdzI·fƛΰêΦTT

wŜyŜøI·ōfŜ NJŜă2dzNJŎŜă τ ō2ΰK dzΰƛfƛΰêI· ăŎI·fŜ I·yŘ ŘƛăΰNJƛōdzΰŜŘ τ I·NJŜƶ K2øŜØŜNJƶ Y˝2NJŜ ØI·NJƛI·ōfŜ ƛy˝ ΰKŜNJ LJ2øŜNJ LJNJ2ŘdzŎΰƛ2y˝ NJŜIjdzNJƛyƎ ƛyØŜăΰY˝Ŝyΰƛy˝ I·ăăŜΰăƶ ăĕăΰŜY˝ăƶ I·yŘ LJNJ2ŎŜăăŜă ΰ2 Y˝ƛΰƛƎI·ΰŜ ădzŎK ØI·NJƛI·ōƛfƛΰêΦ ±9wπ Ř2Y˝ƛyI·ΰŜŘ NJŜă2dzNJŎŜ LJ2NΰŦ2fƛ2ă øƛtf NJŜIjdzNJŜ Y˝2NJŜ NJƛƎ2NJ2dzã ƎNJƛŘ Ŏ2yΰNJ2fã ΰKI·y˝ΰK2ăŜ ŎdzNJNJŜyΰfê ŜÈŜNJŎƛăŜŘ ōè ΰ2ŘI·èΩă ƎNJƛŘ 2LJŜNJI·ΰ2NJăΦ !fă2Σ ƛy˝ ΰKŜ I·ōăŜyŎŜ 2Ŧ Ŏ2Y˝LJNJŜKŜyăƛØŜ Øƛăƛōƛfƛΰêƶ ΰ2 ƎNJƛŘ 2LJŜNJI·ΰ2NJă 2ŦΣ I·yŘ ƛyf2NJY˝I·ΰƛ2y˝I·ō2dzΰΣ 59w I·yŘ I·dzΰ2Y˝I·ΰŜŘ 5w ΰŜŎKyƛIjdzŜăΣ ƛΰ ƛă dzyŎfŜI·NJ K2ø Y˝dzŎK ŘŜŎI·NJō2yƛÎI·ΰƛ2y˝LJ2ΰŜyΰƛI·f ƛă ōŜƛyƎ dzyŘŜNJdzΰƛfƛÎŜŘ I·yŘ dzyŘŜNJØI·fdzŜŘΦ

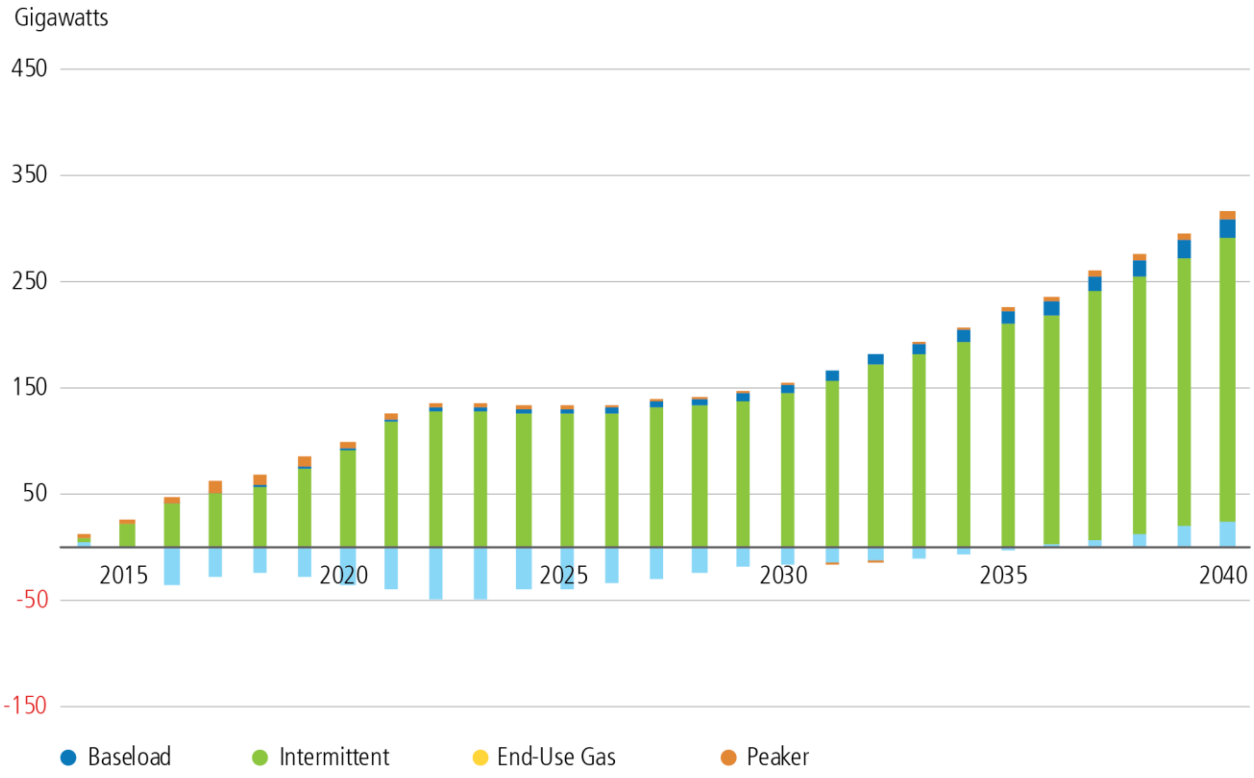
Ly˝I·ŘŘƛΰƛ2yΣ ΰKŜ I·ōăŜyŎŜ 2Ŧ Ŏ2Y˝LJNJŜKŜyãƛØŜ ƛyf2NJY˝I·ΰƛ2y˝2y˝ΰKŜ ΰ2ΰI·f I·ØI·ƛfI·ōfŜ I·yŘ I·ŎΰƛØŜ LJ2øŜNJ LJNJ2ŘdzŎΰƛ2y˝ Ŧ NJ2Y˝ ŘƛăΰNJƛōdzΰŜŘ NJŜă2dzNJŎŜăΣ LJNJƛyŎƛLJI·ffè ă2fI·NJΣ ŎI·y˝ Ŏ2Y˝LJfƛŎI·ΰŜ ƎNJƛŘ Y˝I·yI·ƎŜY˝ŜyΰΦ {ΰI·ΰŜă I·NJŜ ø2NJˆ]ƛyƎ ΰ2 I·ŘŘNJŜăă ΰKŜăŜ ƛăădzŜăΦ ¢KŜ /I·fƛŦ2NJyƛI· {2fI·NJ LyΰΰƛI·ΰƛØŜΣ Ŧ2NJ ŜÈI·Y˝LJfŜΣ ƛă LJI·NJΰ 2Ŧ I· /I·fƛŦ2NJyƛI· tdzōfƛŎ ¦ΰƛfƛΰƛŜă /2Y˝Y˝ƛăăƛ2y˝ Y˝I·yŘI·ΰŜ ΰ2 ōdztfŘ I·yŘ Y˝I·ƛyΰI·ƛy˝ I· LJdzōfƛŎfŜ I·ŎŎŜăăƛōfŜ ŘI·ΰI· ăŜΰ 2Ŧ ŎI·LJI·ŎƛΰêI·yŘ ΰŜŎKyƛŎI·f ăLJŜŎƛŦƛŎI·ΰƛ2yã 2Ŧ 5D ăĕăΰŜY˝ă ΰKNJ2dzƎK2dzΰ ΰKŜ ăΰI·ΰŜΦTY Ly˝ I I·øI·ƛΣ I· Ŏ2ffI·ō2NJI·ΰƛ2y˝ ōŜΰøŜŜy˝ 5h9 I·yŘ ΰKŜ I I·øI·ƛI·y˝9fŜŎΰNJƛŎ /2Y˝LJI·yê ƛă ŘŜăƛƎyƛyƎ yŜø ŎI·LJI·ōƛfƛΰŜă Ŧ2NJ ŜyŜNJƎè Y˝I·yI·ƎŜY˝ŜyΰăĕăΰŜY˝ăΣTΦ ƛyΰNJ2ŘdzŎƛyƎ ƎNJŜI·ΰŜNJ Øƛăƛōƛfƛΰêƶ 2Ŧ 5D ōè ŦI·Ŏΰΰƛ2NJăyƎ I·ŘØI·yŎŜŘ мpπY˝ƛyΰzΰŜΣ ăK2NJΰπΰŜNJY˝ øƛyŘ I·yŘ ă2fI·NJ Ŧ2NJŜŎI·ăΰƛyƎ ƛyΰ2 ƛΰă ŜyŜNJƎè Y˝I·yI·ƎŜY˝ŜyΰăĕăΰŜY˝ă ŘŜŎƛăƛ2yπY˝I·˝ƛyƎ LJNJ2ŎŜăăΦ

1.4.1.2 Role of Baseload Generation

9fŜŎΰNJƛŎƛΰêƶ ŘŜY˝I·yŘ KI·ă I·føI·ëă ōŜŜy˝ ØI·NJƛI·ōfŜΦ ¢2 Y˝I·yI·ƎŜ ΰKƛă ØI·NJƛI·ōƛfƛΰêΣ ăĕăΰŜY˝ 2LJŜNJI·ΰ2NJă KI·ØŜ ΰNJI·Řƛΰƛ2yI·ffè NJŜfƛŜŘ 2y˝I· ƎŜyŜNJI·ΰƛ2y˝Y˝Èƶ ΰKI·ΰ ŦI·ffă ƛyΰ2 ΰKNJŜŜ ƎŜyŜNJI·f ŎI·ΰŜƎ2NJƛŜăY ōI·ăŜf2I·ŘΣ ƛyΰŜNJY˝ŜŘƛI·ΰŜ I·yŘ LJŜI·˝ƛyƎ LJfI·yΰăΣ I·yŘ ă2Y˝Ŝ ŘŜY˝I·yŘπăƛŘŜ NJŜă2dzNJŎŜă ădzŎK I·ă 5wΦ .ŜŎI·dzăŜ ōI·ăŜf2I·Ř dzyΰúă I·NJŜ dzădzI·ffè ŎI·LJƛΰI·fπƛyΰŜyăƛØŜ ƎŜyŜNJI·ΰ2NJă ØƛΰK f2ø 2LJŜNJI·ΰƛyƎ Ŏ2ăΰăΣ ΰKŜè I·NJŜ 2LJŜNJI·ΰŜŘ I·ΰ KƛƎK 2dzΰLJdzΰΣ ΰèLJƛŎI·ffè ØƛΰK ŎI·LJI·Ŏƛΰêƶ ŦI·Ŏΰΰ2NJă I·ō2ØŜ ρл LJŜNJŎŜyΰΦTY LyΰŜNJY˝ŜŘƛI·ΰŜ dzyƛúă ØI·Nè ΰKŜƛNJ fŜØŜf 2Ŧ 2dzΰLJdzΰ ΰ2 ˆ]ŜŜLJ ΰKŜ ăèăΰŜY˝ ƛy˝ ōI·fI·yŎŜ ØƛΰK ŎKI·yƎƛyƎ fŜØŜfă 2Ŧ Ŏdzăΰ2Y˝ŜNJ ŘŜY˝I·yŘΦ tŜI·˝ƛyƎ LJfI·yΰă KI·ØŜ f2ø ŎI·LJƛΰI·f Ŏ2ăΰă I·yŘ KƛƎK 2LJŜNJI·ΰƛyƎ Ŏ2ăΰă I·yŘ I·NJŜ dzăŜŘ ƛy˝ LJŜNJƛ2Řă ØKŜy˝ŘŜY˝I·yŘ ƛă KƛƎK óLJŜI·˝ƛăΰΦ ¢KŜNJŜ ƛă I·y˝2LJΰƛY˝I·f Y˝ƛÈ 2Ŧ ΰKŜăŜ ΰKNJŜŜ ΰèLJŜă 2Ŧ NJŜă2dzNJŎŜă ōI·ăŜŘ 2y˝ΰKŜ ΰNJI·ŘŜ2ŦŦ ōŜΰøŜŜy˝ ŎI·LJƛΰI·f Ŏ2ăΰă I·yŘ 2LJŜNJI·ΰƛyƎ Ŏ2ăΰă τ NJŜŎ2ƎyƛÎƛyƎ ΰKŜ I·Y˝2dzyΰ 2Ŧ ΰƛY˝Ŝ ŜI·ŎK ΰèLJŜ 2Ŧ NJŜă2dzNJŎŜ ƛă ŜÈLJŜŎΰŜŘ ΰ2 2LJŜNJI·ΰŜΦ

b2ΰøƛΰKăΰI·yŘƛyƎ ƎI·ƛyã ƛy˝±9wăΣ ΰ2ŘI·èΩă ŜfŜŎΰNJƛŎƛΰêăĕăΰŜY˝ ƛă KƛƎKfè ŘŜLJŜyŘŜyΰ 2y˝ōI·ăŜf2I·Ř ƎŜyŜNJI·ΰƛ2y˝óăŜŜ CƛƎdzNJŜ мπτúΦ !LJLJNJ2ÈƛY˝I·ΰŜfè yc LJŜNJŎŜyΰ 2Ŧ ΰKŜ ŎdzNJNJŜyΰ ƎNJƛŘπŎ2yyŜŎΰŜŘ ŜfŜŎΰNJƛŎƛΰêƶ ƛă ŦdzŜfŜŘ ōè Ŏ2I·fΣ yI·ΰdzNJI·f ƎI·ăΣ I·yŘ yΩzŎfŜI·NJΦTM .I·ăŜŘ 2y˝ ΰKŜ 9yŜNJƎè LyŦ2NJY˝I·ΰƛ2y˝ !ŘY˝ƛyƛăΰNJI·ΰƛ2yΩă *business-as-usual* LJNJ2ΩŜŎΰƛ2yãΣ ōè нлпл ΰKŜ ¦yƛΰŜŘ {ΰI·ΰŜă ăΰƛtf øƛtf NJŜfè 2y˝ Ŏ2I·fΣ yΩzŎfŜI·NJΣ I·yŘ yI·ΰdzNJI·f ƎI·ă ΰ2 LJNJ2ØƛŘŜ тп LJŜNJŎŜyΰ 2Ŧ ƛΰă ƎNJƛŘπŎ2yyŜŎΰŜŘ LJ2øŜNJΦTH Ly˝ ΰKŜ f2yƎ NdzyΣ ƎNJƛŘπăŎI·fŜ ăΰ2NJI·ƎŜ Ŏ2dztŘ ōŜ I· ƎI·Y˝Ŝ ŎKI·yƎŜNJΣ I·ŦŦŜŎΰƛyƎ ΰKŜ yŜŜŘ Ŧ2NJ ΰNJI·Řƛΰƛ2yI·f ōI·ăŜf2I·Ř ƛy˝ ΰKŜ ØŜNJè f2yƎ ΰŜNJY˝Φ {ΰ2NJI·ƎŜ ΰŜŎKy2f2ƎèŎ2ăΰă I·yŘ ŘƛŦŦdzăƛ2y˝NJI·ΰŜă øƛtfΣ K2øŜØŜNJΣ ƎNJŜI·ΰtê I·ŦŦŜŎΰ ΰKŜ NJ2fŜ 2Ŧ ƎNJƛŘπăŎI·fŜ ăΰ2NJI·ƎŜ ƛy˝ΰNJI·yãŦ2NJY˝ƛyƎ ΰKŜ ŜfŜŎΰNJƛŎƛΰêăĕăΰŜY˝ΦTO

Figure 1-7. Cumulative Utility-Scale Net Capacity Additions, 2015 to 2040[84]



Under business-as-usual assumptions, retirements in baseload capacity are projected to fully offset additions in baseload capacity between 2015 and 2026, where baseload is considered coal, nuclear, and natural gas combined-cycle plants. Variable renewables (wind and solar) capacity is expected to increase throughout the entire time period. Natural gas combustion turbine (peaker) capacity is expected to decline modestly beginning in 2021. By 2027, natural gas net capacity is projected to increase modestly, driven by natural gas combined-cycle plants. Capacity of natural gas-fired combined heat and power plants begins to ramp up in the latter decade of the projection period.

ǀ ƛăűƨNJλǑǀ·ftfè ǀ·yŘ ƛy˝ ōdzăλySăăπǀ·ăπdzădzǀ·f LJNJƨ?ŜǑűλ2yãΣ ōǀ·äŜf2ǀ·Ř ƎŜySŜNJǀ·űλ2y˝ Kǀ·ă LJNJƨØλŘŜŘ ǀ· NJǀ·yƎŜ 2Ŧ ŜăäŜyűλǀ·f NJŜfλǀ·ōλfλűè ăŜNJØλǑŜăφ ǀ ƛƎK Ǒǀ·LJǀ·Ǒλűè Ŧǀ·ǑűƨNJ ǀ·yŘ f2ǿπ ƨNJ ÎŜNJ2πǑǀ·NJō2yπSY˙λűűλyƎ ƎŜySŜNJǀ·űλ2y˝ LJfǀ·yűă Ǒǀ·y˝NJŜŘdzǑŜ NJŜfλǀ·ōλfλűè NJλăʅâΣ ǀ·ă äëăűŜY˙ ƨLJŜNJǀ·ű2NJă ǿ2NJʅ ű2 Yˇǀ·yǀ·ƎŜ űKŜ ƛyǑNJŜǀ·äŜŘ Ǒ2Y˙LJfŜÈλűè ǀ·ăä2Ǒλǀ·ûŜŘ ǿλúK Øǀ·NJǀ·ōfŜ ƎŜySŜNJǀ·űλ2y˝ ǀ·yŘ Ǒ2yűNJ2ftǀ·ōfŜ f2ǀ·Řφ Ly˝ǀ· ŦdzűdzNJŜ ǿKŜNJŜ ăλƎyλŦλǑǀ·yű 5D Ǒ2πŜØ2fØŜă ǿλúK dzűλfλűèπăǑǀ·fŜ NJŜySŜNJǀ·űλ2yΣ ƛyǑfdzŘλyƎY

- /Kǀ·yƎŜă ƛy˝ŘŜŦλySŘ ōǀ·äŜf2ǀ·Ř ǑKǀ·NJǀ·ǑűŜNJăúλǑă ǀ·yŘ NJŜIjdzλNJŜY˙Ŝyűă ǀ·ă úKŜ äŜǑűƨNJ úNJǀ·yãŦƨNJY˙ă ű2 KλƎKŜNJ ±9wă ǀ·yŘ 59w ǀ·yŘ dzűλfλűèπăǑǀ·fŜ ăúƨNJǀ·ƎŜφ
- ¢KŜ ŜĚűŜyű ű2 ǿKλǑK ǑŜyűNJǀ·f ăúǀ·ûλ2yΣ fǀ·NJƎŜπăǑǀ·fŜ LJ2ǿŜNJ ƎŜySŜNJǀ·űλ2y˝ăă úKŜ fŜǀ·ăúű Ǒ2ăúkōŜăúű ŦλúLJfǀ·ûŦ2NJY˙ Ŧ2NJ ǀ·y˝ŜfŜǑűNJλǑλúè äŜǑűƨNJ ǿλúK ŘλØŜNJăλŦλŜŘ dzűλfλűè ăǑǀ·fŜ ǀ·yŘ ŘλăúNJλōdzűŜŘ NJŜă2dzNJǑŜă 2Ŧ ǀ·ft úèLJŜăφ
- ¢KŜ ŘŜƎNJŜŜ ű2 ǿKλǑK f2yƎπűŜNJY˙ NJŜăλfλSyǑè NJŜIjdzλNJŜY˙Ŝyűă Ŧ2NJ SyãdzλyƎ ǀ· NJ2ōdzăű ǀ·yŘ äŜǑdzNJŜ äèäűŜY˙ ǀ·NJƎdzŜ Ŧ2NJ 2NJ ǀ·Ǝǀ·λyãű ōǀ·äŜf2ǀ·Ř ƎŜySŜNJǀ·űλ2yφ
- ǀ 2ǿ NJŜäŜNJØŜ Yˇǀ·NJƎλy˝NJŜIjdzλNJŜY˙Ŝyűă Yˇλ ƎKű ǑKǀ·yƎŜ λy˝f2ǿ ySű ŘŜY˙ǀ·yŘkKλƎK NJŜă2dzNJǑŜ Yˇǀ·NJʅŜűăφ

¢KŜ ǀ·Y˙2dzyű 2Ŧ ōǀ·äŜf2ǀ·Ř ƎŜySŜNJǀ·űλ2y˝ ySŜŘŜŘ ű2 ădzLJLJ2Nű f2ǀ·Ř ǀ·yŘ ōǀ·fǀ·yǑŜ NJŜă2dzNJǑŜă Kǀ·ă f2yƎ ōŜŜy˝ ǀ·ŘŘNJŜăăŜŘ úKNJ2dzƎK Ŝăűǀ·ōfλăKŜŘ NJǀ·úŜY˙ǀ·ʅλyƎ LJNJƨǑŜăăŜă ǀ·yŘ {úǀ·úŜπfŜØŜf ŜySŜNJƎè LJfǀ·yyλyƎφ /2yãλŘŜNJǀ·ûλ2y˝ 2Ŧ úKŜăŜ ƛăădzŜă ǀ·yŘ ûKŜ 2yƎ2λyƎ Øǀ·fdzŜ 2Ŧ úNJǀ·Řλûλ2yǀ·f ōǀ·äŜf2ǀ·Ř NJŜă2dzNJǑŜă ƛăΣ K2ǿŜØŜNJΣ ǀ· ySǿ ǀ·yŘ λY˙LJ2NJűǀ·yű Ijdzŝăûλ2y˝ Ŧ2NJ 5h9Σ ûKŜ CŜŘŜNJǀ·f 9ySNJƎè wŜƎdzfǀ·ű2NJè /2Y˙Yˇλăăλ2y˝ óC9w/úΣ ûKŜ b2NJűK ! Y˙ŜNJλǑǀ·y˝ 9fŜǑűNJλǑ

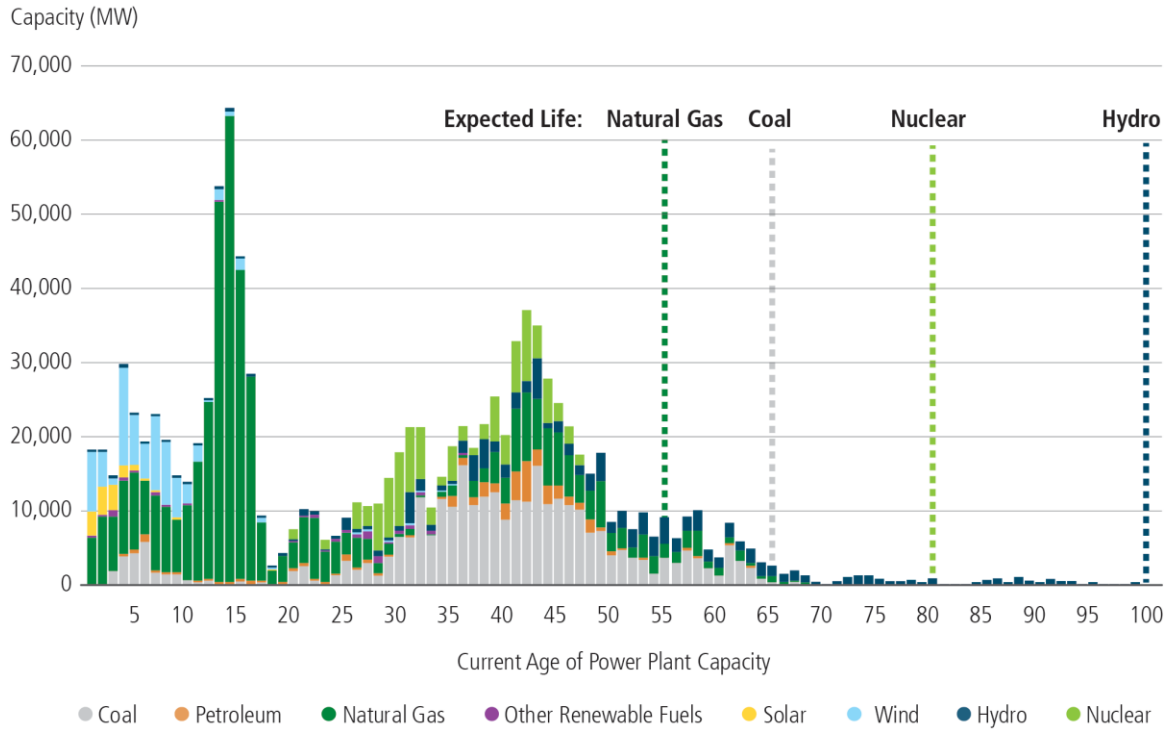
wŜfλI·ōλfλúè /2NLJ2NI·úλ2yΣ úKŜ ăúI·úŜăΣ λyŘdzăúNèΣ I·yŘ úKŜ NI·y∃Ŝ 2ŦăúI·⌈ŜK2fŘŜNă λyØ2fØŜŘ λy˝äèăúŜY˝ ŎKI·y∃Ŝă I·yŘ úNI·yãŦ2NY˝I·úλ2yΦ

1.4.2 Aging Infrastructure: Challenges and Opportunities

[λ⌈Ŝ I·yê λyŦNI·ăúNdzŎúdzNŜΣ úKŜ LJKèăλŎI·f Ŏ2Y˝LJ2ySyúă 2Ŧ úKŜ ŜfŜŎúNλŎλúè äèăúŜY˝ I·NŜ Ŏ2yãúI·yűfê I·∃λy∃Φ ¢KŜ Ŏ2yűλydzI·f Y˝I·λyűŜyI·yŎŜ I·yŘ NŜLJfI·ŎŜY˝Syű 2Ŧ ŜfŜŎúNλŎλúè äèăúŜY˝ λyŦNI·ăúNdzŎúdzNŜ Ŏ2Y˝LJ2ySyűãΣ K2øŜØŜNΣ LJN2ØλŘŜă I·y˝ λY˝LJ2NúI·yű 2LJLJ2Núdzyλúè úž Y˝2ŘŜNyλÎŜ úKŜ ŜfŜŎúNλŎλúè äèăúŜYΦ wŜLJfI·ŎŜY˝Syű 2Ŧ I·yűλIjdzI·úŜŘ λyŦNI·ăúNdzŎúdzNŜ øλúK yŜø úŜŎKy2f2∃è ŎI·y˝ Ŝyl·ōfŜ ōŜúúŜNŦI·λfdzNŜ ŘŜúŜŎúλ2yΣ dzLJ∃NI·ŘŜ úŜŎKyλŎI·f ŎI·LJI·ōλfλúλŜăΣ I·yŘ λY˝LJNN2ØŜ Ŏèō$NăŜŎdzNλúèΦyp LyØŜăúY˝Syűă λy˝ ySø Ŏ2yűN2f I·yŘ ŘλăúNλōdzúλ2y˝ Y˝I·yl·∃ŜY˝Syű äèăúŜY˝ă ŎI·y˝ KI·NyŜăä úKŜ fI·úŜyű ŎI·LJI·ōλfλúλŜă 2Ŧ ăY˝I·Nú Y˝ŜúŜNăΣ Řλ∃λúI·f Ŏ2Y˝Y˝dzyλŎI·úλ2yã äèăúŜY˝ăΣ I·yŘ äèăúŜY˝ Ŏ2yűN2f ŘŜØλŎŜă úž NŜŘdzŎŜ 2dzúI·∃Ŝă I·yŘ λyŎNŜI·ăŜ ŜŦŦλŎλŜyŎè$yc bŜø úNI·yãY˝ăäλ2y˝úŜŎKy2f2∃λŜă I·ff2ø 2LJŜNI·ú2Nă úž ∃Ŝű Y˝2NŜ ŎI·LJI·ŎλúèΦ 2dzú 2Ŧ úKŜ ăI·Y˝Ŝ Nλ∃KúăπΦ2ŦπøI·è I·yŘ ōŜúúŜN Y˝2yλú2N úKŜ KŜI·fúK I·yŘ ăúI·údză 2Ŧ úKŜ ∃NλŘφyT

¢KŜ ŜfŜŎúNλŎλúè λyŦNI·ăúNdzŎúdzNŜ λăΣ K2øŜØŜNΣ fI·N∃Ŝ I·yŘ Ŏ2Y˝LJfŜÈΣ I·yŘ ŜIjdzλLJY˝Syű KI·ă I· f2y∃ fλŦŜăLJI·y˝ Y˝2ŘŜNyλÎI·úλ2y˝λă I·y˝2y∃2λy∃ LJN2ŎŜääφyy hyfè I· ăY˝I·ff Y˝λy2NλúèΦ 2Ŧ LJ2øŜN LJfI·yűă øλff NŜI·ŎK úKŜλN ŜÈLJŜŎúŜŘ fλŦŜăLJI·y˝ 2ØŜN úKŜ ySÈű úø2 ŘŜŎI·ŘŜă óăŜŜ Cλ∃dzNŜ мπyúΦ wŜŦdzNōλăKY˝SyűΣ dzLJ∃NI·ŘŜΣ I·yŘ Y˝I·λyűŜyI·yŎŜ ŎI·y˝ ŜÈúŜyŘ úKŜ dzăŜŦdzf fλŦŜ 2Ŧ I· LJ2øŜN LJfI·yű ŦI·N ōŜè2yŘ λûă LJfI·yyŜŘ ăŜNØλŎŜ fλŦŜΦ t2øŜN LJfI·yűă I·NŜ 2ØŜNKI·dzfŜŘ 2y˝ I· NŜ∃dzfI·N ōI·ăλăΣ I·yŘ ă2Y˝Ŝ I·NŜ NŜLJ2øŜNŜŘ ú2 Ndzy˝2y˝I· ŘλŦŦŜNSyű ŦdzŜf 2N I·ú I· Kλ∃KŜN 2dzűLJdzű ŎI·LJI·ŎλúèΦ I·ú ă2Y˝Ŝ LJ2λyű ŘdzNλy∃ úKŜλN dzăŜŦdzf fλØŜăΦ [I·N∃Ŝ LJ2Núλ2yã 2Ŧ I· ŦI·ŎλfλúèΦ Y˝I·è ōŜ NŜLJfI·ŎŜŘ 2ØŜN Y˝I·yê èŜI·NăΣ LJN2ØλŘλy∃ 2LJLJ2NúdzyλúλŜă ú2 λyŎNŜI·ăŜ ŜŦŦλŎλŜyŎèΣ I·ŘŘ ySø úŜŎKy2f2∃λŜăΣ I·yŘ 2úKŜNøλăŜ Y˝2ŘŜNyλÎŜ LJfI·yűăΦ

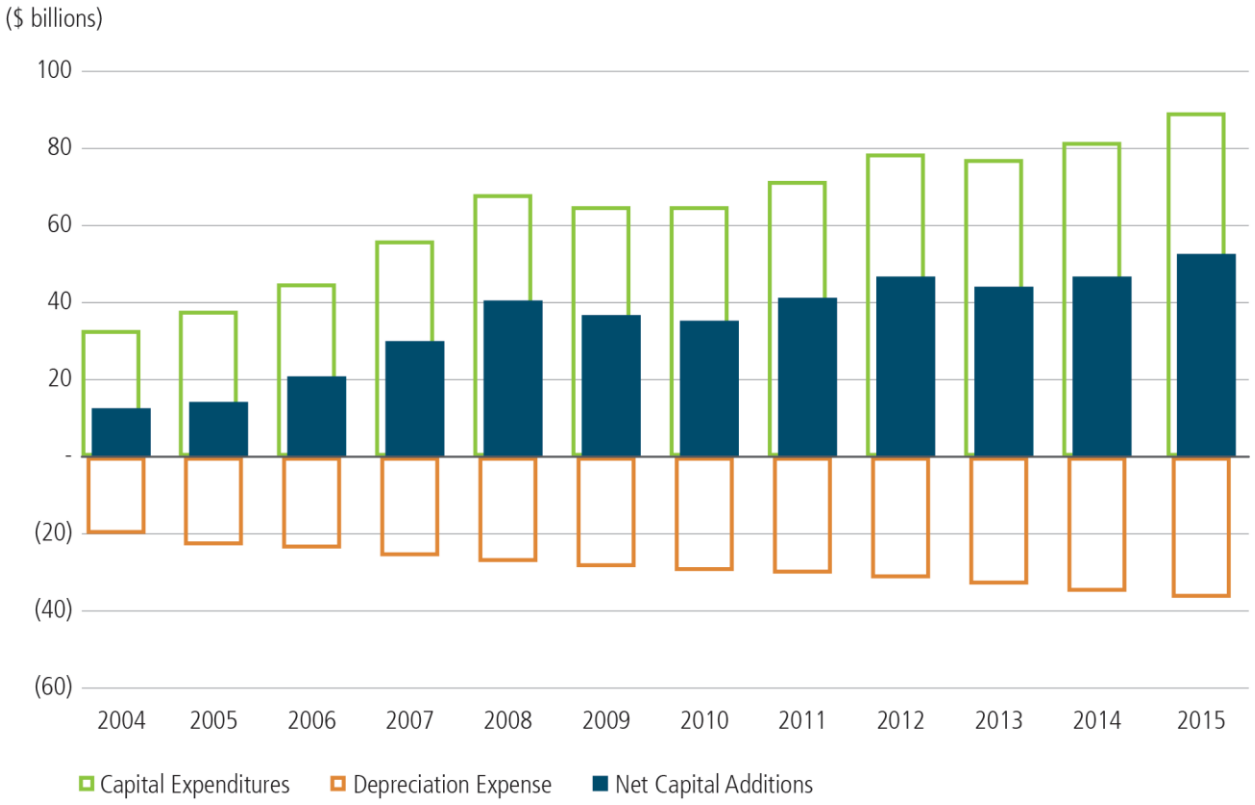
Figure 1-8. Current Age and Expected Life of Generation Fleet by Nameplate Capacity, 2015 [89]



Much of the U.S. generation fleet is 11ï 20 or 41ï 50 years old, with plants over the age of 50 being dominated by coal and hydropower. Much of the U.S. generation fleet is 11ï 20 or 41ï 50 years old. Plants over the age of 50 years are dominated by coal and hydropower. Plants under 20 years of age are dominated by natural gas and wind. Hydropower has the oldest fleet, followed by coal, nuclear, petroleum, and biomass. Expected life of the current fleet ranges from 55 years for natural gas to 100 years for hydropower generation.

C2ℕ Řλăΰℕλōdzΰλ2y˝ăèăΰŜY˝ăΣ l·ăăŜΰ Y˝2yλΰ2ℕλyƎΣ λyØŜăΰY˝ŜyΰΣ l·yŘ ℕŜLJfl·ÔŜY˝Ŝyΰ λă l·ΰ ΰKŜ Ô2ℕŜ 2Ŧ l· dzΰλfΩΰèΩă Y˝λăăλ2y˝ l·yŘ ōdzăλySăă Y˝2ŘŜfΓ dzΰλfΩΰλŜă l·yŘ ΰKŜλℕ ℕŜƎdzfl·ΰ2ℕă l·ℕŜ ŘλfΩƎŜyΰfè Ŝyãdzℕλy3 ΰKŜ Ô2yΰλyΰzŜŘ ℕŜfΩl·ōλfΩΰè 2Ŧ ΰKŜλℕ ăèăΰŜY˝ă ΰKℕ2dzƎK LJℕ2l·ÖΰΩØŜ ℕŜLJfl·ÔŜY˝Ŝyΰ l·yŘ ℕŜLJl·λℕΦ 5l·ΰl· l·Øl·λfl·ōλfΩΰè λă l· ÖKl·ffŜyƎŜ Ŧ2ℕ Ô2Y˝LJℕŜKŜyãλØŜ l·yl·fèăλă 2Ŧ Řλăΰℕλōdzΰλ2y˝ dzΰλfΩΰè λyŦℕl·ăΰℕdzÔΰdzℕŜT 2ØŜℕ oΣллл dzΰλfΩΰλŜă Kl·ØŜ ÔdzY˝dzfl·ΰλØŜfè λyăΰl·ffŜŘ Y˝λffΩ2yã 2Ŧ LJ2fŜăΣ ăY˝l·ff ΰℕl·yãŦ2ℕY˝ŜℕăΣ l·yŘ 2ΰKŜℕ Řλăΰℕλōdzΰλ2y˝ŜIjdzλLJY˝Syΰ℗ Cλyl·yÔλl·f ℕŜÔ2ℕŘă LJℕ2ØλŘŜ ă2Y˝Ŝ λyãλƎKΰă λyΰ2 ΰKŜ l·ƎƎℕŜƎl·ΰŜ l·ƎŜ 2Ŧ l· dzΰλfΩΰèΩă 2ØŜℕl·ff l·ăăŜΰă l·yŘ ădzƎƎŜăΰ ΰKl·ΰ λyØŜăΰY˝Syΰ λy˝ƎℕλŘ l·ăăŜΰă λă 2dzΰLJl·ÔλyƎ ΰKŜ ŘŜLJℕŜÔλl·ΰλ2y˝ 2Ŧ ΰKŜ 2ØŜℕl·ff l·ăăŜΰ ōl·ăŜT ΰKλă λă ăK2ø˝λy˝ CλƎdzℕŜ мπфΣ ØKλÔK ŘŜLJλÔΰă ΰKŜ ØλŘŜyλyƎ ÔKl·yƎŜ ōŜΰøŜŜy˝Ôl·LJλΰl·f λyØŜăΰY˝Syΰă l·yŘ ŘŜLJℕŜÔλl·ΰλ2y˝ÔKl·ℕƎŜă℗

Figure 1-9. Utility Operating Company Annual Capital Expenditures, Depreciation, and Net Capital Additions, 2004–2015[90]



Utility investment in capital (in green) has routinely outstripped depreciation expenses (in red) over the last decade, leading to positive and growing net capital additions (in blue). This means that utilities are adding property, plants, and equipment at a faster rate than they are losing it to wear and tear or obsolescence.

1.4.3 New Technologies Enable Two-Way Electricity Flows and Change Grid Management

C2ℕ 2ØŜℕ млл èŜl·ℕăΣ ΰKŜ ŜfŜÔΰℕλÔλΰè ăèăΰŜY˝ Kl·ă ōŜŜy˝2LJŜℕl·ΰŜŘ ΰKℕ2dzƎK 2yŜπøl·è Ŧf2øă 2Ŧ ŜfŜÔΰℕλÔλΰè l·yŘ λyŦ2ℕY˝l·ΰλ2y℗ CλƎdzℕŜ мπмлŘŜLJλÔΰă ΰKλă Kλăΰ2ℕλÔl·f 2yŜπøl·è Ŧf2ø 2Ŧ ŜfŜÔΰℕλÔλΰè ăSℕØλÔŜΣ ŦℕY˝ LJ2øŜℕ LJℕ2ŘdzÔŜŘ ΰ2 LJ2øŜℕ Ô2yădzY˝ŜŘΣ øλΰK Ôdzăΰ2Y˝Ŝℕă fl·ℕƎŜfè Ŧdzyÿΰλ2yλyƎ λy˝l·y˝l·yl·f2Ǝ ŜyØλℕ2yY˝Syΰ℗[7]

[7] ! yl·f2Ǝ l·yŘ ŘλƎλΰl·f ΰŜÔKy2f2ƎλŜă ō2ΰK ΰℕl·yãŦ2ℕY˝ λyŦ2ℕY˝l·ΰλ2y˝λyΰ2 ŜfŜÔΰℕλÔ ăλƎyl·fă℗ ! yl·f2Ǝ ΰŜÔKy2f2Ǝè ΰℕl·yãfl·ΰŜă λyŦ2ℕY˝l·ΰλ2y˝λyΰ2 ŜfŜÔΰℕλÔ LJdzfăŜă 2Ŧ Øl·ℕèλyƎ l·Y˝LJfΩΰdzŘŜΣ ØKλfŜ ŘλƎλΰl·f ΰŜÔKy2f2Ǝè ΰℕl·yãfl·ΰŜă λyŦ2ℕY˝l·ΰλ2y˝λyΰ2 ōλyl·ℕè Ŧ2ℕY˝ ôΓŜℕ2ă 2ℕ 2yŜăΰ ØKŜℕŜ Ŝl·ÔK ōλΰ λă ℕŜLJℕŜăŜyΰl·ΰλØŜ 2Ŧ ΰø2 ŘλăΰλyÔΰ l·Y˝LJfΩΰdzŘŜă℗

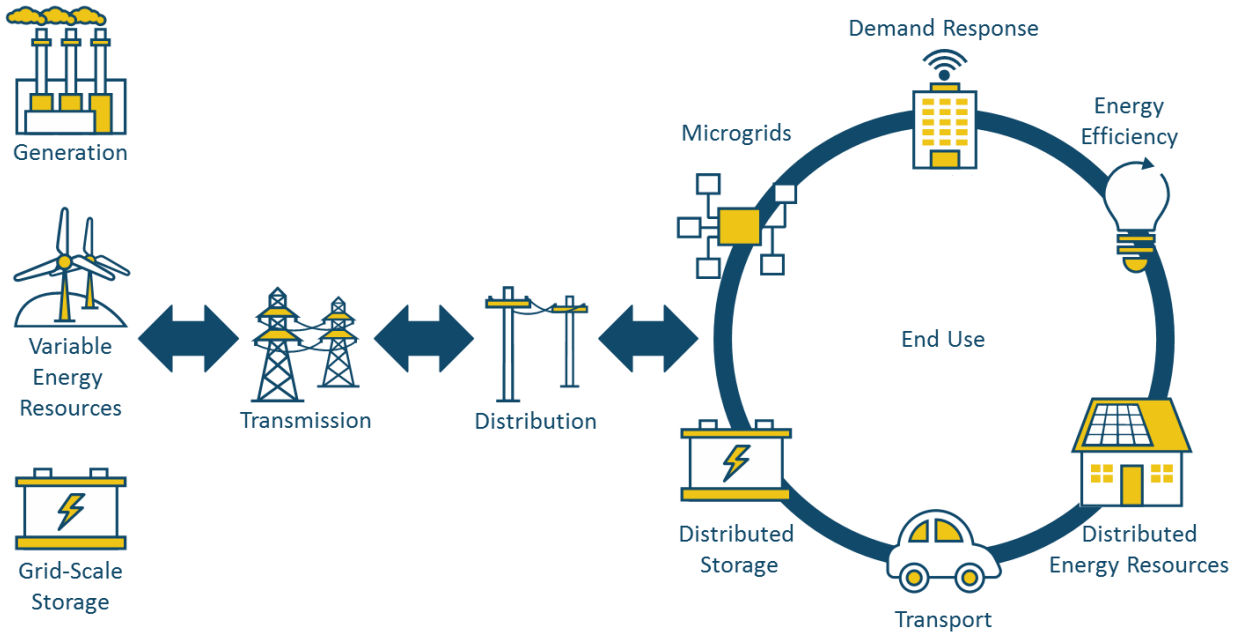
Figure 1-10. Traditional One-Way Flow Electricity Supply Chain[91]



The power grid was traditionally designed to move electricity from large generators to end users. Arrows represent power flows.

¢KŜ ƎŜyŜ№I·ǘλƨƴ I·yŘ ăƴ I·№ǘ Ǝ№λŘ ǘŜŎKyƨƭƨƎè λƴƴƨØI·ǘλƨƴã ŘŜăŎ№λōŜŘ ŜI·№ƭλŜ№ ŎI·ƴ№ŜŘdzŎŜ Ǝ№λŘ Ŏƨăǘă I·yŘ λƴLJ№ƨØŜ ŜŦŦλŎλŜyŎèΣ I·ă øŜƭƭ I·ă ăI·ØŜ ǘλƴŜ I·yŘ ŜŦŦƨ№ǘT ōdzǘ dzyǘλƭ №ŜŎŜyǘƭèΣ ŎƨƴLJdzǘŜ№ LJ№ƨŎŜăăλyƎ ăLJŜŜŘă I·yŘ ƭƨøπŎƨăǘ ŘλƎλǘI·ƭ ƴŜI·ădz№ŜƴŜyǘ I·yŘ ăŜyãƨ№ ǘŜŎKyƨƭƨƎè ƭλƴλǘŜŘ ǘKŜ I·ōλƭλǘè ƨŦ Ǝ№λŘă I·yŘ ŎƨyãdzƴŜ№ă ǘƨ ƴI·yI·ƎŜ ŜyŘπdzăŜ ōŜKI·Øλƨ№ λƴ KλƎKƭè Ǝ№I·ƴdzƭI·№ øI·èăφ ¢KŜ ŘŜØŜƭƨLJƴŜyǘ ƨŦ yŜø ǘŜŎKyƨƭƨƎλŜă ǘƨ ƴI·yI·ƎŜ ǘKŜăŜ ŜyŘ dzăŜă KI·ă I·ƭăƨ ŜyI·ōƭŜŘ ǘøƨπøI·è Ŧƭƨøă ƨƴ ǘKŜ ŜƭŜŎǘ№λŎλǘè ăèăǘŜƴφ CλƎdz№Ŝ мπмм ădzƴƴI·№λÎŜă ʅŜè ŎKI·yƎŜă λƴ ǘKŜ ŜƭŜŎǘ№λŎλǘè ăèăǘŜƴΣ øKŜ№Ŝ ădzŎK ǘøƨπøI·è Ŧƭƨøă I·№Ŝ LJƨăăλōƭŜ I·yŘ ƴƨ№Ŝ ŎƨƴƴƨyΣ I·yŘ øKŜ№Ŝ ŘλƎλǘλÎI·ǘλƨƴλă I·ʅŜè ŜyI·ōƭŜ№ ƨŦ I· yŜø №I·yƎŜ ƨŦ ăŜ№ØλŎŜăΣ λyŎƭdzŘλyƎ λyŎ№ŜI·ăŜŘ ŦƭŜÈλōλƭλǘèΣ KλƎKŜ№ ăèăǘŜƴ ŜŦŦλŎλŜyŎèΣ №ŜŘdzŎŜŘ ŜyŜ№Ǝè ŎƨyãdzƴLJǘλƨyΣ I·yŘ λyŎ№ŜI·ăŜŘ ŎƨyãdzƴŜ№ ƨLJǘλƨyã I·yŘ ØI·ƭdzŜφ

Figure 1-11. Emerging 21st Century Electricity Two-Way Flow Supply Chain[92]



The emerging 21st century power grid will incorporate responsive resources, storage, microgrids, and other technologies that enable increased flexibility, higher system efficiency, reduced energy consumption, and increased consumer options and value, as discussed in Chapter II, *The Electricity Sector: Maximizing Economic Value and Consumer Equity*. Arrows represent power flows. Figure 1-11 also depicts key factors that are disrupting traditional modes of grid management and operations, discussed in greater detail in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

bŜø Ŏƨyǘ№ƨƭ ǘŜŎKyƨƭƨƎλŜă I·yŘ I·ƴ ŜØƨƭdzǘλƨƴ λƴ ŜƭŜŎǘ№λŎλǘè ƴI·№ʅŜǘ ŘŜăλƎƴ øλƭƭ ŦI·ŎλƭλǘI·ǘŜ ǘKŜ №ŜƭλI·ōƭŜ I·yŘ ŜŎƨyƨƴλŎ ƨLJŜ№I·ǘλƨƴƨƦ ǘKŜ yŜø ŎI·LJI·ōλƭλǘλŜă λƴI· нмăǘ ŎŜyǘdz№è Ǝ№λŘφ L/¢ KI·ă I·ƭ№ŜI·Řè λƴLJ№ƨØŜŘ ǘKŜ ƨLJŜ№I·ǘλƨyã ƨŦ ǘKŜ Ǝ№λŘ øλǘKλƴ I·yŘ I·Ŏ№ƨăă №ŜƎλƨyãφ Cƨ№ ŜÈI·ƴLJƭŜΣ I·ŘØI·yŎŜŘ λyØŜ№ǘŜ№ă ƨƴŘλăǘ№λōdzǘŜŘ ăƨƭI·№ №Ŝăƨdz№ŎŜă ŎI·ƴ

LJN2ØλŘŜ I· ØI·NλŜűè 2ŦfžŎI·fλÎŜŘ ƎNλŘ ădzLJLJ2Nú ŦdzyŎűλ2yãΣ λyŎfdzŘλyƎ Ø2fűI·ƎŜ NŜƎdzfI·úλ2y I·yŘ ŦNŜIjdzŜyŎè NλŘŜ úKN2dzƎKΦ[3] ΦοbŜI·NfèI·ff Y I·N]ŜűNλŜƎλ2yã KI·ØŜ λyŎ2NLJ2NJI·űŜŘ I·ŎűλØŜ LJ2ØŜN Ŏ2yúN2f 2Ŧ ØλyŘ ůdzNōλyŜă λyű2 úKŜλN ŘλăLJI·úŎK LJN2ŎŜŘdzNŜă ů2 Y I·yI·ƎŜ úNI·yãY λăăλ2y Ŏ2yƎŜăűλ2yΦ[pn] !fã2Σ âŜØŜNJI·f Y I·N]ŜűNŜƎλ2yã KI·ØŜ ŎKI·yƎŜŘ Y I·N]ŜűNdzfŜă ů2 NŜŦfŜŎű úKŜ ŦI·ăú NŜI·Ŏűλ2y 2Ŧ ŜyŜNƎè ăű2NJI·ƎŜ ů2 ŦNŜIjdzŜyŎè NŜƎdzfI·úλ2y 2LJŜNJI·úλyƎ ăλƎyI·fãΦ[pp]

1.4.4 Customer Engagement, New Business Models, and the Emerging Role of Aggregators

¢KŜ N2fŜ 2Ŧ úKŜ ŜfŜŎűNλŎλúè Ödzăű2YŜN KI·ă ōŜŜy ŎKI·yƎλyƎ ăλyŎŜ ¢K2YI·ă 9Řλă2y ŦANăű fI·dzyŎKŜŘ úKŜ ŜfŜŎűNλŎλúè λyŘdzăűNè¢Φ ¢KN2dzƎK2dzű úKŜ λyŘdzăúNè¢ă ŘŜØŜf2LJYŜyűΣ úKŜ ŜfŜŎűNλŎλúè Ödzăű2YŜN ØI·ă ØλŜØŜŘ I·ă άf2I·Řé τ úKŜ I·ƎƎNŜƎI·úŜ I·ŎŎdzYdzfI·úλ2y 2Ŧ ŘŜY I·yŘ úKI·ú dzűλfλúλŜă âŜNØŜŘΣ ădzLJLJ2NűŜŘ ōè I· άNJI·űŜLJI·èŜN¢é ¢Kλă ØλŜØ 2Ŧ Ödzăű2YŜNă I·ă f2I·Ř I·yŘ NJI·űŜLJI·èŜNΣ fI·NƎŜfè LJI·ăăλØŜ ōŜŎI·dzăŜ úKŜNŜ ØŜNŜ y2 NŜI·f I·fűŜNyI·úλØŜ 2LJűλ2yã ů2 dzűλfλúè âŜNØλŎŜΣ ØI·ă 2LJŜNJI·úλØŜ úKN2dzƎK úKŜ ŜI·NfèмфулăΦ /KI·yƎŜă λyűKŜ ŜfŜŎűNλŎλúè âŜŎű2NJ ăűI·NűλyƎ λyűKŜ YλŘπмфулăΣ K2ØŜØŜNΣ KI·ØŜ LJNN2YLJűŜŘ dzűλfλúλŜă I·yŘ ŜYŜNƎλyƎ Ŏ2YLJŜűλű2Nă ů2 ăf2ØfèăKλŦű úKŜλN άŎdzăű2YŜNJI·ă f2I·Řé ØλŜØă ů2 I· LJ2λyű 2Ŧ ØλŜØ úKI·ű λă YdzŎK Y2NŜΣ I·yŘ Y2NŜ ăλYLJfèΣ Ödzăű2YŜNπŎŜyúNλŎΦ

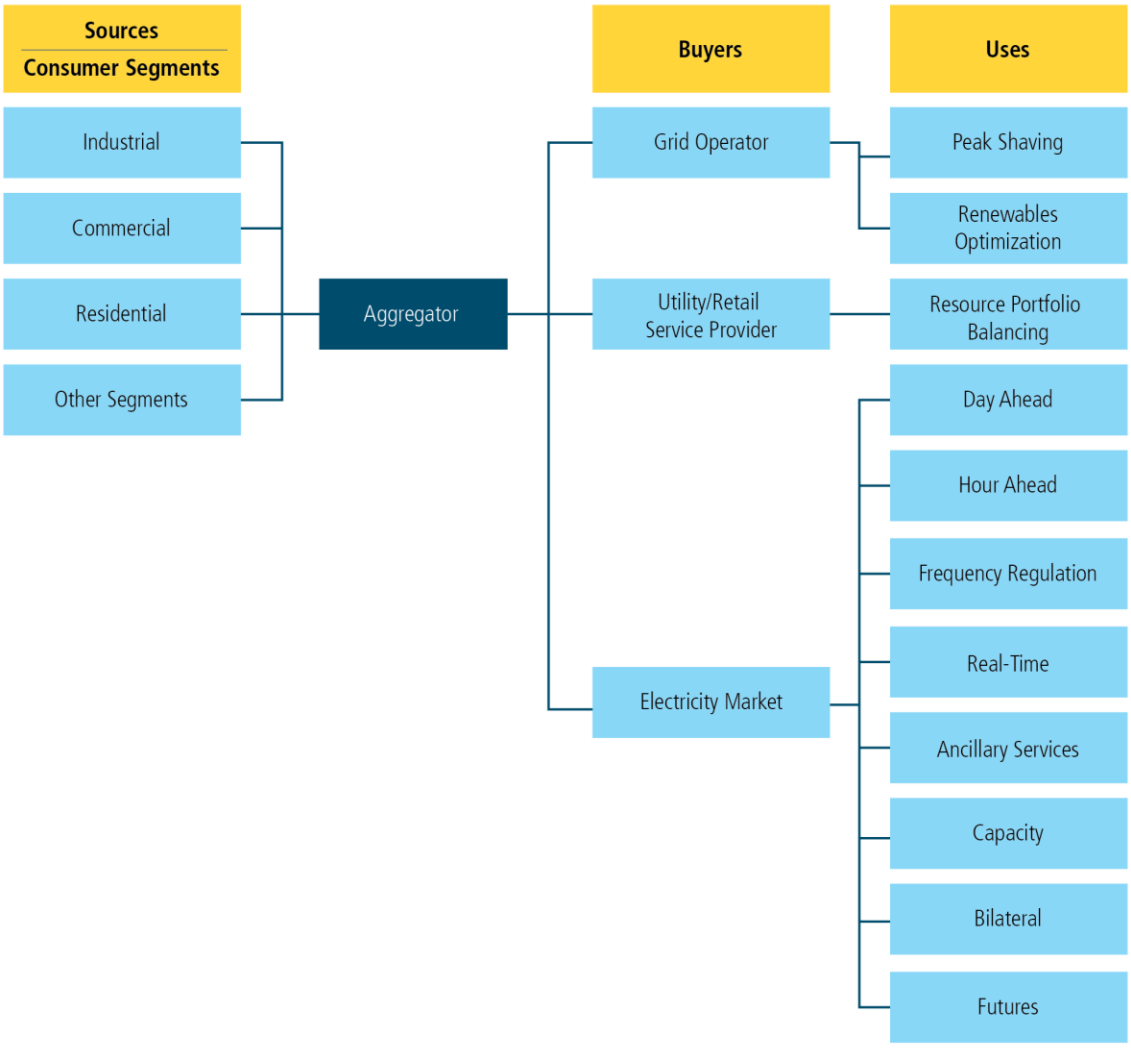
{úI·úŜă I·yŘ dzűλfλúλŜă I·NŜ ŜÈLJf2NλyƎ yŜØ ŘλăűNλōdzűλ2y dzűλfλúè ōdzăλySăă Y2ŘŜfă ØKλfŜ úKŜ LJNλØI·úŜ ăŜŎű2N λă LJN2ØλŘλyƎ yŜØ LJN2ŘdzŎűă I·yŘ ăŜNØλŎŜă ů2 Ŏ2yãdzYŜNă¢ LyűKŜ LJI·ăű ŘŜŎI·ŘŜΣ úKŜ ŜfŜŎűNλŎλúè λyŘdzăúNè KI·ă ăŜŜy I·fI·NƎŜ λyŎNŜI·ăŜ λyűKŜ ydzYōŜN 2Ŧ ōdzăλySăăŜă Ŧ2ŎdzăŜŘ 2yűLJN2ØλŘλyƎ ŜfŜŎűNλŎλúèπNŜfI·úŜŘ LJN2ŘdzŎűă I·yŘ ăŜNØλŎŜă 2dzűăλŘŜ 2Ŧ úNJI·Řλűλ2yI·f dzűλfλúè ōdzăλySăă Y2ŘŜfă¢Φ[pc] ¢KŜăŜ ōdzăλySăăŜă KI·ØŜ Ŧ2dzyŘ 2LJLJ2NűdzyλúλŜă ů2 LJN2ØλŘŜ ØI·fdzŜ ů2 ŎdzăűY2YŜNă úKN2dzƎK λyy2ØI·úλØŜ úŜŎKy2f2ƎλŜăΣ y2ØŜf ōdzăλyŜăă Y2ŘŜfăΣ I·yŘ ădzLJLJ2NűλØŜ {úI·úŜ I·yŘ CŜŘŜNJI·f LJ2fλŎè ŘŜŎλă2yã τ úKŜè I·NŜ I·fă2 ŎKI·yƎλyƎ úKŜ N2fŜ 2Ŧ ă2YŜ NJI·úŜLJI·èŜNă ŦN2Y LJI·ăăλØŜ Ŏ2yãdzYŜNă 2Ŧ ŜfŜŎűNλŎλúè ů2 λyŦ2NJYŜŘ ăK2LJLJŜNă I·yŘ LJN2ŘdzŎŜNă 2Ŧ ŜfŜŎűNλŎλúè I·yŘ NŜfI·úŜŘ ŜyŘπdzăŜ âŜNØλŎŜă¢Φ[pT] aI·yè 2Ŧ úKŜăŜ ăŜNØλŎŜă I·NŜ ŜyI·ōfŜŘ ōè úKŜ NŜŎŜyű ØλŘŜăLJNŜI·Ř I·Ř2LJűλ2y 2Ŧ I·ŘØI·yŎŜŘ ŜfŜŎűNλŎλúè YŜűŜNλyƎ I·yŘ Ŏ2YYdzyλŎI·úλ2yăëăűŜYă úKI·ú LJN2ØλŘŜ NJI·úŜLJI·èŜNă ØλűK dzyLJNŜŎŜŘŜyűŜŘ fŜØŜfă 2Ŧ λyŦ2NJYI·úλ2yNŜƎI·NŘλyƎ úKŜλN 2ØyŜyŜNƎè Ŏ2yãdzYLJűλ2yLJI·ăűŜNyã¢Φ[py] ¢KŜ ŘλăűNλōdzűλ2ydzűλfλúè ōdzăλySăă Y2ŘŜf λă ŘλăŎdzăăŜŘ ŦdzNűKŜNJ λy /KI·LJűŜNJ LLΣ *The Electricity Sector: Maximizing Economic Value and Consumer Equity*.

aI·yè ōdzăλySăăŜă I·NŜ y2Ø LJN2ØλŘλyƎ ŘλăűNλōdzűŜŘ ƎŜyŜNJI·úλ2yΣ ŜyŘπdzăŜ ŜyŜNƎè âŜNØλŎŜăΣ I·yŘ I·ƎƎNŜƎI·úŜŘ ŘŜY I·yŘ âŜNØλŎŜăΦ ¢KŜăŜ áI·ƎƎNŜƎI·ú2NăέI·NŜ LJfI·èλyƎ I· ƎNJ2ØλyƎ N2fŜ λy úKλă ŎdzăűY2YŜNπŎŜyűNλŎ ØλŜØ 2Ŧ f2I·ŘΦ ! ƎƎNŜƎI·úλ2y λyØ2fØŜă ƎN2dzLJλyƎ ŘλăűλyŎű ŜyŘ dzăŜNă λy I·y ŜfŜŎűNλŎλúè äèăűŜY λyŎfdzŘλyƎ úNJI·Řλűλ2yI·f Ŏ2yãdzYŜNăT Ŏ2yãdzYŜNă úKI·ú LJN2ŘdzŎŜ LJ2ØŜN Ŧ2N ƎNλŘ dzăŜT űKλNŘπLJI·Nűè 2yãλűŜ LJN2ŘdzŎŜNăΣ ădzŎK I·ă ŜyŜNJèŜ âŜNØλŎŜ Ŏ2YLJI·yλŜăT Ŏ2YLJŜűλűλØŜ NŜűI·AfŜNăT I·yŘ ŦI·ŎλfűλŜă YI·yI·ƎŜYŜyű âŜNØλŎŜ ŜyűλűλŜă¢Φ ¢KλăI·ƎƎNŜƎI·úλ2y 2Ŧ Ŏ2yãdzYŜNă ŜyI·ōfŜă úKŜY ů2 I·Ŏű I·ă I· ăλyƎfŜ ŜyűλűèΣ LJN2ØλŘλyƎ I· âŜNØλŎŜ ů2 dzűλfλúλŜă dzyŘŜNJ I· Ŏ2yűNJI·ŎűΣ 2NJ ů2 ŎŜyűNJI·ffèπ2NƎI·yλÎŜŘ ØK2fŜăI·fŜ YI·N]ŜűăΣ 2LJŜNJI·úŜŘ ōè L{hăκw¢hă úKN2dzƎK LJI·NűλŎλLJI·úλ2y λyNŜă2dzNŎŜ I·dzŎűλ2yãΦ LyűăK2NűΣ I·ƎƎNŜƎI·ú2Nă I·NŜ ŜyűŜNLJNλăŜă úKI·ú 2NŎKŜăűNJ·úŜ I·yŘ YI·yI·ƎŜ I·ƎƎNŜƎI·úŜŘ ŜfŜŎűNλŎλúèπNŜfI·úŜŘ âŜNØλŎŜă ŜyI·ōfŜŘ ōè ySØ úŜŎKy2f2ƎλŜă I·yŘ úKŜ ăYI·Nű ƎNλŘΦ ±I·fdzŜ NŜI·fλÎŜŘ úKN2dzƎK I·ƎƎNŜƎI·úλ2y úNJI·yãI·Ŏűλ2yã λă úèLJλŎI·ffè ăKI·NŜŘ ōŜűØŜŜyI·ƎƎNŜƎI·ú2Nă I·yŘ úKŜλN ŎfλŜyűăΦ

¢KŜ Ŏ2NŜ Ø2N]Ŧf2Øă 2Ŧ I·ƎƎNŜƎI·ú2Nă λyØ2fØŜ I·LJLJfèλyƎ úŜŎKyλŎI·f âŜNØλŎŜă ădzŎK I·ă ŜyƎλySŜNλyƎ I·yI·fèűλŎăΣ LJN2ŎŜăă âèăűŜY ŘŜăλƎyΣ I·ăăŜű I·ŎIjdzλăλúλ2y I·yŘ λyăűI·ftI·úλ2yΣ I·yŘ 2yƎ2λyƎ 2LJŜNJI·úλ2yã I·yŘ YI·λyűŜyI·yŎŜΣ I·ă ØŜft I·ă ŜŎ2y2YλŎ âŜNØλŎŜă ădzŎK I·ă fŜI·ăλyƎ ů2 ădzLJLJ2NűΣ I·Ř2LJűλ2y 2Ŧ âŜNØλŎŜăΣ âKI·NŜŘ ăI·ØλyƎăπōI·âŜŘ úNJI·yãI·Ŏűλ2yã úKI·ú NŜŘdzŎŜ ŎfλŜyű Ŏ2ăűăΣ I·yŘ 2ØyŜNăKλLJ 2Ŧ âèăűŜYă Ŧ2N ØKλŎK I· Y2yűKfè ŦŜŜ λă ŎKI·NƎŜŘ ů2 ŎfλŜyűăΦ [2] KλfŜ úKŜNŜ I·NŜ YI·yè ØI·NλI·úλ2yã 2Ŧ úKŜăŜ ƎŜyŜNJI·f ŜyűŜNLJNλăŜ I·ŎűλØλúλŜăΣ CλƎdzNŜ мπмн LJN2ØλŘŜă I· ƎŜyŜNJI·f ŘŜLJλŎűλ2y 2Ŧ úKŜ Ŏ2yãdzYŜN I·yŘ ōdzèŜN ŎI·úŜƎ2NλŜă Ŧ2N I·ƎƎNŜƎI·ú2Nă I·yŘ úKŜ LJ2ûŜyűλI·f âèăűŜY ØI·fdzŜ úKI·ű Ŏ2dzfŘ ōŜ I·ăă2ŎλI·úŜŘ ØλűK ØI·NλI2dză I·ƎƎNŜƎI·úλ2yã

[3] CNŜIjdzŜyŎè NλŘŜ úKN2dzƎK NŜŦŜNă ů2 úKŜ I·ōλfλúè Ŧ2N I· ƎŜyŜNJI·úλ2y úŜŎKy2f2ƎèůŜ Y I·λyűI·λy 2LJŜNJI·úλyƎ úKN2dzƎK Y2YŜyűI·NèƎNλŘ ŘλăűdzNōI·yŎŜă fλ]Ŝ I· ŘλLJ λyØ2fűI·ƎŜ 2N ŦNŜIjdzŜyŎè¢Φ

Figure 1-12. Aggregator Sources, Markets, and Services



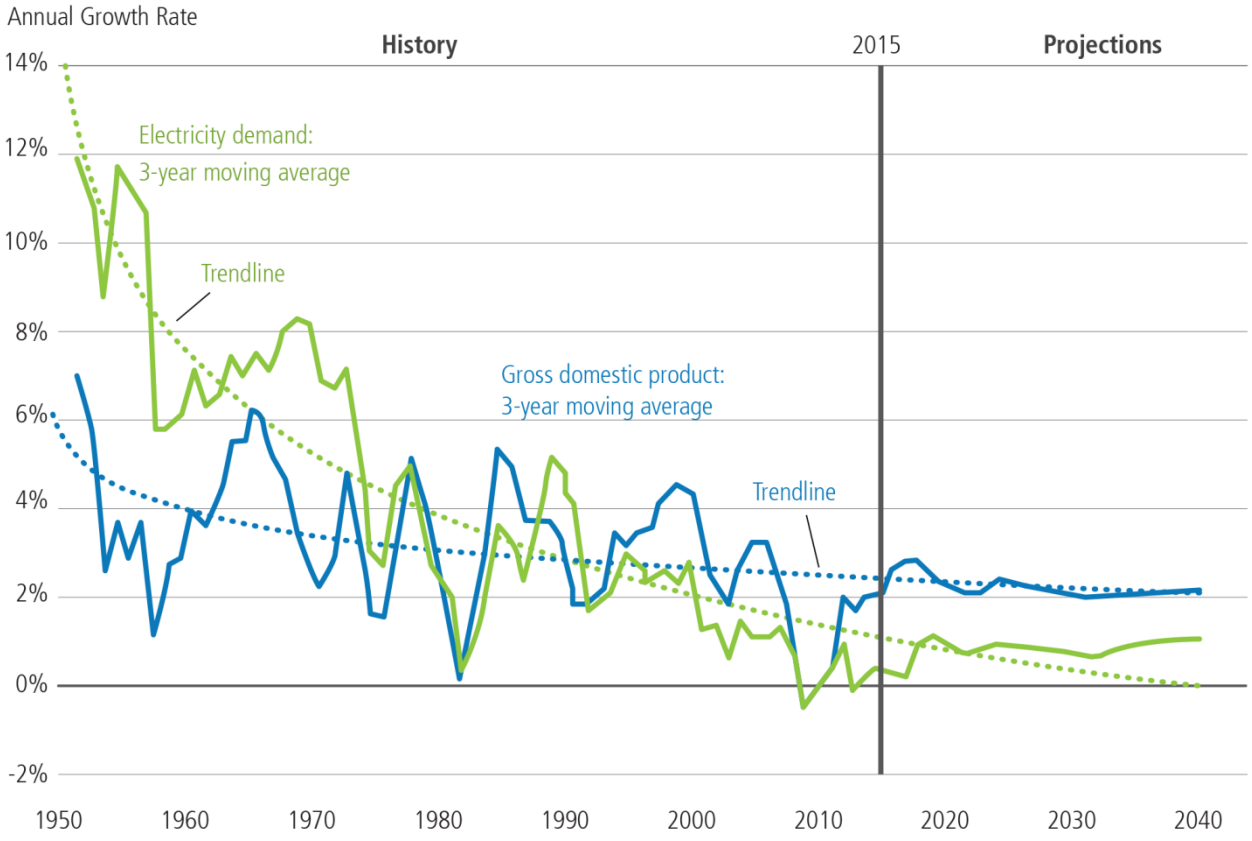
Aggregators develop ñload portfoliosò from various combinations of consumer segments. There are three principal buyers for aggregator services: utility grid operators, utility retailers, and utilities interacting with other wholesale market participants to serve day-ahead, hour-ahead, and real-time markets (which include frequency regulation and other essential reliability services). Aggregators sell DR products for use by utilities across all three buyer types using specific utility-offered DR programs, or through negotiated DR contracts with aggregators.

¢KŜ ℕ2ƒŜă ǘKI·ǘ y2yπdzǘλƒλǘè I·∃∃ℕŜ∃I·ǘ2ℕă LJƒI·è ŎI·y¯ōŜ 2ŦƎℕŜI·ǘ ØI·ƒdzŜ λy¯ădzLJLJ2ℕǘλy∃ ∃ℕλŘ ℕŜƒλI·ōλƒλǘè I·yŘ ŦƒŜÈλōλƒλǘèφ ¢KŜ ∃ℕ2øλy∃ LJŜyŜǘℕI·ǘλ2y¯2Ŧ 59w λyŎℕŜI·ăŜă ǘKŜ ŘŜLJǘK I·yŘ ŘλØŜℕăλǘè 2Ŧ ØI·ƒdzŜπI·ŘŘŜŘ ăŜℕØλŎŜă I·∃∃ℕŜ∃I·ǘ2ℕă ŎI·y¯2ŦŦŜℕφ !∃∃ℕŜ∃I·ǘ2ℕă I·ℕŜ y2ǘΣ K2øŜØŜℕΣ ℕŜ∃dzƒI·ǘŜŘ ŜyǘλǘλŜăT ǘKŜλℕ ØI·ƒdzŜ LJℕ2LJ2ăλǘλ2yã ǘŜyŘ ǘ2 ōŜ ℕλăʅλŜℕ ǘKI·y¯ ǘK2ăŜ 2Ŧ ℕŜ∃dzƒI·ǘŜŘ ŜyǘλǘλŜăφ ¢KŜλℕ ŎƒλŜyǘ Ŝy∃I·∃ŜYŜyǘă I·ℕŜ I·ƒă2 ădzō?ŜŎǘ ǘ2 yŜ∃2ǘλI·ǘŜŘ ǘŜℕYă I·yŘ Ŏ2yŘλǘλ2yã ǘKI·ǘ ŎI·y¯ℕŜădzƒǘ λy¯I·y¯dzyŜØŜy¯Řλăǘℕλōdzǘλ2y¯2Ŧ ōŜyŜŦλǘă ōŜǘøŜŜy¯YŜYōŜℕă 2Ŧ I·y¯I·∃∃ℕŜ∃I·ǘλ2yΣ I·ă øŜƒƒ I·ă ōŜǘøŜŜy¯ǘKŜ I·∃∃ℕŜ∃I·ǘ2ℕ I·yŘ I·ƒƒ ŎƒλŜyǘăφ ¢2 YI·ÈλYλÎŜ ǘKŜλℕ ØI·ƒdzŜ ǘ2 ǘKŜ ŜƒŜŎǘℕλŎλǘè ăèăǘŜY I·yŘ ∃ℕλŘ 2LJŜℕI·ǘλ2yãΣ I·∃∃ℕŜ∃I·ǘ2ℕă yŜŜŘ I·ŘŜIjdzI·ǘŜ ŎI·LJλǘI·ƒλÎI·ǘλ2yΣ ădzŦŦλŎλŜyǘ LJ22ƒλy∃ 2Ŧ ŎƒλŜyǘă ǘ2 ŜyãdzℕŜ ℕŜƒλI·ōƒŜ ŜÈŜŎdzǘλ2y¯2Ŧ 59wπℕŜƒI·ǘŜŘ ăŜℕØλŎŜăΣ I·yŘ λYLJℕ2ØŜŘ ŜÈŜŎdzǘλ2y¯2Ŧ ŎƒλŜyǘπℕŜƒI·ǘŜŘ I·ŎǘλØλǘλŜăφ ¢KŜλℕ I·ŎǘλØλǘλŜă I·ƒă2

1.4.5 Workforce Retirements, New Skillsets, and Shifting Regional Needs Pose Challenges for a Changing Electricity Sector

1.5 The Electricity Sector Is Enabling a More Productive Economy and Reducing Carbon Emissions

Figure 1-13. U.S. GDP and Electricity Demand Growth Rates, 1950–2040[111]



U.S. electricity demand growth has slowed since the 1950s and is projected to remain flat through 2040, based upon business-as-usual assumptions. Though national GDP has slowed over the same time period, electricity growth has slowed significantly more than GDP.

t l·ăű l·yŘ ŦdzűdzNJŜ ŜfŜŎűNJλŎλűê ŘŜY l·yŘ ƎN2ǿűK NJl·úŜă l·NJŜ ŘNJλØŜy ōè ăŜØŜNJl·f ăŜŎű2NJπăLJŜŎλŦλŎ űNJSyŘă űKl·ú NJŜŦfŜŎű ōN2l·ŘŜN ŜŎ2y2Y λŎ ŎKl·yƎŜă C2N ŜÈl·Y LJfŜΣ ǿKλfŜ λyŘdzăűNJλl·f ŘŜY l·yŘ ƎN2ǿűK λă ØλNJűdzl·ffè ŦfI·úΣ LJN2ŘdzŎűλØλűê ól·ă YŜl·ădzNJŜŘ ōè dzyλűă 2Ŧ D5 t LJN2ŘdzŎŜŘ LJŜNJ dzyλű 2Ŧ SyŜNJƎè Ŏ2yădzY ŜŘú λă ƎN2ǿλyƎφ ¢KŜ λyŘdzăűNJλl·f ăŜŎű2NJΩă ŜfŜŎűNJλŎλűê LJN2ŘdzŎűλØλűê ySl·NJfè Ř2dzōfŜŘ ōŜúǿŜŜy мффл l·yŘ нлмпφ tN2ŕŜŎűλ2yã ădzƎƎŜăű űKl·ú ƎNJŘπLJdzNJŎKl·ăŜŘ ŜfŜŎűNJλŎλűê ǿλff NJl·LJλŘfè λyŎNJŜl·ăŜ λy űKŜ λyŘdzăűNJλl·f ăŜŎű2NJ ŦN2Y нлмл dzyűλf нлнрΣ l·ŦűŜNJ ǿKλŎK ƎN2ǿűK λă LJN2ŕŜŎűŜŘ ű2 ăf2ǿ ű2 нлпл ǿKŜy λű NJŜl·ŎKŜă мΣнму űŜNJl·ǿl·úűπK2dzNJă óнр LJŜNJŎŜyű l·ō2ØŜ űKŜ нлмл fŜØŜfúφ ᴹᴹᴴ

1.5.1 Decarbonizing the Electricity System

¦φ{φ LJ2ǿŜN ăŜŎű2N ŜY λăăλ2yã ŘŜŎfλySŘ ōè нл LJŜNJŎŜyű ăλyŎŜ нллрΣ fl·NJƎŜfè ŘdzŜ ű2 l· ăf2ǿλyƎ 2Ŧ ŜfŜŎűNJλŎλűê ŘŜY l·yŘ ƎN2ǿűK l·yŘ űKŜ l·ŎŎŜfŜNJl·úŜŘ ŘŜLJf2èYŜyű 2Ŧ f2ǿŜNJπŎl·NJō2y ƎŜySNJl·úλ2yφᴹᴹᴼ [2ǿ yl·ůdzNJl·f Əl·ă LJNJλŎŜă Kl·ØŜ fŜŘ ű2 ădzōăűl·yűλl·f ădzōăűλűdzűλ2yã 2Ŧ f2ǿŜNJπSY λűűλyƎ Əl·ă Ŧ2N KλƎKπŜY λűűλyƎ Ŏ2l·fφ ¢Kλă ăă λy LJl·Nű ōŜŎl·dzăŜ úKŜ ŜfŜŎűNJλŎλűê ăŜŎű2NJ Kl·ă úKŜ ōN2l·ŘŜăű l·yŘ Y2ăű Ŏ2ăűπŜŦŦŜŎűλØŜ l·ōl·úŜY Ŝyű 2LJLJ2NJůdzyλűλŜă 2Ŧ l·yê ăŜŎű2NJΣ λyŎfdzŘλyƎ Y dztűλLJfŜ ÎŜN2πŎl·NJō2y l·yŘ f2ǿπŎl·NJō2y ƎŜySNJl·úλ2y 2LJűλ2yã τ ădzŎK l·ă ydzŎfŜl·NJΣ KèŘN2LJ2ǿŜNJΣ ă2fl·NJΣ ǿλyŘΣ ƎŜ2űKŜNJY l·fΣ ōλ2Y l·ăăΣ l·yŘ Ŧ2ăăλf ƎSyŜNJl·úλ2y ǿλűK Ŏl·NJō2y Ŏl·LJůdzNJŜ l·yŘ ăű2NJl·ƎŜ τ l·ă ǿŜff l·ă Y l·yê 2LJŜNJl·úλ2yl·f l·yŘ ŜyŘπdzăŜ ŜŦŦλŎλŜyŎè 2LJLJ2NűdzyλűλŜăφ ¢KŜ ŜfŜŎűNJλŎλűê ăŜŎű2NJ Kl·ă ōŜŜy l·yŘ τ ŘŜLJŜyŘλyƎ 2y űKŜ λyűŜNJLJfl·è 2Ŧ úŜŎKy2f2Ǝè λyy2Ǿl·úλ2yΣ Y l·NJ]Sű Ŧ2NJŎŜăΣ l·yŘ LJ2fλŎè τ λă fλ]Sfè ű2 Ŏ2yűλyűzŜ ű2 ōŜ úKŜ ŦλNJăű Y2ǿŜNJ λy ŜŎ2y2Y èπǿλŘŜ D l D ŜY λăăλ2yã NJŜŘdzŎűλ2yãφ Lű ǿλff l·fă2 LJfl·è l· Y l·ê2NJ N2fŜ λy űKŜ fŜØŜfă 2Ŧ ŘŜŎl·NJō2yλÎl·úλ2y

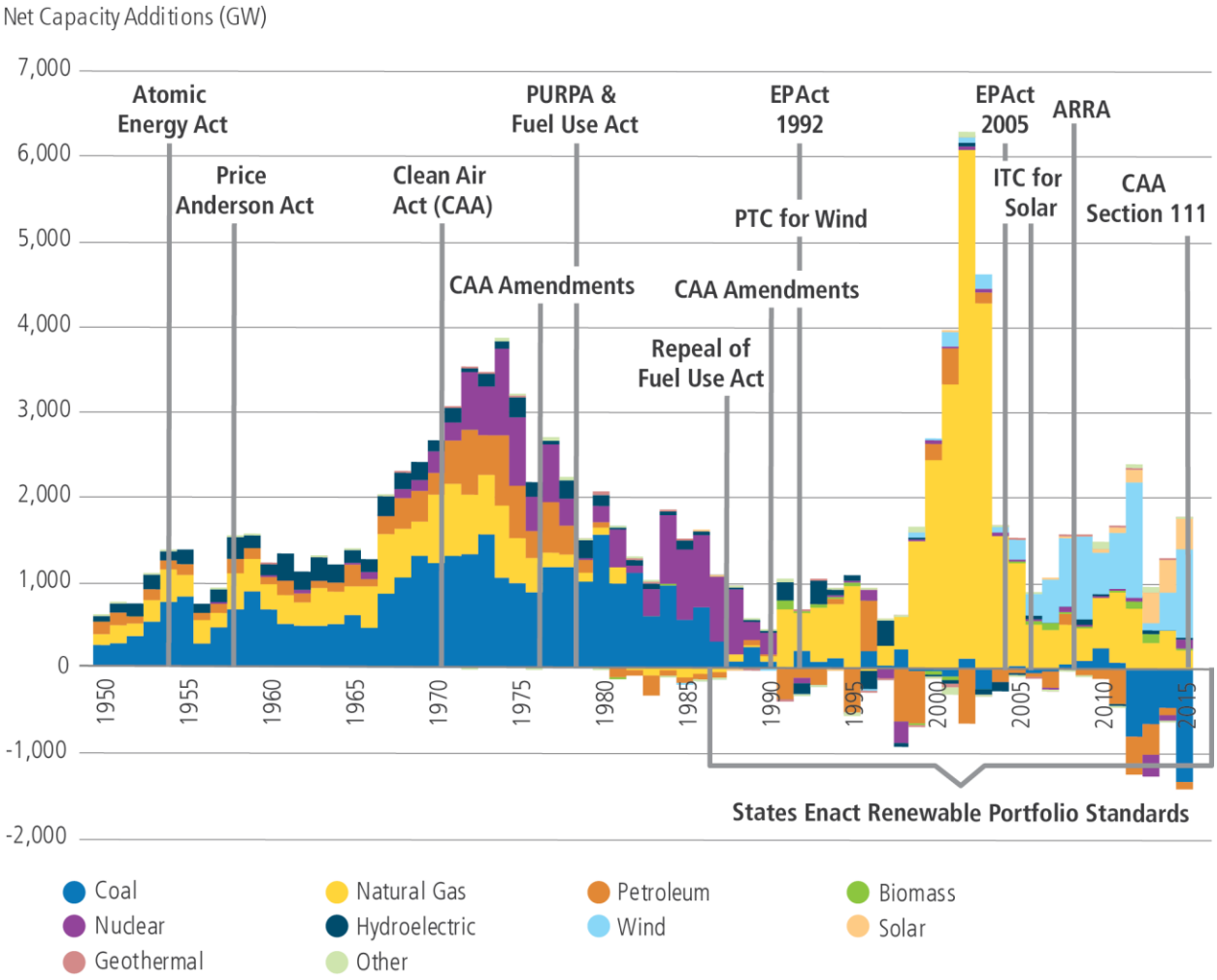
¢KŜ λYˊLJ2₪ŭI·yŌŜ 2₮ ŘŜŎI·₪ō2yλÎI·ûλ2Yˊ I·₪∃dzŜă ₮2₪ Sy℞dz₪λyE ŭKI·ŭ CŜŘŜ₪I·f I·yŘ {úI·ûŜ LJ2fλŎλŜă LJ₪2ØλŘŜ Ŏ2YˊLJŜfflyE λyŌSyflØŜă ₮2₪ ú₪I·yãλûλ2yλyE ŭKŜ ŜfŜŎŭ₪λŌλûè ăŜŎŭ2₪ I·ă LJI·₪ŭ 2₮ I·ŎKλŜØλyE yI·ûλ2yI·f ∃2I·fã℗ hLJŭλ2yã ₮2₪ ŘŜŎI·₪ō2yλÎλyE ŭKŜ ŜfŜŎŭ₪λŌλûè ăŜŎŭ2₪ Yˊdzăŭ I·ŘŘ₪Ŝăă ăλ∃yflλŎI·yŭ ōI·₪₪Ŝ₪ă λYˊúK₪ŜŜ ō₪2I·Ř ŎI·ûŜ∃2₪λŜăY ûŜŎKyflŎI·f óŜ℗∃℗Σ f2yE ûλYˊŜ ₮₪I·YˊŜă ₮2₪ ₪ŜăŜI·₪ŎKΣ ŘŜØŜf2LJYˊŜyúΣ ŘŜY2yãú₪I·ûλ2yΣ I·yŘ ŘŜLJf2èYˊŜyŭ ώw55ɐ5ß ∃ŜăŭI·ûλ2yÚT ăú₪dzŌŭdz₪I·f óŜ℗∃℗Σ f2yE ûλYˊŜ ₮₪I·YˊŜă ₮2₪ ŎI·LJλŭI·f ăú2Ŏ] údz₪y2ØŜ₪úT I·yŘ LJ2fλŎè óŜ℗∃℗Σ Řλ₮₮λŎdzfûλŜă λY Y2ōλflÎλyE ySŜŘŜŘ λyØŜăúYˊŜyúú℗

LyØŜăúYˊŜyú λYˊλyy2ØI·ûλ2yˊλă ySŜŘŜŘΣ λyŌfdzŘλyE λyØŜăúYˊŜyú λYˊI·ŘØI·yŌŜYˊŜyúă 2₮]y2øyˊûŜŌKy2f2∃λŜăΣ I·ă øŜff I·ă λY ₮dzyŘI·YˊŜyúI·f ō₪ŜI·]úK₪2dz∃Kă℗ ¢KŜ LJ2ûŜyúλI·f ₮2₪ ₪ŜăŜI·₪ŌKΣ ŘŜØŜf2LJYˊŜyúΣ I·yŘ ŘŜY2yãú₪I·ûλ2yˊ ú2 λyŌ₪ŜI·ăŜ ŘŜLJf2èYˊŜyú 2₮ ŜÈλăúλyE ûŜŌKy2f2∃λŜă I·yŘ dzyf2Ō] ₮dzűdz₪Ŝ ûŜŌKy2f2∃λŜă λă ăλ∃yflλŎI·yúΣ I·yŘ f2y∃π₪I·y∃Ŝ LJfI·yyλyE Yˊdzăŭ ûI·]Ŝ ûŜŌKy2f2∃è ûλYˊŜ ăŌI·fŜă I·yŘ ŘŜLJf2èYˊŜyú ûλYˊŜflyŜă λyú2 I·ŎŌ2dzyú℗ ¢KŜ λyy2ØI·ûλ2yˊ LJ₪2ŌŜäă λă λûŜ₪I·ûλØŜΣ ₪ŜIjdz₪λyE ŜI·₪fê ŘŜLJf2èYˊŜyú I·yŘ ûŜŌKy2f2∃è fŜI·₪yλyE 2ØŜ₪ ûλYˊŜ℗ ! fã2Σ ōŜè2yŘ Ŝyl·ōflyE Ř2YˊŜăúλŎ D I D ₪ŜŘdzŎûλ2yˊ I·yŘ λYˊLJ₪2ØλyE ŜŌ2y2YλŎ øŜffπōŜλyEΣ λyy2ØI·ûλ2yˊŌI·yˊăλ∃yflλŎI·yűfê I·ŎŌŜfŜ₪I·ûŜ I·yŘ ŜI·ăŜ ûKŜ LJI·ûK ûž ∃f2ōI·f ŜYˊλăăλ2yã ₪ŜŘdzŎûλ2yãΣ ō2ûK 2₮ øKλŎK I·₪Ŝ Ŏ₪λûλŎI·f ûž ₪ŜŘdzŎλyE I·ŘØŜ₪ăŜ ŎflYˊI·ûŜ λYˊLJI·Ŏûă℗

LyˊI·ŘŘλûλ2yΣ ú₪I·yãλûλ2yλyE ûž I· f2ø℘ŎI·₪ō2yˊŜfŜŎû₪λŌλûè ₮dzűdz₪Ŝ ₪ŜIjdz₪ŜăLJ2fλŎλŜă ûKI·ŭ I·ŎŌŜfŜ₪I·ûŜ ŘŜLJf2èYˊŜyú 2₮ f2ø℘ŎI·₪ō2yˊ∃ŜySI·ûλ2y℗ᵐᵐᵐ ¢KŜ f2yE ûλYˊŜ ₮₪I·YˊŜă ₮2₪ ŎI·LJλúI·f ăú2Ŏ] údz₪y2ØŜ₪ I·fă2 YˊžûλØI·ûŜ ŜI·₪fê I·Ŏûλ2y℗ ¢KŜ₪Ŝ I·₪Ŝ CŜŘŜ₪I·f ûI·È Ŏ₪ŜŘλûă I·yŘ {úI·ûŜ LJ2fλŎλŜăΣ ădzŌK I·ă ₪ŜySøI·ōfŜ LJ2₪úŦ2fλ2 ăúI·yŘI·₪ŘăΣ ûKI·ŭ I·₪Ŝ Ř₪λØλyE λyØŜăúYˊŜyú λyˊ ŜySŜ₪∃è ŜŦŦλŎλŜyŌè I·yŘ ₪ŜySøI·ōfŜ LJ2øŜ₪Σ ōdzú I·ŘŘλûλ2yI·f LJ2fλŎλŜă YˊI·è ōŜ ySŜŘŜŘ ₮2₪ ûKŜ I·ŎŌŜfŜ₪I·ûŜŘ ŘŜLJf2èYˊŜyú 2₮ ûKŜăŜ I·yŘ 2ûKŜ₪ Ŏ₪λûλŎI·f ∃₪λŘπ₪ŜfI·ûŜŘ ûŜŌKy2f2∃λŜă℗

² ŜffπŘŜăλ∃ySŘ LJ2fλŎλŜă ŎI·yˊKŜfLJ ₮I·ŎλflûI·ûŜ I·yŘ Ŝyl·ōfŜ YˊI·₪]Ŝú YˊŜŎKI·yλăYˊă ûKI·ú Ř₪ØŜ fŜI·ăűπŌ2ăű I·LJLJ₪2I·ŎKŜă ûž YˊžōλflÎλyE I·yŘ fŜØŜ₪I·∃λyE LJdzōflŎ I·yŘ LJ₪ØI·ûŜ λyØŜăúYˊŜyúΣ YˊλylYˊλÎλyE ûKŜ ₪λă] 2₮ ăú₪I·yŘŜŘ I·ăăŜúă I·yŘ ₪ŜŘdzŎλyE ŜYˊλăăλ2yã℗ /2yØŜ₪ăŜfèΣ LJ2fλŎλŜă ûKI·ú ₪ŜLJfI·ŌŜ 2₪ ăλ∃yflλŎI·yűfê λyúŜ₪₮Ŝ₪Ŝ øλűK YˊI·₪]Ŝú YˊŜŎKI·yλăYˊă ŎI·yˊKI·ØŜ dzylyűŜyŘŜŘ I·yŘ f2yE ûλYˊŜ ₮₪I·YˊŜă ₮2₪ ŎI·LJλúI·f ăú2Ŏ] údz₪y2ØŜ₪ I·fă2 YˊžûλØI·ûŜ ŜI·₪fê I·Ŏûλ2y℗ ¢KŜ₪Ŝ I·₪Ŝ CŜŘŜ₪I·f ûI·È Ŏ₪ŜŘλûă I·yŘ {úI·ûŜ LJ2fλŎλŜăΣ ădzŌK I·ă ₪ŜySøI·ōfŜ LJ2₪úŦ2fλ2 ăúI·yŘI·₪ŘăΣ ûKI·ú I·₪Ŝ Ř₪λØλyE λyØŜăúYˊŜyú λyˊ ŜySŜ₪∃è ŜŦŦλŎλŜyŌè I·yŘ ₪ŜySøI·ōfŜ LJ2øŜ₪Σ ōdzú I·ŘŘλûλ2yI·f LJ2fλŎλŜă YˊI·è ōŜ ySŜŘŜŘ ₮2₪ ûKŜ I·ŎŌŜfŜ₪I·ûŜŘ ŘŜLJf2èYˊŜyú 2₮ ûKŜăŜ I·yŘ 2ûKŜ₪ Ŏ₪λûλŎI·f ∃₪λŘπ₪ŜfI·ûŜŘ ûŜŌKy2f2∃λŜă℗

Figure 1-14. Net Generation Capacity Additions, 1950–2015[115]



Capacity additions of different generation technologies came in waves that were largely influenced by policy, fuel costs, and technology development. The 1930s and 1940s fostered the development of hydropower; nuclear power was widely deployed in the 1970s after nuclear research for peaceful uses was allowed; natural gas additions peaked in the 2000s; and non-hydro renewables are quickly growing in the 21st century. Note that the deployment of these generation technologies followed enabling Federal policies and technology developmentð e.g., nuclear power reactors and natural gas combined-cycle turbinesð by several decades.

a l·yè ƎŜyŜ№l·ǘƛƧƴƧǿyŜ№ă l·yŘ ƳƧăǘ ŜŎƧƴƧƳƛăǘă Ƴ l·ƛyǘl·ƛyǘKl·ǘ l· LJ№ƛŎŜ ƧƴŎl·№ōƧƴƛă ǘKŜ ƳƧăǘ ŜŦŦƛŎƛŜyǘ ƳŜl·yã ƧŦ l·ŎKƛŜǾƛyƎ ŘŜŎl·№ōƧƴƛÎl·ǘƛƧyφ a l·yè ƛyǾŜăǘƧ№ă l·ƭ№Ŝl·Řè l·ăădzƳŜ l· ăKl·ŘƧǿ LJ№ƛŎŜ ƧƴŎl·№ōƧƴ ǿKŜƴ Ƴl·ʅƛyƎ ƛyǾŜăǘƳŜyǘ ŘŜŎƛăƛƧyãφ {ǘl·ǘŜă Kl·ǾŜ l·ƭăƧ ǘl·ʅŜƴ l· ƴdzƳōŜ№ ƧŦ l·ŎǘƛƧyã ǘƧ №ŜŘdzŎŜ ŎƧyǾŜƴǘƛƧƴl·ƭ LJƧƭƭdzǘƛƧƴ l·yŘΣ ƳƧ№Ŝ №ŜŎŜyǘƭèΣ D I D ŜƳƛăăƛƧyã ōŜèƧyŘ ǿKl·ǘ ƛă №Ŝljdzƛ№ŜŘ dzyŘŜ№ yl·ǘƛƧƴl·ƭ ŜyǾƛ№ƧƴƳŜyǘl·ƭ ăǘl·ǘdzǘŜăφ Lƴ l·ŘŘƛǘƛƧƴΣ Ƴl·yè ŎƛǘƛŜă Kl·ǾŜ ăŜǘ ŜÈLJƭƛŎƛǘ ƎƧl·ƭă ǘƧ №ŜŘdzŎŜ D I D ŜƳƛăăƛƧyã l·yŘ Kl·ǾŜ ŜyƧl·ŎǘŜŘ LJƧƭƛŎƛŜă ǘƧ KŜƭLJ ƳŜŜǘ ǘKƧăŜ ƎƧl·ƭăφ CƛyƧl·ƭƭèΣ ăŜǾŜ№l·ƭ w¢hăκL{hă Kl·ǾŜ ƛăădzŜŘ ăǘdzŘƛŜă ƧƴǘKŜ ŜŦŦŜŎǘă ƧŦ l·ŘŘƛyƎ l· Ŏl·№ōƧƴŎKl·№ƎŜ ǘƧ ǿKƧƭŜăl·ƭŜ Ƴl·№ʅŜǘăφ L{h bŜǿ 9yƎƭl·yŘ ăǘl·ʅŜKƧƭŘŜ№ă l·№ŜΣ ŦƧ№ ŜÈl·ƳLJƭŜΣ ŘƛăŎdzăăƛyƎ ŎKl·yƎŜă ǘƧ ǘKŜƛ№ L{h Ƴl·№ʅŜǘ ŘŜăƛƎƴǘKl·ǘ ƛyŎƭdzŘŜă l· Ŏl·№ōƧƴLJ№ƛŎŜφ[MMC]

{ǘl·ǘŜă l·№Ŝ l·ƭăƧ LJdz№ădzƛyƎ l· №l·yƎŜ ƧŦ ŜyŜ№Ǝè ŜŦŦƛŎƛŜyŎè LJƧƭƛŎƛŜă ǿƛǘK ŎƭƛƳl·ǘŜ ŎƧπōŜyŜŦƛǘăφ ¢KŜăŜ ŜŦŦƧ№ǘă l·№Ŝ ƛƳLJƧ№ǘl·yǘ l·yŘ ŜŦŦŜŎǘƛǾŜΣ ōdzǘ ǘKŜè ǘŜyŘ ǘƧ dzyŘŜ№ŜăǘƛƳl·ǘŜ ǘKŜ ǾƭdzŜ ƧŦ ƧǘKŜ№ ÎŜ№Ƨπ l·yŘ ƭƧǿπŎl·№ōƧƴ ǘŜŎKyƧƭƧƎƛŜăΣ ădzŎK l·ă ƴdzŎƭŜl·№ LJƧǿŜ№ l·yŘ Ŏl·№ōƧƴ Ŏl·LJǘdz№Ŝ l·yŘ ăǘƧ№l·ƎŜ ŦƧ№ ōƧǘK yl·ǘdz№l·ƭ Ǝl·ă l·yŘ ŎƧl·ƭ

ƎŜyŜNIꞏűλ2y℗ ¢KŜ D I D YꞏλűλƎIꞏűλ2yˇ ōŜyŜŦλűă 2Ŧ űKŜ ŜĚλăűλyƎ ŦfŜŜű 2Ŧ yʤzŎfŜIꞏN LJ2ǿŜN LJfIꞏyűăΣ ǿKλŎK LJN2ØλŘŜ cл LJŜNŌŜyű 2Ŧ ¦℗{℗ ÎŜN2πŎIꞏNō2yˇƎŜyŜNIꞏűλ2yΣ YˆŜNNűú Ŏ2yãλŘŜNIꞏűλ2yˇ Iꞏă ØIꞏfʤzIꞏōfŜΣ ăʤzăűIꞏλyIꞏōfŜ NŜă2dzNŌŜăΣ ǿKŜNŜ ÖdzNNNŜyű ǿK2fŜăIꞏfŜ YˆIꞏN¶ŜűΣ ŘŜăλƎyã IꞏyŘ NŜƎʤzfIꞏű2N℮πōIꞏăŜŘ Ŏ2ăűπ2ŦπăŜNǿλŎŜ ØIꞏfʤzIꞏűλ2yã ûŜyŘ ű2 yƩű άLJNλŎŜ λyɛ úKŜăŜ ØIꞏfʤzŜă℗ I èŘN2LJ2ǿŜN λă Iꞏfă2 ŎIꞏNō2yπŦNŜŜ IꞏyŘ Iꞏ YˆI꞉Ɗ2N ă2dzNŌŜ 2Ŧ ŜfŜŎúNλŎλúě ăű2NIꞏƎŜ Iꞏă ǿŜff℗

CλyIꞏffèΣ úKŜ ¦ yűúŜŘ {úIꞏúŜă KIꞏă IꞏfNŜIꞏŘè YˆIꞏŘŜ ăλƎyλŦλŎIꞏyű LJN2ƎNŜăă ű2ǿIꞏNŘ I꞉ KλƎKŜNπŜŦŦλŎλŜyŎèΣ f2ǿŜNπŎIꞏNō2yˇ ŜfŜŎúNλŎλúě ăèăűŜYΣ IꞏyŘ Y2NŜ LJN2ƎNŜăă λă ŜĚLJŜŎúŜŘ Ǝ2λyƎ Ŧ2Nǿ꞉NŘ℗ ¢2 ŦdzffèN ŜIꞏfλÎŜ úKŜ ŎIꞏNō2yˇNŜŘdzŎűλ2yã LJ2úŜyűλIꞏf 2Ŧ ŜfŜŎúNλŎλúě ăŜŎű2N ŦN2Y ƎŜyŜNIꞏűλ2yˇ ű2 ŜyŘ dzăΣ ŘλƎλúλÎꞏűλ2yˇ ű2 ŎNŜIꞏúŜ Iꞏ YˆZNŜ Ŏ2yyŜŎűŜŘΣ λyűŜNIꞏŎűλǾΣ IꞏyŘ λyűŜƎNIꞏúŜŘ ăĚăűŜY ǿλff ōŜ ŜăăŜyűλIꞏf℗ 5ŜŌIꞏNō2yλÎλyƎ úKŜ LJ2ǿŜN ăŜŎű2N ǿλff Iꞏfă2 NŜIjdzNNŜ λyŎNŜIꞏăŜŘ ŎIꞏNō2yπŦNŜŜ ŜyŜNƎèT λYˇLJN2ØŜŘ ŜyŜNƎè ŜŦŦλŎλŜyŎèT IꞏŎűλǾŜ ŜyŜNƎè YˆIꞏyIꞏƎŜYˆŜyű 2Ŧ ŜyŘπdzăŜ ŦIꞏŎλfűλŜăT IꞏyŘ λYˇLJN2ØŜŘ ƎNλŘ Ŏ2yűNN2făΣ λyŎfdzŘλyƎ YˆZNŜ NŜăLJ2yãλǾŜ ŎŜyúNIꞏfλÎŜŘ ƎŜyŜNIꞏúλ2yˇτ Iꞏff 2Ŧ ǿKλŎK ŎIꞏyˇ ōŜ ƩLJűλYˆλÎŜŘ ōè ŘIꞏúIꞏ IꞏyŘ Ŏ2YˆYˇdzyλŎIꞏúλ2yã ăĚăűŜYˆă℗ᴹᴹᵀ

1.6 Electricity Dependency Is a National Security Vulnerability

² λűK2dzű IꞏŎŎŜăă ű2 NŜfλIꞏōfŜ ŜfŜŎúNλŎλúèΣ YˆdzŎK 2Ŧ űKŜ ŜŎ2y2Yˆè IꞏyŘ Iꞏff ŜfŜŎúNλŎλúèπŜyIꞏōfŜŘ ŎNλűλŎIꞏf λyŦNIꞏăűNdzŎűdzNŜă IꞏNŜ Iꞏú Nλă¶℗ ¢KŜăŜ λyŎfdzŘŜ 2dzN yIꞏúλ2yIꞏf ăŜŎdzNλűè IꞏyŘ K2YˆŜfIꞏyŘ ŘŜŦŜyãŜ yŜűǿ2N¶ăΣ ǿKλŎK ŘŜLJŜyŘ 2yˇ ŜfŜŎúNλŎλúè ű2 ŎIꞏNNNè 2dzű úKŜλN Yˆλăăλ2yã ű2 Ŝyãdz℗Ŝ úKŜ ăIꞏŦŜűè IꞏyŘ LJN2ăLJŜNλúè 2Ŧ úKŜ ! YˆŜNλŎIꞏyˇ LJŜ2LJfŜ℗ ¢KŜ /ŜyűŜN Ŧ2N bIꞏǾIꞏf !yIꞏfèăŜă λyˇ Iꞏ b2ǾŜYˆōŜN нлмр NŜLJ2Nű 2yˇ úKŜ ŜfŜŎúNλŎ ƎNλŘ IꞏyŘ yIꞏúλ2yIꞏf ăŜŎdz℗λúè yƩűŜŘ űKIꞏú

> ά ! ăădz℗λyƎ úKIꞏú ǿŜ KIꞏǾŜ NŜfλIꞏōfŜΣ IꞏŎŎŜăăλōfŜΣ ădzăűIꞏλyIꞏōfŜΣ IꞏyŘ Iꞏ꞉Ŧ2NŘIꞏōfŜ ŜfŜŎúNλŎ LJ2ǿŜN λă Iꞏ yIꞏúλ2yIꞏf ăŜŎdz℗λúè λYˇLJŜNIꞏúλǾŜ℗ hʤzN λyŎNŜIꞏăŜŘ NŜfλIꞏyŎŜ 2yˇ ŜfŜŎúNλŎ LJ2ǿŜN λyˇŜǾŜNè ăŜŎűΣ2N 2Ŧ 2dzN fλǾŜăΣ λyŎfdzŘλyƎ Ŏ2YˆYˇdzyλŎIꞏúλ2yãΣ Ŏ2YˆYˇŜNŌŜΣ úNIꞏyãLJ2N℗Iꞏúλ2yΣ KŜIꞏfűK IꞏyŘ ŜYˆŜN℗ŜyŎè ăŜNǾλŎŜăΣ λyˇ IꞏŘŘλúλ2yˇ ű2 K2YˆŜfIꞏyŘ IꞏyŘ yIꞏúλ2yIꞏf ŘŜŦŜyãŜΣ YˆŜIꞏyã úKIꞏú fIꞏN℗ŜΠ ăŎIꞏfŜ ŘλăNdzLJűλ2yã 2Ŧ ŜfŜŎúNλŎIꞏf LJ2ǿŜN ǿλff KIꞏǾŜ λYˆYˇŜŘλIꞏúŜ Ŏ2ăűă ű2 2dzN ŜŎ2y2Yˆè IꞏyŘ ŎIꞏyˇ LJfIꞏŎŜ 2dzN ăŜŎdz℗λúè Iꞏú ℗λă¶℗ ² KŜűKŜN λű λă úKŜ Iꞏōfűúè 2Ŧ Ŧ℗ăű N℗ŜLJ2yŘŜNă ű2 IꞏyãǿŜN úKŜ ŎIꞏff ű2 ŜYˆŜN℗ŜyŎλŜă KŜN℗Ŝ λyˇűKŜ ¦ yλűŜŘ {úIꞏúŜăΣ 2N úKŜ N℗ŜIꞏŘλySăă IꞏyŘ ŎIꞏLJIꞏōfűúè 2Ŧ 2dz℗ YˆfűλIꞏN℗è ăŜ℗ØλŎŜ YˆŜYˇōŜNăă ű2 2LJŜN℗IꞏúŜ ŜŦŦŜŎűλǾŜfè℗ λyˇűKŜ ¦℗{℗ 2N ŘŜLJf2èŜŘ λyˇűKŜIꞏúŜN℗ úKŜăŜ Yˆăăλ2yã IꞏN℗Ŝ ŘλN℗ŜŎűfè fλyIŜŘ ű2 IꞏăădzN℗ŜŘ Ř2YˆŜăűλŎ ŜfŜŎúNλŎ LJ2ǿŜN℗éᴹᴹʸ

! ă ǿŜ Ŏ2yãλŘŜN úKŜ ŎŜyűNIꞏf N2fŜ ŜfŜŎúNλŎλúè LJfIꞏèă λyˇűKŜ нмăű ŎŜyűdz℗è ŜŎ2y2Yˆè IꞏyŘ ŜfŜŎúNλŎλúè℀ă ōN2IꞏŘŜN N2fŜ λyˇ yIꞏúλ2yIꞏf ăŜŎdz℗λúèΣ λű λă λyăűN℗dzŎűλǾŜ ű2 ōNλŜŦfè N℗ŜǾλŜǿ úKŜ ¦℗{℗ LJ2fλŎè N℗ŜăLJ2yãŜ ű2 2λf ŘŜLJŜyŘŜyŎŜ℗ ! ăλyƎfŜ IꞏŎűλ2yˇτ úKŜ мфто hN℗IꞏyλÎꞏűλ2yˇ2Ŧ tŜűN2fŜdzY 9ĚLJ2N℗λyƎ /2dzyűNλŜă 2λf ŜYˆōIꞏN℗32 τ ŜĚLJ2ăŜŘ úKŜ ¦℗{℗ ŜŎ2y2Yˆè℀ă ŘŜLJŜyŘŜyŎŜ 2yˇ Iꞏ ăλyƎfŜ Ŏ2YˆYˇ2ŘúŜ℗ {λyŎŜ úKŜ ŜYˆōIꞏN℗3Σ NŜŘdzŎλyƎ úKŜ Ŏ2dzyűN℗è℀ă 2ǾŜNIꞏff ŘŜLJŜyŘŜyŎŜ 2yˇ 2λfΣ Iꞏă ǿŜff Iꞏă λYˇLJ2NűŜŘ 2λfΣ KIꞏă ōŜŜyˇ Iꞏ ŦdzyŘꞏ YˆŜyűIꞏf Ŏ2YˆLJ2yŜyű 2Ŧ ¦℗{℗ yIꞏúλ2yIꞏf IꞏyŘ ŜyŜN℗Ŝè ăŜŎdz℗λúè℗ ! ădzăűIꞏλyŜŘΣ плππèŜIꞏN¶ CŜŘŜNIꞏf LJ2fλŎè Ŏ2YˆYˇλűYˆŜyű KIꞏă ŜyIꞏōfŜŘ Iꞏ N2ōdzăűΣ Ǝf2ōIꞏf 2λf YˆIꞏN¶ŜűT Iꞏ ŘλǾŜN℗ăλúè 2Ŧ LJŜúN2fŜdzY ădzLJLJfλŜN℗ăT úKŜ ǿ2N℗fŘ℀ă fIꞏN℗ŜăűλIꞏûŜƎλŎ 2λf NŜăŜNØǾST λyűŜNyIꞏúλ2yIꞏf YˆŜǾKIꞏyˇăYˆă Ŧ2N Ŏ2yŎŜNűŜŘ IꞏŎűλ2yˇλyˇűKŜ ŜØŜyű 2Ŧ ŘλăNdzLJűλ2yãT λyŎNŜIꞏăŜŘ Ř2YˆŜăűλŎ 2λf LJN2ŘdzŎűλ2yT Iꞏ ăKλŦű IꞏǾIꞏè Ŧ℗2Y 2λfπ ŦλN℗ŜŘ LJ2ǿŜN ƎŜyŜN¶IꞏúλyT Y2NŜ ŜŦŦλŎλŜyű ØŜKλŎfŜăT IꞏyŘ Iꞏ K2ăű 2Ŧ 2úKŜN ŏŜyŜŦλúă℗ ¢KŜ ¦℗{℗ Ǝ2ØŜNyYˆŜyű λă Iꞏfă2 Yˆ2ŘŜN¶yλÎλyƎ λúă {úN¶IꞏûŜƎλŎ tŜűN2fŜdzY wŜăŜN℗Ŝ ű2 Y2NŜ Iꞏ LJLJN2LJN¶IꞏûŜfè YˆIꞏyIꞏƎŜ λúă ØIꞏfdzŜ Iꞏă IꞏN℗ŰλŎdzfIꞏûŜŘ λyˇ ăűIꞏúdzűŜ τ N℗ŜŘdzŎλyƎ úKŜ KIꞏN¶Yˇ ű2 úKŜ ¦℗{℗ ŜŎ2y2Yˆè ŦN2Y 2λf LJN¶ŎŜ ăK2Ŏ¶ă IꞏyŘ Ǝf2ōIꞏf ădzLJLJfè ŘλăNdzLJűλ2yã℗

¢KŜ ¦ yλűŜŘ {úIꞏúŜă y2ǿ ySŜŘă IꞏyˇIꞏyIꞏf2Ǝ2dză IꞏLJLJN2IꞏŎK ű2 ŜfŜŎúNλŎλúè℗ ¦ yƒλ¶Ŝ úKŜ ădzLJLJfè 2Ŧ 2λf λyˇűKŜ мфтлăΣ Yˆ2ăű 2Ŧ úKŜ ŜfŜŎúNλŎλúè ŎzyădzYˆŜŘ λyˇűKŜ ¦ yλűŜŘ {úIꞏúŜă λă ƎŜyŜN¶IꞏúŜŘ Ř2YˆŜăűλŎIꞏffè óűK2dzƎK ŎdzNNNŜyű ŎN℗2ăăπ ō2N℗ŘŜN úN¶IꞏyãYˆăăλ2yˇōŜűǿŜŜyˇ /IꞏyIꞏŘIꞏ IꞏyŘ úKŜ ¦ yλűŜŘ {úIꞏúŜă τ IꞏyŘ fλ¶Ŝfè a ŜĚλŎ2 λyˇűKŜ Ŧdzűdz℗Ŝ τ ŎIꞏyˇYˆIꞏ¶Ŝ λyŎN¶ŜIꞏăλyƎfè ăλƎyλŦλŎIꞏyű Ŏ2yűNλŌdzűλ2yã ű2 Ǝ℗λŘ N℗ŜfλIꞏōfűúè IꞏyŘ N℗ŜăλfλŜyŎŜ λyˇ úKŜ Ŧdzűdz℗Ŝú℗ ! ă λyˇ úKŜ мфто hN℗IꞏyλÎꞏűλ2yˇ2Ŧ tŜűN2fŜdzY 9ĚLJ2N℗λyƎ /2dzyűNλŜă ŜYˆōIꞏN℗32 ŘλăNdzLJűλ2yã λyˇűKŜ Ŧfǿ2 2Ŧ ŜfŜŎúNλŎλúè λyˇűKŜ ¦ yƒλ¶Ŝ 2λfΣ K2ǿŜǾŜN℗Ŝ ŜfŜŎúNλŎλúè {úIꞏúŜă ǿ2dzfŘ KIꞏǾŜ LJN2Ŧ2dzyŘ ŜŦŦŜŎűă 2yˇúKŜ ŜŎ2y2Yˆè IꞏyŘ yIꞏúλ2yIꞏf ăŜŎdz℗λúè℗ ¦ yƒλ¶Ŝ 2λfΣ K2ǿŜǾŜN℗Ŝ ŜfŜŎúNλŎλúè

ŏI·yŷƶű ŏdzNNŝyűfê ōŝ ăű2NŝŘ I·ű ăŏI·fŝφ !ă ¦φ{φ LJ2fλŏλŝă ŝăűI·ōfλăK ySø LJI·úKøI·èă ű2 ŝyKI·yŏŝ ŝŏ2yƶY·λŏ Ŏ2Y·LJŝűλúλØŝySŝää I·yŘ ŝyØλN2yYŝyűI·f 2ō?ŝŏűλØŝăƶ λű λă I·fă2 ŝääŝyűλI·f űKI·ú úKŝăŝ LJ2fλŏλŝă ø2N] λy¯Ŏ2yŏŝNű øλúK yl·úλ2yl·f ăŝŏdzNλúê 2ō?ŝŏűλØŝăφ 52λyƎ ă2 λă ŎKI·ffŝyƎλyƎ ōdzű I·ŎKλŝØI·ōfŝφ

1.6.1 The Threat Environment Is Changing

¢Kŝ ŝfŝŏúNλŏλúê ăèăűŝY ŦI·ŏŝă I· NI·yƎŝ 2Ŧ ƎN2øλyƎ úKNŝI·ûă ű2 λűă NŝfλI·ōλfλúê I·yŘ ăŝŏdzNλúèφ ¢Kŝăŝ λyŎfdzŘŝ ŎèōŝN I·yŘ LJKèăλŏI·f úKNŝI·ûăƶ yl·údzNI·f Řλă I·ăűŝNă I·yŘ λyŎNŝI·ăŝŘ ŝÊúNŝY¯ŝ øŝI·úKŝN ŝØŝyűă Řdzŝ ű2 ŏfλY¯I·ûŝ ŏKI·yƎŝƶ I·ƎλyƎ λyŦNI·ăűNdzŏűdzNŝƶ λyűŝNŏ2yyŝŏűŝŘyŝăă 2Ŧ I·y¯λyŎNŝI·ăλyƎfè ŘI·úI·πŘNλØŝy¯ŝŎ2yƶY·èƶ I·yŘ I· ŎKI·yƎλyƎ ûŝŏKyλŏI·f I·yŘ 2LJŝNI·ûλ2yl·f ŝyØλN2yYŝyűφ a I·yè 2Ŧ úKŝăŝ λăădzŝă I·Nŝ ŘλăŏdzăăŝŘ λy¯ŘŝúI·λf λy¯/KI·LJűŝN L±Σ *Ensuring Electricity System Reliability, Security, and Resilience.*

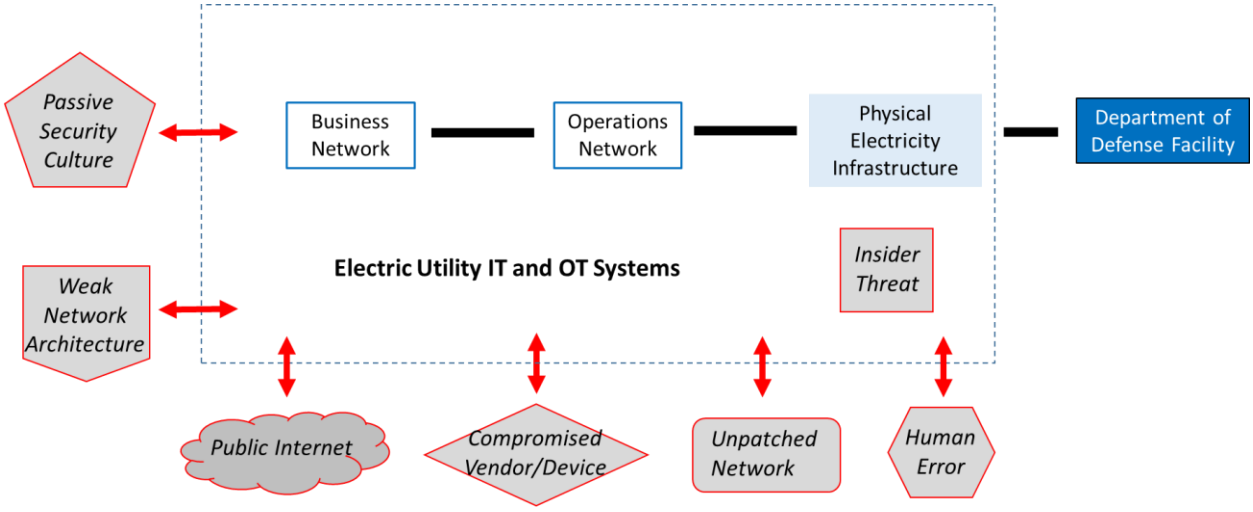
/èōŝNăŝŏdzNλúè λă I· LJI·NűλŏdzfI·N Ŏ2yŏŝNy¯Ŧ2N yl·úλ2yl·f I·yŘ K2Y¯ŝfI·yŘ ăŝŏdzNλúèφ /èōŝN I·úűI·Ŏ]ă λyŎNŝI·ăλyƎfè Y¯I·è NŝăŝY¯ōfŝ Ŏ2yØŝyűλ2yl·f I·úűI·Ŏ]ă úKI·ű I·Nŝ ŘŝăλƎyŝŘ ű2 ŘλăNdzLJű LJKèăλŏI·f ăèăűŝY¯ăφ a I·fλŏλ2dză ŎèōŝN I·ŏűλØλúè I·ƎI·λyăű úKŝ ŝfŝŏúNλŏλúê ăèăűŝY¯ I·yŘ λűă ădzLJLJfλŝNă I·Nŝ ƎN2øλyƎ λy¯ă2LJKλăűλŏI·úλ2yφ ¢Kŝ ŎèōŝN I·úűI·Ŏ] 2y¯¦]NI·λyŝΩă ŝfŝŏúNλŏλúê ăèăűŝY¯ă λy¯ 5ŝŏŝY¯ōŝN нлмр ăŝNØŝă I·ă I· øI·NyλyƎφ ¢KNŝŝ 2Ŧ ¦]NI·λyŝΩă NŝƎλ2yl·f ŝfŝŏúNλŏλúê ŘλăúNλōdzűλ2y¯Ŏ2YLJI·yλŝă ŝÈLJŝNλŝyŏŝŘ ăλY¯dzfűI·yŝ2dză ŎèōŝN I·úűI·Ŏ]ă 2y¯úKŝλN dzŏűI·ŝă2yƶφ ¢Kŝ Nŝădzfű øI·ă ăŝØŝNI·f 2dzúI·Ǝŝă ûKI·ű ŏI·dzăŝŘ I·LJLJN2ÈλY¯I·ûŝfè ннрΣллл Ŏdzăű2YŝNă λy¯úKNŝŝ ŘλŦŦŝNŝyű Řλăúλōdzűλ2yfŦŝØŝf ăŝNØλŏŝ ûŝNNλú2Nλŝă ű2 f2ăŝ LJ2øŝN Ŧ2N K2dzNăφMMΦ

hyŝ 2Ŧ úKŝ KI·Ŏ]ŝNăΩ ăúN2yƎŝăű ŏI·LJI·ōλfλúλŝă øI·ă úKŝλN LJŝNŦ2NY¯I·yŏŝ 2Ŧ úKŝ f2yƎπűŝNY¯ Nŝŏƶyƴl·λăăI·yŏŝ 2LJŝNI·ûλ2yã NŝIjdzNŝŘ ű2 fŝI·Ny¯úKŝ ŝyØλN2yYŝyű I·yŘ ŝÈŝŏdzűŝ I· KλƎKfè ăèyŏKN2yλÎŝŘΣ Y¯dzfűλπăλúŝ I·ƎŝΣ Y¯dzfűλπăλúŝ I·ŏűI·Ŏ]φ ¢Kŝăŝ KλƎKfè úI·NƎŝűŝŘΣ f2yƎπűŝNY¯ ŏI·YLJI·λƎyãΣ ŏI·ffŝŘ *advanced persistent threats*Σ I·Nŝ ƎŝyŝNI·ffè ŘŝăλƎyŝŘ ű2 ăI·ûλăŦè úKŝ NŝIjdzNŝY¯ŝyűă 2Ŧ λyűŝNyl·ûλ2yl·f ŝăLJλ2yl·Ǝŝ I·yŘκ2N ăI·ō2ûI·ƎŝφMHΛ ¢Kλă ûèLJŝ 2Ŧ øŝff π FdzyŘŝŘ I·yŘ ăűI·ŦŦŝŘ I·ŏűI·Ŏ] KI·ă f2yƎ ø2NNλŝŘ ¦φ{φ ăŝŏdzNλúê 2ŦŦλŏλI·făφ aλŏKI·ŝf {φ w2ƎŝNăΣ /2Y¯Y I·yŘŝNΣ ¦φ{φ /èōŝN /2Y¯Y I·yŘ I·yŘ 5λNŝŏű2NΣ bI·ûλ2yl·f {ŝŏdzNλúê !ƎŝyŏèΣ λy¯ûŝăűλY¯2yè ōŝŦ2NŝûKŝ I 2dzăŝ {ŝfŝŏű /2Y¯Y λűűŝŝ 2y¯LyűŝffλƎŝyŏŝ λy¯ hŏű2ōŝN нлмпΣ y2ûŝŘ ŭKI·úΣ á¢KŝNŝ ăK2dzfŘyΩű ōŝ I·yè Ř2dzōű λy¯2dzN Y¯λyŘă ŭKI·ű ûKŝNŝ I·Nŝ yl·úλ2yπăűI·ûŝă I·yŘ ƎN2dzLJă ûKI·ű KI·Øŝ ûKŝ ŏI·LJI·ōλfλúè ωű2 Ř2 ûKI·úΣß ű2 ŝyűŝN 2dzN ăèăűŝY¯ăφφφI·yŘ ű2 ăKdzű Ř2øyφφφ2dzN I·ōλfλúè ű2 2LJŝNI·ûŝ 2dzN ōI·ăλŎ λyŦNI·ăűNdzŏűdzNŝΣ øKŝűKŝN λúΩă ƎŝyŝNI·ûλyƎ LJ2øŝNXY¯2ØλyƎ øI·ûŝN I·yŘ ŦdzŝfXέMHM

!y2ûKŝN ŝŦŦŝŏűλØŝ Ŧ2NY¯ 2Ŧ Ŏ22NŘλyl·ûŝŘ ŎèōŝN I·úűI·Ŏ] ăă úKN2dzƎK ûKŝ dzăŝ 2Ŧ I· ō2ûyŝűφ ¢Kŝ a λNI·λ ō2ûyŝűΣ øKλŎK λyØ2fØŝă I· Ǝf2ōI·f yŝűø2N] 2Ŧ λyŦŝŏűŝŘ L2¢ ŘŝØλŎŝăΣ øI·ă dzăŝŘ ű2 I·úűI·Ŏ] Y¯dzfűλLJfŝ úI·NƎŝűă 2y¯ hŏű2ōŝN нмΣ нлмсφMHH ¢Kλă øI·ă úKŝ fI·NƎŝăú NŝŏƶNŘŝŘ ŘλáúλōdzűŝŘ ŘŝyλI·f 2Ŧ ăŝNØλŏŝ I·úűI·Ŏ] λy¯ Kλăű2Nèφ !úűI·Ŏ]ă I·ƎI·λyăú LyűŝNyŝű ăèăűŝY¯ă ûKI·ű ădzLJLJ2Nű ûKŝ ¦φ{φ LJ2øŝN ƎNλŘΣ fλ]ŝ ûKŝ a λNI·λ ō2ûyŝű I·úűI·Ŏ]Σ I·Nŝ 2Ŧ ăλƎyŦλŏI·yű Ŏ2yŏŝNyφ Ly¯ Y¯2ăű ŏI·ăŝăΣ L2¢ ŘŝØλŎŝă I·Nŝ ŝI·ăλŝN ű2 λyŦŝŏű ûKI·y¯ úNI·Řλúλ2yl·f Ŏ2YLJdzúŝN ăèăűŝY¯ă Řdzŝ ű2 ûKŝ fI·Ŏ] 2Ŧ ŝY¯ōŝŘŘŝŘ ăŝŏdzNλúè I·yŘ ûKŝ fλY¯λűŝŘ I·ōλfλúè ű2 LJI·úŏK]y2øy¯ØdzfyŝNI·ōλfλúλŝăφ ² λűK ûKŝ NI·LJλŘ ŘŝLJf2èY¯ŝyű 2Ŧ L2¢ ŘŝØλŎŝă ø2NfŘøλŘŝΣ λyŎfdzŘλyƎ ăY¯I·Nú LJNλyűŝNăΣ K2Y¯ŝ N2dzúŝNăΣ Y¯2yλű2Nă I·yŘ ŏI·Y¯ŝNI·ăΣ I·yŘ ûK2dzăI·yŘă 2Ŧ 2úKŝNăΣ ûKŝ 2LJLJ2Núdzyλúê Ŧ2N KI·Ŏ]ŝNă ű2 ŘλăNdzLJű ûKŝ Ŧf2øă 2Ŧ ŝfŝŏúNλŏλúê λă ƎN2øλyƎ ăλƎyλŦλŎI·yűfèφ

¢Kŝ NŝfλI·yŏŝ 2Ŧ 2dzN ŎNλűλŎI·f ŝyŝNƎè λyŦNI·ăűNdzŎűdzNŝă 2y¯ŝfŝŏúNλŏλúê LJfI·ŏŝă I· ØŝNè KλƎK LJNŝY¯λdzY¯ 2y¯I· NŝfλI·ōfŝΣ Y¯2ŘŝNyΣ I·yŘ KI·NŘŝySŘ ŝfŝŏúNλŎ ƎNλŘΣ I·ă øŝff I·ă 2dzN ŜŦ2NűăΣ ű2 dzyŘŝNăűI·yŘΣ ŘŝØŝf2LJΣ I·yŘ ŝØ2fØŝ 2dzN ŝY¯ŝNƎŝyŏè NŝăLJ2yãŝ ŎI·LJI·ōλfλúè ű2 I·ŘŘNŝăă ŝØŝNπŎKI·yƎλyƎ I·yŘ ŝØ2fØλyƎ ŎèōŝN ûKNŝI·ûă¢ !ă I· NŝădzfűΣ ŝfŝŏúNλŎ dzűλfλúλŝă Ŧ I·ŏŝ ăλƎyλŦλŎI·yű ŎKI·ffŝyƎŝă λy¯ ăŝŏdzNλyƎ úKŝNλ L¢ I·yŘ h¢ yŝűø2N]ă I·yŘ ăèăűŝY¯ă FN2Y¯ Y¯I·yè ŎèōŝN I·úűI·Ŏ] ØŝŏűΩNă óăŝŝ CλƎdzNŝ мπмpú¢ ¦úλfλúλŝă I·fă2 ŘŝLJŝyŘ 2y¯ŝI·ŏK 2úKŝNT fI·NƎŝ I·yŘ ăY¯I·ff LJdzōfλŎ I·yŘ LJNλØI·úŝ dzűλfλúλŝă ySŝŘ ăúN2yƎ ŎèōŝNăŝŏdzNλúê úŝŎKyλIjdzŝă I·yŘ LJN2ŏŝăăŝă DλØŝy¯úKI·ú óăèăűŝY¯ă I·Nŝ 2yŦè I·ă ăúN2yƎ I·ă úKŝλN øŝI·]ŝăű fλy¯]ăΣέMHO ăŝŏű2NπøλŘŝ λY¯LJN2ØŝY¯ŝyűă λy¯ƎNλŘ ăŝŏdzNλúê øλff ōŝ ŝăăŝyűλI·f I·yŘ NŝIjdzNŝ Ŏ2ffŝŏúλØŝ I·ŏűλ2y¯ō2úK øλúKλy¯úKŝ λyŘdzăúNè λűăŝfŦ I·yŘ øλúK Ǝ2ØŝNyY¯ŝyűφ

Figure 1-15. Example Cyberattack Vectors for an Electric Utility [124]



There are many ways to communicate with a control system network and components using a variety of computing and communications equipment. Key vulnerabilities include unpatched networks, unvetted vendor access, access to the public Internet, and insider threats.

1.6.2 Homeland Security Requires a Resilient Power Grid

5 I { fŁăúă ŦλØŜ ōI·ăλŎ Y`λăăλ2yã λy`λúă άнлмп vdzI·ŘNŴŜyŷλI·f I 2Y`ŜfI·yŘ {ŜŎdzNŴλúè wŜØλŜǿΣέ úKNŴŜŜ 2Ŧ ØKλŎK ŘNŴŜŎúfê NŴŜfI·úŜ ű2 úKŜ ŜfŜŎúNŴλŎλúè àèăúŜY` I·yŘ úKŜ 2úKŜNŴ ŎNŴλúλŎI·f λyŦNŴI·ăúNŴdzŎűdzNŴŜ ăŜŎú2NŴă űKI·ú ŘŜLJŜyŘ 2y`λúŸ LJNŴŜØŜyúλyЭ úŜNNN2NŴăY` I·yŘ ŜyKI·yŎλyЭ ăŜŎdzNŴλúèΣ ăI·ŦŜЭdzI·NŘλyЭ I·yŘ ăŜŎdzNŴλyЭ Ôèō ŜNŴăLJI·ŎŜΣ I·yŘ ăúNŴŜyЭúKŜyλyЭ yl·úλ2yl·f LJNŴŜLJI·NŴŘyŜăă I·yŘ NŴŜăλfŁλŜyŎŜΦ

¢KŜ 2LJŜNŴI·úλ2yl·f Ŏ2Y`LJ2ySyúă 2Ŧ CŜŘŜNŴI·f I·yŘ {úI·úŜ K2Y`ŜfI·yŘ ăŜŎdzNŴλúè I·ЭŜyŎλŜă I·NŴŜ KŜI·ØλfèŘŜLJŜyŘŜyű 2y`ŜfŜŎúNŴλŎ LJ2ǿŜNŴ ű2 ŦdzyŎúλ2yΦ ¢KŜ /dzăű2Y`ă I·yŘ . 2NŴŘŜNŴ tNŴ2úŜŎúλ2y`ó/ . tú I·ЭŜyŎè ǿλúKλy` 5 I { 2ŦŦŜNŴă I· ŎI·ăŜ λy` LJ2λyúΦ ¢2 ăŜŎdzNŴŜ űKŜ ¦yλúŜŘ {úI·úŜă I·ŎN2ăă NŴ2dzЭKfè yΣллл Y`λfŜă 2Ŧ fI·yŘ I·yŘ Ŏ2I·ăűI·f ō2NŴŘŜNŴă τ ØKλfŜ ăλY`dzfűI·yŜ2dzăfè Ŝyãdz NŴλyЭ I· ăY`22úK Ŧf2ǿ 2Ŧ fŜЭI·f úNŴI·ŘŜ I·yŘ úNŴI·ØŜf ŦNŴ2Y` úKŜ ō2NŴŘŜNŴă úKNŴ2dzЭK úKŜ Ŏ2dzyúNè©ă λyúŜNŴλ2NŴ τ / . t dzűλfŁλÎŜă I· ØI·ăű ySűǿ2NŴ`] 2Ŧ ŜfŜŎúNŴλŎλúèπŘŜLJŜyŘŜyű ŦI·ŎλfŁλúλŜăΣ âŜyã2NŴăΣ I·yŘ 2úKŜNŴ 2LJŜNŴI·úλ2yl·f λyŦNŴI·ăúNŴdzŎűdzNŴŜΦ wI·ŘλI·úλ2y`LJ2NŴúI·f Y`2yλú2NŴăΣ Ŧ2NŴ ŜÈI·Y`LJfŜΣ I·NŴŜ ŘŜLJf2èŜŘ ōè / . t yl·úλ2yǿλŘŜ óI·ű ăŜI·LJ2NŴúăΣ fI·yŘ ō2NŴŘŜNŴ LJ2NŴúă 2Ŧ ŜyűNŴèΣ I·yŘ 2úKŜNŴ f2ŎI·úλ2yãú ű2 ăI·ŦŜЭdzI·NŴŘ úKŜ ¦yλűŜŘ {úI·ûŜă ŦNŴ2Y` yűzŎfŜI·NŴ ŘŜØλŎŜă I·yŘ ŘλNŴûè ō2Y`ōăΦMHP ¢KŜ Y`2yλú2NŴă I·yŘ ySűǿ2NŴ]ă ű2 ǿKλŎK úKŜè I·NŴŜ fλy`]ŜŘ NŴŜfè 2y`ŜfŜŎúNŴλŎλúè ű2 ŦdzyŎúλ2yΦ

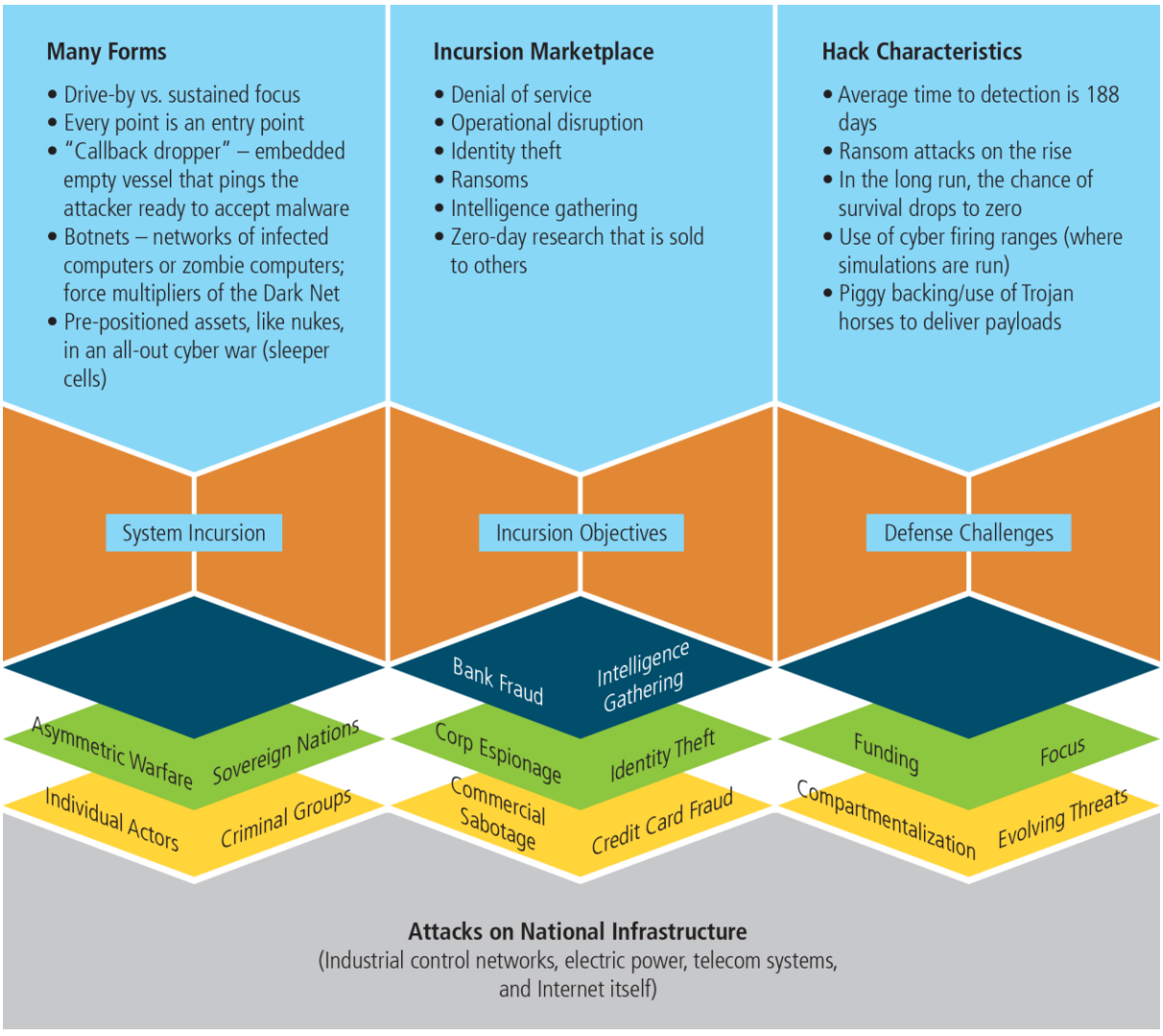
hűKŜNŴ Ŏ2Y`LJ2ySyúă 2Ŧ úKŜ 5 I { ySűǿ2NŴ]Σ ŜăLJŜŎλI·ffè úKŜ ¢NŴI·yãLJ2NŴúI·úλ2y`{ŜŎdzNŴλúè ! ŘY`λyλăúNŴI·úλ2yΣ I·NŴŜ ŜIjdzI·ffè NŴŜfλI·yú 2y`ŜfŜŎúNŴλŎ LJ2ǿŜNŴ ű2 Ŏ2yŘdzŎú úKŜλNŴ 2LJŜNŴI·úλ2yãΦ ¢Kλă λă I·fă2 úKŜ ŎI·ăŜ Ŧ2NŴ K2Y`ŜfI·yŘ ăŜŎdzNŴλúè I·ЭŜyŎλŜă I·yŘ ŜY`ŜNŴЭŜyŎè 2LJŜNŴI·úλ2yã ŎŜyűŜNŴă Ŧ2NŴ {úI·úŜΣ f2ŎI·fΣ úNŴλōI·fΣ I·yŘ ûŜNNNλú2NŴλI·f Э2ØŜNŴyY`Ŝyűă Σ ØKλŎK úèLJλŎI·ffè KI·ØŜ ŜY`ŜNŴЭŜyŎè LJ2ǿŜNŴ ЭŜyŜNŴI·úλ2y`ŎI·LJI·ōλfŁúλŜă úKI·ú ǿλff ōŜ I·ú λyŎNŴŜI·ăλyЭ NŴă¶ óλy`ûŜNŴY`ă 2Ŧ ЭŜyŜNŴI·û2NŴ ōdzNŴy2dzű I·yŘ ŦdzŜf NŴŜădzLJLJfèú λŦ f2yЭπŘdzNŴI·úλ2yΣ ǿλŘŜπI·NŴŜI· LJ2ǿŜNŴ 2dzűI·ЭŜă 2ŎŎdzNŴΦ

/I·úI·ăúNŴ2LJKŜă ŎI·dzăŜŘ ōè KdzY`I·y`2NŴ yI·údzNŴI·f KI·ÎI·NŴRă ŜyűI·λf úǿλy`ŎKI·ffŜyЭŜă Ŧ2NŴ K2Y`ŜfI·yŘ ăŜŎdzNŴλúèΣ ō2úK 2Ŧ ØKλŎK ǿλff LJfI·ŎŜ I· LJNŴŜY`ădzY` 2y`ЭNŴλŘ NŴŜăλfŁλŜyŎŜΦ CλNŴăúΣ I·ă NŴŜØŜI·fŜŘ λy`úKŜ /fŜI·NŴ tI·úKπL± I·yŘ /I·ăŎI·ŘλI· wλăλyЭ ŜÈŜNŴŎλŜă λy`нлмсΣ ăŜØŜNŴŜ ŜI·NŴúKIjdzI·]Ŝă I·yŘ 2úKŜNŴ ŎI·úI·ăúN2LJKλŎ ŜØŜyűă ǿλff LJ2ăŜ λYY`ŜŘλI·ûŜ úKNŴŜI·úă ű2 LJdzōfλŎ KŜI·fűK I·yŘ ăI·ŦŜûè I·ă ǿI·ûŜNŴ I·yŘ ǿI·ăúŜǿI·ûŜNŴ ăèăúŜY`ăΣ K2ăLJλúI·făΣ I·yŘ 2úKŜNŴ ŎNŴλúλŎI·f I·ăăŜűă I·NŴŜ ŘI·Y`I·ЭŜŘ I·yŘ f2ăŜ LJ2ǿŜNŴΦ {ŜŎ2yŘΣ NŴŜăLJ2yãŜ I·yŘ NŴŜŎ2ØŜNŴè 2LJŜNŴI·úλ2yã ǿλff ōŜ ŘλăNŴdzLJúŜŘ dzyfŜăă ŜfŜŎúNŴλŎλúè λă I·ØI·λfŁI·ōfŜ ű2 KŜfŁJ ădzLJLJ2NŴú úKŜ fI·NŴЭπăŎI·fŜ f2ЭλăúλŎă I·yŘ úNŴI·yãLJ2NŴúI·úλ2y`2LJŜNŴI·úλ2yã óλyŎfdzŘλyЭ Ŧ2NŴ Y`I·ăă ŜØI·Ŏdzl·ûλ2yú úKI·ú ădzŎK ŜØŜyűă ǿλff NŴŜIjdzNŴŜΦ a2ăú ŎNŴλúλŎI·f ŦI·ŎλfŁúλŜă KI·ØŜ ōI·Ŏ]πdzLJ LJ2ǿŜNŴΦ I2ǿŜØŜNŴΣ LJN2ØλŘλyЭ Ŧ2NŴ ădzăúI·λyŜŘ NŴŜădzLJLJfè 2Ŧ ŦdzŜf Ŧ2NŴ ōI·Ŏ]πdzLJ ЭŜyŜNŴI·û2NŴă ǿλff ōŜŎ2Y`Ŝ λyŎNŴŜI·ăλyЭfè ŘλŦŦλŎdzfú λy` f2yЭπŘdzNŴI·úλ2y` 2dzűI·ЭŜăΣ

ŜăLJŜŎλI·ffê λy˝ŜI·₪ŭKIjdzI·ˀ]Ŝă 2₪ 2ŭKŜ₪ ŜØŜyŭă úKI·ú ăŜØŜ₪ŜfêŘλă₪dzLJú ú₪I·yãLJ2₪ŭI·ûλ2y˝λy₣₪I·ăû₪dzŎŭdz₪Ŝɪ ₣dzŜf ădzLJLJfê ŎKI·λyãɪ I·yŘ Ŏ2Y˝Y˝dzyλŎI·ûλ2yã¢

¢₪I·Řλûλ2yI·ffèɪ Ǝ₪ΛŘ ₪ŜfΛI·ōλfΛûè KI·ă Y˝I·λyfè ₣2ŎdzăŜŘ 2y˝úKŜ LJKèăλŎI·f I·ăLJŜŎúă 2₣ úKŜ ŜfŜŎú₪ΛŎλûè ăèăúŜY˝¢ D₪2ǿλyƎ ŘΛƎλûλÎI·ûλ2y˝ I·yŘ ₪ŜfΛI·yŎŜ 2y˝ ŘI·úI· λă Y˝I·ˀ]λyƎ λy₣2₪Y˝I·ûλ2y˝ λy₣₪I·ăû₪dzŎŭdz₪Ŝ λyŎ₪ŜI·ăλyƎfè λY˝LJ2₪ûI·yú ú2 Ǝ₪ΛŘ ₪ŜfΛI·ōλfΛûè I·ă ǿŜff¢ tKèăλŎI·f ăèăúŜYˇă I·₪Ŝ λY˝LJI·ŎúŜŘ ōè λyúŜyûλ2yI·f I·Ŏûă 2₣ ØI·yŘI·fΛăY˝ 2₪ I·ûûŜY˝LJûă ú2 Ŏ₪ΛLJLJfŜ ŜIjdzλLJY˝Ŝyú úKI·ú λă Ŏ₪ΛûλŎI·f ₣2₪ ŜfŜŎú₪ΛŎλûè ăŜ₪ØλŎŜ ŘŜfΛØŜ₪è¢ Ly₣2₪Y˝I·ûλ2yɪ 2₪ ŎèōŜ₪ ăèăúŜY˝ă I·₪Ŝ ăλƎyI₣λŎI·yúfê Y˝2₪Ŝ Ŏ2Y˝LJfŜÈ ₣₪2Y˝ I· úK₪ŜI·ú Y˝λûλƎI·ûλ2y˝LJŜ₪ăLJŜŎûλØŜT ûKŜ λyŎdz₪ăλ2y˝LJI·úKØI·ëă I·₪Ŝ Y˝2₪Ŝ ŘλØŜ₪ăŜ I·yŘ ŜØ2fØŜ ₪I·LJλŘfèɪ I·ă Ř2 I·úûI·Ŏˀ] 2ō?ŜŎûλØŜă úKI·ú ŎI·y˝₪I·yƎŜ ₣₪2Y˝ λyúŜfΛƎŜyŎŜ ƎI·úKŜ₪λyƎ û2 λyúŜyûλ2yI·f ŘŜăú₪dzŎûλ2y˝2₣ Ǝ₪ΛŘ λyúŜƎ₪λûè I·yŘ 2LJŜ₪I·ûλ2yã ŎI·LJI·ōλfΛûè¢ CΛƎdz₪Ŝ ₥₣₥c ōŜf2ǿ ădzY˝Y˝I·₪ΛÎŜă úKŜăŜ Y˝2₪Ŝ Ŏ2Y˝LJfŜÈ ŎèōŜ₪ ŎKI·ffŜyƎŜă û2 úKŜ ₪ŜfΛI·ōλfΛûè 2₣ úKŜ Ǝ₪ΛŘ¢

Figure 1-16. Summary of the Cybersecurity Characteristics and Risks Confronting Smart Grid Deployment



Cyber threats have different objectives: typically, incursions by sovereign attackers are warfare-oriented whereas incursions by groups and individuals are driven by pecuniary interests such as corporate espionage, credit card fraud, and ransom. Sovereign and non-sovereign hacking exhibit similar characteristics and patterns, which inform efforts to defend against attacks. *Note: Intended to be illustrative, not comprehensive.*

1.6.3 Electricity Has Significant Value for the National Defense

¢ĸŝ 5ŝŀjı·ŉűϒŝyű 2ŧ 5ŝŧŝyãŝ ó5h5ú ƛă űĸŝ fı·ŉƎŝăű Ödzăű2ϒŝŉ 2ŧ űĸŝ ŝfŝŏűŉƛŏ ƎŉƛŘ ƛy˜űĸŝ ¦ yƛűŝŘ {űı·ûŝăΣ ı· ăèăűŝϒ ǿĸƛŏĸ ƛă fı·ŉƎŝfè 2ǿyŝŘ ı·yŘ 2ŀjŝŉjı·ûŝŘ ōè űĸŝ ŀjŉƛØı·ûŝ ăŝŏűŏ2ŉ¢ Lű dzăŝă ŝfŝŏűŉƛŏƛûè ű2 ŝÈŝŏÖdzűŝ űĸŝ !ŉϒŝŘ {ŝŉØƛŏŝăΩ ϒƛăăƛ2y˜ŝăăŝyűƛı·f ŧdzyŏűƛ2yã ōè ŝyŝŉƎƛÎƛyƎ űĸŝ ăèăűŝϒă ı·yŘ 2űĸŝŉ ƛyăűı·ffı·ûƛ2y˜ƛyŧŉjı·ăűŉdzŏűdzŉŝ ySŏŝăăı·ŉè ŧ2ŉ ϒƛfƛűı·ŉè ōı·ăŝă ű2 ŧdzyŏűƛ2yϒ ı·yŘ ădzŀjŀj2ŉűƛyƎ ı· ǿƛŘŝ ŉjı·yƎŝ 2ŧ 2űĸŝŉ Řŝŧŝyãŝ 2ŀjŝŉjı·ûƛ2yã ı·yŘ ı·ăăŝűă ŝăăŝyűƛı·f ŧ2ŉ ϒƛăăƛ2y˜ ı·ăădzŉjı·yŏŝ¢ ¢ĸŝ Řŝŝŉŝŝ ű2 ǿĸƛŏĸ ŝfŝŏűŉƛŏƛûè ƛă ϒƛăăƛ2y˜ ŏŉƛűƛŏı·f ŧ2ŉ 5h5 ŝfŝØı·ûŝă űĸŝ fŝØŝf 2ŧ ŉŝăƛfƛŝyŏŝ ōŝè2yŘ ǿĸı·ű ϒı·è ōŝ ŘŝŝϒŝŘ ădzŦŦƛŏƛŝyű ŧ2ŉ ϒı·ŉ˜ŀŝű ŀjdzŉŀj2ăŝă¢

¢ĸŝ Ǝŉ2ǿƛyƎ yı·ûƛ2yı·f ăŝŏdzŉƛûè ƛϒŀjfƛŏı·ûƛ2yã 2ŧ űĸŝ ¦¢{¢ ŝfŝŏűŉƛŏƛûè ƎŉƛŘ ĸı·Øŝ ƛyãŀjƛŉŝŘ ySǿ fı·ǿă ı·yŘ ŉŝƎdzfı·ûƛ2yã ű2 ı·Ři·ŀjű ű2 űĸƛă ƛϒŀjŝŉjı·ûƛØŝ ı·yŘ ŝØ2fØƛyƎ ûĸŉŝı·ű fı·yŘăŏı·ŀjŝ¢ tŉŝăƛŘŝyűƛı·f t2fƛŏè 5ƛŉŝŏűƛØŝ ót t5úπ нм ı·ŘØı·yŏŝă ı· dzyƛûè 2ŧ ŝŧŧ2ŉű ű2 ăűŉŝyƎűĸŝy˜ ı·yŘ ϒı·ƛyűı·ƛy˜ ăŝŏdzŉŝΣ ŧdzyŏűƛ2yƛyƎΣ ı·yŘ ŉŝăƛfƛŝyű ŏŉƛűƛŏı·f ƛyŧŉjı·ăűŉdzŏűdzŉŝ ŧ2ŏdzăƛyƎ 2y˜ı·ff Kı·Îı·ŉŘă 2y˜ō2ûK ŀjĸèăƛŏı·f ı·yŘ ŏèōŝŉ ăèăűŝϒă¢ ¢ĸŝ ŏŉƛűƛŏı·f ı·ŉ2fŝ 2ŧ ŝfŝŏűŉƛŏƛûè ű2 űĸŝ bı·ûƛ2yΩă Řŝŧŝyãŝ ǿı·ă ı·fă2 ŉŝŏ2ƎyƛÎŝŘ ƛy˜ űĸŝ CƛÈƛyƎ !ϒŝŉƛŏı·Ωă {dzŉŧı·ŏŝ ¢ŉjı·yãŀj2ŉúı·ûƛ2y˜ !ŏű 2ŧ нлмр óŏ2ϒϒ2yfè ˜ly2ǿy˜ ı·ă űĸŝ C!{¢ !ŏúú {ŝŏűƛ2y˜ смлло 2ŧ űĸŝ !ŏű ŉŝljdzƛŉŝă úĸŝ {ŝŏŉŝûı·ŉè 2ŧ 9yŝŉƎèΣ ƛy˜ ŏ2yãdztűı·ûƛ2y˜ ǿƛúĸ 2űĸŝŉ ı·ŀjŀjŉ2ŀjŉƛı·ûŝ CŝŘŝŉjı·f ı·ƎŝyŏƛŝăΣ ű2 ƛŘŝyűƛŧè ŧı·ŏƛfƛûƛŝă ƛy˜úĸŝ ¦ yƛűŝŘ {űı·ûŝă úĸı·ű ı·ŉŝϒ óмú áŏŉƛűƛŏı·f ű2 úĸŝ Řŝŧŝyãŝ 2ŧ úĸŝ ¦ yűŝŘ {űı·ûŝăΣε ı·yŘ óнú áØdztyŝŉjı·ōfŝ ű2 ı· Řƛăŉdzŀjűƛ2y˜ 2ŧ űĸŝ ădzŀjŀjfè 2ŧ ŝfŝŏűŉƛŏ ŝyŝŉƎè ŀjŉ2ǿƛŘŝŘ ű2 ădzŏK ı· ŧı·ŏƛfƛûè ōè ı·y˜ŝÈűŝŉyı·f ŀjŉ2ǿƛŘŝŉǿε^MHC

9fŝŏűŉƛŏƛûè ƛă ŝăŀjŝŏƛı·ffè Øƛűı·f ŧ2ŉ ŀj2ǿŝŉƛyƎ Řŝŧŝyãŝ ySűǿ2ŉ˜ŀă ı·yŘ ŝyı·ōfƛyƎ ōŉ2ı·Řŝŉ Ö2ϒϒı·yŘΣ Ö2yűŉ2fΣ ı·yŘ Ö2ϒϒdzyƛŏı·ûƛ2yã ŧdzyŏűƛ2yã¢ 5h5Ωă нлмр ά/èōŝŉ {űŉı·ûŝƎèε KƛƎKfƛƎKűă ûĸŝ ŉ2fŝ 2ŧ ı· áǿƛŉŝŘε ǿ2ŉfŘΣ ûĸŝ ŝăăŝyűƛı·f ŉ2fŝ 2ŧ ŝfŝŏűŉƛŏƛûè ı·ă ı·y˜ ŝyı·ōfŝŉ 2ŧ ûĸŝăŝ Ö2yűŝăŝ ŏŉƛűƛŏı·f ŉŝăŝ ŘŝŀjŝyŘŝyŏŝ ŏŉŝŠı·ûŝă¢ ¢ĸŝ ăűŉjı·ûŝƎè yƎûŝă ûĸı·ûΣ ά5h5Ωă 2ǿy˜ ySűǿ2ŉ˜ŀă ı·ŉŝ ı· ŀjı·ûŏĸǿ2ŉ˜ŀ 2ŧ ûĸ2dzăı·yŘă 2ŧ ySűǿ2ŉ˜ŀă ı·ŏŉ2ăă ûĸŝ ƎfƷōŝΣ ı·yŘ 5h5 fı·Ŏˆŀă ûĸŝ Øƛăƛōƛfƛûè ı·yŘ 2ŉƎı·yƛÎı·ûƛ2yı·f ăűŉdzŏűdzŉŝ ŉŝljdzƛŉŝŘ ű2 ŘŝŧŝyŘ ƛűă ŘƛŦŦdzăŝ ySűǿ2ŉ˜ŀă ŝŦŧŝŏűƛØŝfèX 5h5 ŉŝfƛŝă 2y˜ŏŉƛűƛŏı·f ƛyŧŉjı·ăűŉdzŏűdzŉŝ ı·ŏŉ2ăă ûĸŝ ¦ yűŝŘ {űı·ûŝă ı·yŘ 2ØŝŉăŝI·ă ŧ2ŉ ƛűă 2ŀjŝŉjı·ûƛ2yãΣ èŝű ûĸŝ ŏèōŝŉăŝŏdzŉƛûè 2ŧ ădzŏK ŏŉƛűƛŏı·f ƛyŧŉjı·ăűŉdzŏűdzŉŝ ƛă dzyŏŝŉűı·ƛy¢ε^MHT

¢ĸŝ 5ŝŧŝyãŝ {ŏƛŝyŏŝ .2ı·ŉŘΩă нллу yƷűŝŘ ûĸı·ûΣ ά5h5Ωă ˜ŝè ŀjŉ2ōfŝϒ ǿƛúĸ ŝfŝŏűŉƛŏƛûè ƛă ûĸı·ű ŏŉƛűƛŏı·f ϒƛăăƛ2yãΣ ădzŏK ı·ă yı·ûƛ2yı·f ăűŉjı·ûŝƎƛŏ ı·ǿı·ŉŝyŝăă ı·yŘ yı·ûƛ2yı·f Ö2ϒϒı·yŘ ı·dzűĸ2ŉƛűƛŝăΣ ı·ŉŝ ı·fϒ2ăű ŝyűƛŉŝfè ŘŝŀjŝyŘŝyű 2y˜ûĸŝ yı·ûƛ2yı·f ûŉjı·yãϒƛăăƛ2y˜ƎŉƛŘŧε^MHY ¢ĸƛă ŘŝŀjŝyŘŝyŏŝ 2y˜ûĸŝ ƎŉƛŘ τ ǿĸƛŏĸ Ö2yűƛyŒzŝă ű2Řı·è τ ϒŝı·yã ûĸı·ű 5h5 fı·ŏŝă ϒı·yè 2ŧ ûĸŝ ăı·ϒŝ ŏĸı·ffŝyƎŝă fı·ŏŝŘ ōè ı·ff ŝfŝŏűŉƛŏƛûè Ödzăű2ϒŝŉƛ¢ Ly˜ нлмрΣ 5h5 fı·ŏƛfƛûƛŝă ŝÈŀjŝŉƛŝyŏŝŘ ı·ŀjŀjŉ2Èƛϒı·ûŝfè мнт dzűƛfƛûè 2dzűı·Ǝŝăűĸŝı·ű fı·ăűŝŘ y Ķ2dzŉă 2ŉ f2yƎŝŉΣ ı·y˜ƛyŏŉŝı·ăŝ ŧŉ2ϒ ммп ŝØŝyűă ƛy˜ нлмп¢^MHΦ bŝı·ŉfè Kı·fŧ 2ŧ ûĸŝ 2dzűı·ƎŝăØŝŉŝ Ōı·dzăŝŘ ōè ØŝI·ûĸŝŉΣ Øĸƛfŝ ûĸŝ 2ûĸŝŉ Kı·fŧ Øŝŉŝ Ōı·dzăŝŘ ōè ŝljdzƛŀjϒŝyű fı·ƛfdzŉŝ¢ 5h5Ωă нлмр á!yŷdzı·f 9yŝŉƎè a ı·yı·Ǝŝϒŝyű wŝŀj2ŉűΣε ƛy˜ ŘƛăŏdzăăƛyƎ ŉŝfƛı·yŏŝ 2y˜ Ö2ϒϒŝŉŏƛı·f ŀj2ǿŝŉ ădzŀjŀjfƛŝăΣ y2ûŝŘ ûĸı·ûΣ ăűzŏK ŝØŝyűă Ö2dztŘ ŉŝădztű ƛy˜ŀj2ǿŝŉ 2dzűı·ƎŝăI·ŧŧŝŏűƛyƎ ŏŉƛűƛŏı·f 5h5 ϒƛăăƛ2yã ƛyØ2tØƛyƎ ŀj2ǿŝŉ ŀjŉ2ŗŝŏűƛ2yΣ Řŝŧŝyãŝ 2ŧ ûĸŝ Ķ2ϒŝfı·yŘΣ 2ŉ 2ŀjŝŉjı·ûƛ2yã Ö2yŘdzŏűŝŘ ı·ű ƛyãűı·ffı·ûƛ2yã ƛy˜ûĸŝ ¦¢{¢ Řƛŉŝŏűfè ădzŀjŀj2ŉűƛyƎ ǿı·ŉŧƛƎKűƛyƎ ϒƛăăƛ2yã 2ØŝŉăŝI·ă¢ε^MOЛ

{ƛyŏŝ ûĸŝ 5ŝŧŝyãŝ {ŏƛŝyŏŝ .2ı·ŉŘΩă нллу ăűdzŘèΣ ϒƛfƛűı·ŉè ōı·ăŝă ı·yŘ Řŝŧŝyãŝ Ö2ϒϒdzyƛŏı·ûƛ2yã ySűǿ2ŉ˜ŀă Kı·Øŝ ű·ŀj˜ı·ƎƎŉŝăăƛØŝ ı·ŏűƛ2yã ûĸŉŝ2dzƎK ı· ōŉ2ı·Ř ŉı·yŝŝ 2ŧ ƛyƛűƛı·ûƛØŝă ű2 ăűŉŝyƎűĸŝy˜ ûĸŝăŝ ı·ōƛfƛûè ű2 2ŀjŝŉjı·ûŝ 2y˜ ŝϒ˜ŝŉƎŝyŏè ŀj2ǿŝŉ ƛŧ ōfı·Ŏˆŀ2dzűă 2ŏŎdzŉΣ ƛyŎfdzŘƛyƎ ŀjŉ2ØƛŘƛyƎ ōı·Ŏˆŀ¤dzŀJ Ǝŝyŝŉjı·ûƛ2y˜ ı·ű Ŏŉƛűƛŏı·f ŧı·ŏƛfƛûŝăŧ ŘŝØŝfƷŀjyƎ ŀjŉ2ŉƛűƛŝă ŉŝfƛı·yãŘƛăŀjă ǿƛúĸ dzűƛfƛûŝăŧ ı·yŘ ōdzƛfŘƛyƎ ı·fűŝŉyı·ûƛØŝ ŝfŝŏűŉƛŏƛûè ădzŀjŀjfè Ö2yŧƛƎdzŉjı·ûƛ2yãΣ ădzŏK ı·ă ϒ˜ƛŎŉ2ƎŉƛŘ¤ LϒŀjŉƛØŝϒŝyűă ƛy˜ƎŉƛŘ ŉŝăƛfƛŝyŏŝ Ōı·y˜ƎŉŝI·ûfè ŝyĸı·yŏŝ ûĸŝ ϒƛfƛúı·ŉèΩă ı·ōƛfƛûè ű2 Ōı·ŉŉè 2dzű ƛűă ϒ˜ƛăăƛ2yãΣ ŝăŀjŝŏƛı·ffè ƛŧ ŉŝăƛfƛŝyŏŝ ƛyƛűƛı·ûƛØŝă ı·ŉŝ ŧ2ŏdzăŝŘ 2y˜ădzŀjŀj2ŉűƛyƎ ŝăŀjŝŏƛı·ffè Ŏŉƛűƛŏı·f Řŝŧŝyãŝ ŧı·ŏƛfƛûŝă ı·yŘ ŧdzyŏűƛ2yã¢

hyãλúŜ ōI·Ŏ⅂πdzLJ ∃ŜyŜℕI·ûλ2ϒ λă 5h5Ωă LJℕλϒI·ℕè ϒŜűK2Ř ₮2ℕ ădzăűIλyλyE 2LJŜℕI·ûλ2yã ŘdzℕλyE ∃ℕλŘ 2dzúI·∃Ŝă¢ !ŎŎ2ℕŘλyE ûž 5h5 λϒнлммΣ ϒ2ăű ₮I·ŎλfλúλŜă dzãŜ ŘλŜăŜf ∃ŜyŜℕI·ú2ℕă ûž ădzLJLJ2ℕűű 2LJŜℕI·ûλ2yã I·yŘ ŎℕλúλŎI·f ϒλăăλ2yãΣ ØλúK Ŝy2dz∃K ₮dzŜf ûž ădzăűIλyϒōI·ăλŎ ₮dzyŎűλ2yã ₮2ℕ oçт ŘI·èă 2ℕ ϒ2ℕŜ I·ú ϒI·yê λyãűI·ffI·ûλ2yã¢ᴹᴼᴹ LϒLJℕ2ØŜϒŜyűă λϒ∃ℕλŘ ℕŜăλfλŜyŎŜ ŎI·yϒ∃ℕŜI·úfê ŜyKI·yŎŜ ûKŜ ϒλfλúI·ℕèΩă I·ōλfλúè ûž ŎI·ℕℕNè 2dzú λúă ϒλăăλ2yã¢ C2ℕ f2y∃ŜℕπŘdzℕI·ûλ2ϒ 2dzúI·∃ŜăΣ K2ØŜØŜℕΣ ōℕ2I·ŘŜℕ ∃ℕλŘ ℕŜăλfλŜyŎŜ λyλúλI·úλØŜă Øλff ōŜ ŜăăŜyűλI·f ûž λϒLJℕ2ØŜ ϒλăăλ2ϒ I·ăădzℕI·yŎŜ¢ ¢KŜ f2y∃ŜℕI·ϒ 2dzúI·∃Ŝz ûKŜ ϒ2ℕŜ ŎI·ăŎI·ŘλyE ûKŜ ŜŦŦŜŎúΣ ØλúK λyűŜℕŘŜLJŜyŘŜyű ăèăúŜϒă λyŎℕŜI·ăλyE fè λϒLJfλŎI·úŜŘ¢ !ŦűŜℕ т ŘI·èă ØλúK2dzú ŜfŜŎűℕλŎλúê ∃ŜyŜℕI·ûλ2yΣ ûKŜ ōℕ2I·ŘŜℕ λϒLJI·Ŏű 2Ŧ ŘŜŦŜyãŜ ăèăúŜϒă ŘŜLJŜyŘŜyű 2ϒ ŜfŜŎűℕλŎλúê ōŜŎ2ϒŜă I· Ŏ2yŎŜℕyΣ λyŎfdzŘλyE Ø I·ûŜℕΣ ₮dzŜfΣ I·yŘ ûŜfŜŎ2ϒϒdzyλŎI·ûλ2ϒ ăèăúŜϒă¢ 5h9 Ø2ℕ⅂ă ØλúK 5h5 ûž ŘŜØŜf2LJ ōI·Ŏ⅂πdzLJ LJ2ØŜℕ ∃ŜyŜℕI·ûλ2ϒ ûž ădzLJLJ2ℕűű ûKŜ λyűŜℕŘŜLJŜyŘŜyű ăèăúŜϒă ûKI·ú ℕŜfè 2ϒ ŜfŜŎűℕλŎλúê¢ 5h5 λă ădzLJLJ2ℕűλyE 5h9 λϒ ŘŜØŜf2LJλyE Ø I·èă ûž Ŝyãdzℕŝ ûKŜ ℕŜăλfλŜyŎŜ 2Ŧ LJ2ØŜℕ úℕI·yãŦ2ℕϒŜℕă I·yŘ 2ûKŜℕ ŎℕλúλŎI·f ŜIjdzλLJϒŜyű¢ 5h5 λă I·fă2 ăűℕŜy∃úKŜyλy∃ Ŏ2ffI·ō2ℕI·ûλ2ϒ Øλúκ dzűλfλúè LJℕ2ØλŘŜℕăΣ I·yŘ {ű⅂·ûŜ I·yŘ f2ŎI·f ŜϒŜℕ∃ŜyŎè ϒI·yI·∃ŜϒŜyű I·∃ŜyŎλŜă ℕŜϒI·λϒ I· ŎŜyűℕI·f Ŧ2Ŏdză ûž ŜyKI·yŎŜ ûKŜ ℕŜăλfλŜyŎŜ I·yŘ ℕI·LJλŘ ℕŜăű2ℕI·ûλ2ϒ 2Ŧ Ŏ2ϒϒŜℕŎλI·f ∃ℕλŘ λyŦℕI·ăűℕdzŎűdzℕŝ ûKI·ú ădzLJLJ2ℕűă ϒλăăλ2ϒ ŎℕλúλŎI·f λyãűI·ffI·ûλ2yã I·yŘ ŦI·ŎλfλúλŜă¢ᴹᴼᴴ

{úℕŜyλúKŜyλy∃ ûKŜ ℕŜăλfλŜyŎŜ 2Ŧ ûKŜ ŜfŜŎűℕλŎλúè ăèăúŜϒ y2ű 2yfè fλϒλűă ûKŜ Řλăℕdzλ⅂ûØŜ ŜŦŦŜŎűă 2Ŧ I·ŘØŜℕăI·ℕè I·ûű⅂·Ŏ⅂ă 2ϒ5h5 ϒλăăλ2ϒI·ăădzℕI·yŎŜΣ λű ŎI·yϒI·fă2 ℕŜŘdzŎŜ ûKŜ ℕλă⅂ 2Ŧ ŎŜℕúI·λy úèLJŜă 2Ŧ I·ûűI·Ŏ⅂ă 2ŎŎdzℕℕλyE λy ûKŜ ŦλℕăűLJfI·ŎŜ¢ wŜăλfλŜyŎŜ λyλúλI·ûλØŜă ŎI·yϒKŜfLJ ăűℕŜy∃úKŜyϒ áŘŜűŜℕℕŜyŎŜ ōè ŘŜyλI·f¢€ .è λϒLJℕ2ØλyE ûKŜ I·ōλfλúè 2Ŧ ŜfŜŎűℕλŎλúê ăèăúŜϒă ûž ădzℕØλØŜ ŎèōŜℕ I·yŘ ⅂λyŜûλŎ I·ûű⅂·Ŏ⅂ăΣ I·yŘ I·ŎŎŜfŜℕI·ûλyE LJ2ØŜℕ ℕŜăű2ℕI·ûλ2ϒ ØKŜyōfI·Ŏ⅂2dzûă Ř2 2ŎŎdzℕΣ ℕŜăλfλŜyŎŜ LJℕ2?ŜŎűă ŎI·yϒI·λăŜ I·yϒI·ŘØŜℕăI·ℕè Ωă dzyŎŜℕúI·λyûè I·ă ûž ØKŜűKŜℕ I·yϒI·ûű⅂·Ŏ⅂ ØλffI·ŎKλŜØŜ ûKŜ λyűŜyŘŜŘ Ŏ2yãŜIjdzŜyŎŜă¢ ¢KI·ú λyŎℕŜI·ăŜŘ dzyŎŜℕúI·λyûè ŎI·yϒKŜfLJ ℕŜŘdzŎŜ ûKŜ LJ2ûŜyűλI·f I·ûűI·Ŏ⅂ ØλffI·ŎKλŜØŜyŎăă 2Ŧ ădzŎK I·yϒI·ûű⅂·Ŏ⅂ τ ŜăLJŜŎλI·ffè λŦ ûKŜ I·ŘØŜℕăI·ℕè ŌŜfλŜØŜă ûKI·ú ûKŜ ¦yλúŜŘ {úI·ûŜă ŎI·yϒ ŜŦŦŜŎúλØŜfè ℕŜăLJ2yŘ λŦ I·yϒI·ûű⅂·Ŏ⅂ 2ŎŎdzℕă¢ LyϒyΣ2ûλyE ûKŜ λYLJ2ℕúI·yŎŜ 2Ŧ ō2făúŜℕλyE ŘŜúŜℕℕŜyŎŜ ōè ŘŜyλI·fΣ ûKŜ hōI·YI· !ŘYλyλăúℕI·ûλ2y℀ áwŜLJ2ℕú 2y/èōŜℕ 5ŜúŜℕℕŜyŎŜ t2fλŎè€ ŎI·ffă Ŧ2ℕ áōdzλfŘλy∃ ăúℕ2yE LJI·ℕűyŜℕăKλLJă ØλúK ûKŜ LJℕλØI·úŜ âŜŎű2ℕ û2 LJℕ2Y2ûŜ ÔèōŜℕăŜŎdzℕλúè ōŜăú LJℕI·ŎûλŎŜă¢€ ¢KŜ ℕŜLJ2ℕű I·fă2 ℕŜŎ2ϒϒŜyŘă ϒŜI·ădzℕŜă û2 áI·ℕŎKλúŜŎú ℕŜăλfλŜyű ăèăúŜϒă ûKI·ú ℕŜŎ2ØŜℕ IjdzλŎ⅂fè Ŧℕ2ϒ I·ûű⅂·Ŏ⅂ăΣ£ I·yŘ áfŜyŘ ŎℕŜŘλōλfλúè û2 yI·ûλ2yI·f ŜŦŦ2ℕűă û2 λyŎℕŜI·ăŜ yŜúØ2ℕ⅂ ℕŜăλfλŜyŎè€ᴹᴼᴼ

Back-Up Power for Security

In 2011, the Department of Energy and the Department of Defense announced collaboration on 18 fuel cell back-up power generation projects at eight U.S. defense installations. Compared with diesel generators, which are often used for back-up power, fuel cells use no petroleum, are quieter, require less maintenance than either generators or batteries, and can easily be monitored remotely to reduce maintenance time. These projects address interdependencies that are at risk the longer the duration outage, but provide back-up power to computing, telephone, and lighting functions of the military installations they serve.

1.6.4 DOE's Growing Role in Protecting the Electricity System as a Critical National Security Asset

5h9Ωă ℕ2fŜ λy I·ŘŘℕŜăăλyE ûKŜ ŜfŜŎűℕλŎλúê ăèăúŜϒ I·ă I· ŎℕλúλŎI·f Ŏ2ϒLJ2yŜyű 2Ŧ yI·ûλ2yI·f ăŜŎdzℕλúê λă ∃ℕ2ØλyE I·ă ûKŜ ûKℕŜI·ű fI·yŘăŎI·LJŜ KI·ă ŜØ2fØŜŘ¢ t t5 нм ŜăűI·ōfλăKŜă I· LJ2fλŎè ₮ℕI·ϒŜØ2ℕ⅂ I·yŘ dzyλúè 2Ŧ ŜŦŦ2ℕűű û2 ăűℕŜy∃úKŜy I·yŘ ϒ I·λyűI·λy ăŜŎdzℕŜΣ ₮dzyŎűλ2yλy∃Σ I·yŘ ℕŜăλfλŜyű ŎℕλúλŎI·f λy₦ℕI·ăűℕdzŎűdzℕŝ Ŧ2ŎdzăŜŘ 2y I·ff KI·Î I·ℕŘă¢ ¦yŘŜℕ t t5 нмΣ 5h9 λă λŘŜyűλŦλŜŘ I·ă ûKŜ {ŜŎű2ℕπ{LJŜŎλŦλŎ ! ∃ŜyŎè Ŧ2ℕ 9yŜℕ∃èΣ ϒI·⅂λy∃ 5h9 ûKŜ fŜI·Ř CŜŘŜℕI·f λyűŜℕ₦I·ŎŜ ØλúK ŜyŜℕ∃è ăŜŎű2ℕ λy₦ℕI·ăűℕdzŎűdzℕŝ 2øyŜℕă I·yŘ 2LJŜℕI·û2ℕă¢ wŜăLJ2yãλōλfλúλŜă I·fă2 λyŎfdzŘŜ ădzLJLJ2ℕűλy∃ λy₦ℕI·ăűℕdzŎűdzℕŝ LJℕ2ûŜŎűλ2y ŜŦŦ2ℕűă ØλúKλyûKŜ ăŜŎű2ℕ I·yŘ λyŎλŘŜyű ϒI·yI·∃ŜϒŜyŎ¢ ! ă ădzŎK£ 5h9 fŜI·Ră ûKŜ CŜŘŜℕI·f D2ØŜℕyϒŜyűΩă 9ϒŜℕ∃ŜyŎè {dzLJLJ2ℕű CdzyŎűλ2y I мнΣ ØKλŎK λă ŘŜăλ∃yŜŘ û2 ŦI·ŎλfλúI·ûŜ ûKŜ ℕŜŜăűI·ōfλăKYŜyű 2Ŧ ŘI·ϒI·∃ŜŘ ŜyŜℕ∃è ăèăúŜϒă I·yŘ Ŏ2ϒLJ2ySyűă¢ CλyI·ffèΣ /2y∃ℕŜăă LJI·ăăŜŘ ûKŜ C ! {¢ ! Ŏű λy нлмр óŘλăŎdzăăŜŘ λy∃ℕŜI·ûŜℕ ŘŜűI·λf λy /KI·LJűŜℕ ±LLΣ *A 21st Century Electric Sector: Conclusions and Recommendations*ú¢ ¢KŜ C ! {¢ ! Ŏű λyŎfdzŘŜă I·Ŏûλ2yã û2 λϒLJℕ2ØŜ ûKŜ ăŜŎdzℕλúê I·yŘ ℕŜăλfλŜyŎŜ 2Ŧ ŜfŜŎűℕλŎλúê λy₦ℕI·ăűℕdzŎűdzℕŜ¢ hyŜ 2Ŧ ûKŜ ϒ2ăű λϒLJ2ℕűI·yű ϒŜI·ădzℕŜă LJℕ2ØλŘŜă ûKŜ {ŜŎℕŜűI·ℕè 2Ŧ 9yŜ∃èΣ ØλúK ōℕ2I·Ř yŜØ

1.7 The Federal Role in Modernizing and Transforming the Grid

The Electricity System and the Role of the Federal Government

The Federal Government and U.S. electricity system have a complex and longstanding relationship that has enhanced the Nationôs economy, security, and environmental sustainability. This relationship is forged through legislative and administrative actions that cover issues related to markets, financing, environmental and health impacts, and workersô health and safety.

The earliest Federal intervention into the electric system was the encouragement of utility interconnections during World War I to better supply the surging demand. The Federal Power Commission (FPC), the first Federal agency with regulatory authority over aspects of the Nationôs electric industry, was created in 1920 by the Federal Water Power Act to license hydroelectric projects on Federal lands or navigable waters. The powers of the FPC were expanded by the Federal Power Act of 1935, to include the regulation of wholesale sales and transmission of electricity in interstate commerce. The Public Utility Holding Company Act of 1935 charged the Security and Exchange Commission with rationalizing the corporate structure of the electric industry, which had become very concentrated in a small number of holding companies.

During the great depression, the Federal Government developed numerous hydroelectric facilities to harvest Americaôs vast hydroelectric potential. This development resulted in the formation of Federal

entities to market and transport that power, including the Bonneville Power Administration and the Tennessee Valley Authority. The Rural Electrification Administration, created by the Rural Electrification Act of 1936, gave loans and helped rural organizations develop electric cooperatives, many of which received power from the various Federal hydropower projects.

The Federal Governmentôs role in promoting the science of producing electricity began with nuclear energy. The development of nuclear energy was a side benefit of the weapons program. The Nationôs system of National Labs also grew out of the weapons program and has provided useful research to the industry ever since. Development of nuclear power was aided by the Price-Anderson Nuclear Industries Indemnity Act of 1957, which limited liability of commercial reactors and thereby facilitated their inclusion into the utility generation mix. The Federal Governmentôs role in nuclear energy also included licensing nuclear plants with appropriate environmental review.

The electric industry is subject to a wide variety of environmental laws, covering air and water pollutants as well as the disposal of solid wastes associated with electricity production. The focus of environmental laws has changed over time. For example, initial concerns over air quality focused on ñcriteriaò pollutants such as particulates, nitrogen oxides, and sulfur dioxide, and then expanded in 1990 to pollutants causing acid rain. More recently, the Environmental Protection Agency has promulgated health-based regulations on mercury emissions and adopted regulations on greenhouse gas emissions that cause global warming. The Federal Government has played an important role in changing the nature of electric markets. The Public Utilities Regulatory Policies Act of 1978 required utilities to purchase power from non-utility generators, at their avoided costs, thereby creating new markets for independent generation. These markets were further enhanced by provisions of the Energy Policy Act of 1992, as well as by regulations promulgated by the Federal Energy Regulatory Commission (FERC), that provided transmission access for wholesale market participants. Ultimately, the move to competitive wholesale power markets enabled retail competition policiesð allowing end-use customers to select among competing electricity suppliersð adopted by some states. Increasingly, FERC (the successor to the FPC) has recognized the need to protect customers from the exercise of market power by policing anticompetitive behavior in the organized markets.

As the markets have transformed, the Federal Government has continued to lead and participate in market transformations. The Department of Defense has recognized the important role of renewable energy in achieving its mission of protecting the American people. The Department of Homeland Security is playing an important role in increasing cybersecurity and physical security. The Department of Energy is playing an important role as a facilitator and leader of research on the future of the grid and ways to remove technical impediments to getting there. The National Institute of Standards and Technology is developing standards to enable a 21st century grid. FERC is exploring market rules that will enable participation of a broader array of resources, as well as many customer-sided options.

1.7.1 Innovation Is Essential

¢KS ¦ yλűŜŘ {űl·ûŜă Kl·ă ōŜŜy l· ∃f2ōl·f tŜl·ŘŜℕ λy λyy2Øl·ûλ2y Σ l·yŘ ûŜÖKy2f2∃è ŘŜØŜf2LJYŜyű Kl·ă LJℕ2ØŜŘ û2 ōŜ 2yŜ 2ŧ ûKŜ ∃ℕŜl·ú ŜyƎλySă 2ŧ 2dzℕ ŜÖ2y2Yè℗ Lyy2Øl·ûλ2y λyØŠăűYŜyűă ŘλℕŜÖűfè ŜÈLJl·yŘ ûKŜ LJλLJŜfλyŜ 2ŧ ySø ûŜÖKy2f2∃λŜăΣ ℕŜŘdzÖŜ ûŜÖKy2f2∃è Ö2ăűăΣ l·yŘ Yλűλ∃l·ûŜ ℕλă⌈ă 2ŧ ySø ûŜÖKy2f2∃λŜa 2ℕ äèăúŜYă℗ ¢KŜăŜ ōŜySŧλűăΣ λy űdzℕyΣ ℕŜŘdzÖŜ ûKŜ Ö2ăű 2ŧ LJ2fλÖλŜă l·yŘ λyÖŜyűλØŠă℠ l·yŘ l·ff2ø ŘŜÖλăλ2y Yl·⌈Ŝℕăλy ō2ûK ∃2ØŜℕyYŜyű l·yŘ ûKŜ LJℕλØl·ûŜ ăŜÖű2ℕ û2 Ö2yãλŘŜℕ 2LJűλ2yã ûKl·ú ø2dzfŘ 2ûKŜℕøλăŜ y2ú ōŜ l·Øl·λfl·ōfŜ℗

¢KŜ CŜŘŜℕl·f wƻ5 LJ2ℕűŧ2fλ2 λă 2yŜ 2ŧ ûKŜ Y2ăű ăλ∃yλŧλÖl·yű Ö2yűℕλōdzûλ2yã û2 2dzℕ ŜyŜℕ∃è ûℕl·yãλűλ2y℗ ! ÖKλŜØλyƎ l· ÖfŜl·yΣ ŧfŜÈλōfŜΣ ℕŜfλl·ōfŜ ŜfŜÖűℕλÖλûè äèăűŜY ølff ℕŜ⌊jdzℕℕŜ Ö2yăűl·yűfè λYLJℕ2ØλyƎ ûKŜ Ö2ăű l·yŘ LJŜℕŧ2ℕYl·yÖŜ 2ŧ 2dzℕ ŜyŜℕ∃è ûŜÖKy2f2∃λŜă℗ wƻ5Σ Ö2dzLJŧŜŘ øλűK ŘŜY2yãűℕl·ûλ2y l·yŘ ŘŜLJf2èYŜyű óλ℗Ŝ℗Σ w55ƻ5úΣ ÖℕŜl·ûŜă l· ΨűŜÖKy2f2∃è LJdzăK Ω ûKl·ú ℕŜŘdzÖŜă ûKŜ Ö2ăű 2ŧ ûKŜ ΨLJ2fλÖè LJdzŧfΩ ∃ŜySℕl·ûŜŘ ûKℕ2dz∃K ℕŜ∃dzfl·û2ℕèΣ ûl·ÈΣ ŜyØλℕ2yYŜyűl·fΣ l·yŘ 2ûKŜℕ LJ2fλÖλŜă℗ /dzℕℕŜyű fŜØŜfă 2ŧ CŜŘŜℕl·f ădzLJLJ2ℕű ŧ2ℕ ŜfŜÖűℕλÖλûè l·yŘ 2ûKŜℕ ŜyŜℕ∃èπ ŧ2ÖdzăŜŘ ℕŜăŜl·ℕÖKΣ ŘŜØŜf2LJYŜyűΣ l·yŘ ŘŜY2yãűℕl·ûλ2yYŜŜŘ û2 ōŜ ădzōăűl·yűλl·ffè λyÖℕŜl·ăŜŘ℗ wŜ∃λ2yl·f Øl·ℕλl·ûλ2y λyλyy2Øl·ûλ2yÖl·LJl·ōλfλûλŜăΣ λyŧℕJl·ăúℕdzÖűdzℕŜΣ Yl·ℕ⌈Ŝűă LJ2fλÖλŜăΣ l·yŘ ℕŜă2dzℕÖŜă l·fă2 LJ2λyű û2 l· ySŜŘ û2 l·ŘŘℕŜää ŜfŜÖűℕλÖ ăŜÖű2ℕ λyy2Øl·ûλ2y ûKℕ2dz∃K ℕŜ∃λ2yl·f l·LJLJℕ2l·ÖKŜă℗ᴹᴼᶜ LYLJl·Öûă 2ŧ CŜŘŜℕl·f w55ƻ5 l·ℕŜ ŘŜăÖℕλōŜŘ λy ŧdzℕűKŜℕ ŘŜűl·λf λy /Kl·LJűŜℕ LLLΣ *Building a Clean Electricity Future*℗

¢ø2]Ŝè ŜÈI·YLJfŜă 2ŦŜÈLJI·yŘλyƎ CŜŘŜNI·f w55ɔ5 λyØŜăúYŜyú λy ΰKŜ ŜfŜŎΰNΛŎλΰè ăŜŎΰ2N I·NΩŜ aλăăλ2y LyŷØI·ΰλ2y I·yŘ 5h9Ωă DaL óŘλăŎdzăăŜŘ ŜI·NJfŜNΩΰΦ 5h9Ωă DaL λă I· ŎN2ăăŎdzΰΰλyƎ w55ɔ5 ŜŦŦ2NΩΰ ΰ2 ƎŜyŜNJI·ΰŜ ΰŜŎKy2f2ƎλŜă ΰKI·ΰ YŜI·ădzNΩŜΣ I·yI·fèÎŜΣ LJNΩŘλŎΰΣ LJN2ΰŜŎΰΣ I·yŘ Ŏ2yΰN2f ΰKŜ ƎNΛŘ 2Ŧ ΰKŜ ŦdzΰdzNΩŜΦ ¢KŜăŜ ΰŜŎKy2f2ƎλŜă I·NΩŜ ySŜŘŜŘ ΰ2 λyΰŜƎNJI·ΰŜ Ŏ2yØŜyΰλ2yI·f ƎŜySNJI·ΰλ2yΣ NΩŜyŜø I·ōfŜ ƎŜySNJI·ΰλ2yΣ I·yŘ ŜySNΩƎè ăΰ2NJI·ƎŜT Ŝy1·ōfŜ ăY I·Nΰΰ ōdzλfŘλyƎă I·yŘ ŜyŘπdzăŜ ŘŜØλŎŜăT I·yŘ Ŝyãdz NΩŜ ΰKI·ΰ ΰKŜ ƎNΛŘ λă NΩŜăλfΩŜyΰ ΰ2 ƎN2ø λyƎ LJKèăλŎI·fΣ Ŏèō ŜNΩΣ I·yŘ ŜÈΰNŜYŜ øŜI·ΰKŜNJ ΰKNΩŜI·ΰăΦ aλăăλ2y LyŷØI·ΰλ2y λă I·y ŜŦŦ2Nΰΰ ōè нн Ŏ2dzyΰNΛŜă I·yŘ ΰKŜ 9dzN2LJŜI·y ¦yλ2yτ ăLJŜI·NΚŜI·ŘŜŘ ōè ΰKŜ ¦yΰŜŘ {ΰI·ΰŜă I·yŘ I·yŷ2dzyŎŜŘ I·ΰ ΰKŜ tI·NΛă /fλYI·ΰŜ {dzYYλΰ λy нлмр τ ΰ2 ŘNJI·YI·ΰλŎI·ffè I·ŎŎŜfŜNJI·ΰŜ LJdzōfΛŎ I·yŘ LJNΛØI·ΰŜ Ǝf2ōI·f ŎfŜI·y ŜySNƎè λyŷ2ØI·ΰλ2yΣ λyŎfdzŘλyƎ Ř2dzōfλyƎ ΰKŜ LJdzōfΛŎ ăŜŎΰ2N λyØŜăΰYŜyΰ λy ŎfŜI·y ŜySNƎè w55ɔ5 2ØŜN p èŜI·NăΦ

1.7.2 Jurisdictional Relationships and Limitations

wŜăLJ2yãλōλfΛΰè Ŧ2N NŜƎdzfI·ΰλyƎ I·yŘ 2ØŜNăŜŜλyƎ ΰKŜ ydzYŜN2dză I·ŎΰΣ2NăΦ ΰKI·ΰ Ŏ2YLJNΛăŜ ΰKŜ ŜfŜŎΰNΛŎ LJ2øŜN λyŘdzăΰNΩè λă ØŜăΰŜŘ λy Ydzfΰλ LJfŜ Ǝ2ØŜNyYŜyΰ fŜØŜfă I·yŘ I·ƎŜyŎλŜăΣ I·yŘ ySø ΰŜŎKy2f2ƎλŜă I·NΩŜ LJdzΰΰλyƎ LJNΩŜăădzNΩŜ 2y·ΰNJI·Řλΰλ2y1·f ∂dzNΩλăŘλŎΰλ2y1·f Ō2dzyŘI·NΛŜă∅ wŜƎdzfI·ΰ2NΩè I·dzΰK2NΛΰλŜă ăLJI·y·CŜŘŜNJI·fΣ {ΰI·ΰŜΣ f2ŎI·fΣ I·yŘ ΰNΛōI·f fŜØŜfă∅ ! ΰ ΰKŜ CŜŘŜNJI·f fŜØŜfΣ C9w/ λă NŜăLJ2yãλōfŜ Ŧ2N NŜƎdzfI·ΰλ2y 2Ŧ ΰNJI·yãYλăăλ2y I·yŘ øK2fŜăI·fŜ ăI·fŜă λy λyΰŜNăΰI·ΰŜ Ŏ2YYŜNŎŜ∅ Ly I·ŘŘλΰλ2yΣ 2ΰKŜN CŜŘŜNJI·f I·dzΰK2NΛΰλŜă I·NΩŜ λyØ2fØŜŘ øλK ØI·NΛ2dză I·ăLJŜŎΰă 2Ŧ NŜƎdzfI·ΰλ2y 2N 2ØŜNăλƎKΰΣ λyŎfdzŘλyƎ 5h9Σ ΰKŜ 9yØΛN2yYŜyΰI·f tN2ΰŜŎΰλ2y !ƎSyŎèΣ 5ŜLJI·NΰYŜyΰ 2Ŧ WdzăΰΛŎŜΣ {ŜŎdzNΛΰΛŜă I·yŘ 9ÈŎKI·yƎŜ /2YYλăăλ2yΣ /2YY2ŘλΰèCdzΰdzNΩŜă ¢NJI·ŘλyƎ /2YYλăăλ2yΣ 5ŜLJI·NΰYŜyΰ 2Ŧ ΰKŜ LyΰŜNΛ2NΣ 5ŜLJI·NΰYŜyΰ 2Ŧ ! ƎNΛŎdzfΰdzNΩŜΣ ! dzΰ2YI·ΰŜŘ /2YYŜNŎλI·f 9yØΛN2yYŜyΰΣ I·yŘ bdzŎfŜI·N wŜƎdzfI·ΰ2NΩè /2YYλăăλ2yΣ I·Y2yƎ 2ΰKŜNăΦ /2ffŜŎΰΛØŜfèΣ ΰKŜè 2ØŜNăŜŜ YI·yê λyŘdzăΰNΩè I·ŎΰΩ2NΩăΦ wŜăLJ2yãλōfΛΰλŜă I·NΩŜ øλŘŜπNJI·yƎλyƎ I·yŘ NŜfI·ΰŜ ΰ2 ŜyØΛN2yYŜyΰI·f LJN2ΰŜŎΰλ2yΣ fI·yŘ dzăŜΣ I·yΰλπΰNΩdzăΰ LJN2ΰŜŎΰλ2yΣ I·yŘ ΰNJI·yãYλăăλ2y ăλΰλyƎΦ /2yƎNΩŜăă LJI·ăăŜŘ fƎλăfI·ΰλ2yλyнллр ƎΛØλyƎ C9w/ 2ØŜNăλƎKΰ NŜăLJ2yãλōfΛΰè Ŧ2N YI·yŘI·ΰ2NΩè NŜfI·ōλfΛΰè ăΰI·yŘI·NŘă I·yŘ I·dzΰK2NΛΰÎŜŘ ΰKŜ I·ƎŜyŎè ΰ2 LJI·NΰΰλI·ffè ŎŜNΰΰλŦè I·yŜfŜŎΰNΛŎ NŜfI·ōλfΛΰè 2NƎI·yλÎI·ΰλ2yΣ ΰ2 ŘŜØŜf2LJ I·yŘ Ŝy Ŧ2NΩŎŜ ΰK2ăŜ ăΰI·yŘI·NŘă∅MOT C9w/ YdzăΰI·LJLJN2ØŜ I· NŜfI·ōλfΛΰè ăΰI·yŘI·NŘ ōŜŦ2NΩŜ λΰ λă Ŝy Ŧ2NΩŜI·ōfŜ∅ C9w/ ŎŜNΰΰλŦΛŜŘ ΰKŜ b2NΰK !YŜNΛŎI·y 9fŜŎΰNΛŎ wŜfλI·ōλfΛΰè /2NLJ2NJI·ΰλ2yΣ I· y2yLJN2ŦλΰŎ2NLJ2NJI·ΰλ2yΣ I·ă ΰKŜ ŜfŜŎΰNΛŎ NŜfλI·ōλfΛΰè 2NƎI·yλÎI·ΰλ2y∅

Ly ŜI·ŎK ăΰI·ΰŜΣ NŜƎdzfI·ΰ2NΩè LJ2øŜN λă ØŜăΰŜŘ øλΰK ΰKŜ ăΰI·ΰŜ LJdzōfΛŎ dzΰλfΛΰè Ŏ2YYλăăλ2y Ŧ2N NŜƎdzfI·ΰλ2y 2Ŧ ΰKŜ λyØŜăΰ2NπøyŜŘ dzΰλfΛΰλŜă øλΰKλy λΰă ăΰI·ΰŜ ō2dzyŘI·NΛŜă óI·yŘ ŎŜNΰΰI·λy LJdzōfΛŎ LJ2øŜN I·yŘ Ŏ22LJŜNJI·ΰλØŜ dzΰλfΛΰè I·ŎΰΛØΛΰΛŜă λy ă2YŜ ăΰI·ΰŜăΰΦ ! ŘŘλΰλ2yI·ffèΣ {ΰI·ΰŜ LJ2fΛŎèYI·]ŜNă óƎ2ØŜNy2NăI·yŘ fŜƎλăfI·ΰdzNΩŜăΰ ŜăΰI·ōfΛăK fI·øă ΰKI·ΰ λyŘdzăΰNΩè I·Ŏΰ2NăY dzăΰI·ōλŘŜ ōè I·yŘ ΰKI·ΰ ΰKŜ LJdzōfΛŎ dzΰλfΛΰè Ŏ2YYλăăλ2yă ŎI·NJNè 2dzΰΦ {ΰI·ΰŜ ŜyØΛN2yYŜyΰI·fkŜySNƎè I·dzΰK2NΛΰλŜă ŎI·NJNè 2dzΰ NŜfŜØI·yΰ CŜŘŜNJI·f I·yŘ {ΰI·ΰŜ fƎλăfI·ΰλ2y I·yŘ NŜØλŜø ΰKŜ ŜyØΛN2yYŜyΰI·f λYLJI·Ŏΰ 2Ŧ ŎŜNΰΰI·λy λyŘdzăΰNΩè I·ŎΰΛØΛΰΛŜă øλΰKλy ΰKŜ ăΰI·ΰŜΦ ¢KŜè I·fă2 Ŏ2yΰN2f λyŦăΰI·ΰŜ ăλΰλyƎ 2Ŧ ƎŜySNJI·ΰλ2y I·yŘ ΰNJI·yãYλăăλ2yΣ I·fΰK2dzƎK ΰKŜ 9ySNƎè t2fΛŎè !Ŏΰ 2Ŧ нллр ŜăΰI·ōfΛăKŜă I· ăλƎyΦŦλŎI·yΰ N2fŜ Ŧ2N 5h9 λyΰNJI·yãYλăăλ2yăλΰλyƎΦ [2ŎI·f I·dzΰK2NΛΰλŜă ΰèLJλŎI·ffè λyŎfdzŘŜ ΰKŜ f2ŎI·f ƎØŜNyλyƎ ō2Řè 2Ŧ I· ŎλΰèΣ ΰ2øyΣ 2N Ŏ2dzyΰèΣ 2N ΰKŜ ŜfŜŎΰŜŘ 2N I·LJLJ2λyΰŜŘ ō2I·NΰRă ΰKI·ΰ 2ØŜNăŜŜ I·dzōfΛŎ LJ2øŜN 2N Ŏ22LJŜNJI·ΰλØŜ ŜfŜŎΰNΛŎ dzΰλfΛΰλŜă¢ ¢NJλōI·f Ǝ2ØŜNyλyƎ ō2ŘλŜă I·NΩŜ ŜyΰΛΰλŜă ΰKI·ΰ 2ØŜNăŜŜ I· NJI·yƎŜ 2Ŧ ŜfŜŎΰNΛŎ λyŘdzăΰNΩè I·ŎΰΛØΛΰΛŜă ΰKI·ΰ 2ŎŎdzN 2y·ΰNΛōI·f fI·yŘăΦ

¢KŜ ŎdzNΩŜyΰ ∂dzNΛăŘλŎΰλ2y1·f ŘλØλŘŜ 2Ŧ NŜƎdzfI·ΰ2NΩè I·dzΰK2NΛΰè ōŜΰøŜŜyΰKŜ CŜŘŜNJI·f D2ØŜNyYŜyΰ I·yŘ ΰKŜ ăΰI·ΰŜăΣ ŜăΰI·ōfΛăKŜŘ λy ΰKŜ CŜŘŜNJI·f t2øŜN !ŎΰΣ I·yŘ ŎfI·NΛŦΛŜŘ ōè ădzōăŜIjdzŜyΰ {dzLJNŜYŜ /2dzNΰ I·yŘ f2øŜN Ŏ2dzNΰ ŘŜŎλăλ2yãΣ λă ΰKŜ NŜădzfΰ 2Ŧ ΰKŜ ŜØ2fdzΰλ2y 2Ŧ I· NŜƎdzfI·ΰ2NΩè ăΰNdzŎΰdzNΩŜT λy ƎŜySNJI·fΣ CŜŘŜNJI·f NŜƎdzfI·ΰ2NΩă KI·ØŜ I·dzΰK2NΛΰè 2ØŜN ΰKŜ ōdzf¦ LJ2øŜN ăèăΰŜY I·yŘ øK2fŜăI·fŜ ŜfŜŎΰNΛŎ ăI·fŜă λyλyΰŜNăΰI·ΰŜ Ŏ2YYŜNŎŜ øKλfŜ {ΰI·ΰŜ I·yŘ f2ŎI·f NŜƎdzfI·ΰ2NΩă KI·ØŜ 2ØŜNăλƎKΰ 2Ŧ ΰKŜ ŘλăΰNΛōdzΰλ2y ăèăΰŜY I·yŘ NŜΰI·λf ăI·fŜă¢ ¢KλăŘλØλăλ2y 2Ŧ I·dzΰK2NΛΰλŜă ōŜΰøŜŜyΰKŜ CŜŘŜNJI·f D2ØŜNyYŜyΰ I·yŘ ăΰI·ΰŜăΣ I·ă øNΛΰΰŜyλyΰKŜ CŜŘŜNJI·f t2øŜN !ŎΰΣ KI·ă ōŜŜyŘŜăŎNΛōŜŘ I·ă I· áōNΛƎKΰ fλyŜƐŦ ΰKλă ōNΛƎKΰ fλyŜ λăΣ K2øŜØŜNΩ ōŜŎ2YλyΣ λyŎNSI·ăλyƎfè KI·Îè I·ă ySø ΰŜŎKy2f2ƎλŜă I·yŘ ăŜNØλŎŜă ŎNSI·ΰŜ YzNŜ ΰø2πøI·è Ŏ2yyŜŎΰλ2yã ōŜΰøŜŜyΰKŜ ΰNJI·yãYλăăλ2yI·yŘ ŘλăΰNΛōdzΰλ2yăèăΰŜYă∅

a2NŜ2ØŜNΩ ΰKŜ ăΰNdzŎΰdzNΩŜ 2Ŧ ΰKŜ λyŘdzăΰNΩè KI·ă ŎKI·yƎŜŘ ŦN2Y 2yŜ LJNΛYI·NΛfè ŎKI·NJI·ŎΰŜNΛÎŜŘ ōè ØŜNΰλŎI·ffè λyΰŜƎNJI·ΰŜŘ Y2y2LJ2fΛŜă 2LJŜNJI·ΰλyƎ dzyŘŜN Ŏ2ăΰπ2ŦπăŜNØλŎŜ NŜƎdzfI·ΰλ2yΰ2 2yŜ ŎKI·NJI·ŎΰŜNΛÎŜŘ λyăz2YŜ f2ŎI·ΰλ2yã ōè ăλƎyΦŦλŎI·yΰ øK2fŜăI·fŜ I·yŘ NŜΰI·λf Ŏ2YLJŜΰλΰλ2y I·Y2yƎ YI·yê ŘλØŜNăŜ ŜyΰΛΰλŜă¢ ¢KŜăŜ ŎKI·yƎŜă λy

ŭŜŎKy2f2∃ʎŜă I·yŘ ŭKŜ 2ØŜNJ·ff ăúNdzŎŭdzNJŜ 2Ŧ ŭKŜ ŜfŜŎúNJʎŎʎúè ʎyŘdzăúNJè ŎI·y˝ŎNJŜI·úŜ ?dzNJʎăŘʎŎŭʎ2yЛ·f dzyŎŜNJúI·ʎyŭiè I·yŘ Y˝I·NJ]Ŝú Y˝ʎăI·fʎ∃YY˝SyŭΦ

¢KŜ 2LJŜNJI·úʎ2yЛ·f ŎKI·NJI·ŎŭŜNJʎăúʎŎă I·yŘ I·úúNJʎōdzúŜă 2Ŧ ySØ I·yŘ ŜY˝ŜNJ∃ʎy∃ ŜySNJ∃è úŜŎKy2f2∃ʎŜă Ř2 y2ú ŦʎÚ ySI·úfè ʎyŭ2 ŜÈʎăúʎy∃ ?dzNJʎăŘʎŎŭʎ2yЛ·f ŘʎØʎăʎ2yãΦ !ă y2ŭŜŘΣ 5D ŭŜŎKy2f2∃ʎŜă KI·ØŜ Ŝyl·ōfŜŘ ú∅2π∅I·è LJ2∅ŜNJ Ŧf2∅Σ LJNJŜØŜyŭʎy∃ I· ăʎY˝LJfŜ áKI·yŘ 2ŦŦé 2Ŧ ?dzNJʎăŘʎŎŭʎ2y˝ ŦNJ2Y˝ CŜŘŜNJI·f ŭ2 {úI·úŜ NJŜ∃dzfI·úʎ2y˝I·ă ŜfŜŎúNJʎŎʎúè Ŧf2∅ă óI·yŘ ʎyŎNJŜI·ăŜă 2NJ ŘŜŎNJŜI·ăŜă ʎy˝Ø2fúI·∃Ŝú ŦNJ2Y˝ ∃ŜySNJI·úʎ2y˝ ŭKNJ2dz∃K ŘŜfØŜNJè ŭ2 dzfúʎY˝I·úŜ Ŏ2yãdzY˝LJúʎ2yΦ LyãúŜI·ŘΣ ySØ 59w óʎyŎfdzŘʎy∃ ŜySNJ∃è ăú2NJI·∃Ŝú ŎI·y˝ōŜ ʎyúŜNJŎ2yŷŜŎúŜŘ ŭ2 ŜʎúKŜNJ úKŜ C9w/ ?dzNJʎăŘʎŎŭʎ2yЛ·f Kʎ∃KπØ2fúI·∃Ŝ ŭNJI·yãY˝ʎăăʎ2y˝ ∃NJʎŘ 2NJ ŭKŜ {úI·úŜ ?dzNJʎăŘʎŎŭʎ2yЛ·f f2∅πØ2fúI·∃Ŝ f2ŎI·f ŘʎăúNJʎōdzúʎ2y˝ äèăúŜY˝ ó2NJ ōŜKʎyŘ úKŜ Ŏdzăú2Y˝SNJΩă Y˝ŜúŜNJú∅ LY˝I·ŘŘʎúʎ2y˝Σ úKŜăŜ NJŜă2dzNJŎŜăΣ I·f2y∃ ∅ʎúK úKŜ 2úKŜNJ ySØ I·yŘ I·ŘØI·yŎŜŘ ûŜŎKy2f2∃ʎŜă y2ŭŜŘ I·ō2ØŜΣ ŎI·y˝LJNJ2ØʎŘŜ ó2NJ ŜyI·ōfŜ 5w ŭKI·ú ŎI·y˝LJNJ2ØʎŘŜú ăŜØŜNJI·f]ʎyŘă 2Ŧ ō2ŭK ∅K2fŜăI·fŜ I·yŘ NJŜúI·ʎf ∃NJʎŘ ăŜNJØʎŎŜăΣ ∅ʎúK ōSyŜŦʎúă ŭKI·ú ŜÈúŜyŘ I·ŎNJ2ää úKŜ úNJI·Řʎúʎ2yЛ·f ∃ŜySNJI·úʎ2y˝ úNJI·yãY˝ʎăʎ2y˝ I·yŘ ŘʎăúNJʎōdzúʎ2y˝ Ŏfl·ääʎŦʎŎI·úʎ2yã∅MOY

¢KŜ ăŎI·fŜ I·yŘ ăŎ2LJŜ 2Ŧ ŭKŜ úNJI·yãʎúʎ2y˝I·fNJŜI·Řè dzyŘŜNJØI·è I·fă2 NJŜIjdzʎNJŜă úKŜ Ŏ2πŜØ2fdzúʎ2y˝2Ŧ ŭKŜ CŜŘŜNJI·f N2fŜT úKʎă ʎyãúI·ffY˝Syú 2Ŧ ŭKŜ v9w óʎ∅Ŝ∅Σ v9w м∅нú ∅ʎff ŭKŜNJŜŦ2NJŜ Ŏ2yãʎŘŜNJ úKŜ CŜŘŜNJI·f N2fŜ ʎy˝úKʎă úNJI·yãʎúʎ2y∅ ¢KŜ CŜŘŜNJI·f N2fŜ Y˝ŜNJʎúă ŜØI·fdzI·úʎ2y˝ʎy˝úŜNJY˝ă 2Ŧ úKŜ ŜŦŦʎŎʎŜyŎè 2Ŧ Y˝I·NJ]Ŝúă I·yŘ NJI·úŜ ăúNJdzŎŭdzNJŜă ʎy˝ʎyŎŜyúʎy∃ ŏfŜI·yΣ NJŜfʎI·ōfŜΣ I·yŘ I·ŦŦ2NJŘI·ōfŜ LJ2∅ŜNJT ŜY˝ŜNJ∃ʎy∃ úŜŎKyʎŎI·f I·yŘ 2LJŜNJI·úʎ2yЛ·f ʎăădzŜă Ŏ2yŎŜNJyʎy∃ ∃NJʎŘ NJŜfʎI·ōʎfúè΢ NJŜăʎfʎŜyŎŜΣ I·yŘ ŦfŜÈʎōʎfúèT I·yŘ úKŜ N2fŜ 2Ŧ ʎyãúʎúdzúʎ2yЛ·f ăúNJdzŎŭdzNJŜăΣ ʎyŎfdzŘʎy∃ CŜŘŜNJI·fΣ {úI·úŜΣ I·yŘ f2ŎI·f ?dzNJʎăŘʎŎŭʎ2yЛ·f ō2dzyŘI·NJʎŜă∅ YŜè ʎăădzŜă Ŧ2NJ úKʎă ŜØI·fdzI·úʎ2y˝ʎyŎfdzŘŜ I·Ŏúʎ2yЛ·ōfŜ N2fŜă úKŜ CŜŘŜNJI·f D2ØŜNJyY˝Syú ăK2dzfŘ LJfI·è ʎy˝ŦI·ŎʎfʎúI·úʎy∃ ăŜŎú2NJ úNJI·yãʎúʎ2y˝ I·yŘ ØKŜúKŜNJ ySØ NJŜăLJ2yãʎōʎfʎúʎŜă ăK2dzfŘ ōŜ ŜăúI·ōfʎăKŜŘ ú2 Ŝyãdz NJŜ ŘŜăʎNJŜŘ 2dzúŎ2Y˝Ŝă∅

¢KŜ CŜŘŜNJI·f D2ØŜNJyY˝Syú ʎă ŦI·ŎʎfʎúI·úʎy∃ úKŜ úNJI·yãʎúʎ2y˝ú2 úKŜ нмăú ŎŜyfúdzNJè ŜfŜŎúNJʎŎʎúè ăèăúŜY˝ ōè Ŏ2yØŜyʎy∃ ŘʎØŜNJăŜ ăúI·]ŜK2fŘŜNJă ō2úK Ŧ2NJY˝I·ffè I·yŘ ʎyŦ2NJY˝I·ffèΣ Y˝I·yI·∃ʎy∃ ŎNJʎúʎŎI·f I·ŎúʎØʎúʎŜă Ŏ2yŎŜNJyʎy∃ I·y˝ŜY˝ŜNJ∃ŜyŎè NJŜăLJ2yãŜΣ Ŏ2ffŜŎúʎy∃ I·yŘ ŘʎăăSY˝ʎyI·úʎy∃ ŘI·úI·Σ LJNJ2ŎdzNJʎy∃ LJ2∅ŜNJ I·yŘ ăŜffʎy∃ ʎú úKNJ2dz∃K úKŜ t2∅ŜNJ aI·NJ]Ŝúʎy∃ !ŘY˝ʎyʎăúNJI·úʎ2yãΣ ădzLJLJ2NJúʎy∃ ŦʎyI·yŎʎy∃ 2Ŧ ŜySNJ∃è LJNJ2?ŜŎúă úKNJ2dz∃K f2I·y˝ ∃dzI·NJI·yúŜŜăΣ I·yŘ ŦdzyŘʎy∃ úKŜ ∅2NfŘΩă fI·NJ∃Ŝăú CŜŘŜNJI·f ŜySNJ∃è w∋5 LJ2NJúŦ2fʎ2Φ ¢KŜ NJŜŎ2YY˝SyŘI·úʎ2yã ōI·ăŜŘ 2y˝úKŜ I·yI·fèăʎă ʎy˝úKʎă ŎKI·LJúŜNJ I·NJŜ Ŏ2ØŜNJŜŘ /KI·LJúŜNJ ±LLΣ *A 21st Century Electricity Sector: Conclusions and Recommendations.*

1.8 Endnotes

[m] hNNă2y´{ǿŜúú a l·NŘŜyΣ *Little Visits with Great Americans: Or, Success, Ideals, and How to Attain Them* ó{dzŎŎŜăă /2YLJl·yê l l·NØl·NŘ ¦ yNØŜNăλúëΣ мфлоύΣ олφ 5λΞNΰΛÎŜŘ 5ŜÔŜY´ōŜN фΣ ннлуΣ
KΰΰLJăŸккō22]ă¢Ǝ22ƎfŜ¢Ŏ2Yκō22]ăKΛŘĎ´тŘ2y ! ! ! ¸ ! !Wƨ ŘIjĎ´ΰK2Y l·ăbŜŘλă2yƀ^ː ннNΰŜ2NΞl·yλÎŜЬúKŜЬfΛTŜb2ŤЬΰKŜЬǿ2NťŘ^ː ннƨă2dzNŎŜĎ´Ǝ0ăψyΥ·Øfλy]ăψă

[h] ácNŜIjdzŜyΰtê !ă]ŜŘ vdzŜăΰλ2yãY l 2ǿ Y l·yê LJ2ǿŜN LJfl·yΰă l·NŜ ΰKŜNŜ λy´ΰKŜ ¦ yλΰŜŘ {ΰl·ΰŜăKέ 9yŜNƎè Lyf2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ l·ŎŎŜăăŜŘ hŎΰ2ōŜN мфΣ нлмсΣ KΰΰLJŸккǿǿǿ¢Ŝλl·¢Ǝ2Økΰ22făκŤl·IjăκŤl·Ij¢ŎŤYΚΛŘĎ´cpƨΰĎ´н¢

[o] tfl·ΰΰăΣ *2015 UDI Directory of Electric Power Producers and Distributors, 123rd Edition of the Electrical World Directory* óbŜǿ ¸2N]Σ b¸Y tfl·ΰΰăΣ нлмпύΣ ØλçØΛΣ KΰΰLJăŸккǿǿǿ¢LJfl·ΰΰă¢Ŏ2YκλY¢LJfl·ΰΰă¢Ŏ2yΰŜyΰκŘ2ǿyŤ2l·ŘăκdzŘλκŜLJLJŘκŜLJLJŘŘNN¢LJŘŤ¢

[n] WdzfΛl· tèLJŜNΣ á¢ΚŜ ¦{ {2fl·N a l·N]Ŝΰ Lă b2ǿ м aλfΛ2y´Lyăΰl·tfl·ΰλ2yã {ΰN2yƎΣé *Greentech Media*Σ !LJNλf нмΣ нлмсΣ
KΰΰLJăŸккǿǿǿ¢ƎNŜŜyΰŜŎKY´ŜŘλl·¢Ŏ2YκlNΰλŎfŜăκNŜl·Řκ¢KŜπ ¦ ¢{¢π{2fl·Nπ a l·N]Ŝΰπb2ǿπhyŜπ aλfΛ2yΤLyăΰl·tfl·ΰλ2yãπ{ΰN2yƎ¢

[p] á9fŜŎΰNλŎ {dzōăΰl·ΰλ2yãΣé tfl·ΰΰăΣ ƎŜyŜNl·ΰŜŘ a l·N0K cΣ нллф Σ
KΰΰLJŸккǿǿǿ¢LJfl·ΰΰă¢Ŏ2Y´κL a¢tfl·ΰΰă¢/2yΰŜyΰκtN2ŘdzŎΰă{ŜNØλŎŜăκtN2ŘdzŎΰăκƎλăY´ŜΰI·Řl·ΰl·kădzōăΰl·ΰy¢LJŘŤ¢

[c] tfl·ΰΰăΣ *2015 UDI Directory of Electric Power Producers and Distributors, 123rd Edition of the Electrical World Directory* óbŜǿ ¸2N]Σ b¸Y tfl·ΰΰăΣ нлмпύΣ ØλçØΛΣ KΰΰLJăŸккǿǿǿ¢LJfl·ΰΰă¢Ŏ2YκλY¢LJfl·ΰΰă¢Ŏ2yΰŜyΰκŘ2ǿyŤ2l·ŘăκdzŘλκŜLJLJŘκŜLJLJŘŘNN¢LJŘŤ¢

[T] tfl·ΰΰăΣ *2015 UDI Directory of Electric Power Producers and Distributors, 123rd Edition of the Electrical World Directory* óbŜǿ ¸2N]Σ b¸Y tfl·ΰΰăΣ нлмпύΣ ØλΣ KΰΰLJăŸккǿǿǿ¢LJfl·ΰΰă¢Ŏ2YκλY¢LJfl·ΰΰă¢Ŏ2yΰŜyΰκŘ2ǿyŤ2l·ŘăκdzŘλκŜLJLJŘκŜLJLJŘŘNN¢LJŘŤ¢

[y] 9yŜNƎè Lyf2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ á¢l·ōfŜ н¢м¢ bdzYōŜN 2Ť ¦ fΰλYl·ΰŜ /dzăΰ2YŜNă {ŜNØŜŘ ōè {ŜÔΰ2NΣ ōè tN2ØλŘŜNΣ нллр ΰKN2dzƎK нлмрΣé *Electric Power Annual 2014*, 9yŜNƎè Lyf2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ l·ŎŎŜăăŜŘ hŎΰ2ōŜN нлΣ нлмсΣ
KΰΰLJŸккǿǿǿ¢Ŝλl·¢Ǝ2ØkŜfŜŎΰNλŎλΰëκl·yΥdzl·fkKΰΥfkŜLJl·ψлнψлм¢KΰΥf¢

[Φ] 9yŜNƎè Lyf2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ á9fŜŎΰNλŎ LJ2ǿŜN ăl·fŜăΣ NŜØŜyΰdzŜΣ l·yŘ ŜyŜNƎè ŜŤŤλŎλŜyŎè C2NY 9L ! πycм ŘŜΰl·λfŜŘ Řl·ΰl· ŤλfŜăΣé 9yŜNƎè Lyf2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ fl·ăΰ dzLJŘl·ΰŜŘ hŎΰ2ōŜN cΣ нлмсΣ KΰΰLJăŸккǿǿǿ¢Ŝλl·¢Ǝ2ØkŜfŜŎΰNλŎΰëκŘl·ΰl·kŜλl·ycмk¢

[мл] LyΰŜNyΥ·ΰλ2yΥl·f a2yŜΰl·Nѐ CdzyŘΣ *World Economic Outlook database, Entire Dataset, By Country Groups, GDP, Current Prices,* !LJNλf нлмсΣ KΰΰLJăŸккǿǿǿ¢λY´Ť¢2NƎkŜĚΰŜNyΥ·fkLJdzŏăκΰkǿŜ2кнлмскlмкǿŜ2ŘlΛΰl·kŘ2ǿyŤ2l·Ř¢l·ăLJĚ¢

[мм] ±λLJλy´ !N2Nl· l·yŘ W2ÎŜŤ [λŜă]2Øă]èΣ *Electricity Use as an Indicator of U.S. Economic Activity* ó ² l·ăKλyƎΰ2yΣ 5 /Y 9yŜNƎè LyŤ2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ нлмпύΣ ǿ2N]λyƎ LJl·LJŜN ăŜNλŜăΣ KΰΰLJăŸккǿǿǿ¢Ŝλl·¢Ǝ2ØkǿǿN]λyƎLJl·LJŜNăkLJŘŤkŜfŜŎΰNλŎλΰëψλyŘλŎl·ΰ2N¢LJŘŤ¢

[мн] ±λLJλy´ !N2Nl· l·yŘ W2ÎŜŤ [λŜă]2Øă]èΣ *Electricity Use as an Indicator of U.S. Economic Activity* ó ² l·ăKλyƎΰ2yΣ 5 /Y 9yŜNƎè LyŤ2NYl·ΰλ2y´ ! ŘYλyΛăΰNl·ΰλ2yΣ нлмпύΣ ǿ2N]λyƎ LJl·LJŜN ăŜNλŜăΣ нΣ KΰΰLJăŸккǿǿǿ¢Ŝλl·¢Ǝ2ØkǿǿN]λyƎLJl·LJŜNăkLJŘŤkŜfŜŎΰNλŎλΰëψλyŘλŎl·ΰ2N¢LJŘŤ¢

[мо] 5h9 ó5ŜLJl·NΰΥŜyΰ 2Ť 9yŜNƎèύΣ *Energy Sector-Specific Plan 2015* ó ² l·ăKλyƎΰ2yΣ 5 /Y 5h9 l·yŘ 5ŜLJl·NΰΥŜyΰ 2Ť l 2YŜfl·yŘ {ŜŎdzNΰëΣ нлмрύΣ λØΣ KΰΰLJăŸккǿǿǿ¢ŘKă¢Ǝ2ØkăλΰŜăkŘŜŤl·dzfΰκŤλfŜăκLJdzŏfΛÔl·ΰλ2yăκyΛLJLJπăăLJπŜyŜNƎèπнлмрπрлу¢LJŘŤ¢

[мп] [dz ! yy´5l·KfY´l·yΣ á /fΛY´l·ΰŜ /Kl·yƎŜY Df2ōl·f ¢ŜY´LJŜNl·ΰdzNŜΣé bl·ΰλ2yl·f hŎŜl·yΛÔ l·yŘ ! ΰY´2ăLJKŜNΛÔ ! ŘY´λyΛăΰNl·ΰλ2yΣ Wl·yΰzl·Nѐ мΣ нлмрΣ
KΰΰLJăŸккǿǿǿ¢Ŏfλ´Y l·ΰŜ¢Ǝ2ØkyŜǿăπŤŜl·ΰdzNŜăκdzyŘŜNăΰl·yŘλyƎπŎfΛ´Y l·ΰŜkŎfΛ´Y l·ΰŜπŎKl·yƎŜπƎf2ōl·fπΰŜY´LJŜNl·ΰdzNŜ¢

[мр] [dz ! yy´5l·KfY´l·yΣ á /fΛY´l·ΰŜ /Kl·yƎŜY Df2ōl·f ¢ŜY´LJŜNl·ΰdzNŜΣé bl·ΰλ2yl·f hŎŜl·yΛÔ l·yŘ ! ΰY´2ăLJKŜNΛÔ ! ŘY´λyΛăΰNl·ΰλ2y´ Wl·yΰzl·Nѐ мΣ нлмрΣ
KΰΰLJăŸккǿǿǿ¢Ŏfλ´Y l·ΰŜ¢Ǝ2ØkyŜǿăπŤŜl·ΰdzNŜăκdzyŘŜNăΰl·yŘλyƎπŎfΛ´Y l·ΰŜkŎfΛ´Y l·ΰŜπŎKl·yƎŜπƎf2ōl·fπΰŜY´LJŜNl·ΰdzNŜ¢

[мс] tl·ΰNΛÔ] [èyŎKΣ ánлмс /fΛY´l·ΰŜ ¢NŜyŘă /2yΰλyΰzŜ ΰ2 .NŜl·] wŜÔ2NŘăΣé bl·ΰλ2yl·f ! ŜN2yl·dzΰλÔă l·yŘ {LJl·ÔŜ ! ŘY´λyΛăΰNl·ΰλ2yΣ Wdzfѐ мфΣ нлмсΣ KΰΰLJŸккǿǿǿ¢yΥ·ăl·¢Ǝ2ØkŤŜl·ΰdzNŜk¢Ǝ2ŘŘl·NŘknлмскÔfΛ´Y l·ΰŜπΰNŜyŘăπŎ2yΰλyΰzŜπΰ2πŎNŜl·]πNŜÔ2NŘă¢

[мт] W¢ hØŜNΰfl·yŘΣ 9¢ l l·yΥl·Σ L¢ l l·yăăŜyπ. l·dzŜNΣ {¢πW¢ YλY´Σ W¢ 9¢ ² l·făKΣ a¢ ² l·yΣΣ ¦¢{¢ .Kl·ΰΰΣ l·yŘ w¢ [¢¢K2Y´l·yΣ á ! NŎΰλÔ wŜLJ2Nΰ /l·NŘY ¦LJŘl·ΰŜ Ť2N нлмсΣ tŜNăλăΰŜyΰ ǿ l·NY´λyƎ ΰNŜyŘ l·yŘ f2ăă 2Ť ăŜl· λÔŜ l·NŜ ΰNλƎƎŜNλyƎ ŜĚΰŜyăλØŜ ! NŎΰλÔ ŎKl·yƎŜăΣé l·ŎŎŜăăŜŘ 5ŜŎŜY´ōŜN нyΣ нлмсΣ KΰΰLJŸккǿǿǿ¢l·NŎΰλÔ¢y2l·l·¢Ǝ2ØkwŜLJ2NΰΠ¢/ l·NŘkwŜLJ2NΰΠ¢/ l·NŘπнлмск ! Nΰ aL5крлнн ! NΰλÔfŜL5кнтмк{dzNŤl·ÔŜπ ! NNπ¢ŜY´LJŜNl·ΰdzNŜ¢

[му] 5h9 ó5ŜLJl·NΰΥŜyΰ 2Ť 9yŜNƎèύΣ *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water* ó ² l·ăKλyƎΰ2yΣ 5 /Y 5h9Σ 5ŜÔŜY´ōŜN нллсύΣ нрΣ KΰΰLJŸккǿǿǿ¢ÔNNÔfŜ2Ťōfdzŝ2NƎkǿLJπÔ2yΰŜyΰkdzLJf2l·Řăκнлмлклфкмнмπ wLJΰ¢2/2yƎNŜăăπ9 ² ǿ9L ! Ő2YY´ŜyΰăπCL b ! [н¢LJŘŤ¢

[mφ] / I·fλŦ2ℕyλI· 5ŜLJI·ℕúŶŜyű 2Ŧ ² I·úŜℕ wŜă2dzℕÔŜăΣ *Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water* ó{I·ŎℕI·ŶŜyű2Σ / !ᵞ / I·fλŦ2ℕyλI· 5ŜLJI·ℕúŶŜyű 2Ŧ ² I·úŜℕ wŜă2dzℕÔŜăΣ hŎű2ōŜℕ нллуύΣ yΣ Kΰΰ̈LJϒκκǿǿǿφǿI·úŜℕφÔI·φ∃2ØκÔfλŶI·úŜÔKI·yƎŜκŘ2Ôăκ/fλŶI·úŜ/KI·yƎŜ ² KλúŜtI·LJŜℕφLJŘŦφ

[нл] 5λI·yŀ· .I·dzŜℕΣ aI·ℕ] tKλfōℕλÔ]Σ .2ō ±I·ffI·ℕλ2Σ I2ëΰ .I·úΰŜèΣ ½I·ÔKI·ℕè /fŜŶŜyűΣ CfŜúÔKŜℕ CλŜfŘăΣ WŜyϒλŦŜℕ [λΣ ŜΰI·fφΣ *The Water-Energy Nexus: Challenges and Opportunities* ó ² I·ăKλyƎΰ2yΣ 5/ᵞ 5ŜLJI·ℕúŶŜyű 2Ŧ 9yŜℕƎèΣ WdzyŜ нлмпύΣ
Kΰΰ̈LJϒκκŜyŜℕƎè φƎ2ØκăλúŜăκLJℕ2ŘκŦλfŜăκнлмпклтκŦмтк ² I·úŜ[̈ нл9yŜℕƎ[̈ нлbŜ[̈dz[̈ нлCdz[̈ нлwŜLJ2ℕ[̈ нлWdzf[̈ нлнлмпφLJŘŦφ

[нм] aφ CλyăúŜℕΣ Wφ tKλffλLJăΣ I·yŘ Wφ tλff2yΣ *State Energy Resilience Framework* ó[ŜŶ2yΰΣ L[ᵞ !ℕƎ2yϒŜ bI·úλ2yI·f [I·ō2ℕI·ú2ℕèΣ Wdzfè нлмсύφ

[нн] άLyΰŜℕŘŜLJŜyŘŜyŎŜΣέ CŜŘŜℕI·f /2ŶŶdzyλÔI·úλ2yă /2ŶŶλăăλ2yΣ I·ÔÔŜăăŜŘ 5ŜÔŜŶōŜℕ τΣ нлмсΣ
Kΰΰ̈LJăϒκκǿǿǿφŦÔÔφƎ2ØκƎŜyŜℕI·fκλyΰŜℕŘŜLJŜyŘŜyÔŜφ

[но] 5I{ ó5ŜLJI·ℕúŶŜyű 2Ŧ I2ŶŜfI·yŘ {ŜÔdzℕλúëύΣ *Financial Services Sector-Specific Plan 2015* ó ² I·ăKλyƎΰ2yΣ 5/ᵞ 5I{Σ нлмрύΣ
Kΰΰ̈LJăϒκκǿǿǿφŘKăφƎ2Ø̈κăλúŜăκŘŜŦI·dzfúκŦλfŜăκLJdzōΰÔI·úλ2yăκyλLJLJπăăLJπŦλyI·yÔλI·fπăŜℕØλÔŜăπнлмрπрлуφLJŘŦφ

[нп] C9w/ óCŜŘŜℕI·f 9yŜℕƎè wŜ∃dzfI·úΣℕè /2ŶŶλăăλ2yΰ I·yŘ b9w/ ób2ℕúK !ŶŜℕλÔI·yˇ9fŜÔúℕλÔ wŜfλI·ōλfλúè /2ℕLJ2ℕI·úλ2yΰΣ *Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1–5, 2011: Causes and Recommendations*Σ
ó ² I·ăKλyƎΰ2yΣ 5/ᵞ C9w/ I·yŘ b9w/Σ нлммύΣ Kΰΰ̈LJăϒκκǿǿǿφŦŜℕÔφƎ2ØκfŜƎI·fκăΰI·ŦŦπℕŜLJ2ℕúăκлуπмсπммπℕŜLJ2ℕúφLJŘŦφ

[нр] tŜúŜℕ YŜffèπ5ŜúǿλfŜℕΣ *Mind the Gap: Energy Availability and the Disconnect with Data*Σ ó I 2dzăΰ2yΣ ¢·ᵞ b2ℕúKōℕλŘƎŜ 9yŜℕƎè tI·ℕΰyŜℕăΣ [[/Σ нлмрύΣ oΣ Kΰΰ̈LJϒκκŘI·úI·ÔŜyΰŜℕŦℕ2yΰλŜℕφÔ2ϒκϒλyŘπƎI·úI·πŘλăÔ2yŷŷŜÔΰπŜyŜℕƎèπI·ØI·λfI·ōλfΰΰèκφ

[нс] aλÔKI·Ŝf /KdzλΣ aI·ℕ]dză [2ŦŦfŜℕΣ I·yŘ w2ƎƎŜℕ w2ōŜℕΰăΣ á¢KŜ LyΰŜℕyŜú 2Ŧ ¢KλyƎăΣέ *McKinsey Quarterly*Σ aI·ℕÔK нлмлΣ
Kΰΰ̈LJϒκκǿǿǿφϒÔ]λyãŜèφÔ2ϒκλyŘdzăΰℕλŜăκKλƎKπΰŜÔKκ2dzℕπλyãλƎKΰăκΰKŜπλyΰŜℕyŜΰπ2ŦπΰKλyƎăφ

[нт] C¢/ óCŜŘŜℕI·f ¢ℕI·ŘŜ /2ŶŶλăăλ2yΰΣ *Internet of Things: Privacy and Security in a Connected World* ó ² I·ăKλyƎΰ2yΣ 5/ᵀ C¢/Σ нлмрύΣ
Kΰΰ̈LJăϒκκǿǿǿφŦΰÔφƎ2ØκăëăΰŜϒκŦλfŜăκŘ2ÔdzϒŜyΰăκℕŜLJ2ℕΰăκŦŜŘŜℕI·fπΰℕI·ŘŜπÔ2ϒϒλăăλ2yπăΰI·ŦŦπℕŜLJ2ℕΰπyƵØŜϒōŜℕπнлмοπǿ2ℕ]ăK2LJπ
ŜyΰλΰfŜŘπλyΰŜℕyŜΰπΰKλyƎăπLJℕλØI·Ôëкмрлмнтλ2ΰℕLJΰφLJŘŦφ

[ну] C// óCŜŘŜℕI·f /2ŶŶdzyλÔI·úλ2yă /2ŶŶλăăλ2yΰΣ *2016 Broadband Progress Report* ó ² I·ăKλyƎΰ2yΣ 5/ᵞ C// Σ WI·yΰzI·ℕè нфΣ нлмсύΣ
Kΰΰ̈LJăϒκκǿǿǿφŦÔÔφƎ2ØκℕŜLJ2ℕΰăπℕŜăŜI·ℕÔKκℕŜLJ2ℕΰăκōℕ2I·ŘōI·yŘπLJℕ2ƎℕŜăăπℕŜLJ2ℕΰăκнлмсπÔℕ2I·ŘōI·yŘπLJℕ2ƎℕŜăăπℕŜLJ2ℕΰφ

[нф] ¢K2Ŷ CλfŜ I·yŘ /I·YλffŜ wèI·yΣ *Computer and Intranet Use in the United States: 2013* ó ² I·ăKλyƎΰ2yΣ 5/ᵞ /ŜyădzăλdzℕŜI·dzΣ нлмпύΣ nΣ
Kΰΰ̈LJϒκκǿǿǿφÔŜyădzăφƎ2ØκKλăΰ2ℕèκLJŘŦκнлмοÔ2ϒLJdzΰŜℕdzăŜφLJŘŦφ

[ол] LyΰŜℕyλI·f wŜØŜyΰzŜ {ŜℕØλÔŜΣ á!ă ŜπŦλfŜ DℕΣ2ǿăΣ Lw{ wŜÔŜλØŜă CŜǿŜℕ ¢I·È wŜΰdzℕyăλ2yˇ tI·LJŜℕΣέ LwπнлмπππпΣ !LJℕλfοΣ нлмпΣ
Kΰΰ̈LJăϒκκǿǿǿφℕℕăφƎ2ØκdzI·ÔκyŜǿăℕ22ϒκI·ăπŜŦλfŜπƎℕ2ǿăπλℕăπℕŜÔŜλØŜăπŦŜǿŜℕπΰI·ĒπℕŜΰdzℕyăπ2yπLJI·LJŜℕφ

[ом] WI·ϒŜă aI·yĒλ]I·Σ {ℕŜŜ wI·ϒI·ăǿI·ϒĒΣ {2ϒŜăK YKI·yλyλI·Σ IdzƎ2 {I·ℕλI·ÎλyΣ DI·ℕè tλy]dzăΣ DdzℕdzΣ {ŜΰKdzLJI·úKĒΣ I·yŘ !yŘℕŜǿ ¸I·ŦŦŜΣ *Digital America: A Tale of the Haves and Have-Mores* óaÔYλyãŜè Df2ōI·f LyãΰλΰdzΰŜΣ нлмрύΣ мнΣ
Kΰΰ̈LJϒκκǿǿǿφϒÔ]λyãŜèφÔ2ϒκλyŘdzăΰℕλŜăκKλƎKπΰŜÔKκ2dzℕπλyãλƎKΰăκŘλƎλΰI·fπI·ϒŜℕλÔI·πI·πΰI·fŜπ2ŦπΰKŜπKI·ØŜăπI·yŘπKI·ØŜπϒ2ℕŜăφ

[он] WI·ϒŜă aI·yĒλ]I·Σ {ℕŜŜ wI·ϒI·ăǿI·ϒĒΣ {2ϒŜăK YKI·yλyλI·Σ IdzƎ2 {I·ℕλI·ÎλyΣ DI·ℕè tλy]dzăΣ DdzℕdzΣ {ŜΰKdzLJI·úKĒΣ I·yŘ !yŘℕŜǿ ¸I·ŦŦŜΣ *Digital America: A Tale of the Haves and Have-Mores* óaÔYλyãŜè Df2ōI·f LyãΰλΰdzΰŜΣ нлмрύΣ мнΣ
Kΰΰ̈LJϒκκǿǿǿφϒÔ]λyãŜèφÔ2ϒκλyŘdzăΰℕλŜăκKλƎKπΰŜÔKκ2dzℕπλyãλƎKΰăκŘλƎλΰI·fπI·ϒŜℕλÔI·πI·πΰI·fŜπ2ŦπΰKŜπKI·ØŜăπI·yŘπKI·ØŜπϒ2ℕŜăφ

[оо] WI·ϒŜă aI·yĒλ]I·Σ {ℕŜŜ wI·ϒI·ăǿI·ϒĒΣ {2ϒŜăK YKI·yλyλI·Σ IdzƎ2 {I·ℕλI·ÎλyΣ DI·ℕè tλy]dzăΣ DdzℕdzΣ {ŜΰKdzLJI·úKĒΣ I·yŘ !yŘℕŜǿ ¸I·ŦŦŜΣ *Digital America: A Tale of the Haves and Have-Mores* óaÔYλyãŜè Df2ōI·f LyãΰλΰdzΰŜΣ нлмрύΣ пΣ
Kΰΰ̈LJϒκκǿǿǿφϒÔ]λyãŜèφÔ2ϒκλyŘdzăΰℕλŜăκKλƎKπΰŜÔKκ2dzℕπλyãλƎKΰăκŘλƎλΰI·fπI·ϒŜℕλÔI·πI·πΰI·fŜπ2ŦπΰKŜπKI·ØŜăπI·yŘπKI·ØŜπϒ2ℕŜăφ

[оп] 5I·ØλŘ {ÔKℕI·yλΣ .λff 9lăŜfŜΣ ¢λϒ [2ϒI·ĒΣ I·yŘ Wλϒ .I·]Σ *2015 Urban Mobility Scorecard* ó/2ffŜƎŜ {ΰI·ΰλ2yΣ ¢·ᵞ ¢ŜĒI·ă !ɜa ¢ℕI·yãLJ2ℕΰI·úλ2yˇLyãΰλΰdzΰŜ I·yŘ LbwL·Σ LyÔφΣ нлмрύΣ Kΰΰ̈LJϒκκŘнŘΰfpyϒfLJFℕлℕφÔf2dzŘFℕ2yΰφyŜΰκΰΰλφΰI·Yˇdzφ ŜŘdzκŘ2ÔdzYˇŜyΰăκY2ōλfΰΰèπ ăÔ2ℕŜÔI·ℕŘπнлмрφLJŘŦφ

[ор] WI·ϒŜă aI·yĒλ]I·Σ aλÔKI·ŜfλÔKI·ŜfΣ tŜΰŜℕ .λăă2yΣ W2yI·úKI·yˇ ²2ŜΰÎŜfΣ wλÔKI·ℕŘ 52ōōăΣ WI·ÔIjdzŜă .dzƎKλyΣ I·yŘ 5I·yˇ !KI·ℕ2yΣ *Unlocking the potential of the Internet of Things* óaÔYλyãŜè Df2ōI·f LyãΰλΰdzΰŜΣ нлмрύΣ Kΰΰ̈LJϒκκǿǿǿφϒÔ]λyãŜèφÔ2ϒκōdzăλyŜăăπ
ŦdzyÔΰλ2yãκōdzăλyŜăăπΰŜÔKyˇ2f2Ŧ∃èκ2dzℕπλyãλƎKΰăκΰKŜπλyΰŜℕyŜΰπ2ŦπΰKλyƎăπΰKŜπØI·fdzŜπ2ŦπŘλƎλΰÎλyƎπΰKŜπLJKèăλÔI·fπǿ2ℕŦŘφ

[ос] bw5/ óbI·ΰdzℕI·f wŜă2dzℕÔŜă 5ŜŦŜyãŜ /2dzyÔλfΰΣ *America's Data Centers Are Wasting Huge Amounts of Energy: Critical Action Needed to Save Billions of Dollars and Kilowatts* ó ² I·ăKλyƎΰ2yΣ 5/ᵞ bw5/Σ нлмрύΣ λăădzŜ ōℕλŜŦΣ
Kΰΰ̈LJăϒκκǿǿǿφyℕŘÔφ2ℕƎκăλúŜăκŘŜŦI·dzfúκŦλfŜăκŘI·úI·πÔŜyΰŜℕπŜŦŦλÔλŜyÔèπI·ăăŜăăYˇŜyΰπL .φLJŘŦφ

[от] 5ŜLJI·ℕúŶŜyű 2Ŧ 9yŜℕƎèΣ άмл CI·Ôΰăΰ2 Yy2ǿ !ō2dzΰ 5I·úI· /ŜyΰŜℕăΣέ b2ØŜϒōŜℕ мтΣ нлмпΣ Kΰΰ̈LJϒκκŜyŜℕƎèφƎ2ØκŜŜℕŜκI·ℕΰλÔfŜăκмлπ
Ŧ]I·Ôΰăπ]y2ǿπI·ō2dzΰπŘI·úI·πÔŜyΰŜℕăφ

oy !ℕΥl·y´{KŜKl·ōλΣ {l·ℕ]l·K W2ăŜLJKλyŜ {Yλύ KΣ 5l·fŜ !φ{l·ℕύ2ℕΣ wλÖKl·ℕŘ 9φ .ℕ2ǿyΣ a l·Ǝyʤžă lŜℕℕfλyΣ W2yl·úKl·y´Dφ Y22YŜèΣ 9ℕΛÖ wφ a l·ăl·yŜύΣ Ŝύ l·fφΣ *United States Data Center Energy Usage Report* ó.Ŝℕ]ŜfŜèΣ / !Ύ [l·ǿℕŜyÕŜ .Ŝℕ]ŜfŜè bl·úλ2yl·f [l·ō2ℕl·ύ2ℕèΣ WdzyŜ нлмсύΣ Kύύ LJăΥκκŜύl·φfōfφ∃2Ø kăλύŜăkl·ffkŦλfŜăkLJdzōfλÖl·úλ2yâkfōyfπмллрттрψÓн φLJŘŦ

oφ W2ăK ² Kλúy Ŝè l·yŘ tλŜℕℕŜ 5ŜfŦ2ℕ∃ŜΣ *Data Center Efficiency Assessment: Scaling Up Energy Efficiency Across the Data Center Industry: Evaluating Key Drivers and Barriers* ó² l·ăKλyЭύ2yΣ 5 / Ύ bl·údzℕl·f wŜă2dzℕÖŜă 5ŜŦŜyãŜ /2dzyÖλfΣ !dzЭdzăύ нлмпύΣ λăădzŜ LJl·LJŜℕΣ pΣ Kύύ LJăΥκκǿǿǿφyℕŘÖφ2ℕ∃kăλύŜăkŘŜŦl·dzfŭκŦλfŜăkŘl·úl·πÔŜyύŜℕπŜŦŦλÖλŜyÖèπl·ăăŜăăΥŜyΰπLtφLJŘŦφ

nл !ℕΥl·y´{KŜKl·ōλΣ {l·ℕ]l·K W2ăŜLJKλyŜ {Yλύ KΣ 5l·fŜ !φ{l·ℕύ2ℕΣ wλÖKl·ℕŘ 9φ .ℕ2ǿyΣ a l·Ǝyʤžă lŜℕℕfλyΣ W2yl·úKl·y´Dφ Y22YŜèΣ 9ℕΛÖ wφ a l·ăl·yŜύΣ Ŝύ l·fφΣ *United States Data Center Energy Usage Report* ó.Ŝℕ]ŜfŜè bl·úλ2yl·f [l·ō2ℕl·ύ2ℕèΣ WdzyŜ нлмсύΣ Kύύ LJăΥκκŜύl·φfōfφ∃2Ø kăλύŜăkl·ffkŦλfŜăkLJdzōfλÖl·úλ2yâkfōyfπмллрттрψÓнφLJŘŦφ

nм 9yŜℕ∃è LyŦ2ℕΥl·úλ2y´!ŘΥλyλăύℕl·úλ2yΣ á9fŜÖύℕÖ LJ2ǿŜℕ ăl·fŜăΣ ℕŜØŜyʤzŜΣ l·yŘ ŜyŜℕ∃è ŜŦŦλÖλŜyÖè C2ℕΥ 9L!πycм ŘŜύl·λfŜŘ Řl·úl· ŦλfŜăΣέ 9yŜℕ∃è LyŦ2ℕΥl·úλ2y´!ŘΥλyλăύℕl·úλ2yΣ fl·ăύ dzLJŘl·úŜŘ hÖú2ōŜℕ cΣ нлмсΣ Kύύ LJăΥκκǿǿǿφŜλl·φ∃2ØκŜfŜÖύℕλÖλύèκŘl·úl·κŜλl·усмкφ

nн .λff [2ØŜfŜăăΣ άLyύŜℕyŜύ 2Ŧ ¢Kλy∃ă LJdzύă ŜyŜℕ∃è ∃ℕλŘ ű2 ûŜăύΣέ *USA Today*Σ 5ŜÖŜΥōŜℕ нлΣ нлмрΣ Kύύ LJΥκκǿǿǿφdzăl·ú2Řl·è φÔ2Υkăú2ℕèkΥ2ySèkÔ2fdzΥyλăúκнлмркмнκлкf2ØŜfŜăăπλyύŜℕyŜύπ2ŦπύKλy∃ănŜyŜℕ∃èπ∃ℕλŘκттрмрсуук φ

nо 5λΥŜyãλ2yl·f wŜăŜl·ℕÖKΣ *Business Impact of IT Incident Communications: A Global Survey of IT Professionals* ó{l·y´W2ăŜΣ / !Ύ 5λΥŜyãλ2yl·f wŜăŜl·ℕÖK l·yŘ È a l·úύŜℕăΣ a l·ℕÖK нлмрύΣ Kύύ LJΥκκλyf2φÈΥ l·úύŜℕăφÔ2Υkℕăkl·fl·ℕΥLJ2λyύκλΥ l·∃ŜăkÈ a l·úύŜℕăπнлмрπ{dzℕØŜèπ wŜLJ2ℕύφLJŘŦφ

nп 5λΥŜyãλ2yl·f wŜăŜl·ℕÖKΣ *Business Impact of IT Incident Communications: A Global Survey of IT Professionals* ó{l·y´W2ăŜΣ / !Ύ 5λΥŜyãλ2yl·f wŜăŜl·ℕÖK l·yŘ È a l·úύŜℕăΣ a l·ℕÖK нлмрύΣ oΣ Kύύ LJΥκκλyf2φÈΥ l·úύŜℕăφÔ2Υkℕăkl·fl·ℕΥLJ2λyύκλΥ l·∃ŜăkÈ a l·úύŜℕăπнлмрπ{dzℕØŜèπ wŜLJ2ℕύφLJŘŦφ

np {úŜØŜy´{Kl·LJℕ2Σ þCh a нφoΥ .Ŝăύ tℕl·ÖúλÔŜă Ŧ2ℕ hLJŜℕl·úλyЭ l· 5l·úl· /ŜyύŜℕþ óLJℕŜăŜyύl·úλ2y´∃λØŜy´l·ú úKŜ 5l·úl· /ŜyύŜℕ ² 2ℕfŘ /2yŦŜℕŜyÖŜΣ bŜǿ hℕfŜl·yãΣ [!Σ {ŜLJύŜΥōŜℕ мнçмрΣ нлмсύΣ Kύύ LJΥκκŦl·ffφŘl·úl·ÔŜyύŜℕǿ2ℕfŘφÔ2ΥκŘÖŦмск /dzăύ2Υκ l l·yŘ2dzύκ{LJŜl·]Ŝℕлψ{Ŝăăλ2yмлмслрпψмφLJŘŦφ

nс á5l·úl· /ŜyύŜℕ {úl·yŘl·ℕŘă óφλŜℕă LπL±úΣέ /2f2Ôl·úλ2y´!ΥŜℕλÖl·, Kύύ LJăΥκκǿǿǿφÖ2f2Ôl·úλ2yl·ΥŜℕλÖl·φÔ2ΥκŘl·úl·πÔŜyύŜℕκύλŜℕπăúl·yŘl·ℕŘăπ 2ØŜℕØλŜǿφKύΥφ

nт Cℕ2ăύ ɜ {dzfflØl·yΣ *Analysis of the US Power Quality Equipment Market* ó.Ŝℕ]ŜfŜèΣ / !Ύ [l·ǿℕŜyÖŜ .Ŝℕ]ŜfŜè bl·úλ2yl·f [l·ō2ℕl·ύ2ℕèΣ !dzЭdzăύ нлмрύΣ [.b[πмллоффлΣ онΣ Kύύ LJăΥκκŜΥLJφfōfφ∃2ØκăλύŜăkl·ffkŦλfŜăkfōyfπмллоффлφLJŘŦφ

ny Cℕ2ăύ ɜ {dzfflØl·yΣ *Analysis of the US Power Quality Equipment Market* ó.Ŝℕ]ŜfŜèΣ / !Ύ [l·ǿℕŜyÖŜ .Ŝℕ]ŜfŜè bl·úλ2yl·f [l·ō2ℕl·ύ2ℕèΣ !dzЭdzăύ нлмрύΣ [.b[πмллоффлΣ Kύύ LJăΥκκŜΥLJφfōfφ∃2ØκăλύŜăkl·ffkŦλfŜăkfōyfπмллоффлφLJŘŦφ

nф 5h9 ó5ŜLJl·ℕύΥŜyύ 2Ŧ 9yŜℕ∃èύΣ *The Potential Benefits of Distributed Generation and Rate-Related Issues that May Impede Their Expansion: A Study Pursuant to Section 1817 of the Energy Policy Act of 2005* ó² l·ăKλyЭύ2yΣ 5 / Ύ 5h9Σ CŜōℕdzl·ℕè нллτύΣ λΛΣ Kύύ LJăΥκκǿǿǿφŦŜℕÖφ∃2ØκfŜ∃l·fκŦŜŘπăúl·κŜĚLJπăúdzŘèφLJŘŦφ

pл DℕŜ∃ {λy∃fŜú2yΣ 5ŜLJl·ℕύΥŜyύ 2Ŧ 9yŜℕ∃èΣ 2ōăŜℕØŜℕ l·yŘ l·úύŜyŘŜŜ 2Ŧ /fŜl·ℕ tl·úK L± ŜĚŜℕÖλăŜΣ LJŜℕă2yl·f y2úŜăΣ !LJℕλf мфçнлΣ нлмсφ

pм /l·úKŜℕλyŜ ² 2fŦℕl·YΣ áLă ŭKŜ ¦φ{φ LyØŜăúλyЭ 9y2dz∃K λy´9fŜÖύℕλÖλúè DℕλŘ wŜfλl·ōλfλúèKé *Energy Institute at Haas*Σ Wdzy Ŝ мрΣ нлмрΣ Kύύ LJăΥκκŜyŜℕ∃èl·úKl·l·ă φǿ2ℕŘLJℕŜăă φÔ2ΥкнлмркслскмркλăπύKŜπdzπăπλyØŜăúλy∃πŜy2dz∃Kπλyπ ŜfŜÖύℕλÖλúè π∃ℕλŘπℕŜfλl·ōλfλúèκφ

pн ! . . Dℕ2dzLJΣ áφKŜ 9Ø2fdzύλ2y´2Ŧ {/ !5 !κ9a {κDa {Ύ a l·yl·∃λy∃ úKŜ ² 2ℕfŘλă t2ǿŜℕ bŜύǿ2ℕ]ăΣέ ! . . Dℕ2dzLJΣ l·ÖÔŜăăŜŘ {ŜLJύŜY´ōŜℕ нфΣ нлмсΣ Kύύ LJΥκκǿǿǿφl·ōōφdzăκÔl·ǿLJκŘōллоŘоллнсфукōотнŦмомÕмl·рпŜрŦÔмнртнŜÖллrŘÖōпφl·ăLJĚφ

po l φ [ŜŜ {Yλύ KΣ á! .ℕΛŜŦ l λăύ2ℕè 2Ŧ ύKŜ 9fŜÖύℕλÖ ¦úλfλúè !dzύ2Υl·úλ2y´{ëăύŜYă,*" Electric Energy T&D Magazine,* !LJℕλf нлмлΣ оφçппΣ Kύύ LJΥκκǿǿǿφŜfŜÖύℕλÖŜyŜℕ∃ë2yfιyŜφÔ2ΥκăK2ǿψl·ℕύλÖfŜφLJKLJKΥl·∃Ґсоɜl·ℕύλÖfŜҐпфмφ

pп l φ [ŜŜ {Yλύ KΣ á! .ℕΛŜŦ l λăύ2ℕè 2Ŧ 9fŜÖύℕλÖ ¦úλfλúè !dzύ2Υl·úλ2y´{ëăύŜYăΣέ,*" Electric Energy T&D Magazine,* !LJℕλf нлмлΣ оφçппφ Kύύ LJΥκκǿǿǿφŜfŜÖύℕλÖŜyŜℕ∃ë2yfιyŜφÔ2ΥκăK2ǿψl·ℕύλÖfŜφLJKLJKΥl·∃Ґсоɜl·ℕύλÖfŜҐпфмφ

pp ² λffλl·Y tl·ℕ]ăΣ YŜØλy´[ëyŷΣ /l·ℕf LΥK2ŦŦΣ .Nël·y´l l·yŷŜ∃l·yΣ /Kl·ℕfŜă D2fŘΥl·yΣ WŜŦŦŜℕë 5l·∃fŜΣ W2Ky´Dℕ2ăKΣ ŜύlφfφΣ *Grid Modernization Multi-Year Program Plan* ó² l·ăKλyЭύ2yΣ 5 / Ύ 5ŜLJl·ℕύΥŜyύ 2Ŧ 9yŜℕ∃èΣ нлмрύΣ Kύύ LJăΥκκŜyŜℕ∃ë φ∃2ØκăλύŜăkLJN2ŘκŦλfŜăκнлмсклмκŦнукDℕλĚ ς нлa2ŘŜℕyλÎl·úλ2y ς нлa dzfúλπ ,Ŝl·ς нлtℕ2∃ℕl·Υ ς нлtfl·yφLJŘŦφ

pc !Řℕλl·y´.22ύKΣ bλ]2 a2KℕΣ l·yŘ tŜύŜℕ tŜύŜℕăΣ á¢KŜ 5λ∃λύl·f ¦úλfλúèΥ bŜǿ hLJLJ2ℕúdzyλύλŜă l·yŘ /Kl·ffŜyΞŜăΣέ aÔYλyãŜè ɜ /2YLJl·yêΣ a l·è нлмсΣ Kύύ LJΥκκǿǿǿφΥÔ]λyãŜè Ô2ΥκλyŘdzăύℕλŜăκŜfŜÖύℕλÖπLJ2ǿŜℕπl·yŘπyl·údzℕl·fπ∃l·ăκ2dzℕπλyãλ∃Kύăκύ KŜπŘλ∃λύl·fπdzύλfλúèπyŜǿπ 2LJLJ2ℕúdzyλύλŜăπl·yŘπÔKl·ffŜyΞŜă φ

[pt] a l·№ʅŜűă l·yŘ a l·№ʅŜűăΣ *Energy and Utility Analytics Market by Type, Application, Vertical, Deployment - Global Forecast to 2021* ó a l·№ʅŜűă l·yŘ a l·№ʅŜűăΣ {ŜLJúŜϒōŜ№ нлмсύΣ Kűűl Jϒκκǿǿǿ℗ϒ l·№ʅŜúǿ l·ΰÕK℗Ò2ϒkăú2№ëkŜyŜ№∃ëπ l·yŘπdzΰλfΩûëπ l·yJ·fëúλÕăπϒ l·№ʅŜúπ ǿ2№ûKπoπmπōλffλ2yπdzăŘπÕëπнлнмπнлмсπлфπмнπмонломм℗

[py] ! . . D№2dzLJΣ *Convergence of Information and Operation Technologies (IT & OT) to Build a Successful Smart Grid* ó½ŇЖÕKϒ ! . .Σ нлмрύΣ Kűűl JϒκκyŜǿ℗l·ōō℗Ò2ϒkŘ2Õăkfλō№l·K№ŠăLJ№2Ø℠ŘŜ№moфkŘŜŦl·dzfűπŘ2Ôdzϒŝyűπfλō№l·№ëkǿLJπмнψÔ2yØŜ№∃ŜyÕŜπλúπ2úπăϒ l·№ûπ ∃№ŘΩLJŘŦKăŦØ№ăyΓн℗

[pф] wl·Øλ Yl·№yl·Ř l·yŘ adz№l·fλ /Kl·yŘ№l·Kl·ăl·yΣ á . dzλfŘλyЭ ûKŜ CdzúdzЖŜ {Yl·№ú ¦ûλfλûë ûK№2dz∃K L¢ h¢ LyűŜ∃№l·ûλ2y ç [ŜØŜ№l·∃λyЭ l·y ! ăăŜú LyŦ2№Yl·ûλ2y a l·yl·∃ŜYŝyű C№l·YŜǿ2№ʅΣé ¢l·úl· /2yãdzfúl·yÕë {Ŝ№ØλÕŜăΣ нлмрΣ Kűűl Jϒκκǿǿǿ℗úÕă℗Ò2ϒkŜyЭλyŜŜ№ΩyЭπăŜ№ØλÕŜăκ№ŜfIl·úŜŘπ λyãλ∃KűăκtI·∃Ŝăκ . dzλfŘλyЭπCdzűdz№Ŝπ{Yl·№ûπ ¦ûλfλûëπL¢πh¢πLyűŜ∃№l·ûλ2y℗l·ăLJÈ℗

[cл] ¢KŜ 9Řλă2yˇC2dzyŘl·ûλ2yˇLyãúλúdzúŜ Ŧ2№ 9fŜÕú№ΩÕ LyŷŸ2Ø l·ûλ2yˇóL9LύΣ *Utility-Scale Smart Meter Deployments: Building Block of the Evolving Power Grid,* ó ² l·ăKλyЭű2yˇ5 /Y L9LΣ нлмпύΣ м℠ Kűűl Jϒκκǿǿǿ℗ŜŘλă2yŦ2dzyŘl·ûλ2y℗yŜúkλŜλkLJdzõfλÕ l·ûλ2yλăk52ÕdzϒŝyűăkL9Lψ{Yl·№ú a ŜúŜ№ ¦ LJŘl·úŜψлфмп℠LJŘŦ℗

[cм] 9yŜ№∃ë LyŦ2№Yl·ûλ2yˇ ! ŘYˇλyЯăú№l·ûλ2yΣ άC2№Yˇ 9L ! πусл ŘŜűl·λfŜŘ Řl·úl·,έ 9yŜ№∃ë LyŦ2№Yl·ûλ2yˇ ! ŘYˇλyЯăú№l·ûλ2yΣ fl·ăú dzLJŘl·úŜŘ hÕú2õŜ№ cΣ нлмсΣ Kűűl Jϒκκǿǿǿ℗Ŝλl·℗∃2ØkŜfŜÕú№ÕλúëκŘl·úl·κŜλl·усл℗

[ch] [λăl· {ÕKǿl·№úÎΣ a l·È ² ŜΣ ² λffλl·Y a2№№2ǿΣ WŜŦŦ 5Ŝl·ă2yΣ {úŜØŜyˇw℗ {ÕKλffŜ№Σ D№ŜЭ [ŜØŜyűλăΣ {l·№l·K {YˇλúKΣ Ŝű l·ŧ℗Σ *Electricity End Uses, Energy Efficiency, and Distributed Energy Resources Baseline* ó ² l·ăKλyЭűΩyΣ 5 /Y 5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëΣ нлмсύΣ 59π ! /лнπ лр/ l ммномΣ мр℗

[co] þb¸ t№ΛÎŜΣþ bŜø ¸2№ʅ {úl·úŜ 9yŜ№∃ë wŜăŜl·№ÕK l·yŘ 5ŜØŜf2LJYˇŜyű ! dzúK2№úëΣ fl·ăú dzLJŘl·úŜŘ hÕú2õŜ№ мнΣ нлмсΣ Kűűl Jăϒκκǿǿǿ℗yëăŜ№Řl·℗yë℗∃2Øk ! ffπt№2∃№l·Yˇăκt№2∃№l·Yˇăκb¸πt№ΛÎŜ℗

[cn] ά aλÕ№2∃№ΛŘ t№2∃№l·YˇΣé {úl·úŜ 2Ŧ /2yŷŜÕúλÕdzú 5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ë ϑ 9yØλ№2yϒŜyűl·f t№2úŜÕúλ2yΣ fl·ăú dzLJŘl·úŜŘ ! dz∃dzăú нлмсΣ Kűűl Jϒκκǿǿǿ℗Õú℗∃2ØkŘŜŜLJκÕǿLJκØλŜǿ℗l·ăLJKl·Γпмнлϑvlˇрлутул℗

[cp] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ {ŜLJúŜϒōŜ№ нлмрύΣ стΣ Kűűl JϒκκŜyŜ№∃ë℗∃2ØkăλúŜăκLJ№2ŘκŦλfŜăκнлмрклфкŦнскvdzl·Ř№ŜyŷλI·fπ ¢ŜÔKy2f2∃ëπwŜØλŜǿπнлмрψлℓLJŘŦ℗

[cc] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ 5ŜÔŜϒōŜ№ нлмпύΣ λλçØΣ Kűűl Jăϒκκǿǿǿ℗aYˇl·№úЭ№ΛŘ℗∃2ØκŦλf Ŝăκ . pψŘ№l·TúψЖŜLJ2№ûπмнπмуπнлмп℠LJŘŦ℗

[ct] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *Voltage and Power Optimization Saves Energy and Reduces Peak Power* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ {ŜLJúŜϒōŜ№ нлмрύΣ пΣ Kűűl Jăϒκκǿǿǿ℗aYˇl·№úЭ№ΛŘ℗∃2ØkŘ2ÕdzYˇŜyűk±2fúl·∃Ŝπt2ǿŜ№πhLJúλYˇλÎl·úλ2yπ{l·ØŜăπ9yŜ№∃ëπwŜŘdzÕŜăπtŜl·]π t2ǿŜ№℗KúYf℗

[cy] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *Synchrophasor Technologies and their Deployment in the Recovery Act Smart Grid Programs* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ ! dz∃dzăú нлмоύΣ мçрΣ Kűűl Jăϒκκǿǿǿ℗aYˇl·№úЭ№ΛŘ℗∃2ØκŦλfŜăκ{ëyÕK№2LJKl·ă2№ψwŜLJ2№ûψлуψлфψнлмоψ5h9ψнψØŜ№ăλ2yψл℗LJŘŦ℗

[cф] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *The American Recovery and Reinvestment Act Smart Grid Highlights* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ hÕú2õŜ№ нлмпύΣ срçстΣ Kűűl JϒκκŜyŜ№∃ë℗∃2ØkăλúŜăκLJ№2ŘκŦλfŜăκнлмпкмнκŦмфк{DŁD{D5tπlλ∃KfλЭKűăπhÕú2õŜ№нлмп℠LJŘŦ℗

[тл] W2ăŜLJK tl·fl·ŘλyΣ þ¢2 l· 5λ∃λúl·fΣ LyűŜ∃№l·ûŜŘ D№ΛŘΣþ *T&D World Magazine*Σ CŜõ№dzl·№è cΣ нлмсΣ KűűL JϒκκűŘǿ2№ŦŘ℗Õ2ϒkλ∃№ΛŘπ2LJúπăϒ l·№ûπ ∃№ΛŘκŘλ∃λúl·fπλyűŜ∃№l·ûŜŘπ∃№ΛŘ℗

[тм] ó5h9ú 5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ë℗ нлмс t№2ΣŜÔú t2№ûŦ2fλ2Σ óD№ΛŘ a2ŘŜ№yλÎl·ûλ2yˇ[l·õ2№l·û2№è /2yã2№ûλdzYˇY нлмсú Kűűl Jăϒκκ∃№ΛŘYˇ2Ř℗fl·ōǿ2№ʅă℗2№∃κăλúŜăκŘŜŦl·dzfűκŦλfŜăκŘ2ÔdzYˇŜyűăκD a [/ψt2№ûŦ2fλ2ψ . №2ÕKdz№Ŝπb9 ² м℗LJŘŦ

[тн] ó5h9ú 5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ë℗ нлмс t№2ΣŜÔú t2№ûŦ2fλ2Σ óD№ΛŘ a2ŘŜ№yλÎl·ûλ2yˇ[l·õ2№l·û2№è /2yã2№ûλdzYˇY нлмсú Kűűl Jăϒκκ∃№ΛŘYˇ2Ř℗fl·ōǿ2№ʅă℗2№∃κăλúŜăκŘŜŦl·dzfűκŦλfŜăκŘ2ÔdzYˇŜyűăκD a [/ψt2№ûŦ2fλ2ψ . №2ÕKdz№Ŝπb9 ² м℗LJŘŦ

[то] 5h9 ó5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëύΣ *Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure* ó ² l·ăKλyЭű2yΣ 5 /Y 5h9Σ ! LJ№λf нлмрύΣ оπоΣ Kűűl JϒκκŜyŜ№∃ë℗∃2ØkăλúŜăκLJ№2ŘκŦλfŜăκнлмрκлукŦнрκv9ψ℠ нл /Kl·LJúŜ№℠ нлŁ℠ нл9fŜÕú№ÕλúË℠ нл ! LJ№λf℠ нлнлмр℗LJŘŦ℗

[тп] W$ŦŦ№Ŝë [2∃l·yΣ YŜyŷŜűK .℗ aŜŘf2Õʅ ŁŁΣ l·yŘ ² λffλl·Y /℗ .2ëŘΣ *A Review of Sector and Regional Trends in U.S. Electricity Markets: Focus on Natural Gas* óD2fŘŜyΣ /hY bl·ûλ2yl·f wŜyŜǿl·ōfŜ 9yŜ№∃ë [l·õ2№l·û2№ëΣ hÕú2õŜ№ нлмрύΣ bw9[κ¢t πc ! рлπспсрнΣ оуΣ Kűűl Jϒκκǿǿǿ℗y№Ŝf℗∃2ØkŘ2ÕăκŦëмс2ăûλкспсрн℗LJŘŦ℗

[тр] 9L ! ó9yŜ№∃ë LyŦ2№Yl·ûλ2yˇ ! ŘYˇλyЯăú№l·ûλ2yύΣ *Annual Energy Outlook 2016 With Projections to 2040* ó ² l·ăKλyЭű2yΣ 5 /Y 5ŜLJl·№úYˇŜyű 2Ŧ 9yŜ№∃ëΣ 9L ! Σ нлмсύΣ 5h9κ9L ! πлоуоóнлмсύΣ Kűűl Jϒκκǿǿǿ℗Ŝλl·℗∃2Øκ2dzúf22ʅăκl·Ŝ2κLJŘŦκлоуоóнлмсú℗LJŘŦ℗

[tc] t l·dzf 5Ø2ℕl·ℓΣ ђ/9h 2ŦΛ/ l·fλŦ2ℕyλl· L{h ăŜŜă pƒ{ĵ≥ ℕŜyŜǿl·ōfŜ ŜyŜℕ∃è LJŜyŜúℕl·úλ2y´l·yŘ Y´2ℕŜΣђ *Windpower Engineering & Developmen*tΣ WdzyŜ cΣ нлмсΣ KúúLJɣккǿǿǿ◊λyŘLJ2ǿŜℕŜyƎλySŜℕλyƎ◊Ò2Yκŧ$l·údzℕŜŘkǿdzăλySăăπyŜǿăπLJℕ2≥ŜÒúăkÒŜ2πÒl·fλŦ2ℕyλl·πλă2π ăŜŜăπpлπℕŜyŜǿl·ōfŜπŜyŜℕ∃èπLJŜyŜúℕl·úλ2y◊

[tt] !wt !π9 ó!ŘØl·yÒŜŘ wŜăŜl·ℕÒK tℕ2≥ŜÒúă !∃ŜyÒèπ9yŜℕ∃èúΣ *NODES Program Overview,* ó² l·ăKλyƎú2yΣ 5/ɣ 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ !wt !π9úΣ pΣ l·ÒÒŜăăŜŘ 5ŜÔŜYˆōŜℕ мнΣ нлмсΣ KúúLJăɣккl·ℕLJl·π Ŝ◊ŜyŜℕ∃è◊∃2ØkăλúŜăkŘŜŦl·dzfúkŦλfŜăkŘ2ÒdzYˆŜyfăkŦλfŜăkbh59{ψtℕ2∃ℕl·Yˆh ØŜℕØλŜǿ◊LJŘŦ◊

[ty] *Order Instituting Rulemaking Regarding Policies, Procedures and Rules for the California Solar Initiative, the Self Generation Incentive Program and Other Distributed Generation Issues*Σ wdzfŜYˆl·ℓλyƎ мнπммπллрΣ tdzōfλÒ ¦úλfúλŜă /2YˆYˆăăλ2yˆ2Ŧ úKŜ {úl·úŜ 2Ŧ /l·fλŦ2ℕyλl· óbƵØŜYˆōŜℕ cΣ нлмпúΣ KúúLJɣккŘ2Ôă◊ÒLJdzÒ◊Ò l·◊∃2Øk tdzōfλăKŜŘ52Ôăk tdzōfλăKŜŘkDллл к а мпмкYммркмпммрлтп◊t5C◊

[tф] ά5λăúℕλōdzúŜŘ wŜă2dzℕÒŜ 9yŜℕ∃è !yl·fèăλă l·yŘ a l·yl·∃ŜYˆŜyú {èăúŜY´ ó5w9! a{ú 5ŜØŜf2LJYˆŜyú Ŧ2ℕ wŜl·fπ¢λYˆŜ DℕλŘ hLJŜℕl·úλ2yãΣé 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ hŦŦλÒŜ 2Ŧ 9yŜℕ∃è 9ŦŦλÒλŜyÒè l·yŘ wŜyŜǿl·ōfŜ 9yŜℕ∃èΣ {dzy{K2ú LyλúλI·úλØŜΣ I·ÒÒŜăăŜŘ hÒú2ōŜℕ oмΣ нлмсΣ KúúLJɣккŜyŜℕ∃è◊∃2ØkŜŜℕŜkădzyãK2ůkŘλăúℕλōdzúŜŘπℕŜă2dzℕÒŜπŜyŜℕ∃èπl·yl·fèăλănl·yŘπYl·yl·∃ŜYˆŜyúπăèăúŜY´πŘℕŜl·Yˆăπ ŘŜØŜf2LJYˆŜyúπℕŜl·fπ úλYˆŜ◊

[yл] 9L! ó¦◊{◊ 9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ *Average utilization for natural gas combined-cycle plants exceeded coal plants in 2015* ó¢2Řl·è λy´9yŜℕ∃èɣ ² l·ăKλyƎú2yΣ 5◊/◊ÙΣ KúúLJɣккǿǿǿ◊Ŝλl·◊∃2Økú2Řl·èλySyŜℕ∃èkŘŜúl·λf◊LJKLJKλŘΓнрсрн

[yм] 9L! ó9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ *Annual Energy Outlook 2016 With Projections to 2040* ó² l·ăKλyƎú2yΣ 5/ɣ 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ 9L!Σ !dz∃dzăú нлмсúΣ 5h9к9L!πлоуоóнлмсúΣ a¢πмрΣ KúúLJɣккǿǿǿ◊Ŝλl·◊∃2Øk2dzúf22ˆ]ăkl·Ŝ2kLJŘŦклоуоóнлмсú◊LJŘŦ◊

[yн] 9L! ó9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ *Annual Energy Outlook 2016 With Projections to 2040* ó² l·ăKλyƎú2yΣ 5/ɣ 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ 9L!Σ !dz∃dzăú нлмсúΣ 5h9к9L!πлоуоóнлмсúΣ a¢πмрΣ KúúLJɣккǿǿǿ◊Ŝλl·◊∃2Øk2dzúf22ˆ]ăkl·Ŝ2kLJŘŦклоуоóнлмсú◊LJŘŦ◊

[yo] 5h9 ó5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èúΣ *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* ó² l·ăKλyƎú2yΣ 5/ɣ 5h9Σ {ŜLJúŜYˆōŜℕ нлмрúΣ yнΣ KúúLJɣккŜyŜℕ∃è◊∃2ØkăλúŜăkLJℕ2ŘkŦλfŜăknлмрклфкŦнскvdzl·Řℕŝyƴλl·fπ ¢ŜÔKy2f2∃èπwŜØλŜǿπнлмрψл◊LJŘŦ◊

[yп] 9L! ó9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ *Annual Energy Outlook 2016 With Projections to 2040* ó² l·ăKλyƎú2yΣ 5/ɣ 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ 9L!Σ !dz∃dzăú нлмсúΣ 5h9к9L!πлоуоóнлмсúΣ a¢πмрΣ KúúLJɣккǿǿǿ◊Ŝλl·◊∃2Øk2dzúf22ˆ]ăkl·Ŝ2kLJŘŦклоуоóнлмсú◊LJŘŦ◊

[yp] 5h9 ó5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èúΣ *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* ó² l·ăKλyƎú2yΣ 5/ɣ 5h9Σ {ŜLJúŜYˆōŜℕ нлмрúΣ pcΣ KúúLJɣккŜyŜℕ∃è◊∃2ØkăλúŜăkLJℕ2ŘkŦλfŜăknлмрклфкŦнскvdzl·Řℕŝyƴλl·fπ ¢ŜÔKy2f2∃èπwŜØλŜǿπнлмрψл◊LJŘŦ◊

[yc] 5h9 ó5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èúΣ *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* ó² l·ăKλyƎú2yΣ 5/ɣ 5h9Σ {ŜLJúŜYˆōŜℕ нлмрúΣ pф Σ KúúLJɣккŜyŜℕ∃è◊∃2ØkăλúŜăkLJℕ2ŘkŦλfŜăknлмрклфкŦнскvdzl·Řℕŝyƴλl·fπ ¢ŜÔKy2f2∃èπwŜØλŜǿπнлмрψл◊LJŘŦ◊

[yт] w2ŘŜℕλÒ]ℓ Wl·Ò]ăλ2yΣ hYˆŜℕ /◊ hyl·ℕΣ l l·ℕ2fŘ Yℕλ]ĸl·YΣ 9Yˆλfè CλăĸŜℕΣ Yfl·ŜKyˆ.dzℕ]ŜăΣ aλÒKl·Ŝf {úl·ℕ]ŜΣ hfl·Yl· a2Kl·YYˆŜŘΣ Ŝú l·f◊Σ *Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System* óhl·] wλŘ∃ŜΣ ¢bƴ hl·] wλŘ∃Ŝ bl·úλ2yl·f [l·ō2ℕl·ú2ℕèΣ нлмрúΣ hwb[к¢aπнлмркрΣ oçτΣ KúúLJăɣккŜyŜℕ∃è◊∃2ØkăλúŜăkLJℕ2ŘkŦλfŜăknлмрклпкŦннкv9ŵ≥ нл!yl·fèăλă[≥ нлπ ≥^≥ нлhLJLJ2ℕúdzyλúλŜă≥ нлŦ2ă≥ нл9yŜℕ∃ë≥ нл9ŦŦλÒλŜyÒë≥ нлLYˆLJℕ2ØŜYˆŜyúă≥ нлλy≥ нлúKŜ≥ нл¦ă≥ нл9fŜÔúℕλÒλúë≥ нл¢ℕl·yãYˆăăλ2y≥ нл l·yŘ≥ нл5λăúℕλōdzúλ2y≥ нл{èăúŜYψл◊LJŘŦ◊

[yy] 5h9 ó5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èúΣ *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* ó² l·ăKλyƎú2yΣ 5/ɣ 5h9Σ {ŜLJúŜYˆōŜℕ нлмрúΣ poçpc◊ KúúLJɣккŜyŜℕ∃è◊∃2ØkăλúŜăkLJℕ2ŘkŦλfŜăknлмрклфкŦнскvdzl·Řℕŝyƴλl·fπ ¢ŜÔKy2f2∃èπwŜØλŜǿπнлмрψл◊LJŘŦ◊

[yф] 9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ ά9fŜÔúℕλÒ LJ2ǿŜℕ ălŦfŜăΣ ℕŜØŜyƵzŜΣ l·yŘ ŜyŜℕ∃è ŜŦŦλÒλŜyÒè C2ℕYˆ 9L! πycм ŘŜúl·λfŜŘ Řl·úl· ŦλfŜăΣé 9yŜℕ∃è LyŦ2ℕYˆl·úλ2y´!ŘYˆλyλăúℕl·úλ2yÙΣ fl·ăú dzLJŘl·úŜŘ hÒú2ōŜℕ cΣ нлмсΣ KúúLJăɣккǿǿǿ◊Ŝλl·◊∃2ØkŜfŜÒúℕλÒλúëkŘl·úl·kŜλl·ycмk◊

[фл] .f22YˆōŜℕ∃ [◊t◊Σ á!yƴƵzl·fÒl·LJλúl·fŜĖLJŜyŘλúdzℕŜăΣ ŘŜLJℕŜÒλl·úλ2yΣ l·yŘ yŜú Òl·LJλúl·fl·ŘŘλúλ2yã Ŧ2ℕ фy fl·ℕ∃Ŝ dzúλfλúè 2LJŜℕl·úλyƎ Õ2YˆLJl·yλŜăΣ нллп π нлмрΣé l·ÒÒŜăăŜŘ bƵØŜYˆōŜℕ oΣ нлмс◊

[фм] 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ hŦŦλÒŜ 2Ŧ 9yŜℕ∃è t2fλÒè l·yŘ {èăúŜY´ă !yl·fèăλăΣ нлмс◊

[фн] 5ŜLJl·ℕúYˆŜyú 2Ŧ 9yŜℕ∃èΣ hŦŦλÒŜ 2Ŧ 9yŜℕ∃è t2fλÒè l·yŘ {èăúŜY´ă !yl·fèăλăΣ нлмс◊

[фо] bw9[óbl·úλ2yl·f wŜyŜǿl·ōfŜ 9yŜℕ∃è [l·ō2ℕl·ú2ℕèúΣ *Advanced Inverter Functions to Support High Levels of Distributed Solar: Policy and Regulatory Considerations* óDƵfŘŜyΣ /hƴ bw9[Σ нлмпúΣ pΣ KúúLJɣккǿǿǿ◊yℕŜf◊∃2ØkŘ2Ôăkŧèmp2ăúλкснсмн◊LJŘŦ◊

фп 9ф 9fI·Σ ±ф DŜØ2ℕ∃ΛI·yΣ tф CfŜYʹλyΣ ¸ф/ф ½KI·yΣ aф {λyΣKΣ 9ф aʤfƫI·ŘΛΣ !ф {ŎK2fōℕ22ʾΣ ŜΰI·fƫΣ *Active Power Controls from Wind Power: Bridging the Gaps* óD2fŘŜyΣ / hʏ bI·ΰΛ2yʾI·f wŜyŜøI·ōfŜ 9yŜℕ∃è [I·ō2ℕI·ΰ2ℕèΣ нлмпΰΣ bw9[кȼtπ5рллπслртпΣ ØΛΣ KΰΰLJʏккøøøфyℕŜƫ∋2ØкŘ2ŎăкŦèмп2ăΰΛкслртпфLJŘŦф

фр .2ƫʤzyʾ·ʤzΣ ¸ʤzℕè 5Ø2ℕʾλyΣ 5I·yΛŜf {ф YℕăÔKŜyΣ /ф!ф {λfØI·л a2yℕ2èΣ I·yŘ ℕŜI·yπtI·ʤzf ² I·ΰă2yΣ á! /2YʹLJI·ℕăă2yʾ2Ŧ t2fƫÔΛŜă 2yʾΰKŜ tI·ℕΰΰÔΛLJI·ΰΛ2yʾ2Ŧ {ΰ2ℕI·∃Ŝ λyʾ¦ф{ф CℕŜIjʤzŜyÔè wŜ∃ʤzfI·ΰΛ2yʾ aI·ℕʾŜΰăΣέ L999 tΣøŜℕ 9fŜÔΰℕ2yΛÔă {2ÔΛŜΰè DŜyŜℕI·f aŜŜΰλyΣI нлмсΣ KΰΰLJăʏккI·ℕĚλØ©2ℕ∃кLJŘŦкмслнфлппнлфLJŘŦф

фс {Ô2ΰΰ tф .ʤzℕ∃ŜℕI·yŘ aI·È [ʤzʾŜΣ *Business Models for Distributed Energy Resources: A Review and Empirical Analysis: An MIT Energy Initiative Working Paper* ó/I·YŌℕĂŘ∋ŜΣ a!ʏ aL¢Σ !LJℕăf нлмсΰΣ pΣ KΰΰLJʏккŜyŜℕ∃ètYʾλΰ©ŜŘʤzкøLJπ Ô2yΰŜyΰkʤzLJf2I·Řăкнлмскплк aL¢9Lπ ² tπнлмсπлн©LJŘŦф

фт YŜyʾ/2ăΰŜff2Σ þ¢KŜ /KI·ffŜyƎSă 2Ŧ bŜø 9fŜÔΰℕΛÔΰè /ʤzăΰ2YʹŜℕ 9yƎI·ƎŜYʹŜyΰ Ŧ2ℕ ¦ΰλfƫΰΛŜă I·yŘ {úI·ΰŜ wŜ∃ʤzfI·ΰ2ℕăþ óLJℕŜăŜyΰŜŘ I·ΰ bwwL ² ŜôλyʾI·ℕΣ hÔΰ2ōŜℕ нсΣ нлмсΰΣ KΰΰLJʏккyℕℕ⊗2ℕ∃кøLJπÔ2yΰŜyΰkʤzLJf2I·Řăкнлмскмлкbwwlπ ² ŜôλyʾI·ℕπhÔΰ2ōŜℕπнсπнлмсπ/2ăΰŜff2©LJŘŦф

фу t! /2yãʤzfΰλyΣ *Delivering the Next Generation Utility Customer Experience* óbŜø ¸2ℕʾʏ t! /2yãʤzfΰλyΣ нлмсΰΣ пπсΣ KΰΰLJʏккøøø©LJI·Ô2yãʤzfΰλyƎ©Ô2Yʹк2ʤzℕπΰKʎyʾλyƎкyŜĚΰπƎŜyŜℕI·ΰΛ2yñʤzΰΛƫΰĕф

фф !fI·yʾDℕŜŜyŏfI·ΰΰΣ άwʤzℕI·f !ℕŜI·ă [2ăŜ tŜ2LJfŜ .ʤzΰ b2ΰ t2øŜℕΣé *Governing the States and Localities*Σ !LJℕăf нлмпΣ KΰΰLJʏккøøø©∃2ØŜℕyʎyƎ©Ô2YʹкΰΣ2LJŌăкLJ2fƫΛÔăк∃2Ø℘ℕʤzℕI·ƭπI·ℕŜI·ăπf2ăŜπLJŜ2LJfŜπy2ΰπLJ2øŜℕ©KΰYʹf

млл !fƫŌλI· Iф aʤzyŷŜffΣ á¢KŜ LʏʹLJI·Ŏΰ 2Ŧ !∃λyƎ .I·ōè .22YʹŜℕă 2yʾ[I·ō2ℕ C2ℕŌŜ tI·ℕΰΛÔΛLJI·ΰΛ2yΣé *Center for Retirement Research at Boston College*Σ y2ф мпπп óнлмпύʏ пΣ KΰΰLJʏккŌℕℕ⊗ŏÔ©ŜŘʤzкøLJπÔ2yΰŜyΰkʤzLJf2I·Řăкнлмпклнк L.ψмππп©LJŘŦф

млм /9 ² 5 ó/ŜyΰŜℕ Ŧ2ℕ 9yŜℕ∃è ² 2ℕʾŦ2ℕŌŜ 5ŜØŜf2LJYʹŜyΰΰΣ *Gaps in the Energy Workforce Pipeline: 2015 CEWD Survey Results* ó² I·ăKΛyƎΰ2yΣ 5/ʏ /9 ² 5Σ нлмрύΣ oΣ KΰΰLJʏкøøø©ŌŜøŘ©2ℕ∃кăʤzℕØŜĚℕŜLJ2ℕΰк/9 ² 5нлмр{ʤzℕØŜè{ʤzYʹYI·ℕĚ©LJŘŦф

млн t! /2yãʤzfΰλyΣ *The Nimble Utility: Creating the Next Generation Workforce* ót! /2yãʤzfΰλyΣ нлмсΰΣ нлΣ KΰΰLJʏккøøø©LJI·Ô2yãʤzfΰλyƎ©Ô2Yʹк2ʤzℕπΰKʎyʾλyƎкyŜĚΰπƎŜyŜℕI·ΰΛ2yñʤzΰΛƫΰĕкIKŜℕŜф

мло 5ŜyŷΛă wI·ĕΣ άwŜăLJ2yŘλyƎ ΰ2 /KI·yƎλyƎ ² 2ℕʾŦ2ℕŌŜ bŜŜŘă I·yŘ /KI·ffŜyƎŜăþ óLJℕŜăŜyΰI·ΰΛ2yʾƎλØŜyʾI·ú úKŜ !∃λyƎ ¦ΰλfƫΰè ² 2ℕʾŦ2ℕŌŜ /2yŦŜℕŜyÔŜΣ bI·ăKØλffŜΣ ¢ŜyŷŜăăŜŜΣ b2ØŜYʹŌŜℕ муçмфΣ нлмоΰΣ KΰΰLJʏккLJăŜℕÔ©øλăÔ©ŜŘʤzкŘ2ÔʤzYʹŜyΰăкLJʤzōƫÔI·ΰΛ2yãкăLJŜÔλI·fψλyΰŜℕŜăΰψLJʤzōƫÔI·ΰΛ2yãкø2ℕʾŦ2ℕŌŜкŘℕI·ĕψI·∃λyƎψʤzΰλfƫΰèψø2ℕʾŦ2ℕŌŜψy2Øψнлмо©LJŘŦф

млп ¦ΰλfƫΰè 5λØŜΣ *2016 State of the Electric Utility Survey* ó¦ΰλfƫΰè 5λØŜΣ нлмсΰΣ фΣ KΰΰLJăʏккăо©I·YI·Î2yI·øăфÔ2YкŘλØŜψI·ăăŜΰăкℕfLJăĕăкăΰI·ΰŜψ2ŦψŜfŜÔΰℕÔψʤzΰΛƫΰèψнлмс©LJŘŦф

мlр aI·ʾ .ℕΛŘ∃ŜℕăΣ á²K2 ²λff 52 ΰKŜ ² 2ℕʾŦ2ℕŌŜ bŜŜŘă I·yŘ /KI·ffŜyƎŜăþ óLJℕŜăŜyΰI·ΰΛ2yʾƎλØŜyʾI·ú úKŜ !∃λyƎ ¦ΰλfƫΰè ² 2ℕʾŦ2ℕŌŜ {ʤzLJLJfĕ Øă© 5ŜYI·yŘé óLJℕŜăŜyΰI·ΰΛ2yʾƎλØŜyʾI·ú úKŜ bI·ΰΛ2yI·f !ăă2ÔλI·ΰΛ2yʾ2Ŧ wŜ∃ʤzfI·ΰ2ℕè ¦ΰλfƫΰè /2YʹYλăăΛ2yŜℕăΣ {ʤzYʹYʹŜℕ /2YʹYʹλΰΰŜŜ aŜŜΰλyƎăΣ bI·ăKØλffŜΣ ¢ŜyŷŜăăŜŜΣ Wʤzfĕ нсΣ нлмсΰΣ KΰΰLJʏккLJʤzōă©yI·ℕʤzÔ©2ℕ∃кLJʤzōкол.5/фсрπ.лмоπСн9тπ9п..π5.5т!с9мфСон©

млс 9t! ó9yØλℕ2yʹYŜyΰI·f tℕ2ΰŜÔΰΛ2yʾ!∃ŜyÔèΰΣ *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014* ó² I·ăKΛyƎΰ2yΣ 5/ʏ 9t!Σ !LJℕăf нлмсΰΣ 9t! полπwπмсπллнΣ 9{πноΣ KΰΰLJăʏккøøø©ŜLJI·©∃2ØкÔfIʏI·ΰŜÔKI·yƎŜk52øyf2I·ŘăкƎKƎŜʏʾλăăΛ2yăк¦{πDIDπ LyØŜyΰ2ℕèπнлмсπаI·λyπ¢ŜĚΰ©LJŘŦф

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млу 9L! ó9yŜℕ∃è LyŦ2ℕʏI·ΰΛ2yʾ!ŘʏλyΛăΰℕI·ΰΛ2yΰΣ *U.S. Energy-Related Carbon Dioxide Emissions, 2014* ó² I·ăKΛyƎΰ2yΣ 5/ʏ 9L!Σ b2ØŜYʹŌŜℕ нлмрύΣ мнΣ KΰΰLJʏккøøø©ŜΛI·©∃2ØкŜyØℕ2yʏŜyΰкŜYʹλăăΛ2yăкÔI·ℕō2yкLJŘŦкнлмпψÔ2нI·yI·fĕăΛă©LJŘŦф

млф 9L! ó9yŜℕ∃è LyŦ2ℕʏI·ΰΛ2yʾ!ŘʏλyΛăΰℕI·ΰΛ2yΰΣ *Annual Energy Outlook 2015 With Projections to 2040* ó5ŜLJI·ℕΰʏŜyΰ 2Ŧ 9yŜℕ∃èΣ 9L!Σ нлмрύΣ 5h9к9L!плоуоónлмрύΣ уΣ KΰΰLJʏккøøø©ŜΛI·©∃2Ø℘2dzΰf22ʾăкI·Ŝ2кLJŘŦклоуоónлмрύ©LJŘŦф

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ммм 9L! ó9yŜℕ∃è LyŦ2ℕʏI·ΰΛ2yʾ!ŘʏλyΛăΰℕI·ΰΛ2yΰΣ *Annual Energy Outlook 2016 With Projections to 2040* ó² I·ăKΛyƎΰ2yΣ 5/ʏ 5ŜLJI·ℕΰʏŜyΰ 2Ŧ 9yŜℕ∃èΣ 9L!Σ нлмсΰΣ 5h9к9L!плоуоónлмсΰΣ CΛ∃ʤzℕŜ aφπнтΣ aφπмрΣ KΰΰLJʏккøøø©ŜΛI·©∃2Ø℘2dzΰf22ʾăкI·Ŝ2кLJŘŦклоуоónлмсΰ©LJŘŦф

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9yŘ ¦ ăŜăΣ 9yŜ№∃è 9ŦŦλÔλŜyÕèΣ I·yŘ 5λăúЖōdzúŜŘ 9yŜ№∃è wŜă2dz№ÕŜă . I·ăŜŧλyŜ ó ² I·ăKλyЭűƨyΣ 5 / Ƴ ¦◊{◊ 5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 9yŜ№∃èΣ нлмсúΣ мсоΣ 59π ! / лнπлр / I ммном◊

ммо 9L ! ó9yŜ№∃è LyŦ2№Ƴ I·ûλ2y´ ! ŘƳλyλăúЖI·ûλ2yűΣ *Monthly Energy Review* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 9L ! Σ ! dzЭdzăΰ нлмсúΣ 5h9к9L ! π ллорóнлмскyúΣ мурΣ Kΰΰ LJƳккǿǿǿ◊ŜλI·◊Э2ØkΰƨűI·fŜyŜ№∃èkŘI·úI·кƳ2yΰKfèkI·№ÕKλØŜkллормслу◊LJŘŦ◊

ммп 5h9 ó5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 9yŜ№∃èúΣ *Low Carbon Workshop Report* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 5h9Σ нлмсú◊

ммр 9L ! ó9yŜ№∃è LyŦ2№Ƴ I·ûλ2y´ ! ŘƳλyλăúЖI·ûλ2yűΣ *Electric Power Annual* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 9L ! Σ нлмрúΣ Kΰΰ LJƳккǿǿǿ◊ŜλI·◊Э2ØkŜfŜÔúЖÕλúèkI·yƳűzI·fk◊

ммс ² λffλI·Ƴ hLJI·f`]I·Σ áb◊9◊ w2dzyŘúI·ŒfŜ / 2yãλŘŜ№ă / I·№ō2y´ t№ЖÕλyЭΣ {ûI·ûŜ t t ! ăΣé *RTO Insider*Σ hÕú2ōŜ№ oΣ нлмсΣ Kΰΰ LJăƳккǿǿǿ◊№ú2λyãλŘŜ№◊Ô2Ƴ кyŜǿπŜyЭfI·yŘπ№ŜăúЖdzÕúdz№λyЭπ№2dzyŘúI·ŒfŜπÕI·№ō2yπLJЖÔλyЭπоннтмк◊

ммт ² Ŝă C№èŜΣ *Smart Grid: Transforming the Electricity System to Meet Future Demand and Reduce Greenhouse Gas Emissions* ó{I·y´W2ăŜΣ / ! Ƴ / λăÔ2 {èăúŜƳăΣ bƨØŜƳŒŜ№ нллуúΣ нçтΣ Kΰΰ LJƳккǿǿǿ◊ÔλăÕ2◊Ô2Ƴ кÔкŘI·Ƴ кЭf2ōI·fкŘŜψŘŜSкI·ăăŜΰăкÔλăÔ2yŷŜÕΰкнллфπ млкλƳI·ЭŜăк{ Ƴ I·№ΰψDЖλŘψ ² KλΰŜψt I·LJŜ№ψн◊LJŘŦ◊

мму / b ! aλfλΰI·№è ! ŘØλă2№è . 2I·№ŘΣ *National Security and Assured U.S. Electrical Power* ó / b ! ! yI·fèăλă ɜ {2fdzΰλ2yãΣ нлмрúΣ мΣ Kΰΰ LJăƳккǿǿǿ◊Ôy I·◊2№Эк / b ! ψŦλfŜăкt 5Ckb I·ûλ2yI·fπ{ŜÕdz№λúèπ ! ăădz№ŜŘπ9fŜÕΰ№λÕI·fπt ƨ2ǿŜ№◊LJŘŦ◊

ммф w2ōŜ№ΰ a◊ [ŜŜΣ aλÕKI·Ŝf W◊ ! ăăI·yΰŜΣ I·yŘ ¢λƳ / 2yǿI·ëΣ *Analysis of the Cyber Attack on the Ukrainian Power Grid: Defense Use Case* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 9fŜÕΰ№λÕλúè LyŦ2№Ƴ I·ûλ2y´{KI·№λyЭ I·yŘ ! yI·fèăλă / ŜyΰŜ№Σ a I·№ÕK нлмсúΣ λØΣ Kΰΰ LJăƳккλÕă◊ă I·yƨ◊2№ЭкƳ ŜŘλI·к9π L{ ! / ψ{ ! b{ψ ¦]№I·λyŜψ5 ¦ / ψp◊LJŘŦ◊

мнл {èƳI·yΰŜÕΣ *Advanced Persistent Threats: A Symantec Perspective, Preparing the Right Defense for the New Threat Landscape* ó a 2dzyΰI·λy´±λŜǿΣ / ! Ƴ {èƳI·yΰŜÕΣ нлммúΣ мΣ Kΰΰ LJăƳккǿǿǿ◊ăèƳI·yΰŜÕ◊Ô2Ƴ кÕ2yΰŜyΰкŜyKdzăкŜyΰŜ№LJ№ăŜкØKλΰŜψLJI·LJŜ№ăкō◊π I·ŘØI·yÕŜŘψLJŜ№ăλăΰŜyΰψúK№ŜI·ΰăψ ² t ψнмнмрфрт◊ŜyƬdză◊LJŘŦ◊

мнм *Hearing of the House (Select) Intelligence Committee on "Cybersecurity Threats: The Way Forward,"* ób2ØŜƳōŜ№ нлΣ нлмпú óΰŜăΰλƳ2yè õè ! ŘƳλ№I·f aλÕKI·Ŝf w2ƨŜ№ăΣ / 2ƳƳI·yŘŜ№Σ ¦◊{◊ / èõŜ№ / 2ƳƳI·yŘ I·yŘ 5Λ№ŜÕΰ2№Σ bI·ûλ2yI·f {ŜÕdz№úè ! ƨŜyÕè№Σ Kΰΰ LJăƳккǿǿǿ◊yãI·◊Э2ØkyŜǿăπŦŜI·ûdz№ŜăkăLJŜŜÕKŜăπΰŜăΰλƳ2yΰŜăкΰŜăΰλƳ2yΰπŜăкI·ŘƳπ№Э3Ŝ№ăπΰŜăΰλƳ2yè¤нлуƨØнлмп◊ăKΰƳ◊

мнн {Õ2ΰΰ I λfΰ2yΣ á5èy´ ! yI·fèăλă {dzƳƳI·№è 2Ŧ C№λŘI·è hÕΰ2ōŜ№ нм ! ΰΰI·Õ`]Σé *Dyn*Σ hÕΰ2ōŜ№ нсΣ нлмсΣ Kΰΰ LJƳккŘèyΦÔ2Ƴ кōf2ЭkŘèyπ I·yI·fèăλăπădzƳƳI·№è¤2Ŧ¤Ŧ№λŘI·è¤2Õΰƨ2ōŜ№¤нмπI·ΰΰI·Õ`]к◊

мно a I·№ΰè W2ăΰ I·yŘ aλÕKI·Ŝf /2ōõΣ *IIS Security* óbŜǿ ¸2№]Σ b¸Ƴ aÕD№I·ǿπ I λffkhăõ2№yŜΣ нллнúΣ ф◊

мнп LyŘdzăΰ№λI·f / 2yΰ№2f {èăΰŜƳă / èõŜ№ 9Y´Ŝ№∃ŜyÕè wŜăLJ2yãŜ ¢ŜI·Y´ óL / {π / 9w¢úΣ *Overview of Cyber Vulnerabilities,* Kΰΰ LJăƳккλÕăπ ÕŜ№Ωdzăπ ÕŜ№Ω◊∃ƨØkÕ2yΰŜyΰкƨØŜ№ØλŜǿπÕèõŜ№πØdzfyŜ№I·õλfΰΰλŜă I dzyŘŜ№

мнр áwI·ŘλI·ûλ2y´ t2№ΰI·f a2yλΰΰ2№ă {I·ŦŜ∃dzI·№Ř ! Y´Ŝ№λÕI· ŦЖ2Y´ bdzÕfŜI·№ 5ŜØλÕŜă I·yŘ wI·Řλ2f2∃λÕI·f aI·ΰŜ№λI·făΣé / dzăΰ2Y´ă I·yŘ . 2№ŘŜ№ t№2ΰŜÕΰλ2yΣ fI·ăΰ dzLJŘI·ûŜŘ bƨØŜƳŒŜ№ мнΣ нлмоΣ Kΰΰ LJăƳккǿǿǿ◊ÕŒLJ◊Э2ØkŒ2№ŘŜ№ŦăŜÕdz№λΰèkLJ2№ΰŦŜyΰ№èkÕI·№Э2ŦăŜÕdz№λΰèkÕI·№Э2π ŜÈI·Y´k№I·ŘŦLJ2№ΰI·fм◊

мнс CλÈλyЭ ! Y´Ŝ№λÕI·ΩăΣ / dz№ŦI·ÕŜ ¢№I·yãLJ2№ΰI·ûλ2y´ ! ÕΰΣ t dzŒ◊ [◊ b2◊ ммπфп óнлмрúΣ Kΰΰ LJăƳккǿǿǿ◊Ô2yЭ№ŜăăΦЭ2ØkммпkŒλffăkK№ннк . L[[{π ммпK№ннŜyΰ◊LJŘŦ◊

мнт 5h5 ó5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 5ŜŦŜyãŜΣ *The DOD Cyber Strategy* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 5h5Σ нлмрúΣ тΣ Kΰΰ LJƳккǿǿǿ◊ŘŜŦŜyãŜ◊Э2Øкt2№ΰI·făкмкŦŜI·ûdz№ŜăкнлмрклпмрψÕèõŜ№πăΰ№I·ΰŜЭèkCλyI·fψнлмрψ525ψ/ ¸ . 9wψ{¢w ! ¢9D ¸ψŦ2№ΰψǿŜō◊LJŘŦ◊

мну 5{ . ó5ŜŦŜyãŜ {ÕλŜyÕŜ . 2I·№ŘΣ *Report of the Defense Science Board on DoD Energy Strategy: "More Fight – Less Fuel"* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ hŦŦλÕŜ 2Ŧ ΰKŜ ¦ yŘŜ№ {ŜÕ№ŜΰI·№è 2Ŧ 5ŜŦŜyãŜ Ŧ2№ ! Õljdzλăλΰΰλ2yΣ ¢ŜÕKyƳ2f2∃èΣ I·yŘ [2∃λăΰλÕă I·yŘ 5{ .Σ нллуúΣ муΣ Kΰΰ LJƳккǿǿǿ◊I·Ôlj◊2ăŘ◊Y´λfкŘăōк№ŜLJ2№ΰăк ! 5 ! пттсмф◊LJŘŦ◊

мнф 5h5 ó5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 5ŜŦŜyãŜΣ *Department of Defense Annual Energy Management Report: Fiscal Year 2015* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 5h5Σ hŦŦλÕŜ 2Ŧ ΰKŜ ! ăăλăΰI·yΰ {ŜÕ№ŜΰI·№è 2Ŧ 5ŜŦŜyãŜΣ WdzyŜ нлмсúΣ пфΣ Kΰΰ LJƳккǿǿǿ◊I·Ôlj◊2ăŘ◊Y´λfкŜλŜк52ǿyƒ2I·ŘăкL9кCâ^ã нлнлмβ^ã нл ! 9 a w◊LJŘŦ◊

мол 5h5 ó5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 5ŜŦŜyãŜΣ *Department of Defense Annual Energy Management Report: Fiscal Year 2015* ó ² I·ăKλyЭűƨyΣ 5 / Ƴ 5h5Σ hŦŦλÕŜ 2Ŧ ΰKŜ ! ăăλăΰI·yΰ {ŜÕ№ŜΰI·№è 2Ŧ 5ŜŦŜyãŜΣ WdzyŜ нлмсúΣ пфΣ Kΰΰ LJƳккǿǿǿ◊I·Ôlj◊2ăŘ◊Y´λfкŜλŜк52ǿyƒ2I·ŘăкL9кCâ^ã нлнлмβ^ã нл ! 9 a w◊LJŘŦ◊

мом *Hearing before the Committee on Energy and Commerce Subcommittee on Energy and Power* ó a I·è oмΣ нлммú ó№ŜƳI·№`]ă õè ΰKŜ I 2yƨ№I·õŦŜ t I·dzf {ΰ2Õ`]ΰ2yΣ ! ăăλăΰI·yΰ {ŜÕ№ŜΰI·№è 2Ŧ 5ŜŦŜyãŜΣ I 2Y´ŜfI·yŘ 5ŜŦŜyãŜ I·yŘ ! Y´Ŝ№λÕI·ăΩ {ŜÕdz№λúè ! ŦŦI·№ăΣ 5ŜLJI·№ΰ Ƴ Ŝyű 2Ŧ 5ŜŦŜyãŜΰΣ Kΰΰ LJƳккǿǿǿ◊ŘƨŘ◊Y´λfкŘ2ŘƎÕk2fÕкŘ2ÕăкΰŜăΰ{ΰ2Õ`]ΰ2yУлромнлммм◊LJŘŦ◊

[MOH] 5h5 ó5ŜLJI·ℕΰΥŜyΰ 2ŦŦ 5ŜŦŜyãÂÛΣ *Department of Defense Annual Energy Management Report: Fiscal Year 2015* ó ² I·ăKΛyƎΰ2yΣ 5/ϒ 5h5Σ hŦŦΛÔŜ 2Ŧ úKŜ ! ăăΛăΰI·yΰ {ŜÖℕŜΰI·ℕè 2Ŧ 5ŜŦŜyãŜΣ ℕdzyŜ нлмсύΣ пфΣ KΰΰLJΥккόόόΦI·ÖIj⇳2ăŘΦΥΛfkŜΛŜk52óγf2I·ŘăkL9кCậ^ậ нлнлмβ^ậ нл!9 a wΦLJŘŦΦ

[MOO] 9ĖŜÕdzΰΛØŜ hŦŦΛÔŜ 2Ŧ úKŜ tℕŜăΛŘŜyΰΣ *Report on Cyber Deterrence Policy* ó ² I·ăKΛyƎΰ2yΣ 5/ϒ ² KΛΰŜ I 2dzăŜΣ 9ĖŜÕdzΰΛØŜ hŦŦΛÔŜ 2Ŧ úKŜ tℕŜăΛŘŜyΰΣ нлмрύΣ pçcΣ KΰΰLJΥккŦŜŘŜℕI·fγŜόăℕI·ŘΛ2ΦÔ2ΥκόLJπÔ2yΰŜyΰкdzLJf2I·ŘăкнлмркмнкwŜLJ2ℕΰπ2yπ/ĕōŜℕπ5ŜΰŜℕℕŜyÕŜπt2fΛÔĕπ CΛyI·fΦLJŘŦΦ

[MOП] tdzōfΛÕ [I·ó ммππфпΣ CΛĖΛyƎ ! ΥŜℕΛÕI·ЧăЗ {dzℕŦI·ÔŜ ¢ℕI·yãLJ2ℕΰI·ΰΛ2Υ ! ÕΰΣ нлмрΣ KΰΰLJăΥккόόόΦÔ2γƎℕŜăăΦƎ2ØкммпкōΛffăкKℕннк.L[[{π ммпKℕннŜyℕΦLJŘŦΦ

[MOP] [ŜΰKI· ¢I·óγŜĕΣ CℕI·yÕΛăÔ2 !fΥŜyŘℕI·Σ tI·ōf2 ¢2ℕℕŜăΣ I·yŘ [dzúÎ ² ŜΛăÕKŜℕΣ *Two Degrees of Innovation—How to seize the opportunities in low-carbon power* ó ² I·ăKΛyƎΰ2yΣ 5/ϒ ² 2ℕfŘ wŜă2dzℕÕŜă Lyãΰ\ΰdzΰŜΣ нлммύΣ ó2ℕ]ΛyƎ LJI·LJŜℕΣ oΣ KΰΰLJΥккόόόΦόℕΛΦ2ℕƎkLJdzōfΛÕI·ΰΛ2yкΰó2πŘŜƎℕŜŜăπΛγŸ2ØI·ΰΛ2yΦ

[MOC] b!{óbI·ΰΛ2yI·f !ÕI·ŘŜΥĕ 2Ŧ {ÕΛŜyÕÔŜăΰΣ *The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies* ó ² I·ăKΛyƎΰ2yΣ 5/ϒ b!{Σ нлмсύΣ p I·yŘ млçммΣ KΰΰLJăΥккόόόΦyI·LJΦŜŘdzkÕI·ΰI·f2ƎknмтмнкΰKŜπ LJ2óŜℕπ2ŦπÕKI·yƎŜπΛγŸ2ØI·ΰΛ2yπŦ2ℕπŘŜØŜf2LJΥŜγΰπI·yŘπŘŜLJf2ĕΥŜγΰπ2ŦΦ

[MOT] *FERC's Role in Electric Security* óℕŜΥI·ℕ]ă õĕ aΛÕKI·Ŝf . I·ℕŘŜŜΣ 5ΛℕŜÕΰ2ℕΣ hŦŦΛÔŜ 2Ŧ 9fŜÕΰℕΛÕ wŜfΛI·ōΛfΰΰĕΣ ¦Φ{Φ CŜŘŜℕI·f 9yŜℕƎè wŜƎdzfI·ΰ2ℕè /2ΥΥλăăΛ2yΣ I·ΰ úKŜ LyΰŜℕyI·ΰΛ2yI·f 9yŜℕƎè ! ƎŜyÕè ² 2ℕ]ăK2LJY 9fŜÕΰℕΛÕΛΰè {ŜÕdzℕΛΰè !Õℕ2ăă . 2ℕŘŜℕăΣ tI·ℕΛăΣ CℕI·yÕŜΣ ! LJℕΛf нуΣ нлмсύΣ мΣ KΰΰLJăΥккόόόΦΛŜI·Φ2ℕƎkΥŜŘΛI·kó2ℕ]ăK2LJăкнлмскŜăI·LJó2ℕ]ăK2LJØΛλк . I·ℕŘŜŜΦLJŘŦΦ

[MOY] 5h9 ó5ŜLJI·ℕΰΥŜyΰ 2Ŧ 9yŜℕƎèύΣ *Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure* ó ² I·ăKΛyƎΰ2yΣ 5/ϒ 5h9Σ ! LJℕΛf нлмрύΣ oтмоΣ KΰΰLJΥккŜyŜℕƎĕΦƎ2ØкăΛΰŜăкLJℕ2ŘкŦΛfŜăкнлмрклукŦнркv9w^ậ нл/KI·LJΰŜ‰^ậ нлLĕ^ậ нл9fŜÕΰℕΛÕΛΰĕ^ậ нл!LJℕΛf^ậ нлнлмрΦLJŘŦΦ

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FIRE

II The Electricity Sector: Maximizing Economic Value and Consumer Equity

¢ŜŎKy2f2∃èπŜyl·ōfŜŘ ŎKl·y∃Ŝă 2y ō2űK űKŜ Ŏ2yãdzYŜNJ l·yŘ dzűλfλűè ăλŘŜ 2ŦŰKŜ ŜfŜŎűNJλŎ YŜűŜNJ l·NJŜ ŎNJŜl·űλy∃ ăλ∃yλŦλŎl·yű ŜŎ2y2YλŎ Ø l·fdzŜ Ŧ2NJ űKŜ bl·űλ2yΩă ŜfŜŎűNJλŎλűè Ŏ2yãdzYŜNJăΣ l·ă øŜff l·ă ŎKl·y∃λy∃ űKŜ NJ2fŜ 2Ŧ Ŏ2yãdzYŜNJă l·yŘ űKŜλNJ NJŜfl·űλ2yãKλLJ øλűK űKŜλNJ dzűλfλűλŜă l·yŘ NJŜfl·űŜŘ ăŜNJØλŎŜ LJNJ2ØλŘŜNJăφ ¢KŜăŜ ŎKl·y∃Ŝă l·NJŜΣ λy űdzNJy ŎNJŜl·űλy∃ yŜø ŎKl·ffŜy∃Ŝă λy NJl·űŜ ŘŜăλ∃yΣ űKŜ NJ2fŜ 2Ŧ Yl·NJ⌊ŜűăΣ l·yŘ CŜŘŜNJl·f l·yŘ ăűl·űŜ ∂dzNJλăŘλŎűλ2yl·f NJ2fŜăT Ŝyl·ōfλy∃ yŜø ōdzăλyŜăă Y2ŘŜfăT l·yŘ ŎNJŜl·űλy∃ ŜfŜŎűNJλŎλűè ŜyŘπdzăŜ l·yŘ ∃NJλŘπYl·yl·∃ŜYŜyű 2LJLJ2NJűdzyλűλŜăφ ¢KŜè Ŏ2dzfŘ l·fă2 Kl·ØŜ ŘλăLJNJ2LJ2NJűλ2yl·űŜ λYLJl·Ŏűă ς ō2űK LJ2ăλűλØŜ l·yŘ yŜ∃l·űλØŜ ς 2y ØdzfyŜNJl·ōfŜ LJ2LJdzfl·űλ2yã l·yŘ Ŏ2YYdzyλűλŜăφ

Maximizing Economic Value and Consumer Equity: Summary of Key Findings

- Advanced metering infrastructure has had a profound impact on the nature of interactions between the electricity consumer and the electricity system, allowing a two-way flow of both electricity and information and enabling the integration of assets behind the meter into the larger electric grid.
- Interconnection standards and interoperability are critical requirements for seamless integration of grid-connected devices, appliances, and building energy-management systems, without which grid modernization and further energy efficiency gains may be hindered.
- Evolving consumer preferences for electricity services are creating new opportunities.
- The convergence of the electric grid with information and communications technology creates a platform for value creation and the provision of new services beyond energy.
- There is enormous potential for electric end-use efficiency improvement based on (1) technical analyses, and (2) the differences in energy efficiency performance between states and utilities with and without ambitious electric end-use efficiency policies and programs.
- Tribal lands and American territories have the highest rates of un-electrified homesð more than half of a million homes. The extreme rurality of some tribal communities. coupled with high levels of poverty. present an economic challenge for the electric utilities trying to serve them.
- Optimization of behind-the-meter assets will require the design of coordination, communication, and control frameworks that can manage the dispatch of these devices in a way that is both economical and secure, while maintaining system reliability.
- Mobile, internet-connected devices foster new ways of consumer engagement, as well as enable consumers to have more efficient and real-time management of their behind-the-meter assets.
- Consumers and third-party merchants who produce electricity can provide economic, environmental, and operational benefits.
- New grid services, modern technologies, and evolving system topologies and requirements are straining traditional methods of valuation. Appropriate valuation of the grid services by various technologies is technically and administratively challenging and may depend on spatial and temporal variables unique to different utilities, states, and regions.
- Currently, about 90 percent of residential, 60 percent of commercial, and 30 percent of industrial energy consumption are used in appliances and equipment that are subject to Federal minimum efficiency standards implemented, and periodically updated, by the Department of Energy. Between 2009 and 2030, these cost-effective standards are projected to save consumers more than $545 billion in utility costs, reduce energy consumption by 40.8 quads, and reduce carbon dioxide emissions by over 2.26 billion metric tons.
- Miscellaneous electric loads, devices that are often inadequately addressed by minimum standards, labeling, and other initiatives, are expected to represent an increasing share of total electricity demand, particularly for the residential and commercial sectors.
- Connected devices and energy-management control systems are decreasing in cost and improving in functionality, although their market penetration is still low, particularly in residences and small-to-medium-sized commercial buildings. These new technologies and systems, as well as the broader ñInternet of Things,ò provide a wide range of options for consumers to manage their energy use, either passively using automated controls or through active monitoring and adjustment of key systems.
- Energy-management control systems with communication capabilities are increasing opportunities for demand response services in support of grid operations. Third-party aggregators and other business models are facilitating the expanded use of demand response, but the regulatory environment remains unsettled in many states.

- Lower-income households use less energy, but pay a considerably higher fraction of their after-tax income for electricity services.
- Insufficient broadband access in rural areas could inhibit the deployment of grid-modernization technologies and the economic value that these technologies can create.

2.1 Maximizing Economic Value and Consumer Equity

¢KŜ ŜfŜŐúNλÕλúè ăŜŐú2N KI·ă ōŜŜy I·y ŜŐ2y2YλÕ ŜyƎλyŜ ₮2N úKŜ ¦ yλúŜŘ {úI·úŜă ₮2N Y2NŜ úKI·y I· ÔŜyűdzNNèΣ LJN2ØλŘλyƎ NŜfλI·ōfŜ I·yŘ Ō2YLJŜúλúλØŜfè LJNλÕŜŘ ŜfŜŐúNλÕλúè úKI·ú λă ÕNλúλÕI·f ₮2N úKŜ ¦ yλúŜŘ {úI·úŜăΩ LJN2ŘdzÕúλØλúè¢ ¢KŜ ØI·ăú YI·ȼ2NλúèΣ 2₮ ! YŜNλÕI·y Ō2yădzYŜNă τ λyŐfdzŘλyƎ K2dzăŜK2fŘăΣ ōdzăλySăăŜăΣ I·yŘ λyăúλúdzúλ2yă τ Ŝyȼ2è NŜfλI·ōfŜ I·yŘ I·₮₮2NŘI·ōfŜ ŜfŜŐúNλÕλúè úKI·ú ŜyI·ōfŜă I· Y2ŘŜNyŜŐ2y2Yè I·yŘ I· KλƎK ăúI·yŘI·NŘ 2₮ fØλyƎ¢ ¢KŜ ¦ {¢ NŜfλŜă 2y ŜfŜŐúNλÕλúè ú2 λffdzYλyI·úŜ ăÕK22făΣ KŜI·ú I·yŘ Ō22f K2YŜăΣ LJ2øŜN YI·ydzŦI·ŐűdzNλyƎ ₮I·ÔλfλúλŜăΣ I·yŘ ădzLJLJ2Nű yŜI·Nfè I·ff ₮2NYă 2₮ ŜŐ2y2YλÕ I·ÔűλØλúè¢ {2YŜ ! YŜNλÕI·y K2dzăŜK2fŘăΣ K2øŜØŜNΣ ăűλ₮ff fI·Ō ōI·ăλÕ I·ŐŐŜää ú2 ŜfŜŐúNλÕλúè¢

9fŜŐúNλÕλúè Ödzăű2YŜNă ŐI·y y2ø ō2úK LJN2ŘdzŐŜ I·yŘ Ō2yădzYŜ ŜfŜŐúNλÕλúè¢ ¢Kλă λă ₮dzyŘI·YŜyűI·ffè ŐKI·yƎλyƎ úKŜ NŜfI·úλ2yăKλLJ ōŜűøŜŜy úKŜ Ödzăű2YŜN I·yŘ λúă dzúλfλúè ₣N2Y úKI·ú 2₮ I· Ō2yădzYŜN øK2 ăλYLJfè LJI·ëă ₮2N ŜfŜŐúNλÕλúè ăŜNØλŐŜăΣ ú2 I· ά LJN2ădzYŜNé ς I· Ödzăű2YŜN øK2 ŐI·y I·fă2 ăŜff ŜfŜŐúNλÕλúè ădzLJLJfλŜă I·yŘ ăŜNØλŐŜă ú2 úKŜ ƎNλŘ¢ bŜø úŜŐKy2f2ƎλŜă úKI·ú I·ff2ø úKŜ ű ø2πøI·è ₮f2ø 2₮ ō2úK ŜfŜŐúNλÕλúè I·yŘ λy₮2NYI·úλ2y KI·ØŜ ŜÈLJI·yŘŜŘ úKŜ ØI·fdzŜ LJN2LJ2ăλúλ2y 2₮ úKŜ ƎNλŘ ōè ŜyI·ōfλyƎ úKŜ λyúŜƎNI·úλ2y 2₮ I·ăăŜúă ōŜKλyŘ úKŜ YŜúŜN λyú2 úKŜ fI·NƎŜN ŜfŜŐúNλÕ ƎNλŘ¢ ¢KŜăŜ Õ2yădzYŜN I·ăăŜúă ŐI·y LJN2ØλŘŜ ŜyŜNƎèΣ ŐI·LJI·ÕλúèΣ I·yŘ I·yÕλ₮fI·Nè ăŜNØλŐŜăΣ I·yŘ úKŜè KI·ØŜ úKŜ LJ2úŜyűλI·f ú2 LJN2ØλŘŜ yŜø ăŜNØλŐŜă λy úKŜ ₮dzűdzNŜ¢

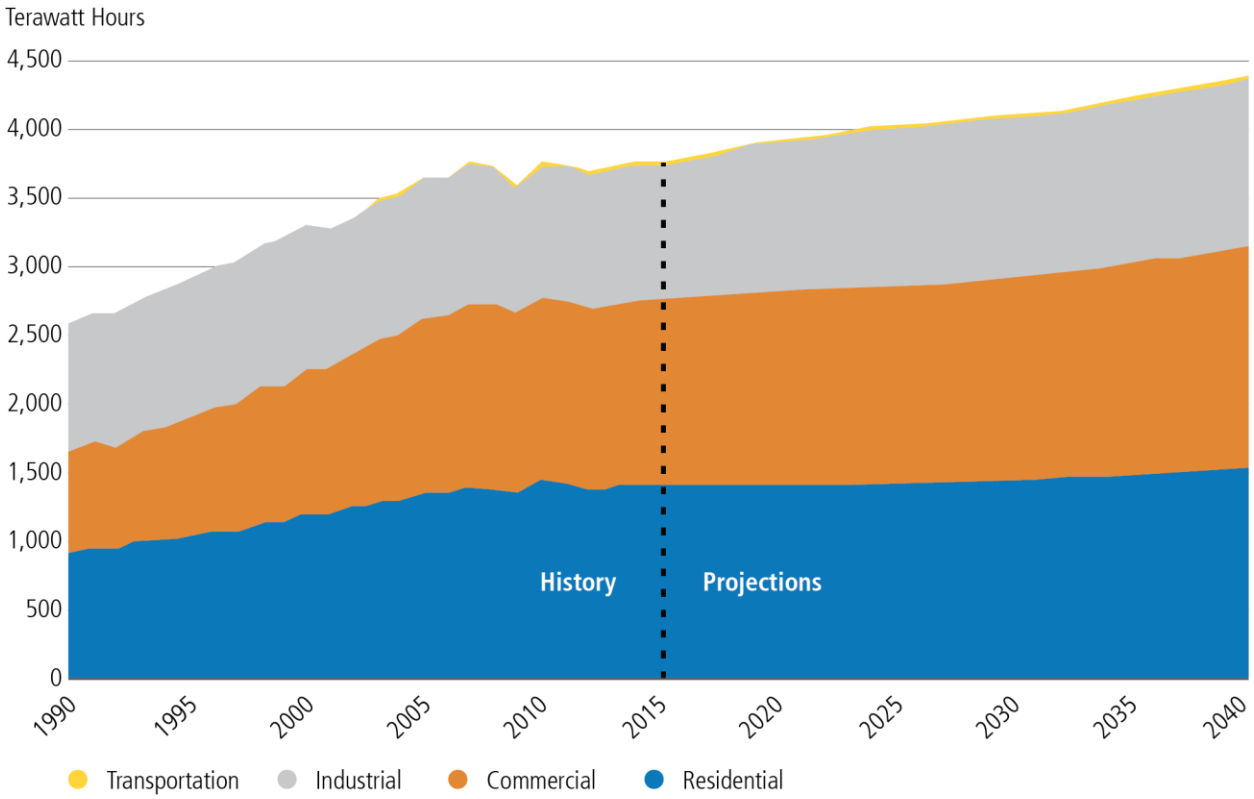
¢Kλă ŐKI·yƎλyƎ NŜfI·úλ2yăKλLJ λă ₮dzNúKŜN ŘNλØλyƎ úKŜ Ō2yØŜNƎŜyŐŜ 2₮ äëäúŜY ăΣ ōdzăλySää Y2ŘŜfăΣ ăŜNØλŐŜăΣ LJ2fλÕλŜăΣ I·yŘ yŜø űŜŐKy2f2ƎλŜă úKN2dzƎK I· ŘŜØŜf2LJY Ŝyűκ₮ŜŜŘōI·Ō¦ f22LJ¢ /2yădzYŜNă ŐI·y y2ø I·Ř2LJű I· øλŘŜ I·NNI·è 2₮ úŜŐKy2f2ƎλŜă I·yŘ LJN2ƎNI·Y 2LJúλ2yă¢ ¢KŜăŜ λyŐfdzŘŜY N22₮ű2LJ ă2fI·NΣ ŜfŜŐúNλÕ ōI·úúŜNè ăú2NI·ƎŜΣ ŜfŜŐúNλÕ ØŜKλÕfŜă ó9±ăúΣ ƎNλŘπÕ2yúN2ffŜŘ úKŜNY2ăúI·úă I·yŘ I·LJLfλI·yŐŜăΣ I·ff2ŐI·úλ2yă ₣N2Y Ō2YY dzyλúè øλyŘ I·yŘ ă2fI·N LJN2ȼŜŐúăΣ f2ŐI·ffè LJN2ŘdzŐŜŘ 2N млл LJŜNÕŜyú NŜyŜøI·ōfŜ ŜyŜNƎè LJfI·yăΣ I·fúŜNyI·úλØŜ LJNλÕλyƎ NŜƎλYŜăΣ I·yŘ ŘŜYI·yŘ NŜăLJ2yăŜ ó5wú I·yŘ ŜyŜNƎè ŜŦ₣λÕλŜyÕè LJN2ƎNI·Yă I·yŘ λyÕŜyúλØŜă¢ a2ōλfŜΣ λyúŜNyŜúπÕ2yŷŜÕúŜŘ ŘŜØλÕŜă ₮2ăúŜN yŜø Õ2yădzYŜNπŜyƎI·ƎŜYŜyú Y2ŘŜă I·yŘ ŜyI·ōfŜ ŜŦ₣λÕλŜyú I·yŘ NŜI·fπúλYŜ YI·yI·ƎŜYŜyú 2₮ ōŜKλyŘπúKŜπYŜúŜN I·ăăŜúă¢ ¦ LJúI·ĵŜ 2₮ úKŜăŜ I·ŘØI·yÕŜŘ 2LJúλ2yă λă ÕdzNNŜyúfè fλYλúŜŘ ōdzű λă NI·LJλŘfè ƎN2øλyƎ¢

/2yădzYŜNă KI·ØŜ ƎNŜI·ú fI·úλúdzŘŜ λy úKŜλN fŜØŜf 2₮ ŜyƎI·ƎŜYŜyú øλúK ŜfŜŐúNλÕλúè úŜÕKy2f2Ƭè I·yŘ LJN2ƎNI·Yă¢ Ly ă2YŜ ăλúdzI·úλ2yăΣ Õ2yădzYŜNă YI·ĵŜ I· 2yŜπúλYŜ ŘŜÕλăλ2yúΩ2 I·Ř2LJú I· úŜÕKy2f2ƎèΣ 2N NI·úŜ ăúNdzÕúdzNŜΣ ŜfλYλyI·úλyƎ úKŜ ySŜŘ ₮2N Õ2yűλyűdz2dză ŘŜÕλăλ2y YI·ĵλyƎ¢ LyÕNŜI·ăλyƎfèΣ úKŜ Õ2yØŜNƎŜyÕŜ 2₮ úKŜ ŜfŜŐúNλÕ ƎNλŘ øλúK λyf2NYI·úλ2y I·yŘ Õ2YYdzyλÕI·úλ2yă úŜÕKy2f2ƎèΣ óL/¢ú λă ÕNŜI·úλyƎ I· LJfI·úŦ2NY ₮2N ØI·fdzŜ ÕNŜI·úλ2y I·yŘ úKŜ LJN2Øλăλ2y2₮ yŜø ăŜNØλÕŜă ōŜè2yŘ ŜfŜŐúNλÕλèΣ úKI·ú YI·è 2N YI·è y2ű NŜIjdzNNŜ Y2NŜ Õ2yădzYŜN ŜyƎI·ƎŜYŜyú¢ Ly úKŜ fI·ăú ăŜØŜNI·f èŜI·NăΣ ₮2N ŜÈI·YLJfŜΣ YI·ȼ2N Õ2YLJI·yÑŜă KI·ØŜ λyØŜăűŜŘ λyλyűŜffλƎŜyű úKŜNY2ăűI·ú ă2₮úøI·NŜ I·yŘ KI·NŘøI·NŜ LJN2ŘdzŐűăΣ ú2 ō2úK YI·yI·ƎŜ ōdzλfŘλyƎ ŰŜYLJŜNI·údzNŜă I·yŘ ăŜNØŜ I·ăÕ2yűN2f ÕŜyűŜNă ₮2N ăYI·NűK K2YŜ LJfI·úŦ2NYă℠ ¢KŜ Yè NλI·Ř ŐKI·yƎŜă úI·ĵλyƎ LJfI·ÔŜ I·ű úKŜ Õ2yădzYŜN fŜØŜf I·NŜ ŐKI·ffŜyƎλyƎ ă2YŜ ŜfŜŐúNλÕπdzűλfλúè ōdzăλySää Y2ŘŜfă I·yŘ ₮2NÕλyƎ úKŜY ú2 Y2ŘŜNyλÎŜ LJKèăλÕI·f λy₣NI·ăúNdzÕűdzNŜ ú2 YI·λyűI·λy KλƎKπIjdzI·fλúè ăŜNØλÕŜ¢ LyŷØI·úλØŜ I·yŘ LJ2ûŜyűλI·ffè ŘλăNdzLJûλØŜ ŐKI·yƎŜă ₮2N ŘλŦ₮ŜNŜyű Õ2yădzYŜN ÕfI·ăăŜă I·NŜ úI·ĵλyƎ LJfI·ÔŜ úKI·ú LJ2fλÕè YI·ĵŜNăΣ dzűλfλúλŜăΣ I·yŘ 2úKŜN ăúI·ĵŜK2fŘŜNă Y dzăű Õ2yăλŘŜN λy 2NŘŜN ú2 ŜyădzNŜ úKŜ Õ2yűλydzŜŘ ăŜÕdzNλúèΣ I·₮₮2NŘI·ōλfλúèΣ I·yŘ ŜyØλN2yYŜyűI·f LJŜN₮2NYI·yÕŜ 2₮ úKŜ ŜfŜŐúNλÕλúè ăèäúŜY¢

9YŜNƎλyƎ LJI·úúŜNyă 2₮ I·ăăŜű 2øyŜNăKλLJ I·yŘ Ō2yădzYŜN ōŜKI·Ø2NI ·NŜ ŐKI·ffŜyƎλyƎ ŜÈλăúλyƎ NŜƎdzfI·ú2Nè ăúNdzÕűdzNŜăΣ λyăúλúdzúλ2yăΣ I·yŘ dzúλfλúè ōdzăλySää Y2ŘŜfăΣ I·ă øŜff I·ă ÕNŜI·úλyƎ ySø ōdzăλySää 2LJLJ2NűdzyλúλŜă¢ ¢KλăΣ λYűdzNyΣ Šăú I·ōfλăKŜŘ úKŜ ySŜŘ ₮2N ySø ŘŜăλƎyă ₮2N λyűŜƎNI·úλyƎ λy₮2NYI·úλ2y ySűø2N ĵλ øλúK úKŜ LJKèăλÕI·f ƎNλŘT úKŜăŜ ŘŜăλƎyă Ydzăű ăŜÕdzNŜfè I·yŘ NŜfλI·ōfè YI·yI·ƎŜ ŘλăúNλōdzűŜŘ Ō2YYdzyλÕI·úλ2yăΣ Ō2yúN2fΣ I·yŘ Ō22NŘλyI·úλ2y

2.2 The 21st-Century Energy Consumer

Figure 2-1. U.S. Electricity Consumption Projections to 2040[3]



In 2014, the residential sector consumed the most electricity of any sector (1,415 terawatt-hours [TWh], 38 percent of total consumption), followed by the commercial sector (1,358 TWh, 36 percent of total consumption), and the industrial sector (959 TWh, 26 percent of total consumption), with transportation using just 7.6 TWh (less than one percent of total consumption). Overall, electricity consumption is expected to grow by about 18 percent between 2014 and 2040, based on business-as-usual assumptions.

2.2.1 Industrial Consumers of Electricity: Price-Sensitive, On-Site Generation

¢ΚŜ ƛyŘdzăΰΝΩƛΙ·ŧ ăŜŎΰƨΝ ƛă ŜĖΰΝΩŜΥŜfè ŘƛØŜΝΩăŜΣ Ŏ2ΥLJΝΩƛăƛyΞ Ι· ǿƛŘŜ ØΙ·ΝΩƛŜΰè 2ŧ ăΥΙ·ŧf ΰ2 ØŜΝΩè ŧΙ·ΝΩΞŜ ŦΙ·ŎƛŧΩΰƛŜăφ tΝΩΥΙ·ΝΩè ădzōăŜŎΰƨΝΩă ƛyŎŧdzŘŜ ΥΙ·yΩzŦΙ·ŎΰdzΝΩƛyΞΣ ΥƛyƛyΞΣ Ŏ2yãΰΝΩdzŎΰƛ2yΣ Ι·yŘ Ι·ΞΝΩƛŎdzŧΰdzΝΩŜφ LyŘdzăΰΝΩƛΙ·ŧ ŜfŜŎΰΝΩƛŎƛΰè Ŏ2yãdzΥLJΰƛ2Υ Ι·ŎŎ2dzyΰă Ŧ2Ν нс LJŜΝΩŎŜyΰ 2ŧ ΰ2ΰΙ·ŧ Ι·yΥΩzΙ·ŧ ¦φ{φ ŜfŜŎΰΝΩƛŎƛΰè Ŏ2yãdzΥLJΰƛ2yφⁿ

LyŘdzăΰΝΩƛΙ·ŧ ŜfŜŎΰΝΩƛŎƛΰè ăΙ·ŧŜă ǿŜΝΩŜ ΝΩŜfΙ·ΰƛØŜfè ŦfΙ·ΰ ōŜΰǿŜŜΥ мффл ΰ2 нлмпΣ ŘdzŜ ƛΥ LJΙ·ΝΩΰ ΰ2 Ŏ2yΰƛΥΩzŜŘ ƛΥLJΝΩ2ØŜΥŜyΰă ƛΥ ŜyŜΝΩƎè ŜŦŦƛŎƛŜyŎè Ι·yŘ ΰ2 ΰΚŜ Ŏ2yΰƛΥΩzŜŘ ăΚƛŦΰƛyΞ 2ŧ ΰΚŜ ¦φ{φ ŜŎ2yΥ2Υè ΰ2 fŜăă ŜyŜΝΩƎèπ ƛyΰŜyãƛØŜ ƛyŘdzăΰΝΩƛŜăφᵖ ᶜ LyŘdzăΰΝΩƛΙ·ŧ Ŏ2yãdzΥŜΝΩă ΰèLJƛŎΙ·ffè dzăŜ fΙ·ΝΩΞŜ Ι·Υ2dzyΰă 2ŧ ŜfŜŎΰΝΩƛŎƛΰè Ι·yŘ LJŧΙ·ŎŜ KƛΞΚ ØΙ·ŧdzŜ 2Υ Ι·ŦŦ2ΝΩŘΙ·ōƛŧΰè Ι·ă ŜfŜŎΰΝΩƛŎƛΰè Ŏ2ăΰă ƛΥLJΙ·Ŏΰ ΰΚŜΛΝ ō2ΰΰ2Υ fΛyŜφ ¢ΚŜăŜ Ŏdzăΰ2ΥŜΝΩă ΰèLJƛŎΙ·ffè LJΙ·è fŜăă Ŧ2Ν ŜfŜŎΰΝΩƛŎƛΰèφ 9L ! ŘΙ·ΰΙ· ăΚ2ǿ Ι· yΙ·ΰƛ2yΙ·ŧ мнπΥ2yΰΚ ΝΩ2ffΛyΞ Ι·ØŜΝΩΙ·ΞŜ LJΝΩƛŎŜ Ŧ2Ν ƛyŘdzăΰΝΩƛΙ·ŧ Ŏdzăΰ2ΥŜΝΩă 2ŧ cφтп ŎŜyΰă LJŜΝ ⎫ƛf2ǿΙ·ΰΰπΚ2dzΝ ó⎫ ² Kú ØŜΝΩădză мнφрт ŎŜyΰăκ⎫ ² K Ŧ2Ν ΝΩŜăŘŜyΰƛΙ·ŧ Ŏdzăΰ2ΥŜΝΩă Ι·yŘ млφпл ŎŜyΰăκ⎫ ² K Ŧ2Ν Ŏ2ΥΥŜΝΩŎƛΙ·ŧ Ŏdzăΰ2ΥŜΝΩă Ι·ă 2ŧ {ŜLJΰŜΥσŜΝ нлмсφᵀ LŦ ΰΚŜ ƛyŘdzăΰΝΩƛΙ·ŧ Ŏdzăΰ2ΥŜΝΩăΩ ŜfŜŎΰΝΩƛŎƛΰè ySŜŘă Ι·ΝΩŜ ŦΙ·ΝΩΞŜ ŜyƩdzΞΚΣ ΰΚŜ Ŧ2Ŏdză 2yΥLJΝΩŎŜ ŎΙ·yΥfŜΙ·Ř ΰΚŜΥ ΰ2 LJdzΝΩŎΚΙ·ăŜ ŜfŜŎΰΝΩƛŎƛΰè ŘΛΝΩŜŎΰfè ƛyΥΝΩŜΞƛ2yΙ·ŧ LJ2ǿŜΝ Υ Ι·ΝΩ⎫ŜΰăΝΩΙ·ΰΚŜΝΩ ΰΚΙ·yΥΰΚΝΩ2dzΞΚ ΰΚŜ f2ŎΙ·f ƛyŎdzΥσŜyΰ dzΰΛŧΰèΣ ǿΚŜΝΩŜ ΰΚŜ ăΰΙ·ΰŜ Ι·ff2ǿăφ [Ι·ΝΩΞŜ ƛyŘdzăΰΝΩƛΙ·ŧ Ŏ2yãdzΥŜΝΩă Υ Ι·è ŜǾŜyσŜ ΥŜΥσŜΝΩă 2ŧ Ι· ΝΩŜΞƛ2yΙ·ŧ ΰΝΙ·yãΥăăƛ2Υ 2ΝΩΞΙ·yΛÎ Ι·ΰƛ2Υ ów¢hú 2Ν ƛyŘŜLJŜyŘŜyΰ ăèăΰŜΥ 2LJŜΝΙ·ΰ2Ν óL{hú ΰ2 Ι·ff2ǿ ΰΚŜΥ ΰ2 LJΙ·ΝΩΰŎƛLJΙ·ΰŜ ƛΥǿΚ2fŜăΙ·fŜ Υ Ι·Ν⎫Ŝΰăφ

9fŜŎúNλŎλúè LJN2ŘdzŎúλØλúè λy űĸŜ λyŘdzăúNλI·f ăŜŎű2N óYŜI·ădzNŜŘ λy] ² K LJŜN Ř2ffI·N 2Ŧ 2dzűLJdzű LJN2ŘdzŎŜŘú KI·ă λYLJN2ØŜŘ NI·LJλŘfè 2ØŜN úĸŜ fI·ăű мp èŜI·Nă¹ I·yŘ Ŏ2yűλyđzŜŘ λYLJN2ØŜYŜyű ø λff ŘŜLJŜyŘ 2y LJŜNăλăúŜyű I·úűŜyűλ2y ű2 ŜŦŦλŎλŜyŎè9 ySNƎèπλyűŜyãλØŜ ădzōπăŜŎű2Nă óSΦƎΦΣ YŜúI·fă I·yŘ ŎĸŜYλŎI·fă YI·ydzŦI·ŎűdzNλyƎú NŜLJNŜăŜyű úĸŜ ƎNŜI·úŜăű 2LJLJ2Núdzyλúλŝă Ŧ2N úI·NƎŜúŜŘ ŜŦŦλŎλŜyŎè λYLJN2ØŜYŜyűăΦ Ly úĸŜ YI·ydzŦI·ŎűdzNλyƎ ădzōπăŜŎű2NΣ øĸλŎĸ I·ŎŎ2dzyűă Ŧ2N 2ØŜN y±ˆ÷ 2Ŧ ű2űI·f λyŘdzăúNλI·f ƎNλŘπŜfŜŎúNλŎλúè Ŏ2yãdzYLJúλ2y óCλƎdzNŜ нπнúΣ YI·ŎĸλyŜ ŘNλØŜă° YI·]Ŝ dzLJ KI·fŦ 2Ŧ λyŘdzăúNλI·f ŜfŜŎúNλŎλúè dzăΦ ¢ĸŜ ySÈű ōλƎƎŜăű ŜyŘ dzăΣ LJN2ŎŜää KŜI·úλyƎ I·yŘ Ŏ22fλyƎΣ YI·]Ŝă dzLJ ∂dzăű 2ØŜN 2yŜπúŜyűĸ 2Ŧ ű2úI·f λyŘdzăúNλI·f ŜfŜŎúNλŎλúè dzăΦ ¢ĸŜ Ŧ2Ŏdzã 2y LJNλŎŜ I·fă2 LJN2ØλŘŜă I· yI·ůdzNI·f λyŎŜyűλØŜ Ŧ2N I·y ˆλyŘdzăúNλI·f Ŏdzăú2YŜN ű2 ăŜfŦπŦλyI·yŎŜ ŜŎ2y2YˆλŎ ŜyŜNƎèπŜŦŦλŎλŜyŎè YŜI·ădzNŜă λy 2NŘŜN ű2 úI·]Ŝ I·ŘØI·yűI·ƎŜ 2Ŧ NŜŘdzŎŜŘ Ŏ2ăúă I·yŘ ƎNŜI·úŜN LJN2ŘdzŎűλØλúè hLJLJ2NúdzyλúλŝăŦ2N YŒNŜ ŜyŜNƎè ŜŦŦλŎλŜyŎè ăűλff ŜÈλăúΦ Ly úĸŜ YI·ydzŦI·ŎűdzNλyƎ ădzōăŜŎű2NΣ øĸλŎĸ I·ŎŎ2dzyűă Ŧ2N 2ØŜN yл LJŜNŎŜyű 2Ŧ ű2űI·f λyŘdzăúNλI·f ƎNλŘπŜfŜŎúNλŎλúè Ŏ2yãdzYLJúλ2yΣ YI·ŎĸλyŜ ŘNλØŜă YI·]Ŝ dzLJ KI·fŦ 2Ŧ λyŘdzăúNλI·f ŜfŜŎúNλŎλúè dzăŜ I·yŘ Ŏ2dzfŘ ōŜ I· ű I·NƎŜú Ŧ2N ŦdzNúĸŜN λyy2ØI·úλ2yΦ

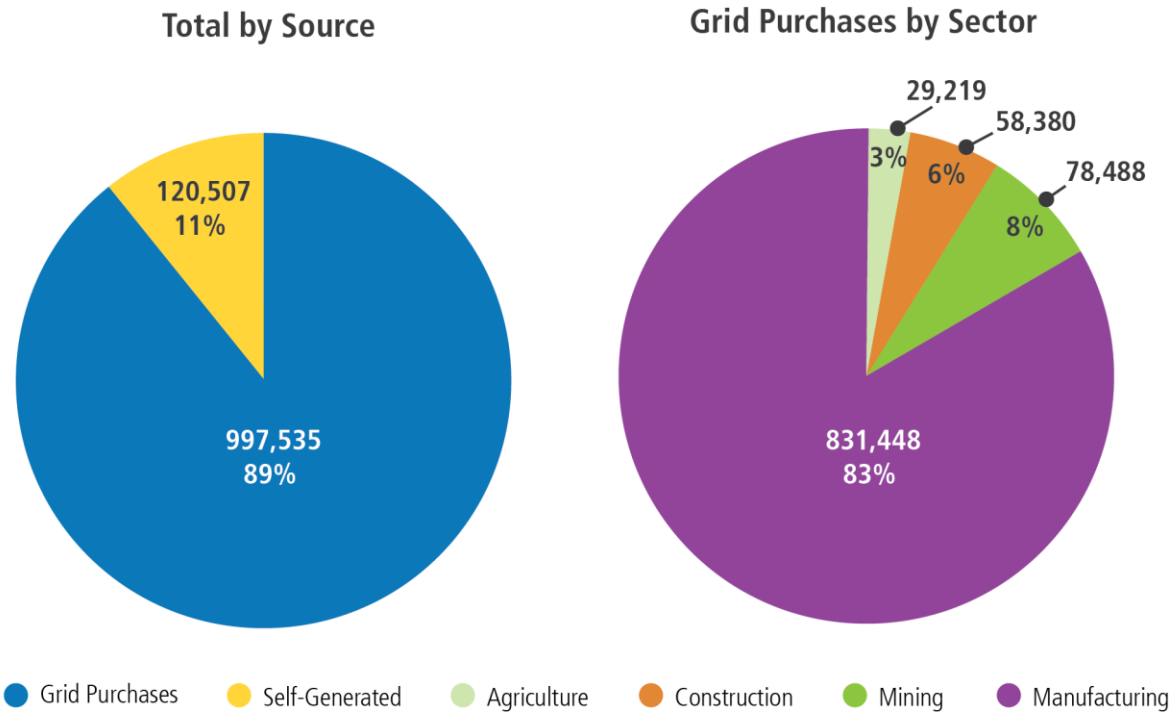
5w óăĸλŦűλyƎ 2N ŘŜŎNŜI·ăλyƎ ŜfŜŎúNλŎλúè dzăŜ λy NŜăLJ2yãŜ ű2 úλYŜπōI·ăŜŘ NI·úŜă 2N 2úĸŜN Ŧ2NYă 2Ŧ Ŧλyl·yŎλI·f λyŎŜyűλØŜáú ĸŜfLJă YI·]Ŝ ¦Φ{Φ YI·ydzŦI·ŎűdzNŜNă Y2NŜ Ŏ2YLJŜúλúλØŜΦ Ly úĸŜ tWa NŜƎλ2yΣ fI·NƎŜ λyŘdzăúNλI·f Ödzăú2YŜNă 2Ŧúŝy ōλŘ 5w λyű2 úĸŜ YI·NˆŜű I·ă I· NŜă2dzNŎŜΦ

! NŜŎŜyű ŎĸI·yƎŜ I·Y2y3 ă2YŜ λyŘdzăúNλI·f Ödzăű2YŜNăΣ ŜăLJŜŎλI·ffè I·Y2yƎ úĸK2ăŜ ø λúK NŜúI·λf Ödzăű2YŜNăΣ λă úĸŜ ŘŜØŜf2LJYŜyű 2Ŧ Ŏ2NLJ2NI·úŜ ădzăúI·λyI·ōλfλúè Ǝ2I·fă ! ŎĸλŜØλyƎ úĸŜăŜ Ǝ2I·fă YI·è λyØ2fØŜ ăŜfŦπƎŜySNI·úλ2yΣ LJdzNŎĸI·ăŜ 2Ŧ ŎNŜŘλúăΣ 2N øĸ2fŜăI·fŜ LJ2øŜN LJdzNŎĸI·ăŜă λyØ2fØλyƎ f2øπ 2N ÎŜN2πŎI·N ō2yˆƎŜySNI·úλ2yΣ ădzŎĸ I·ă FN2Y NŜySøI·ōfŜă óCλƎdzNŜ нπнúΦ C2N ŜÈI·YLJfŜΣ DŜySNI·f a2ű2NăΣ I· ØŜNè fI·NƎŜ Ŏ2yãdzYŜN 2Ŧ ŜfŜŎúNλŎλúèΣ λă ŎdzNNŜyűfè úĸŜ fI·NƎŜăű I·dzű2Y2úλØŜ dzăŜN 2Ŧ ă2fI·N LJ2øŜN I·yŘ λă I·Y2yƎ úĸŜ ű2LJ нp ă2fI·NπLJ2øŜNŜŘ ¦Φ{Φ Ŏ2YLJI·yλŜăΦ[y]

[1] 9fŜŎúNλŎλúè LJN2ŘdzŎúλØλúèΣ YŜI·ădzNŜŘ I·ă Ř2ffI·Nă 2Ŧ ƎN2ăă Ř2YŜăúλÔ LJN2ŘdzŎű óD5 tú LJN2ŘdzÔŜŘ LJŜN]λf2øI·úűπK2dzN ô] ² KúΣ yŜI·Nfè Ř2dzōfŜŘ ōŜúøŜSyˆмффл I·yŘ нлмпΣ øĸλfŜ λyŘdzăúNλI·f ŜfŜŎúNλŎλúè ăI·fŜă øŜNŜ Ŧfl·úΦ

[2] a I·ŎĸλyŜ ŘNλØŜă Ő2yØŜNű ŜfŜŎúNλŎ ŜyŜNƎè λyű2 YŜŎKI·yλŎI·f ŜyŜNƎè I·yŘ I·NŜ Ŧ2dzyŘ λyˆI·fY2ăű ŜØŜNè LJN2ŎŜää λyˆYI·ydzŦI·ŎűdzNλyƎT úĸŜè Ő2YLJNλăŜ Y2ú2Nă I·yŘ úĸŜ LJN2ŎŜää ăèăúŜYă úĸŜè ŘNλØŜΦ

Figure 2-2. U.S. Industrial Electricity Consumption in 2014 (Million Kilowatt Hours)[9]



The left chart shows the industrial sectorôs purchased electricity consumption, combined heat and power self-generation by source, and the right chart shows purchased electricity by industrial subsector.

C2ℕ Y l·yê ƛyŘdzăúℕƛl·f ŦI·ÖƛfℓúƛŜăΣ ŜyŜℕƎè ƛă y2ú l·ÖúƛØŜfê Y l·yl·ƎŜŘΦ ² KƛfŜ ă2Y Ŝ Ŧl·ÖƛfℓúƛŜă ƛY LJfŜY Ŝyű ăű l·yŘπl·f2yŜ ŜyŜℕƎè ŜŦŦƛÖƛŜyÖè LJℕ2ΣŜÖúă űKl·ú ăl·ØŜ ŜyŜℕƎèΣ Y l·yê Ř2 y2ú ƛY LJfŜY Ŝyű úKŜăŜ LJℕ2ΣŜÖúă l·ă LJl·ℕú 2Ŧ l·Ö2Y LJℕŜKŜyăƛØŜ ăúℕl·úŜ3è ú2 Ö2yúƛyƍzl·ffê ƛY LJℕ2ØŜ ŜyŜℕƎè LJŜℕŦ2ℕY l·yÖŜΦ C2ℕ ŜÈl·Y LJfΣ ØKƛfŜ ySl·ℕfê oƛ¦ˆ 2Ŧ ¦Φ{Φ Y l·yƍzŦl·ÖúdzℕƛyƎ Ŧl·ÖƛfℓúƛŜă ℕŜLJ2ℕú ăŜúúƛyƎ Ǝ2l·fă Ŧ2ℕ ƛY LJℕ2ØƛyƎ ŜyŜℕƎè ŜŦŦƛÖƛŜyÖè£ᵐⁿ 2yfè l·ō2dzú ƛ¦ˆ 2Ŧ Ŧl·ÖƛfℓúƛŜă ℕŜLJ2ℕú ŜY LJfƨèƛyƎ l· ŦdzffπúƛY Ŝ ŜyŜℕƎè Y l·yl·ƎŜℕΦ {úℕl·úŜ3ƛÖ ŜyŜℕƎè Y l·yl·ƎŜY Ŝyű l·LJLJℕ2l·ÖKŜăΣ ădzÖK l·ă 9b9wD¸ {¢!w Ŧ2ℕ ƛyŘdzăúℕƛl·f ŜyŜℕƎè Y l·yl·ƎŜY ŜyűΣ L{h рллгм l·yŘ {dzLJŜℕƛ2ℕ 9yŜℕƎè tŜℕŦ2ℕY l·yÖŜ KŜfℓJ ƛyŘƛØƛŘdzl·f ōdzăƛyŜăăŜă ƛŘŜyúƛŦè 2LJŜℕl·úƛ2yl·f ŜŦŦƛÖƛŜyÖè 2LJLJ2ℕúdzyℕúƛŜăΦ⁰ / 2ăűπōŜyŜŦƛú l·ăăŜăăY Ŝyűă Ŧ2ℕ {dzLJŜℕƛ2ℕ 9yŜℕƎè tŜℕŦ2ℕY l·yÖŜ ŦƛyŘ l·yyƍzl·f ăl·ØƛyƎă ōŜűØŜŜy Þoc Σллл l·yŘ Þфoy Σллл Σ ØƛúK LJl·èōl·Ö¦ă 2Ŧ fŜăă úKl·y мΦp èŜl·ℕă Ŧ2ℕ fl·ℕƎŜ ŜyŜℕƎè Ö2yădzY ƛyƎ Ŧl·ÖƛfℓúƛŜă óúK2ăŜ ØƛúK l·yyƍzl·f ŜyŜℕƎè Ö2ăúă 2Ŧ Y2ℕŜ Þн Yƛffℓ2yΦúᴹᴹ . è LJℕ2ŘdzÖƛyƎ 9yŜℕƎè . l·yŘØƛŘúK {údzŘƛŜăΣ úKŜ ¦Φ{Φ 5ŜLJl·ℕúY Ŝyű 2Ŧ 9yŜℕƎè Kl·ă l·fă2 ƛŘŜyűƛŦƛŜŘ LJ2úŜyűƛl·f ŜyŜℕƎè ăl·ØƛyƎă Ŧ2ℕ ăŜfŜÖúŜŘ ƛyŘdzăúℕƛl·f ăŜÖű2ℕă ōè Ôl·fÖdzfl·úƛyƎ ŘƛŦŦŜℕŜyÖŜă ōŜúØŜŜy úèLJƛÖl·f ŜyŜℕƎè Ö2yădzYLJúƛ2y fŜØŜfă Ŧ2ℕ ăLJŜÖƛŦƛÖ LJℕ2ÖŜăăŜă l·yŘ f2ØŜℕ Ö2yădzYLJúƛ2y fŜØŜfă ℕŜljdzℕŜŘ ōè ăúl·úŜ 2Ŧ úKŜ l·ℕú úŜÖKy2f2ƎèΣ l·ă ØŜft l·ă úŜÖKy2f2Ǝè ÖdzℕℕŜyúfê dzyŘŜℕ ℕŜăŜl·ℕÖK l·yŘ ŘŜØŜf2LJY Ŝyúφᴹᴴ

[9] L{h рллгм ƛă l·yƛyúŜℕyl·úƛ2yl·f ŜyŜℕƎè Y l·yl·ƎŜY Ŝyű ăúl·yŘl·ℕŘ l·yŘ {dzLJŜℕƛ2ℕ 9yŜℕƎè tŜℕŦ2ℕY l·yÖŜ ƛă l· LJℕ2Ǝℕl·Y úKl·ú KŜfℓJă Ö2YLJl·yƛŜă ú2 ƛyÖ2ℕLJ2ℕl·úŜ L{h рллгм ƛyú2 úKŜℕ LJℕ2Ředzúƛ2y Y l·yl·ƎŜY Ŝyű LJℕl·ÖúÖŜă l·yŘ Y2úØl·úŜă úKŜY ú2 ăŜú l·yŘ ℕŜl·ÖK ăl·ØƛyƎă Ǝ2l·fă a 2ℕŜ ƛyŦ2ℕY l·úƛ2y 2yLyŘdzăúℕƛl·f 9yŜℕƎè a l·yl·ƎŜY Ŝyű úKℕ2dzƎK 9b9wD¸ {¢!w Ŧ2ℕ ăă l·Ø l·ƛfl·ōtŜ l·ú KúűLJăŸκκøøø⁰ŜyŜℕƎèăúl·ℕ⁰Ǝ2ØκōdzƛfŘƛyƎăκŦl·Öƛfℓúêπ2øyŜℕăπl·yŘπY l·yl·ƎŜℕăκƛyŘdzăúℕƛl·fπLJfl·yűă

LY I·ŘŘλúλ2yΣ λyŘdzăúNλI·f / I t NŜLJNŜăŜyűă 2LJLJ2NűdzyλúλŜă Ŧ2N yŜI·NπúŜNY ă2fdzűλ2yã ű2 NŜŘdzÔŜ ŜyŜNƎè λyűŜyãλúè⌀R / I t ƎŜyŜNI·ûλyƎ ÔI·LJI·ÖλúèÌă ŜIjdzλØI·fŜyű ű2 I·ō2dzű y LJŜNŴÔŜyű 2Ŧ ¦⌀{⌀ ƎŜyŜNI·ûλyƎ ÔI·LJI·ÖλúèŦN2Y dzűλfűúèπăÖI·fŜ LJ2ØŜN LJfI·yűă λY нлмр⌀Ŝ ᴍᴏ . è Ô2yÔdzNNŜyűfè LJN2ŘdzÔλyƎ ŜfŜÔűNλÖλúè I·yŘ KŜI·ű I·ű űKŜ ăλúŜ 2Ŧ dzăŜΣ / I t ăèăúŜYă dzăŜ нр LJŜNŴÔŜyű ű2 op LJŜNŴÔŜyű fŜää LJNλY I·Nè ŜyŜNƎè úKI·Y ƎNλŘ ŜfŜÔűNλÖλúè LJfdză Ô2yØŜyűλ2yI·f KŜI·ûλyƎ ŜyŘπdzăŜă óŜ⌀Ə⌀Σ Ø I·ûŜN KŜI·ûŜNăΣ ō2λfŜNăúΣ Øλú{K I· ûèLJλÔI·f тр LJŜNŴÔŜyű 2ØŜNI·ff ŜŦŦλÔλŜyÔè ØŜNädză рл LJŜNŴÔŜyű Øλú{K Ô2yØŜyűλ2yI·f ƎŜyŜNI·ûλ2Y ó{ŜÔűλ2Y cфнфмфpúф LY NŜƎλ2yã ØKŜNŜ úKŜ ŜY λăăλ2Y λyűŜyãλúè 2Ŧ ÔŜyűNI·f ŜfŜÔűNλÖ ƎŜyŜNI·ûλ2Y λă KλƎKΣ ăØλúÖKλyƎ ű2 / I t Øλff KI·ØŜ ûKŜ ōλƎƎŜăú ŜY λăăλ2yã λY LJI·Öúф 5h9 ŜăúλY I·ûŜă úKI·ú ûKŜNŜ λă ûŜÔKyλÔI·f LJ2űŜyűλI·f Ŧ2N N2dzƎKfè нпм D ² 2Ŧ / I t ÔI·LJI·ÖλúèλY úKŜ ¦yλűŜŘ {űI·ûŜăΣ λyÖfdzŘλyƎ λyŘdzăúNλI·f I·yŘ Ô2Y Y ŜNŴλI·f / I t I·ă ØŜff I·ă Ø I·ăúŜ KŜI·ú û2 LJ2ØŜNфᴍᴨ

hØŜNI·ff ƎN2ØűK λY / I t ÖI·LJI·ÖλúèKI·ă ăúI·ffŜŘ ăλyÖŜ ûKŜ ŜI·NfèнллlăŘdzŜ û2 dzLJŦN2yű ŜIjdzλLJY Ŝyű Ô2ăúăΣ ûŜÖKyλÔI·f Ô2Y LJfŜÈλúèΣ I·yŘ LJ2fλÖè ÖKI·yƎŜă⌀ ¢KŜNŜ I·NŜ ăλƎyλŦλÖI·yű 2yƎ2λyƎ ŘŜLJf2èY Ŝyű ŜŦŦ2NúăûΣ LJN2Y2ûŜ ûKλă ûŜÖKy2f2ƎèΣ λyÖfdzŘλyƎ 5h9Ωă ¢ŜÖKyλÔI·f !ăăλăúI·yÖŜ t I·NúyŜNăKλLJΣᴍᴘ I·ă ØŜff I·ă ăŜØŜNI·f I·ÖűλØŜ ăúI·ûŜ λyÖŜyűλØŜăΣ ădzÖK I·ă λyÖfdzŘλyƎ / I t ƎŜyŜNI·ûλ2Y λY wt{Σ I·yŘ dzűλfλúè λyÖŜyűλØŜă Ŧ2N / I t ăèăúŜY ă⌀ᴍᴄ ¢KŜ KλƎKŜăú yűzY ōŜN 2Ŧ / I t λyăúI·ffI·ûλ2yã λY нлмо I·yŘ нлмп 2ÖÖdzNNŜŘ λY ăúI·ûŜă Øλú{K Y dzfűλèŜI·N / I tπλyÖŜyűλØŜ LJN2ƎNI·Y ă óbŜØ ¸2N]I·yŘ / I·fλŦ2NyλI·Σ {ŜÔűλ2Y c⌀p⌀м⌀o⌀

2.2.2 Commercial Consumers: Optimizing Building Design, Lighting and Space Conditioning

¢KŜNŜ λă I·ō2dzű yт ōλffλ2Y ăIjdzI·NŜ ŦŜŜú 2Ŧ Ô2Y Y ŜNŴÔλI·f ăLJI·ÔŜ λY úKŜ ¦yλúŜŘ {úI·ûŜăΣ ăLJNŜI·Ř I·ÖN2ăă Y2NŜ ûKI·y p Y λffλ2Y Ô2Y Y ŜNŴÔλI·f I·yŘ λyăűλúdzűλ2yI·f ōdzλfŘλyƎă⌀ᴍᴛ /2Y Y ŜNŴÔλI·f ŜfŜÔűNλÖλúè Ô2yãdz Y LJúλ2Y I·ÖÔ2dzyűă Ŧ2N I·ō2dzű oc LJŜNŴÔŜyű 2Ŧ ű2úI·f ¦⌀{⌀ ŜfŜÔűNλÖλúè ŘŜY I·yŘ⌀ ¢KλăăŜÔű2N λă ØŜNè ŘλØŜNăŜ I·yŘ λyÖfdzŘŜă 2ŦŦλÖŜΣ NŜúI·λfΣ KŜI·fűK ÖI·NŜΣ ŜŘdzÔI·úλ2yΣ ø I·NŜK2dzăŜΣ I·yŘ ăŜØŜNI·f 2úKŜN ōdzλfŘλyƎ ûèLJŜăΣ N I·y ƎλyƎ λY ăλÎŜ FN2Y I· ŦŜø ûK2dzăI·yŘ ű2 Y λffλ2yã 2Ŧ ălJdzI·NŜ ŦŜŜú LJŜN ōdzλfŘλyƎ⌀ C2dzN úèLJŜă 2Ŧ Ô2Y Y ŜNÔλI·f ōdzλfŘλyƎă I·ÖÔ2dzyű Ŧ2N Y 2NŜ ŪK I·y рл LJŜNŴÔŜyű 2Ŧ úźúI·f ŘŜfØŜNŜŘ ŜfŜÔűNλÖλúè Ô2yãdz Y LJúλ2Y τ 2ŦŦλÖŜΣ NŜúI·λfΣ ŜŘdzÔI·úλ2yΣ I·yŘ KŜI·fűK ÖI·NŜ⌀ᶠΣ ᴍʏ

wŜÔŜyű I·yI·fèăλă ăK2øă ûKI·ú λY ăúI·ûŜă Ô2yãλáúŜyűfè I·Ř2LJúλyƎ ûKŜ Y 2ăú NŜÔŜyű ØŜNăλ2yã 2Ŧ ûKŜ Y 2ŘŜf ōdzλfŘλyƎ ŜyŜNƎè Ô2ŘŜăΣ K2Y Ŝ2øyŜNăΣ ōdzλfŘλyƎ 2øyŜNăΣ I·yŘ ûŜyI·yűă Ô2dzfŘ ăI·ØŜ Þмнс ōλffλ2Y 2y ŜyŜNƎè ōλffă⌀ a I·yè 2Ŧ ûKŜ KλƎK ŜŦŦλÖλŜyÔè ûŜÔKy2f2ƎλŜăΣ ōdzλfŘλyƎ ŜyØŜf2LJŜ ŘŜăλƎyãΣ I·yŘ ŜyŜNƎè Y I·yI·ƎŜY Ŝyű LJNJI·ÔűλÖŜă ûKI·ú Ŝyl·ōfŜ ălƎyλŦλÖI·yű ŜyŜNƎè ăI·ØλyƎă I·yŘ DID NŜŘdzÔűλ2yã ōŜè2yŘ ű2ŘI·è⌀ă ōdzλfŘλyƎ Ô2ŘŜă KI·ØŜ ōŜŜY ŘŜY 2yãúNI·ûŜŘ I·yŘ I·NŜ Ô2Y Y ŜNŴÔλI·ffè I·ØI·λfI·ōfŜ⌀

/2Y Y ŜNŴÔλI·fπăŜÔűN2N ălJdzI·NŜ Ŧ22úI·ƎŜ I·yŘ ŜyŜNƎè dzăŜ KI·ă ƎN2øY áúŜI·ŘλfèΣ I·fûK2dzƎK ŜfŜÔűNλÖλúè λyűŜyãλúè ó] ² KkălJdzI·NŜ Ŧ22úú λă λY LJN2ØλyƎΣ fI·NƎŜfè ŘNλØŜY ōè λyÔNŜI·ăŜă λY ŜyŜNƎè ŜŦŦλÖλŜyÔè I·ÔN2ăă ŜyŘ dzăŜă⌀ wŜÔŜyű I·yI·fèăλă λyŘλÖI·ûŜă ûKI·ú ûKŜ Y I·2N Ô2yűNλōdzűλyƎ ŦI·ÔűΣNă ű2 ûKŜ ÔKI·yƎŜ λY Ô2Y Y ŜNÔλI·f ŜfŜÔűNλÖλúè Ô2yãdz Y LJúλ2Y ŦN2Y нллу ű2 нлмн ØŜNŜ ăI·ØλyƎă ŦN2Y I·LJLJfλI·yÔŜ I·yŘ ŜIjdzλLJY Ŝyű ăúI·yŘI·NŘă I·yŘ dzűλfűúè ŜyŜNƎè ŜŦŦλÖλŜyÔè LJN2ƎNI·Y ă⌀ᴍᶲ a 2ØλyƎ Ŧ2N⌀I·NŘΣ ûKŜăŜ ŜŦŦλÖλŜyÔè úNŜyŘă ø λff Ô2yűλyűzŜ û2 Y I·]Ŝ I· ăλƎyλŦλÖI·yű λY LJI·ÖűΣ LY ŦI·ÖűΣ ŦN2Y нлмо û2 нлплΣ Ô2Y Y ŜNÔλI·f ŜyŘπdzăŜ λyűŜyãλúèΣ Y ŜI·ădzNŜŘ λY] ² KkălJdzI·NŜ Ŧ22úΣ λă LJN2ŝŜÔűŜŘ û2 ŘŜÔNŜI·ăŜ ōè I·ō2dzű y LJŜNŴÔŜyű⌀ᴍᴨ ¢KλăŘŜÔNŜI·ăŜ λă fŜŘ ōè I· ăλƎyλŦλÖI·yű ŘŜÔfλyŜ λY úKŜ ŜfŜÔűNλÖλúè λyűŜyãλúè 2Ŧ fλƎKűλyƎΣᴴᴍ ōdzű λű λă I·fă2 2ŦŦăŜű ōè I· ăλƎyλŦλÖI·yű λyÔNŜI·ăŜ λY Y ăÔŜffI·yŜ2dză ŜfŜÔűNλÖ f2I·Ră ó a 9[ăú⌀Ǝ

Ř ² λúKλY úKŜ Y I·y0zŦI·ÖűdzNλyƎ ădzōπăŜÔű2NΣ ¢KŜ a I·y0zŦI·ÖűdzNλyƎ 9yŜNƎè I·yŘ / I·Nō2Y C22úLJNλyűă I·yI·fèăλă ŜăúλY I·ûŜă úKI·ú TΣнну úNλffλ2Y . údzΣ 2N рм LJŜNŴÔŜyű 2Ŧ úKŜ мпΣлсп úNλffλ2Y . údz 2Ŧ úźúI·f ŘŜfØŜNŜŘ ŜyŜNƎè û2 úKŜ ¦⌀{⌀ Y I·y0zŦI·ÖűdzNλyƎ ăŜÔű2NΣ ø I·ă ø I·ăúŜŘ I·ă ŜŦŦλÖλŜyÔè f2ăăŜă λY нлмл⌀

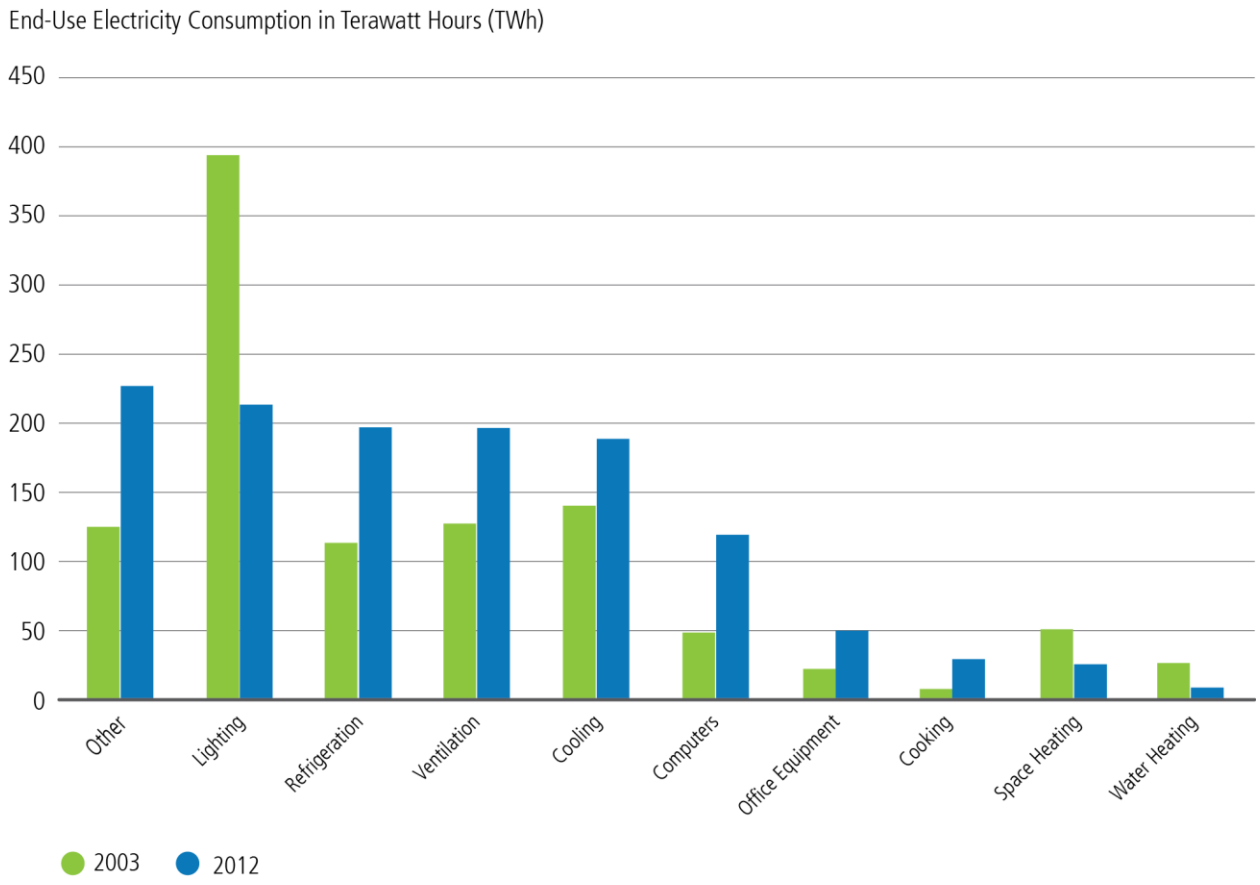
Ŝ / I t ăă 2ŦúŜY Ô2yãλŘŜNŜŘ I· Ŧ2NY 2Ŧ ŜyŜNƎè ŜŦŦλÖλŜyÔèΣ ōdzű ăă ÖI·Y I·fă2 ōŜ Ô2yãλŘŜNŜŘ I· Ŧ2NY 2Ŧ ŘλăúNλōdzúŜŘ ƎŜyŜNI·úλ2y⌀

ᵀ ! ű2úI·f 2Ŧ pc⌀п LJŜNÔŜyűY 2ŦŦλÖŜă I·ÖÔ2dzyű Ŧ2N нл⌀п LJŜNÔŜyűΣ Y ŜNÔI·yűλfŜ óY I·ffă I·yŘ y2yπY I·ff NŜúI·λfú I·ÖÔ2dzyűă Ŧ2N мс⌀с LJŜNŴÔŜyűΣ ŜŘdzÔI·úλ2Y I·ÖÔ2dzyűă Ŧ2N млфy LJŜNŴÔŜyűΣ I·yŘ KŜI·fűK ÖI·NŜ I·ÖÔ2dzyűă Ŧ2N y⌀c LJŜNŴÔŜyű⌀

ᶟ a 9[ă NŜLJNŜăŜyű I· NI·yƎŜ 2Ŧ ŜfŜÔűNλÖ f2I·Ră 2dzűăλŘŜ 2Ŧ I· ōdzλfŘλyƎΩă Ô2NŜ ŜyŘ dzăŜă 2Ŧ KŜI·úλyƎΣ ØŜyűλfI·úλ2yΣ I·NN Ô2yŘλúλ2yλyƎΣ fλƎKűλyƎΣ ø I·ûŜN KŜI·úλyƎΣ I·yŘ NŜŦNλƎŜNI·úλ2y⌀ {I·Y LJfŜ a 9[ă λyÖfdzŘŜ ûŜfŜØλăλ2yãΣ LJ22f KŜI·ûŜNă I·yŘ LJdzY LJăΣ ăŜúπű2LJ ō2ÈŜăΣ I·yŘ ÔŜλfλyƎ ŦI·yã⌀

¢ĸŝ ŝŦŦλŏλŝyŏè 2Ŧ Ύ2ăú Ŏ2ΥΎŝℕŏλl·f ŝyŘ dzăŝă λă λyŏℕŝl·ăλyƎ ǿλűĸ űĸŝ ŘŝLJf2èΎŝyű 2Ŧ l·ŘØl·yŏŝŘ fλƎĸűλyƎΣ ălJl·ÔŝŎ2yŘλűλ2yλyƎΣ ŜfŝŎŏúℕ2yλŎă l·yŘ ōdzλfŘλyƎ ŘŝăλƎyã¢ ¢ĸŝ ℕŝűℕ2Ŧλű 2Ŧ ŜÈλăűλyƎ Ŏ2ΥΎŝℕŎλl·f ōdzλfŘλyƎă l·yŘ úĸŝ l·Ř2LJűλ2y 2Ŧ yŝǿ ŝyŝℕƎèπΥl·yl·ƎŜΥŝyű ű22fă l·ℕŝ l·fă2 Ύl·ℸλyƎ ăλƎyλŦλŎl·yű Ŏ2yúℕλōdzúλ2yã ű2 ΥŜŝűλyƎ ō2ûĸ ŝyØλℕ2yΎŝyűl·f Ǝ2l·fă l·yŘ ℕŝŘdzŎλyƎ Ŏ2yãdzΎŝℕ ŝfŝŎúℕλŎλúè Ŏ2ăűã¢ ¢ĸŝ ŝŦŦλŏλŝyŏè LJℕ2Ǝℕl·Ύă úĸl·ű dzúλfλúλŝă l·yŘ CŝŘŝℕl·fΣ ăűl·úŝΣ l·yŘ f2ŏl·f l·Ǝŝyŏλŝă l·ℕŝ y2ǿ λΎLJfŝΎŝyűλyƎ Kl·Øŝ ŝyl·ōfŝŘ úĸŝăŝ úℕŝyŘă¢ᴴᴴ

Figure 2-3. Comparison of Commercial End-Use Electricity Consumption between 2003 and 2012 [23] [24]



Consumption across most end uses is increasing, including MELs, refrigeration, computing, and cooling. Lighting and space heating consumption have each decreased by about 50 percent between 2003 and 2012.

2.2.2.1 "Dispatchable" Smart, Green Buildings

!yΎλΎLJ2ℕúl·yű úℕŝyŘ ǿλűĸ λΎLJfλŎl·úλ2yã Ŧ2ℕ úĸŝ ŝfŝŎúℕλŎλúè ăëăúŝΎ λă úĸŝ λyŏℕŝl·ăλyƎ ŘλƎλúλÎl·úλ2y2Ŧ Ŏ2ΥΎŝℕŏλl·f 2ŦŦλŏŝ ălJl·ÔŝŎ l·yŘ úĸŝ ℕŝăđzfűλyƎ 2LJLJ2ℕűdzyλűλŝă ű2 dzăŝ ōdzλfŘλyƎă úĸŝΎăŝfØŝă l·ă LJl·ℕú 2Ŧ úĸŝ ŝfŝŎúℕλŎ ăëăúŝΎ¢ .dzλfŘλyƎ f2l·Řă l·ℕŝ ōŝŎ2ΎλyƎ áŘλălJl·úŎĸl·ōfŝé ōè dzúλfλÎλyƎ 5w ûŝŎĸy2f2ƎλŝăΣ Ύl·ℕℸŝűăΣ l·yŘ úĸŝ ƎℕǿǿλyƎ λyŘdzăúℕè Ŧ2ℕ LJŝl·ℸπf2l·Ř 5w úĸℕ2dzƎK l·ƎƎℕŝƎl·ú2ℕăφᴴᵖ ! ℕŝŎŝyű ℕŝLJ2ℕú ŜăúλΎl·úŝă úĸl·ú úĸŝ Ǝf2ōl·f Ύl·ℕℸŝű Ŧ2ℕ ōdzλfŘλyƎ ŜyŝℕƎèπΥl·yl·ƎŜΥŝyű ă2Ŧúǿl·ℕŝ ǿλff Ǝℕǿǿ ŦℕǿΎ Þнφп ōλffλ2y λy млмр ű2 Þмлфy ōλffλ2y λy млнпφᴴᶜ 9yŝℕƎèπΥl·yl·ƎŜΥŝyű ăëăúŝΎă l·ℕŝ λyŏℕŝl·ăλyƎfè l·ōfŝ ű2 Ŏ2yúℕ2f ℕ22Ύ ûŝΎLJŝℕl·údzℕŝăΣ KdzΎλŘúèΣ ØŝyűλfI·ûλ2y ℕl·ûŝăΣ LJfdzƎ f2l·ŘăΣ l·yŘ ŘλΎΎl·ōfŝ fλƎĸűăΣ l·yŘ λy űĸŝ Ŧdzűdzℕŝ ŎI·LJl·ōλfλúλŝă ű2 Ŏ2yúℕ2f ǿλyŘ2ǿă l·yŘ f2dzØŝℕă Ύl·è ŜÈλăúφᴴᵀ {λΎλfl·ℕfèΣ fλƎĸűλyƎΣ ǿλyŘ2ǿăΣ l ± ! / ŜIjdzλLJΎŝyúΣ ǿ l·ûŝℕ KŝI·ûŝℕăΣ l·yŘ 2úĸŝℕ ōdzλfŘλyƎ ŜIjdzλLJΎŝyű ŎI·y ōŝ ŜIjdzλLJLJŜŘ ǿλűĸ ăΎl·ℕű Ŏ2yűℕ2ffŝℕă l·yŘ ǿλℕŝfŝăă Ŏ2ΥΎdzyλŎI·ûλ2yã ŎI·LJl·ōλfλúλŝăφᴴʸ l λƎKπLJŝℕŦ2ℕΎl·yŏŝ

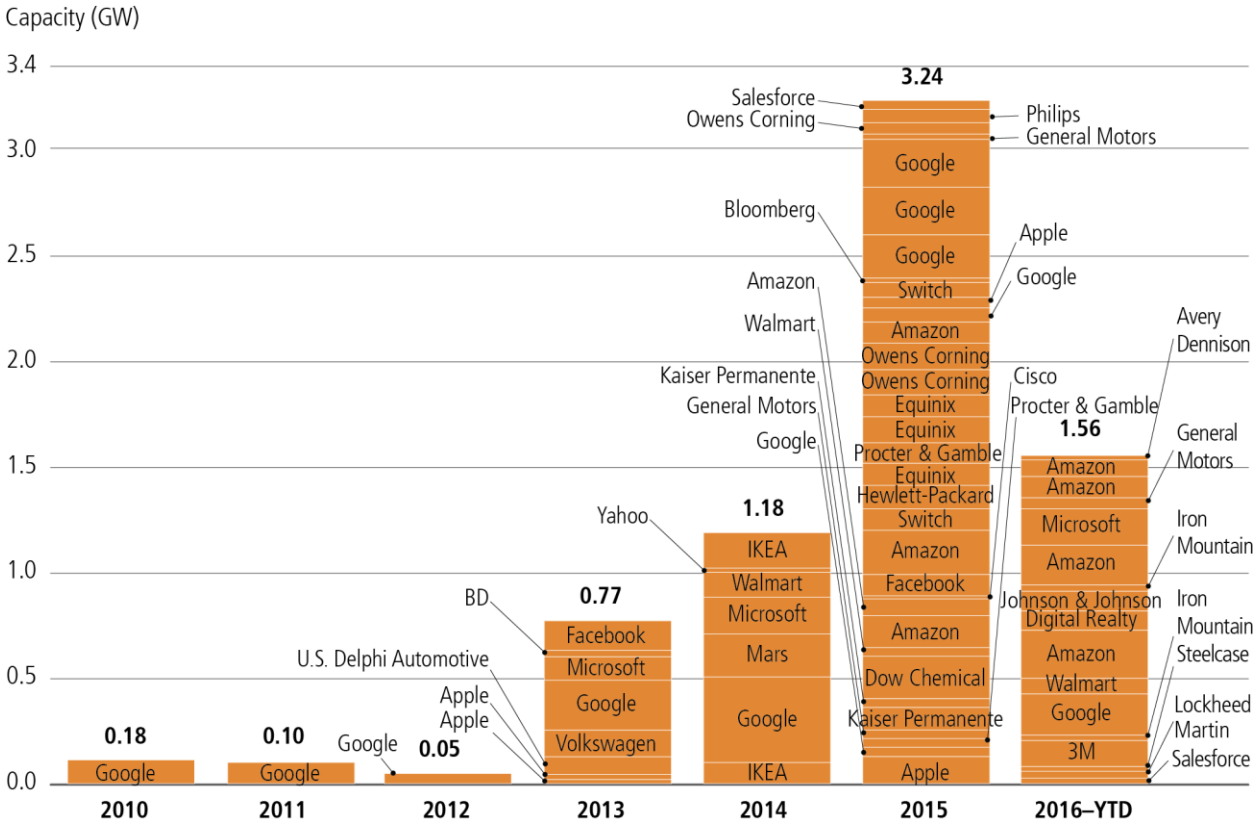
ōdzλƭŘλyƎ l·ǘǘŃλōdzǘŜă l·ŃŜ λyŎŃŜl·ăλyƎƭè ŦI·ŎǘƻŃλyƎ λyǘƻ ǘŜyl·yǘăΩ ŘŜŎλăλƻyã l·ōƻdzǘ ƭŜl·ăλyƎ ăLJl·ŎŜ l·yŘ ōdzèŜŃăΩ ŘŜŎλăλƻyã l·ōƻdzǘ LJdzŃŎKl·ăλyƎ LJŃƻLJŜŃǘλŜăφ

CƻŃ ōƻǘK ăYl·ƭƭ ŎƻYYŜŃŎλl·ƭ ŎdzăǘƻYŜŃă l·yŘ KƻdzăŜKƻƭŘăΣ ǘKŜŃŜ l·ŃŜ λyŦƻŃYl·ǘλƻy l·yŘ ŦλŃăǘπŎƻăǘ ōl·ŃŃλŜŃă ǘKl·ǘ ƭλYλǘ LJŜyŜǘŃl·ǘλƻy ƻŦ ǘKŜăŜ ŎƻYYdzyλŎl·ǘλyƎ ŘŜØλŎŜăφ Ly нлмнΣ l·ōƻdzǘ тл LJŜŃŎŜyǘ ƻŦ ŎƻYYŜŃŎλl·ƭ ōdzλƭŘλyƎă ƭl·ŃƎŜŃ ǘKl·y млл∑ллл ăljdzl·ŃŜ ŦŜŜǘΣ ŦƻŃ ŜÈl·YLJƭŜΣ Kl·Ř ăƻYŜ ʅλyŘ ƻŦ ŜyŜŃƎè Yl·yl·ƎŜYŜyǘ ƻŃ ŎƻyǘŃƻƭ ăèăǘŜY ŦƻŃ l ± ! / Σ ōdzǘ ƻyƭè l·ōƻdzǘ мр LJŜŃŎŜyǘ ƻŦ ōdzλƭŘλyƎă ăYl·ƭƭŜŃ ǘKl·y нр∑ллл ăljdzl·ŃŜ ŦŜŜǘ dzăŜŘ ǘKŜYφнφ

2.2.2.2 Meeting Sustainability Goals through Direct Procurement of Renewable Energy

Ly ăƻYŜ ăǘl·ǘŜăΣ ƭl·ŃƎŜ ŜƭŜŎǘŃλŎλǘè ŎƻyãdzYŜŃă l·ŃŜ l·ōƭŜ ǘƻ LJdzŃŎKl·ăŜ ŜƭŜŎǘŃλŎλǘè ŦŃƻY LJŃƻØλŘŜŃă ƻǘKŜŃ ǘKl·y ǘKŜ ƭƻŎl·ƭ λyŎdzYōŜyǘ dzǘλƭλǘèφ Ly ŃŜŎŜyǘ èŜl·ŃăΣ ăƻYŜ ƭl·ŃƎŜ ŎƻYYŜŃŎλl·ƭ ŎdzăǘƻYŜŃăΣ LJl·ŃǘλŎdzƭl·Ńƭè ǘKƻăŜ ǘKl·ǘ l·ŃŜ ŎƻyãdzYŜŃπŦl·ŎλyƎΣ Kl·ØŜ l·ŘƻLJǘŜŘ ŎƻŃLJƻŃl·ǘŜ ădzăǘl·λyl·ōλƭλǘè Ǝƻl·ƭă ǘKl·ǘ λyŎƭdzŘŜ ŃŜyŜø l·ōƭŜ ŜƭŜŎǘŃλŎλǘè óCλƎdzŃŜ нπпύφ Ly нлмрΣ ŎƻŃLJƻŃl·ǘλƻyã óōƻǘK ŎƻYYŜŃŎλl·ƭ l·yŘ λyŘdzăǘŃλl·ƭύ ŎƻyǘŃl·ŎǘŜŘ yŜl·Ńƭè oφп ƎλƎl·ø l·ǘǘă óD ² ύ ƻŦ ŃŜyŜø l·ōƭŜ ŜyŜŃƎèол τ dzLJ ăλƎyλŦλŎl·yǘƭè ŦŃƻY ǘKŜ срл а ² ŎƻyǘŃl·ŎǘŜŘ ōŜǘøŜŜy нллу l·yŘ нлмнφом

Figure 2-4. Corporate Procurement of Renewable Energy-Based Electricity 2010–2016[32]



Large corporate customers (including commercial and industrial sectors) can specify the type of generation underlying the electricity provided through procurement contracts, including PPAs, Green Tariffs and Project Ownership. Corporate procurements represent an important new mechanism for developing renewable energy projects. Last updated December 15, 2016.

{2Y Ô2YLJI·yλŝă I·NŜ Ǝ2łyƎ ōŜè2yŘ ŘλNŜŐű LJdzNŐKI·ăŜ 2Ŧ ŜfŜŐúNλÕλúè♦ LyʹнлмлΣ úKŜ CŜŘŜNI·f 9yŜNƎè wŜƎdzfI·ű2Nè /2YYλăăλ2yʹ óC9w/ú ƎNI·yűŜŘ D2Ƨ2ƎfŜ 9yŜNƎè űKŜ I·dzűK2Nλúè ű2 ăŜff ǿK2fŜăI·fŜ ŜfŜŐúNλÕλúè♦oo Lyʹ I·y2űKŜNJ łyy2ØI·úλØŜ I·NJNI·yƎŜYʹŜyűΣ ! Y I·Î2yΩă Ôf2dzŘ Ô2YʹLJdzűλyƎ ŘλØλă2yΣ ! Y I·Î2yʹ ² Šō {ŜNJØλÕŜă ó ! ² {úΣ ăłƎySŘ I· ySǿ úèLJŜ 2Ŧ LJ2ǿŜNJ LJdzNŐKI·ăŜ I·ƎNŜŜYʹŜyű ót t ! ú ǿλűK 52YʹłyI2yʹ±λNƎλyλI· t2ǿŜN♦ ¢KŜ I·ƎNŜŜYʹŜyű I·ff2ǿă úKŜ dzűλfλúè úž Y I·yI·ƎŜ ! ² {Ω ŜÈłăúłyƎ I·yŘ ŦdzúdzNŜ łyØŜăúYʹŜyűă łyʹă2fI·NJ I·yŘ ǿλyŘ LJN2ŜÕűăT ÕKI·NƎŜă ! ² { I· NŜűI·łf NJI·úŜ Ŧ2NJ ŜfŜŐúNλÕλúè Ôf2ăŜ ű2 úKŜ ǿK2fŜăI·fŜ NJI·úŜ ŰKI·ú úKŜλNJ łyØŜăúYʹŜyűă ŜI·NyʹłyʹúKŜ Y I·N⌉ŜúT I·yŘ LJNŜØŜyűă úKŜ Ô2ăűă 2Ŧ ! ² {Ω NŜyŜǿI·ōfŜ ŜyŜNƎè łyØŜăúYʹŜyű ŦN2Yʹ ăKλŦúλyƎ ű2 2úKŜNJ Ô2yãdzYʹŜNă♦on

¢KŜNŜ I·NŜ ăŜØŜNJI·f ǿI·ëă łyʹǿKλÕK Ô2NLJ2NJI·úλ2yã ÕI·yʹØ2fdzyűI·NλfÈ LJN2ÕdzNŜ NŜyŜǿI·ōfŜ ŜyŜNƎèΣ łyÕfdzŘλyƎ t2ǿŜNJ tdzNŐKI·ăŜ !ƎNŜŜYʹŜyűă ót t !Ωáú♦ Lyʹ I·NŜI·ă ǿKŜNŜ Y I·N⌉Ŝű ăűNdzÕűdzNŜă LJNŜÕfdzŘŜ t t ! ă Ŧ2NJ ŘλNŜÕű Ô2NLJ2NJI·ûŜ LJN2ÕdzNŜYʹŜyűΣ ă2YŜ dzűλfλúλŜă I·yŘ NŜűI·łf ŜfŜÕúNλÕλúèπăŜNJØλÕŜ LJN2ØλŘŜNă 2ŦŦŜN ƎNŜŜyʹ ÕK2łÕŜ 2N ƎNŜŜyʹ úI·NJλŦŦ LJN2ƎNI·YʹăT Ŧ2NJ ŜÈI·YʹLJfŜΣ ă2YʹŜ ŜyŜNƎè LJN2ØλŘŜNă łyʹ¢ŜÈI·ă 2ŦŦŜN млл LJŜNŐŜyű ǿλyŘ LJfI·yã ű2 Ödzăű2YʹŜNă♦

2.2.3 Federal Agencies

² λúK Y2NŜ űKI·yʹорлΣллл ōdzλfŘłyƎă łyʹdzăŜΣ úKŜ CŜŘŜNI·f D2ØŜNJYYŜyű łă úKŜ bI·úλ2yΩă fI·NƎŜăű ŜyŜNƎè dzăŜN♦op ¢KŜ CŜŘŜNI·f D2ØŜNJyYŜyű dzăŜŘ фпт úNλfłλ2yʹ . NλúλăK úKŜNJYI·f dzyłúă łyʹнлмр♦oc 9fŜÕúNλÕλúè YI·ŘŜ dzLJ мф♦ф LJŜNŐŜyű 2Ŧ CŜŘŜNI·f ŜyŜNƎè dzăŜΣ ōŜKłyŘ 2yfè ?Ŝú ŦdzŜf I·ú ппфн LJŜNŐŜyű♦oт a 2ăű CŜŘŜNI·f ōdzλfŘłyƎă KI·ØŜ ƎNŜŜyK2dzăŜ ƎI·ă óD I DúπNŜŘdzÕúλ2yʹ Ǝ2I·făΣ I·yŘ CŜŘŜNI·f fI·ǿ Ŝyŏ2dzNI·ƎŜă CŜŘŜNI·f I·ƎŜyŐλŜă ű2 λYLJfŜYŜyű I·ff Ô2ăúπŝŦŦŜÕúλØŜ

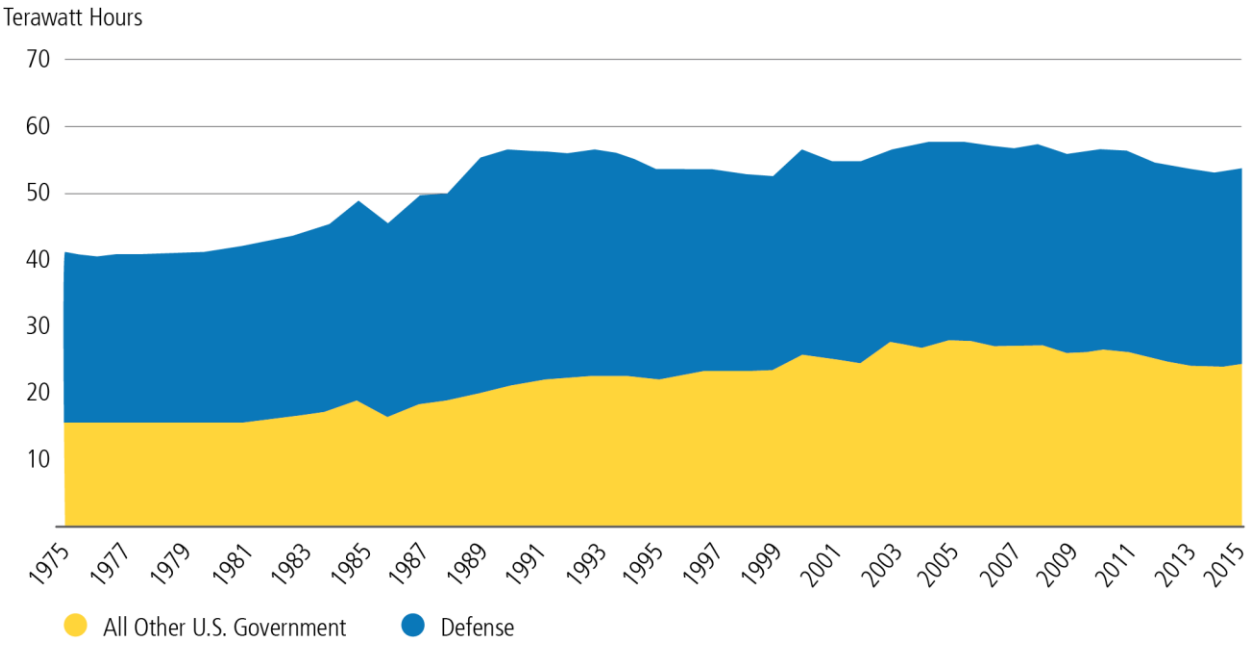
ŜyŜ₪∃è ŜŦ₣λÕλŜyÕè ϒŜI·ădz₪Ŝăφ CŜŘŜ₪I·f fI·ø I·fă2 ₪ŜIjdz₪Ŝă I·∃ŜyÕλŜă ú2 dzăŜ fλŦŜπÕèÕfŜ Õ2ăú I·yI·fèăŜă øKŜϒ Õ2yãλŘŜ₪λyƎ ōdzλtŘλyƎ ăèăúŜϒăφºy

¦ yŘŜ₪ 9ÈŜÕdzúλØŜ h₪ŘŜ₪ мормп ₪ŜIjdz₪Ŝă CŜŘŜ₪I·f I·∃ŜyÕλŜă ú2 ₪ŜŘdzÕŜ D I D Ŝϒλăăλ2yã ōè пл LJŜ₪ÕŜyú Õ2ϒLJI·₪ŜŘ ú2 I· ннлу ōI·ăŜfλyŜ ōè нлнрφ Lú I·fă2 ₪ŜIjdz₪Ŝă CŜŘŜ₪I·f ŦI·ÕλfλúλŜă ú2 ϒŜŜú I· ол LJŜ₪ÕŜyú ₪ŜyŜøI·ōfŜ ŜfŜÕú₪λÕλúè ăúI·yŘI·₪Ř ōè нлнрΣºφ I·yŘ ŦI·ÕλfλúλŜă ÕI·yˇϒŜŜú ŭKŜ ăúI·yŘI·₪Ř λyˇ2yŜ 2Ŧ Ŧ2dz₪ øI·èă ófλăúŜŘ λyˇLJ₪λ2₪λúè 2₪ŘŜ₪ú мú λyãúI·ffλyƎ I·∃ŜyÕè¤ŦdzyŘŜŘ ₪ŜyŜøI·ōfŜ ŜyŜ₪∃è 2yãλúŜ I·ú CŜŘŜ₪I·f ŦI·ÕλfλúλŜăT óнú Õ2yú₪I·ÕúλyƎ úKŜ LJdz₪ÕKI·ăŜ 2Ŧ ŜyŜ₪∃èΣ øKλÕK λyÕfdzŘŜă úKŜ λyãúI·ffI·úλ2yˇ2Ŧ ₪ŜyŜøI·ōfŜ ŜyŜ₪∃è 2yãλúŜ I·yŘ 2ŦŦăλúŜ I·ú I· CŜŘŜ₪I·f ŦI·ÕλfλúèT óoú LJdz₪ÕKI·ăλyƎ ₪ŜyŜøI·ōfŜ ŜfŜÕú₪λÕλúèΣ I·yŘ óпú LJdz₪ÕKI·ăλyƎ wŜyŜøI·ōfŜ 9fŜÕú₪λÕλúè /₪ŜŘλúăφ∩∩ CλŦúŜŜyˇLJŜ₪ÕŜyú 2Ŧ ŜÈλăúλyƎ I·∃ŜyÕè ōdzλtŘλyƎă Yˇdzăú ōŜ ∃₪ŜŜyˇōdzλtŘλyƎăΣ ŜλúKŜ₪ ōè yдzYˇōŜ₪ 2₪ ăljdzI·₪Ŝ Ŧ22úI·∃Sφ⊓™

2.2.3.1 Department of Defense is Single Largest Consumer of Electricity

¢KŜ 5ŜLJI·₪úYˇŜyú 2Ŧ 5ŜŦŜyãŜ ó5h5ú λă 2yŜ 2Ŧ úKŜ fI·₪∃Săú ŜyŜ₪∃è Õ2yãdzYˇŜ₪ă λyˇúKŜ ¦ yλúŜŘ {úI·úŜăΣ λă úKŜ fI·₪∃Săú Õdzăú2YˇŜ₪ 2Ŧ úKŜ ŜfŜÕú₪λÕ ∃₪λŘΣ⁻ᴴ I·yŘ dzăŜă Y2₪Ŝ úKI·yˇI·ff 2úKŜ₪ I·∃ŜyÕλŜă Õ2Yˇōλy ŜŘ óCλ∃dz₪Ŝ нπpúφ 5h5 ₪ŜIjdz₪Ŝă ŜfŜÕú₪λÕλúè ú2 ădzLJLJ2₪úú λúă Yˇλăăλ2yã ō2úK Ř₪ŜÕúfè ōè ŜyŜ₪∃λÎλyƎ úKŜ ŦI·ÕλfλúλŜă I·yŘ ăèăúŜYˇă úKI·ú ŦdzŜf ŦfŜŜúă 2Ŧ ú₪dzÕ⌈ăΣ úI·yˇ⌈ăΣ I·yŘ ăKλLJăΣ I·yŘ λyŘ₪₪ŜÕúfè ōè ŜyŜ₪∃λÎλyƎ 2úKŜ₪ ădzLJLJ2₪úλyƎ λyŦ₪I·ăú₪dzÕúdz₪ŜΣ ădzÕK I·ă úKŜ Õ2YˇYˇdzyλÕI·úλ2yã ăèăúŜYˇă úKI·ú ŘŜfλØŜ₪ λyŦ2₪YˇI·úλ2yˇI·Õ₪2ăă úKŜ ∃f2ōŜφ ¢2 ŜyãdzN₪Ŝ λú ÕI·yˇLJŜ₪Ŧ2₪Yˇ λúă Yˇλăăλ2yΣ 5h5 λyØŜăúă λyˇ yдzYˇŜ₪2dză I·ŘØI·yÕŜŘ úŜÕKy2f2∃λŜă úKI·ú λYˇLJ₪2ØŜ ŜyŜ₪∃è ŜŦŦλÕλŜyÕè I·yŘ λyÕ₪ŜI·ăŜ ŜyŜ₪∃è ădzLJLJfè ₪ŜăλfλŜyÕŜ I·yŘ ŦI·ÕŜă YˇI·yê 2Ŧ úKŜ ăI·YˇŜ ÕKI·ffŜyƎŜă I·ă 2úKŜ₪ LJdzōfλÕ λyãúλúdzúλ2yãφ

Figure 2-5. Electricity Use by the U.S. Government and Department of Defense, 1975–2015[43]



DOD uses more electricity than the rest of the U.S. Government combined. This relationship has remained relatively steady for the past 40 years.

5h5 KI·ă ōŠŠy l·y Ŝl·№fê l·yŘ l·ÔŰλØŠ dzăŜ№ 2ŦŷŜyŠ№∃è ăl·ØλyЭă LJŜ№Ŧ2№Y l·yÕŠ Ô2yŰ№l·ÔŰă ű2 λYLJfŜYŠyŰ ŜyŠ№∃è ŜŦŦλÔλŜyÕè LJ№2ȼŜÔŰă ŰKl·ű ălØŜ Y2ySè l·yŘ №ŜŘdzÔŠ ŜfŜÔŰ№ÔλÚê ŘŠYl·yŘΦ 5h5 l·fă2 LJdz№ădzŜă №ŜyŠØl·ōfŜ ŜyŠ№∃è ű2 l·ŘØl·yÕŠ λÚă ŜyŠ№∃è №ŜăλfλŜyÕŠΦ w2dz∃Kfê н LJŜ№ÔŠyŰ 2Ŧ 5h5Ωă ű2ŰI·f ŜyŠ№∃è Ô2yãdzYLJŰλ2y ÕI·YŠ Ŧ№2Y №ŜyŠØl·ōfŜ ă2dz№ÔŠă λy ŦλăÔI·f èŜI·№ нлмрΦ hyãλÚŜ 2LJŜ№l·Ûλ2yl·f LJ№2ȼŜÔŰă óY2ăŰfê ∃Ŝ2ŰKŠ№YI·fΣ ōλ2YI·ăăΣ l·yŘ Ydzyλ ÔλLJl·f ă2fλŘ ØI·ăÚŜú l·ÔÕ2dzyŰŜŘ Ŧ2№ yн LJŜ№ÔŠyŰ 2Ŧ ŰKŠ 5ŜLJl·№ÚYŜyŰΩă №ŜyŠØl·ōfŜ ŜyŠ№∃è ădzLJLJfèΣ ØKλfŜ LJdz№ÕKl·ăŜŘ №ŜyŠØl·ōfŜ ŜyŠ№∃è Õ№ŠŘλûă №ŜLJ№ŠăŜyŰŜŘ ŰKŠ 2ŰKŠ№ my LJŜ№ÔŠyŰΦ Ly нлмрΣ 5h5 KI·Ř 2ØŜ№ mΣофл 2LJŜ№l·Ûλ2yl·f №ŜyŠØl·ōfŜ ŜyŠ№∃è LJ№2ȼŜÔŰăΣ Õ2YLJl·№ŜŘ ű2 мΣмол λyнлмпΦⁿⁿ DŜ2ŰKŠ№YI·f ŜfŜÔŰ№λÕ LJ2ØŜ№ λă ōè Ŧl·№ ŰKŠ Y2ăÚ ălЭyλŦλÕl·yÚ №ŜyŠØl·ōfŜ ŜyŠ№∃è ă2dz№ÔŠ λy5h5Σ l·ÔÕ2dzyÚλyЭ Ŧ2№ 2ØŜ№ пм LJŜ№ÔŠyŰ 2Ŧ ŰKŠ 5ŜLJl·№ÚYŜyÚΩă №ŜyŠØl·ōfŜ ŜyŠ№∃è ∃ŜyŠ№l·Ûλ2yLJ2№ÚŦ2fλ2Φ .λ2YI·ăă YI·ȉŜă dzLJ l·ō2dzÚ мф LJŜ№ÔŠyÚΣ ØKλfŜ Ydzyλ ÕλLJl·f ă2fλŘ ØI·ăÚŜΣ ØKλÕK λă dzăŜŘ Ŧ2№ ō2ŰK ŜfŜÔŰ№λÕλÚê l·yŘ ăÚŜI·Y LJ№2ŘdzÔŰλ2yΣ l·ÕÕ2dzyÚă Ŧ2№ мр LJŜ№ÔŠyÚΦ ¢KŠ№Ŝ l·№Ŝ умл ă2fl·№ LJK2Ű2Ø2fÚl·λÕ ót±ú ăèăÚŜYă ŰK№2dz∃K2dzÚ ÚKŠ 5h5 ăèăÚŜY ÚKl·Ú Ô2yÚ№λōdzÚŜ l·LJL J№2ÈλYl·ÚŜfê мо LJŜ№ÔŠyÚΦ Ly hÕÚ2ōŠ№ нлмсΣ ŰKŠ ¦Φ{Φ bl·Øè l·yŘ {ŜYLJ№l· 9y Ŝ№∃è 2LJŜySŘ ŰKŠ мрлπa ² aŠălјdzλÚŜ {2fl·№ o LJ№2ȼŜÔŰ ű2 ădzLJLJfè l·LJLJ№2ÈλYl·ÚŜfê 2yŜπÚKλ№Ř 2Ŧ ŰKŠ ŜfŜÔŰ№λÕλÚè №ŜljdzλŠŘ ōè мп bl·Øè l·yŘ al·№λyŠ λyãÚl·ffl·Ûλ2yã τ ŰKŠ fl·№∃ŠÚ CŜŘŠ№l·f LJdz№ÕKl·ăŜ 2Ŧ ÕfŜl·y ŜyŠ№∃è λyKλăÚ2№èΦⁿᵖΣ ⁿc

5h5 λă l·fă2 ŜÈLJf2№λyЭ Ô2ăÚπŜŦŦŜÕŰλØŠ Øl·èă ű2 λyÕ2№LJ2№l·ÚŜ YλÕ№2∃№JŘ l·LJLJfλÕl·Ûλ2yã ű2 №ŜŘdzÕŠ ŜyŠ№∃è ŘŠYl·yŘΣ λyÕ№Ŝl·ăŜ ŜyŠ№∃è ădz№ŜÚèΣ l·yŘ LJ№2ØλŘŠ ŘλăÚ№λōdzÚŜŘ ∃ŜyŠ№l·Ûλ2yó5Dú l·yŘ ăÚ2№l·∃ŜΦ {Yl·№Ú t2ØŜ№ LyŦ№l·ăÚ№dzÕÚdz№Ŝ 5ŜY2yãÚ№l·Ûλ2yŦ2№ 9y Ŝ№∃è wŜfλl·ōλfλÚè l·yŘ {ŜÕdz№λÚè ó{tL59w{ú W2λyÚ /l·LJl·ōλfλÚè ¢ŜÕKy2f2∃è 5ŜY2yãÚ№l·Ûλ2y óW/¢5ú λă l· ∃№2dzyŘō№Ŝl·ȉλy∃ LJ№2∃№l·Y ŘŠăλ∃ySŘ ű2 ō2făÚŜ№ ÚKŠ ÒèōŜ№ăŠÕdz№λÚè l·yŘ ŜyŠ№∃è ŜŦŦλÕλŜyÕè 2Ŧ ¦Φ{Φ Yλfλú l·№è λyãÚl·ffl·Ûλ2yã l·yŘ Ú№l·yãŦŜ№ ÚKŠ ȉy2ØK2Ø ű2 y2yπYλfλÚl·№è Õ№λÚλÕl·f λyŦ№l·ăÚ№dzÕÚdz№ŜΦⁿᵀ 5h5 fl·dzyÕKŠŘ ÚKŠ {tL59w{ W/¢5 LJ№2∃№l·Y λy №ŠăLJ2yãŜ ű2 ∃№2ØλyЭ Õ2yÕŜ№y l·ō2dzÚ ÚKŠ YλfλÚl·№è№ã ŜyŠ№∃è λyŦ№l·ăÚ№dzÕÚdz№ŜΩă ØdzfyŠ№l·ōλfλÚè ű2 yl·Údz№l·f Řλăl·ăÚŜ№ă l·yŘ Õ2YLJdzÚŜ№πō2№yŜ ÕèōŜ№ l·ÚÚl·Ô ȉΣ ØKλÕK Õ2dzfŘ λYLJl·ÕÚ ÚKŠ ∃№λŘΦ

2.2.4 Municipalities, Universities, Schools, and Hospitals

tdzōfλÕ l·yŘ λyãÚλÚdzÚλ2yl·f Õ2yãdzYŜ№ăΣ ădzÕK l·ă Ydzyλ ÕλLJl·fλÚλŜăΣ dzyλØŜ№ăλÚλŜăΣ ăÕK22făΣ l·yŘ K2ăLJλÚl·făΣ 2ŦÚŜyÕl·ffŜŘ ÚKŠ a¦{l Yl·№ȉŜÚΣ l·№Ŝ l·y2ŰKŠ№ ∃№2ØλyЭ Ol·ÚŜ∃2№è 2Ŧ ŜfŜÔŰ№λÕλÚè Ödzăú2YŜ№ă¢KŠăŜ Ödzăú2YŜ№ăΣ ŜăLJŜÕλl·ffè

[illegible]

[illegible]

[illegible]

ŦIꞏÖʎfɫúëΣ ŜfŜÖúNɅÖʎúê IꞏÖÖ2dzyűă Ŧ2NJ yŜIꞏNfê но LJŜNJÖŜyű 2Ŧ ʎűă 2LJŜNJIꞏűʎyƎ Ö2ăűă⌀ᶜᵀ ¢NJŜIꞏűϒŜyű ŦIꞏÖʎfɫúʎŜăΣ K2ǿŜØŜNJΣ KIꞏØŜ yʤϒŜNJ2dzä 2LJLJ2NJűdzyɅúʎŜă úƨ2 ōŜÖ2ϒŜ ySű LJNJ2ŘdzÖŜNJă 2Ŧ ŜyŜNJƎè⌀ᶜʸ adzyɅÖʎLJIꞏf ǿIꞏăűŜǿIꞏűŜNJ Ö2yűIꞏʎyă ŦɅØŜ úƨ2 ûŜyűʎϒŜă IꞏăϒʤÖK ÖKŜϒʎÖIꞏf IꞏyŘ úKŜNJϒIꞏf ŜyŜNJƎè IꞏăúKŜ fIꞏǿ ÖdzNJNJŜyűfê NJŜIjdzʎNJŜă Ŧ2NJ ǿIꞏűŜNJ úNJŜIꞏűϒŜyű úƨ2 ϒŜŜú ŘʎăÖKIꞏNJƎŜ ăűIꞏyŘIꞏNJŘă⌀¢⌀ᴱ ᴛʌᴱ ™

¢KŜNJŜ IꞏNJŜ Iꞏ yʤϒōŜNJ 2Ŧ ǿIꞏèă úƨ2 ăʎƎyɅŦɅÖIꞏyűfê ʎYʿLJNJ2ØŜ úKŜ ŜyŜNJƎè ŜŦŦɅÖʎŜyÖè 2Ŧ ŜfŜÖúNJɅÖ ǿIꞏúŜNJ LJdzYʿLJă dzăŜŘ ʎʏ ϒdzyɅÖʎLJIꞏf ăëăúŜϒă űKNJ2dzƎK ŜŦŦɅÖʎŜyÖè ăűIꞏyŘIꞏNJŘă⌀ ¢KŜ 5ŜLJIꞏNJúϒŜyű 2Ŧ 9yŜNJƎè ó5h9ú KIꞏă NJŜƎdzfIꞏúƨNJè IꞏdzúK2NJɅúè 2ØŜNJ LJdzYʿLJăΣ ʎyÖfdzŘʎyƎ ǿIꞏúŜNJ LJdzYʿLJă⌀ ! yŘ ʎʏ нлмсΣ 5h9 ăŜű YʎyɅϒdzY ăűIꞏyŘIꞏNJŘă Ŧ2NJ ÖŜNJúIꞏʎʏÖIꞏúŜƎ2NJɅŜă 2Ŧ ǿIꞏúŜNJ LJdzYʿLJă IꞏyŘ úKŜ IꞏŘ2LJúɅ2ʏ 2Ŧ ØIꞏNJʌIꞏōfŜ ăLJŜŜŘ ŘNJɅØŜăT 5h9 NJŜIjdzɅNJŜŘ Ö2YʿLJfɫIꞏyÖŜ ăűIꞏNJúʎyƎ ʎʏ нлнл⌀ᴷ a2NJŜ2ØŜNJΣ NJŜIjdzɅNJŜYˆŜyűă Ŧ2NJ Ö2ϒʿLJfɫIꞏyÖŜ ǿʎúK úKŜăŜ ăűIꞏyŘIꞏNJŘă Ö2dzfŘ KIꞏØŜ úKŜ IꞏyÖʎffIꞏNJè ōŜyŜŦɅű 2Ŧ ŜyƘIꞏyÖŜŘ ŘIꞏúIꞏ Ö2ffŜÖúʌ2ʏ 2ʏ ŜyŜNJƎè dzăŜ ōè LJdzYʿLJă⌀ᵀᴴ húKŜNJ YʿIꞏyIꞏƎŜYˆŜyű ûŜÖKyʎIjdzŜă ű2 NJŜŘdzÖŜ LJdzYʿLJăΩ ŜfŜÖúNJɅÖʎúê ŘŜYʿIꞏyŘ IꞏNJŜ IꞏfăƨŽ 2ʏ úKŜ NJɅăŜ⌀ C2NJ ŜÈIꞏYʿLJfŜΣ ōŜÖIꞏdzăŜ ǿIꞏúŜNJ LJdzYʿLJă dzăŜŘ Ŧ2NJ ɅNJNJɅƎIꞏúʌ2ʏ IꞏyŘ YʤϒÖʎLJIꞏf ǿIꞏúŜNJ ăëăúŜYˆă ÖIꞏyˆōŜ ûŜYʿLJ2NJIꞏNJɅfê ûdzNJyŜŘ 2ŦŦ ű2 NJŜŘdzÖŜ f2IꞏŘ ŘdzNJɅyƎ LJŜNJɅ2Řă 2Ŧ LJŜIꞏ] ŘŜYʿIꞏyŘΣ IꞏyʤϒōŜNJ 2Ŧ dzúʌfɫúʌŜă IꞏfNJŜIꞏŘè 2ŦŦŜNJ ʎyÖŜyűʎØŜă Ŧ2NJ 2LJŜNJIꞏú2NJă ű2 LJIꞏNJúÖʎLJIꞏûŜ ʎʏ 5w LJNJ2ƎNJIꞏϒă⌀

2.2.5 Residential Consumers

¢KŜ NJŜăʎŘŜyűʌIꞏf ăŜÖű2NJ IꞏÖÖ2dzyűă Ŧ2NJ Iꞏōƨdzű oy LJŜNJÖŜyű 2Ŧ ű2úIꞏf ¦⌀{⌀ ŜfŜÖúNJɅÖʎúê ŘŜYʿIꞏyŘ⌀ {ʎyƎfŜπŦIꞏYʿʎfê ŘŜúIꞏŎKŜŘ K2YˆŜă Ö2yãdzYˆŜ úKŜ YʿIꞏ2ƨNJúê τ тп LJŜNJÖŜyű τ 2Ŧ ŜfŜÖúNJɅÖʎúê IꞏÖNJ2ăä úKŜ bIꞏúʌ2yΩă ű2úIꞏf ăű2Ö] 2Ŧ ммо⌀c Yʿʎfɫʌ2ʏNJŜăʎŘŜyÖŜă⌀ ² KʎfŜ NJŜăʎŘŜyűʌIꞏf ŜfŜÖúNJɅÖʎúê ŘŜYʿIꞏyŘ ʎyÖNJŜIꞏăŜŘ ōŜűǿŜŜyˆмффл IꞏyŘ нллсΣ ʎyˆYƨNJŜ NJŜÖŜyű èŜIꞏNJăΣ úKŜNJŜ KIꞏă ōŜŜyˆfɫúúfŜΣ ƨNJ ŜØŜyˆ ySƎIꞏúʌØŜΣ IꞏyʏΩzIꞏf ŜfŜÖúNJɅÖʎúêπÖ2yãdzYˆLJúʌ2ʏ ƎNJ2ǿúK ʎʏ úKŜ NJŜăʎŘŜyűʌIꞏf ăŜÖű2NJ⌀ LˆYˆLJNJ2ØŜYˆŜyűă ʎyˆúKŜ ŜfŜÖúNJɅÖʎúê ʎyűŜyãʎúê óYˆŜIꞏǿIꞏúű K2dzNJă ώa ² K6кK2dzăŜK2fŘú 2Ŧ úKŜ NJŜăʎŘŜyűʌIꞏf ăŜÖű2NJΣ fIꞏNJƎŜfê IꞏúúNJɅōdzúŜŘ ű2 úKŜ ʎyÖNJŜIꞏăʎyƎ ŜŦŦɅÖʎŜyÖè 2Ŧ Yˆ2ăű ŜyŘ dzăŜăΣ KIꞏØŜ Ö2yúNJɅōdzúŜŘ ű2 úKʌă NJŜÖŜyű f2ǿ ƎNJ2ǿúK⌀

¢KŜ yʤϒōŜNJ 2Ŧ ¦⌀{⌀ K2dzăŜK2fŘă KIꞏă ōŜŜyˆʎyÖNJŜIꞏăʎyƎΣ IꞏyŘ úKʌă ƎNJ2ǿúK ʎyˆyʤϒōŜNJ 2Ŧ K2dzăŜK2fŘă ʌă ŜÈLJŜÖúŜŘ ű2 Ö2yúʎyʤzŜ⌀ tŜNJ K2dzăŜK2fŘΣ K2ǿŜØŜNJΣ нлпл ŜfŜÖúNJɅÖʎúê dzăIꞏƎŜ ʌă LJNJ2ƨŜÖúŜŘ ű2 ōŜ f2ǿŜNJ úKIꞏyˆ нлмо τ мл LJŜNJÖŜyű f2ǿŜNJ LJŜNJ K2dzăŜK2fŘΣ y LJŜNJÖŜyű f2ǿŜNJ LJŜNJ ÖIꞏLJʎúIꞏΣ IꞏyŘ мy LJŜNJÖŜyű f2ǿŜNJ LJŜNJ ăljdzIꞏNJŜ Ŧ22úǿ /2yűʎyʤzŜŘ ʎYˆLJNJ2ØŜYˆŜyűă ʎyˆŜyŜNJƎè ŜŦŦɅÖʎŜyÖè IꞏyŘ 2úKŜNJ ŜyŜNJƎè ûŜÖKyʏf2Ƨ3ʎŜăΣ fʎ]Ŝ 2yãʎúŜ ƎŜyŜNJIꞏúʌ2yˆIꞏyŘ ăű2NJIꞏƎŜΣ IꞏNJŜ fʎ]Ŝfê ű2 IꞏÖÖŜfŜNJIꞏûŜ ʎyˆySǿ IꞏyŘ ŜÈʌăúʎyƎ K2YˆŜă IꞏyŘ IꞏÖNJ2ăä IꞏLJLJfɫIꞏyÖŜăΣ fʎƎKűʎyƎΣ ǿIꞏûŜNJ KŜIꞏűʎyƎΣ KŜIꞏűʎyƎ IꞏyŘ Ö22fɫyƎ ŜIjdzʌLJYˆŜyűΣ IꞏyŘ ŜfŜÖúN2yɅÖăΣ LJdzúűʎyƎ Ř2ǿyǿIꞏNJŘ LJNJŜăădzNJŜ 2ʏ f2IꞏŘ ƎNJ2ǿúK⌀ w Ŝ yˆŜ ǿ Iꞏ ōf Ŝ Ŝ yˆŜ NJ Ǝ è Iꞏ yˆŘ ŜŦŦɅÖʎŜyÖè LJNJ2ƎNJIꞏYʿă ʎYˆLJfŜYˆŜyűŜŘ ōè dzúʌfɫúʌŜă IꞏyŘ CŜŘŜNJIꞏfΣ ăűIꞏúŜΣ IꞏyŘ f2ÖIꞏf Ǝ2ØŜNJyYˆŜyűă KIꞏØŜ LJfIꞏèŜŘ IꞏyˆʎYˆLJ2NJúIꞏyű NJ2fŜ ʎyˆŜyIꞏōɫʎyƎ úKŜăŜ úNJŜyŘă⌀

2.2.5.1 Energy Management through DR, Automation, and Smart Homes

{ʎyÖŜ úKŜ мфулăΣ Iꞏ yʤϒōŜNJ 2Ŧ dzúʌfɫúʌŜă KIꞏØŜ 2LJŜNJIꞏúŜŘ NJŜúIꞏʌf 5w LJNJ2ƎNJIꞏYʿă dzăʎyƎ NJIꞏŘʌ2Σ LJ2ǿŜNJfɫyŜ ÖIꞏNJNJɅŜNJΣ IꞏyŘ yʏ2ǿ Iꞏfă2 úKNJ2dzƎK ăYˆIꞏNJú YˆŜúŜNJπŜyIꞏōfŜŘΣ dzúʌfɫúêπădzLJLJfɫʌŜŘΣ ÖŜyúNJIꞏf Iꞏ ʎNJπÖ2yŘʌúʌ2yŜNJ IꞏyŘ ŜfŜÖúNJɅÖ ǿIꞏúŜNJπ KŜIꞏúŜNJ ăǿʎúÖKŜă⌀ . 2úK ŜfŜÖúNJɅÖ dzúʌfɫúʌŜă IꞏyŘ LJNJɅØIꞏúŜ Ö2YˆLJIꞏyɅŜă yʏ2ǿ IꞏƎƎNJŜƎIꞏúŜ NJŜăʌŘŜyűʌIꞏf f2IꞏŘă ʎyˆNJŜúIꞏʌf IꞏyŘ ǿK2fŜăIꞏfŜ ŜfŜÖúNJɅÖʎúê YˆIꞏNJ]ŜúăϕΩ ² KʎfŜ ƎNJ2ǿʎyƎΣ úKŜ ǿʌŘŜăLJNJŜIꞏŘ IꞏyŘ ŘŜŜLJ dzăŜ 2Ŧ NJŜăʌŘŜyűʌIꞏf Ödzăúʏ2YˆŜNJ f2IꞏŘă IꞏăLJIꞏNJű 2Ŧ ŜfŜÖúNJɅÖ ƎNJɅŘ 2LJŜNJIꞏúʌ2yã ʌă ăúʌff NJŜfIꞏúɅØŜfê yIꞏăÖŜyű ʎyˆNJŜfIꞏúʌ2yˆű2 ʌűă LJ2ûŜyűʌIꞏf⌀

/dzNJNJŜyűfêΣ Y2ăú NJŜăʌŘŜyűʌIꞏf ōdzʌfŘʎyƎă IꞏNJŜ ŜIjdzʌLJLJŜŘ ű2 Iꞏdzú2YIꞏúŜ 2yfè Iꞏ ăYIꞏff yʤϒōŜNJ 2Ŧ úIꞏăʅă ăʎyÖŜ IꞏŦŦ2NJŘIꞏōfŜ Iꞏdzú2YIꞏúʌ2yˆûŜÖKy2f2ƎèΣ ǿʌúK ă2YˆŜ ŜÈÖŜLJúʌ2yãΣ ʌă y2ű Ö2YˆYˆŜNJÖʌIꞏffê IꞏØIꞏʌfIꞏōfŜ 2NJ ǿʌŘŜfè dzăŜŘ⌀ LyˆIꞏŘŘʌúʌ2yΣ ăYˆIꞏNJú YˆŜúŜNJăΣ Iꞏ]Ŝè ŜyIꞏōfŜNJ 2Ŧ ădzÖK IꞏÖúɅØʌúʌŜăΣ KIꞏØŜ ōŜŜyˆNJŜÖŜyűfê ǿʌŘŜfè ŘŜLJf2èŜŘ IꞏyŘ IꞏNJŜ 2yfè IꞏúIꞏyˆŜIꞏNJfè ăúIꞏƎŜ 2Ŧ ŘŜØŜf2LJYˆŜyű Ŧ2NJ Ö2yãdzYˆŜNJ IꞏyŘ yʏ2ú 2yfè dzúʌfɫúê dzăŜă⌀

[K] мл /⌀C⌀w⌀ пнф∑ мл /⌀C⌀w⌀ пом⌀ ¢KŜ 9yŜNJƎè t2fɫÖè IꞏyŘ /2yãŜNJØIꞏúʌ2yˆ ! ŏú 2Ŧ мфтр∑ Iꞏă IꞏYˆŜyŘŜŘΣ ăŜúă Ŧ2NJúKꞏ IꞏØIꞏNJŜúê 2Ŧ LJNJ2Øʎăʌ2yã ŘŜăʌƎyŜŘ ű2 ʎYˆLJNJ2ØŜ ŜyŜNJƎè ŜŦŦɅÖʎŜyÖè⌀ tIꞏNJú / 2Ŧ ¢ʌúfŜ LLL ŠăűIꞏōfɫăKŜă úKŜ ά9yŜNJƎè /2yãŜNJØIꞏúʌ2yˆ tNJ2ƎNJIꞏYˆ Ŧ2NJ /ŜNJúIꞏʎyˆLyŘdzăúNJɅIꞏf 9IjdzʌLJYˆŜyűϕέ ¢KŜ Ö2ØŜNJŜŘ ŜIjdzʌLJYˆŜyű ʎyÖfdzŘŜă LJdzYʿLJă⌀

t№2∃№I·Y'Y'I·ōfŜ ΰKŜ№Y'2ăΰ'I·ΰă I·№Ŝ ǿλŘŜfè I·ØI·λfI·ōfŜ I·yŘ I·№Ŝ LJ№ŜăŜyΰ λy'oT LJŜ№ÕŜyΰ 2Ŧ K2dzăλy∃ dzyΛΰăT K2ǿŜØŜ№Σ 2yfè po LJŜ№ÕŜyΰ 2Ŧ K2dzăŜK2fŘă ǿλΰK ΰKŜăŜ ΰKŜ№Y'2ăΰ'I·ΰă dzăŜ ΰKŜY' ΰ2 f2ǿŜ№ ΰŜY'LJŜ№I·ΰdz№Ŝă ŘdzNλy∃ ΰKŜ ŘI·èΣ I·yŘ 2yfè cм LJŜ№ÕŜyΰ dzăŜ ΰKŜY' ΰ2 f2ǿŜ№ ΰŜY'LJŜ№I·ΰdz№Ŝă 2ØŜ№yλ∃Kΰφ^φ

!fă2Σ άăY'I·№ΰέ ΰKŜ№Y'2ăΰ'I·ΰăΣ ǿKλÕK ÕI·y' fŜI·№y' ŦN2Y' 2ÕÕdzLJI·yΰ ōŜKI·Øλ2№ I·yŘ I·Ř2dzăΰ ăŜΰΰλy∃ă ΰ2 Y'λyλY'λÎŜ ŜyŜ№∃è dzăŜΣ I·№Ŝ y2ǿ I·ØI·λfI·ōfŜφ ¢KŜăŜ ŘŜØλÕŜă ÕI·y' I·fă2 Ŝy1·ōfŜ I·dzΰ2Y'I·ΰŜŘ 5w ΰK№2dz∃K I· K2Y'Ŝ2ă ăY'I·№ΰ Y'ŜΰŜ№Σ I·Ř2dzăΰΛy∃ ΰKŜ№Y'2ăΰ'I·ΰă ŘdzN№y∃ LJŜI·'ļ f2I·Ř ŜØŜyΰă ΰ2 ăKI·ØŜ dzăI·∃Ŝφ^^ {2Y'Ŝ ăY'I·№ΰ ΰKŜ№Y'2ăΰ'I·ΰă ÕI·y'y2ǿ dzăŜ ǿ№ŜfŜää Õ2Y'Y'dzyλÕI·ΰλ2yã ΰ2 Õ2yΰ№2f I·LJLJfλI·yÕŜă I·yŘ 2ΰKŜ№ ăY'I·№ΰ ŘŜØλÕŜă ǿλΰKλy'K2Y'ŜăT ΰKŜè Y'I·è ŜØŜy' ăŜ№ØŜ I·ă ΰKŜ Õ2yΰ№2f LJfI·ΰŦ2№Y' Ŧ2№ άăY'I·№ΰ K2Y'Ŝă¢£ I2Y'Ŝ2ǿyŜ№ă ÕI·y' I·fă2 λyΰŜ∃№I·ΰŜ ΰKŜăŜ ŘŜØλÕŜă ǿλΰK №ŜăλŘŜyΰλI·f ă2fI·№ 2dzΰLJdzΰ I·yŘΣ I·f2y∃ ǿλΰK ăΰ2№I·∃Ŝ 2№ 9±ăΣ dzăŜ ΰKŜY' ΰ2 №ŜI·Õΰ ΰ2 LJ№λÕŜ ăλ∃y1·fă ΰ2 2LJΰλY'λÎŜ 9± ōI·ΰΰŜ№è ÕKI·№∃λy∃ I·yŘ 2ØŜ№I·ff ăèăΰŜY' LJŜN¦2№Y'I·yÕŜφ 9±ă Õ2dzfŘ I·Õΰ I·ă Y'2ōλfŜ ōI·ΰΰŜ№è №Ŝă2dz№ÕŜă ΰKI·ΰ Õ2yãdzY'Ŝ ŜfŜÕΰ№λÕλΰè 2№ LJ№2ØλŘŜ λΰ ōI·Õ'ļ ΰ2 ΰKŜ ∃№λŘ I·ă ŜyŜ№∃è 2№ Ŧ№ŜIjdzŜyÕè Y'I·yI·∃ŜY'Ŝyΰ ăŜ№ØλÕŜă ǿKŜ№Ŝ λyÕŜyΰλØŜă ŜÈλăΰφ^

2.2.5.2 Consumer Preferences for New Technologies and Services

¦ΰλfΰΰλŜă I·yŘ 2ΰKŜ№ ăŜ№ØλÕŜ LJ№2ØλŘŜ№ă I·№Ŝ λyÕ№ŜI·ăλy∃fè ăŜ∃Y'Ŝyΰλy∃ ΰKŜ ō№2I·Ř Õ2yãdzY'Ŝ№ ÕfI·ăăŜă λyΰ2 ăY'I·ffŜ№Σ Y'2№ŜπăLJŜÕλŦλÕ ∃№2dzLJă ōI·ăŜŘ 2y'LJ№ŜŦŜ№ŜyÕŜă Ŧ2№ Y'I·№'ļŜΰλy∃ LJdz№LJ2ăŜăφ^

¢ŜÕKy2f2∃è λΰăŜfŦ ÕI·y' KŜfLJ dzΰλfλΰλŜă ōŜΰΰŜ№ dzyŘŜ№ăΰI·yŘ ΰKŜ ySŜŘă I·yŘ λyΰŜ№Săΰă 2Ŧ Õ2yãdzY'Ŝ№ăφ 9fŜÕΰ№λÕ dzΰλfλΰλŜă I·№Ŝ ōŜ∃λyyλy∃ ΰ2 dzăŜ άōλ∃ ŘI·ΰI· I·yI·fèΰλÕăέ ΰ2 ōŜΰΰŜ№ Y'ŜŜΰ ΰKŜλ№ Õdzăΰ2Y'Ŝ№ăΩ ySŜŘă I·yŘ ŘŜfλØŜ№ ăŜ№ØλÕŜă ΰ2 ΰKŜY'φ^^ ! ă Y'2№Ŝ №ŜăλŘŜyΰλI·f ΰèLJŜă Õ2yΰλyΰzŜ ΰ2 ŜY'Ŝ№∃ŜΣ ŜfŜÕΰ№λÕ dzΰλfλΰλŜă I·yŘ ΰKλ№Ř LJI·№ΰλŜă I·№Ŝ y2 f2y∃Ŝ№ ΰ№ŜI·ΰλy∃ №ŜăλŘŜyΰλI·f Õdzăΰ2Y'Ŝ№ă I·ă Y'2y2fλΰKλÕφ Ly'№ŜăLJ2yãŜΣ ΰKŜè KI·ØŜ I·ÕÕ2№Řλy∃fè I·Ř2dzăΰŜŘ ΰKŜλ№ LJ№2ŘdzÕΰ 2ŦŦŜ№λy∃ă τ I·ff 2Ŧ ǿKλÕK KI·ØŜ λY'LJfλÕI·ΰλ2yã Ŧ2№ ΰKŜ ŜfŜÕΰ№λÕ LJ2ǿŜ№ ăèăΰŜY'φ

LY'LJfλÕI·ΰλ2yã Ŧ2№ ΰKŜ ŜfŜÕΰ№λÕπLJ2ǿŜ№ ăèăΰŜY' λyÕfdzŘŜ λyΨfdzŜyÕŜă 2y' ΰèLJŜă 2Ŧ ∃ŜyŜ№I·ΰλ2y' ΰKI·ΰ I·№Ŝ ōdzλfΰΰT K2ǿ ŘλăΰN№λōdzΰλ2y' ăèăΰŜY'ă I·№Ŝ ŘŜăλ∃ySŘ I·yŘ 2LJŜ№I·ΰŜŘT K2ǿ ŦI·ăΰ ŘλăΰN№λōdzΰλ2y' 2dzΰI·∃Ŝă I·№Ŝ №Ŝăΰ2№ŜŘT №ŜΰI·λf №I·ΰŜ ŘŜăλ∃y' I·yŘ Õdzăΰ2Y'Ŝ№ ōλffăT I·yŘ K2ǿ dzΰλfλΰèλ λyŘdzăΰN№è ōdzăλySăă I·yŘ №Ŝ∃dzfI·ΰ2№è Y'2ŘŜfă ŜØ2fØŜφ ! ÕSyΰ№I·f IjdzŜăΰλ2y' Ŧ2№ ăΰI·ΰŜ ŜfŜÕΰN№λÕλΰè №Ŝ∃dzfI·ΰ2№ăΣ Õ2yãdzY'Ŝ№ I·ŘØ2ÕI·ΰŜăΣ I·yŘ ŜfŜÕΰN№λÕ dzΰλfλΰλŜă λă K2ǿ ΰ2 ōI·fI·yÕŜ ΰKŜ dzΰλfλΰèΩă ySŜŘ ΰ2 №ŜÕ2ØŜ№ ŦλÈŜŘ Õ2ăΰă I·yŘ λΰă 2ōfλ∃I·ΰλ2y' ΰ2 LJ№2ØλŘŜ ăI·ŦŜΣ №ŜfλI·ōfŜΣ I·yŘ I·ŦŦ2№ŘI·ōfŜ ŜyŜ№∃è ΰ2 I·ff Õ2yãdzY'Ŝ№ă ǿλΰK ăY'I·ffΣ I·ōŜλΰ ∃№2ǿλy∃Σ ŘŜăλ№Ŝ Ŧ2№ Y'2№Ŝ LJ№2ŘdzÕΰă I·yŘ ăŜ№ØλÕŜă 2Ŧ ŜfŜÕΰN№λÕλΰè Õ2yãdzY'Ŝ№ăφ^^

> A central question for state electricity regulators, consumer advocates, and electric utilities is how to balance the utilityôs obligation to provide safe, reliable, and affordable energy to all consumers with a growing desire for more products and services from a smaller subset of consumers.

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^ /KI·LJΰŜ№ LLL ó*Building a Clean Electricity Future*ú ŘλăÕdzăăŜă 9±ă I·yŘ ΰKŜ ySŜŘ Ŧ2№ ÕKI·№∃λy∃ λyŦ№I·ăΰN№dzÕΰdz№Ŝ ΰ2 LJ№2ØλŘŜ Y'2№Ŝ ÕKI·№∃λy∃ 2LJΰλ2yã ΰ2 Õ2yãdzY'Ŝ№ăφ

² {ŜŜ ΰKŜ ō2Řè 2Ŧ ǿ2№'ļ ōè ΰKŜ 9Řλă2y'C2dzyŘI·ΰλ2yΰă LyãΰλΰdzΰŜ 2Ŧ 9fŜÕΰN№λÕ LyY'2ØI·ΰλ2yΣ KΰΰLJYKKǿǿǿφŜŘλă2yŦ2dzyŘI·ΰλ2yΦyŜΰkλŜI№kφ

Retail Electric Choice Markets

In the late 1990s and early 2000s, some state legislatures passed legislation opening the retail electricity market to firms beyond the incumbent distribution utility. Currently, 14 states and the District of Columbia have programs that allow end-use customers to buy electricity from competitive retail suppliers.[k, 76] Under this structure, the regulated distribution utility still manages and provides the distribution of electricity through wires, with retail marketers procuring and selling the commodity itself. State retail open-access policies typically apply only to investor-owned utilities, though some states conditionally require it for electric cooperatives as well. States with retail open access typically do not require it for public power utilities, leaving competition policy to their local governing boards. Some states, such as Michigan, cap retail open access as a percentage of electricity sales (i.e., alternative retail electric supplies, besides the incumbent distribution utility, can provide up to 10 percent of retail electric sales).

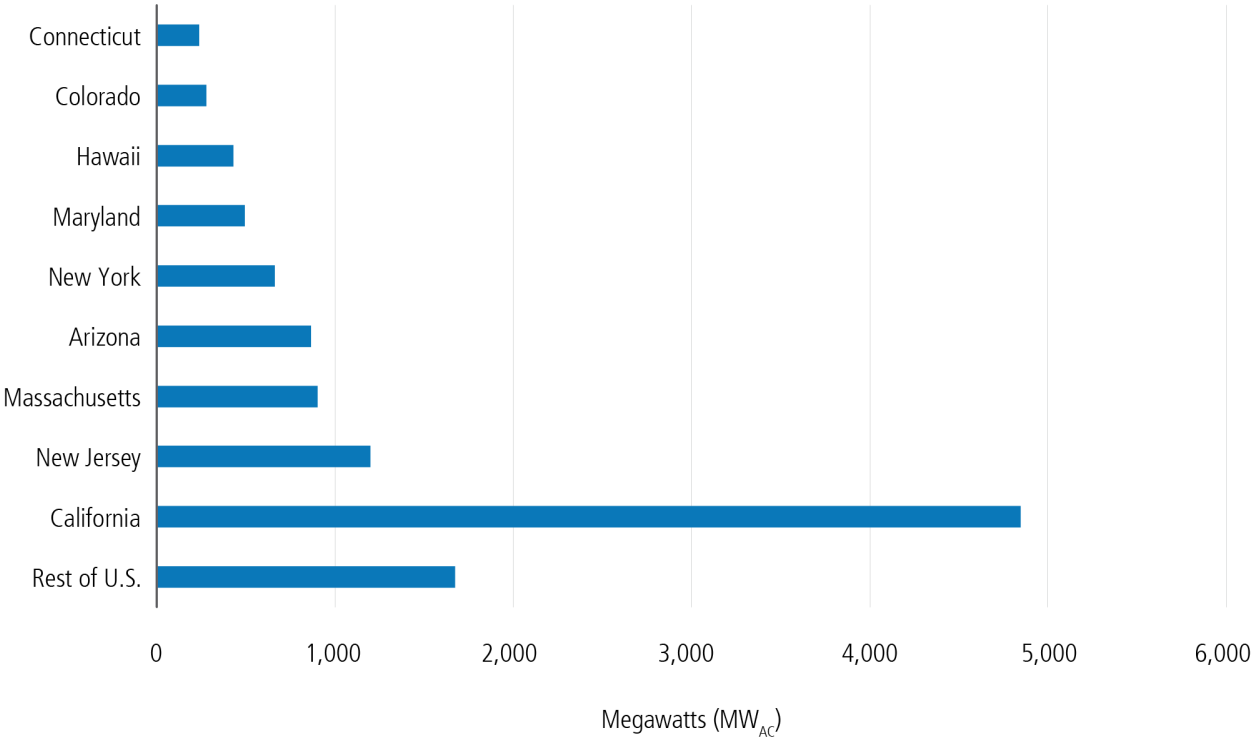
The outcome of retail electric choice has been mixed. Retail choice has introduced dynamic pricing programs and new services, and it has encouraged the growth of renewable energy. However, electricity prices in areas with retail choice have been more variable and possibly even higher than in areas without it.[77, 78] Most states with retail choice also rely on the distribution utility that serves as the default energy commodity provider, with administratively determined rates for customers who choose not to participate in the retail market.

2.2.5.3 Distributed Generation: A Consumer Choice

LyNSOSyu esI-Na; uKSNS KI-a OSSyNaXEyXFXOI-yu ENe2euK XyNRXauNXOdzuSR ESySNI-uX2yS LJI-NuXOdzfI-NfeN N22FU2LJ a2fI-N t±S eKXOK KI-a OSSyF2auSNSR oe f2eSN XyauI-ffI-uX2yNI-yR KI-NReI-NS O2auaI-yR adzLJLJ2NuXeS LJ2fXOXSa; adzOK I-a ySu YSuSNXyE I-yR aSfFpESySNI-uX2yNuI-NXFFa I-yR wt{a eXuK aSupI-aXRSa 2N YNdzfuXLJfXSNa F2N RXauNXOdzuSR ESySNI-uX2ye I2eSeSNS a2YS auI-uSa I-yR dzuXfXuXSa I-NS I-R?dzauuXyE uKSXNN ySu YSuSNXyE LJ2fXOXSa I-a uKS RXauNXOdzuSR t± YNIQSu EN2eae {uI-uSa eXuK f2yESNpuSNYN LJ2fXOXSa oSeE?S uI-NESuaS XyOSyuXeSauU KI-eS aSSyNY2NS RXauNXOdzuSR ESySNI-uX2yN I-R2LJuX2ye CdzudzNS EN2euK eXff O2yuXydzS u2 oS KXEKfe RSLJSyRSyu 2yNf2OI-t I-yR auI-uS LJ2fXOXSa I-a eSff I-a NSuI-Xf SfSOuNXOXue LJNXOS I-yR NSa2dzNOS I-eI-XfI-oXfue I-yR uKdza eI-Ne E$2ENI-LJKXOI-ffe

[k] LyNлмпS нл LJSNOSyu 2F SfSOuNXOXue aI-fSa o a ² Ku u2 dzfuXYI-uS O2yadzYSNa eSNS oe O2YLJSuXuXeS NSuI-Xf adzLJLJfXSNaS *2016–2017 Annual Directory and Statistical Issue*S pmS RSNXeSR FN2Y 9L! C2NY ycм RI-uI-e

Figure 2-6. Distributed Solar PV Capacity, Top 10 States, As Of August 2016 (in MW Alternating Current [AC])[79]



Distributed solar PV capacity is unevenly distributed in the US. As of August 2016, roughly a third of capacity was installed in California, followed by New Jersey and Massachusetts.

5λăűNλōdzűŜŘ ă2fI·N t± ƎŜyŜNI·űλyƎ ŎI·LJI·ŎλűèƎNŜø ōè I· ŦI·Ŏű2N 2Ŧ 2ØŜN ул ōŜűøŜŜY нллп I·yŘ нлмпΣул øKλfŜ ŘλăűNλōdzűŜŘ øλyŘ λyŎNŜI·ăŜŘ ōè I·ō2dzű I· ŦI·Ŏű2N 2Ŧ мпΦм ¢KŜ LJNλŎŜ 2Ŧ λyăűI·ffŜŘ NŜăλŘŜyűλI·f ă2fI·N t± λă LJN2ȻŜŎűŜŘ ű2 ŦI·ff ōŜf2ø Þнк ² 5/ λY űKŜ ySĚű мл èŜI·Nă I·yŘ ŘλăűNλōdzűŜŘ ă2fI·N t± ŜfŜŎűNλŎλűè ƎŜyŜNI·ûλ2Y λă LJN2ȻŜŎűŜŘ ű2 ƎN2ø ōè I· ŦI·Ŏű2N 2Ŧ ySI·Nfè мф ŦN2Y нлмр ű2 нлплΦун yo a2ăű ŘλăűNλōdzűŜŘ øλyŘ λă λyăűI·ffŜŘ I·ű Ŏ2YYŜNŎλI·f ŦI·Ŏλfλúè ăλűŜăΣ λyŎftdzŘλyƎ λyăűλűdzűλ2yI·f I·yŘ Ǝ2ØŜNyYŜyű ŦI·ŎλfλűλŜăΦ ¢KŜ YI·ȻN2úè 2Ŧ ŘλăűNλōdzűŜŘ øλyŘ ŎI·LJI·ŎλűèλăI·ű λyŘdzăűNλI·f óoŧ̂ ûΣ λyăűλűdzűλ2yI·f óнŧ̂ ú ŦI·ŎλfλűλŜăΦун ¢2űI·f ŎI·LJI·ŎλűèƎNŜø ăűŜI·ŘλfèŦN2Y нлло ű2 нлмнΣ ōdzű ƎN2øűK ŘŜŎNŜI·ăŜŘ ăλƎyλŦλŎI·yűfè ōŜƎλyŷλyƎ λY нлмоΣ LJNλYI·Nλfè ŘdzŜ ű2 űKŜ ŎKI·yƎŜă λY ŦŜŘŜNI·f I·yŘ ăűI·ûŜă λyŎŜyűλØŜăΦур 5ŜăLJλűŜ ûKŜ NI·LJλŘ ƎN2øűK 2Ŧ ŘλăűNλōdzűŜŘ t±Σ ûKŜăŜ NŜă2dzNŎŜă Ŏ2yűNλōdzűŜ I·ăYI·ff LJ2Nűλ2Y2Ŧ ƎŜyŜNI·ûλ2Yű2 ûKŜ 2ØŜNI·ff ¦Φ{Φ ŜfŜŎűNλŎλűè ădzLJLJfèT I·ă ăK2øyλY CλƎdzNŜ нπcΣ ûKŜè LJfI·è I· fI·NƎŜN N2fŜ λY ă2YŜ ăűI·ûŜăΦ ¢KŜ LJŜySűNI·ûλ2Y2Ŧ ŘλăűNλōdzűŜŘ ă2fI·N t± λY нлмр øI·ă I·ō2dzű лΦоп LJŜNŎŜyű 2Ŧ ű2űI·f ¦{ ƎŜySNI·ûλ2yΦус

2.2.5.4 Small-Scale Distributed Storage

{YI·ffπăŎI·fŜ ŘλăűNλōdzűŜŘ ŜfŜŎűNλŎλűè ăű2NI·ƎŜ λă ōŜŎ2YλyƎ Y2NŜ øλŘŜfè I·ØI·λfI·ōfŜ I·yŘ ŎI·YNŜŘdzŎŜ LJŜI·ʅ f2I·ŘΣ λYLJN2ØŜ ŜfŜŎűNλŎI·f ăűI·ōfλűèΣ NŜŘdzŎŜ LJ2øŜN Ijdz I·fλűè ŘλăűdzN ōI·yŎŜăΣ I·yŘ ŦI·ŎλfλúI·ûŜ λyŎNŜI·ăŜŘ LJŜySűNI·ûλ2Y 2Ŧ ØI·NλI·ōfŜ øλyŘ I·yŘ ă2fI·N NŜă2dzNŎŜă¦ yŘŜN ă2YŜ ŎλNŎdzYăűI·yŎŜăΣ ŘλăűNλōdzűŜŘ ăű2NI·ƎŜ ŎI·YNŜŘdzŎŜ NŜăλŘŜyűλI·f ŜfŜŎűNλŎλűè ōλftă óăŜŜ CλƎdzNŜ нπтúΦ ¢KŜNŜ I·NŜ yűzYŜN2dză ûŜŎKy2f2ƎλŜă I·ØI·λfI·ōfŜΣ λyŎftdzŘλyƎ ăűI·ûλ2yI·Nè ōI·ûűŜNè ăű2NI·ƎŜΣ ûKŜNYI·f ŜyŜNƎè ăű2NI·ƎŜ óŎNŜI·ûλyƎ λŎŜ 2N ŎKλftfŜŘ øI·ûŜNúΣ I·yŘ LJftdzƎπλY ŜfŜŎűNλŎ ØŜKλŎfŜă ót9±ăú øλűK 2yō2I·NŘ ōI·ûűŜNλŜăΦ ¢K2dzƎK ûKŜ ûŜŎKy2f2ƎèƎ 2LJűλ2yă Ŧ2N ŘλăűNλōdzűŜŘ ăű2NI·ƎŜ I·NŜ λyŎNŜI·ăλyƎΣ ûKŜNŜ λă ŎdzNNŜyűfè 2yfè I·ō2dzű орл a ² 2Ŧ ŘλăűNλōdzűŜŘ ăű2NI·ƎŜ ŎI·LJI·ŎλűèI·ØI·λfI·ōfŜ λY űKŜ ¦Φ{Φ øKλŎK NŜLJNŜăŜyűă fŜăă úKI·Yɕ 2Ŧ

ű2ű l·f ŜfŜŎúNλŎλúê ăű2NI·ƎŜ ŎI·LJI·Ŏλúè I·yŘ fŜăă űKI·y˙ л⚮ 2Ŧ ű2ű l·f ŜfŜŎúNλŎλúè ƎŜySNI·ûλyƎ ŎI·LJI·Ŏλúè⚮ʸᵀ ᶠ 5ŜŎfλyλyƎ Ŏ2ăúă Ŧ2N ăű2NI·ƎŜ ûŜŎKy2f2Ɛèᴇ ŘNλØŜy˙ōê ƎNŜI·ûŜN LJN2ŘdzŎûλ2y˙2Ŧ ōI·ûûŜNλŜă Ŧ2N ŜfŜŎúNλŎ ØŜKλŎfŜă I·yŘ ăűI·ûŜπfŜØŜf ăű2NI·ƎŜ Y˙I·yŘI·ûŜăᴇʸ ǿλtf ŘNλØŜ ƎNŜI·ûŜN I·Ř2LJűλ2y˙2Ŧ Řλăú NλōdzűŜŘ ŜySNƎè ăű2NI·ƎŜ⚮ . Ŝűǿ ŜŜy˙нллт I·yŘ нлмпᴇ úKŜ Ŏ2ăű 2Ŧ fλúKλdzY˙πλ2y˙ōI·ûûŜNè LJI·Ŏ]ă ŘŜŎfλySŘ ōè I·fY˙2ăű сл LJŜNŎŜyűᴇʸ KŜfLJλyƎ û2 Ŏ2yúNλōdzűŜ û2 Ŧ2NŜŎI·ăűă ăK2ǿλyƎ NI·LJλŘ ƎN2ǿúK λy˙ŘλăúNλōdzűŜŘ ŜySNƎè ăű2NI·ƎŜ 2ØŜN úKŜ ySĖű ŘŜŎI·ŘŜ⚮ʸʸ

5λăúNλōdzűŜŘ ăű2NI·ƎŜᴇ λyŎfdzŘλyƎ I·Ř2LJűλ2y˙2Ŧ LJfdzƎ λy˙ŜfŜŎúNλŎ ØŜKλŎfŜă ót9±ăú ǿλúK ōI·ûúŜNè ăű2NI·ƎŜᴇ Ŏ2dzfŘ ōŜ I·úNI·yāŦ2NY˙I·ûλØŜ ûŜŎKy2f2Ɛè⚮ʸᵠ YŜè LJ2fλŎè Ŏ2yāλŘŜNI·ûλ2yã λyŎfdzŘŜ λŘŜyűλŦèλyƎ ûèLJŜă 2Ŧ LJ2fλŎλŜă I·yŘ NŜƎdzfI·ûλ2yã ûKI·ú Ŏ2dzfŘ ŦI·ŎλfλúI·ûŜ LJI·λNλyƎ ŘλăúNλōdzűŜŘ ăű2NI·ƎŜ ǿλúK ŘλăúNλōdzűŜŘ ƎŜySNI·ûλ2y˙ 2N ŘŜY˙I·yŘ NŜăLJ2yāŜ û2 LJN2ØλŘŜ ØI·fdzŜ û2 ō2úK dzűλfλúλŜă I·yŘ Ŏdzăű2Y˙SNā⚮ Ly˙I·ŘŘλúλ2yᴇ LJ2fλŎλŜăᴇ NŜƎdzfI·ûλ2yãᴇ I·yŘ LJN2ű2Ŏ2fă Ŏ2dzfŘ KŜfLJ λyűŜƎNI·ûŜ Y˙2ōλfŜ ŘλăúNλōdzűŜŘ ăű2NI·ƎŜ óλ⚮Ŝ⚮ᴇ t9±ăú λyű2 úKŜ ŘλăúNλōdzűλ2y˙ ăèăűSY˙ û2 ŦI·ŎλfλúI·ûŜ ŜfŜŎúNλŦλŎI·ûλ2y˙ 2Ŧ úKŜ úNI·yãLJ2NűI·ûλ2y˙ ăŜŎű2N⚮ /ż2yãλŘŜNλyƎ LJ2fλŎλŜă I·yŘ LJN2ƎNI·Y˙ă úKI·ú úI·NNλŜNă û2 ŘŜLJf2èY˙Syű 2Ŧ Ŏ2ăúπŜŦŦŜŎúλØŜ ŜySNƎè ăű2NI·ƎŜ λă I·y˙I·ŘŘλúλ2yI·f λY˙LJ2NűI·yű ăúŜLJ⚮

ᶠ ¢KŜ ØI·ăú Y˙I·ż2NλúêᴇτI·ō2dzű ф LJŜNŎŜyűᴇτ2Ŧ ű2úI·f ŜySNƎè ăű2NI·ƎŜ ŎI·LJI·ŎλúêλY˙ûKŜ ¦yλûŜŘ {úI·ûŜă λă LJdzY˙LJŜŘ KèŘN2LJ2ǿŜNᴇ ǿKλŎK λă úNI·Řλúλ2yI·ffê Ŏ2yāλŘŜNŜŘ ƎNMŘπōI·ăŜŘ ăű2NI·ƎŜ I·yŘ λă yƵű λyŎfdzŘŜŘ λy˙ûKλă NŜLJ2N⚮ /λűI·ûλ2yᵞ
KúûLJăŸккǿǿǿ⚮SySNƎè⚮Ǝ2ØkăλúŜăkLJN2ŘkŦλfŜăкнлмрклпкŦннк I èŘN2LJ2ǿŜNπ a I·N]ŜűπwŜLJ2NûπI λƎKfλƎKúă⚮LJŘŦT 5h9 Df2ōI·f 9ySNƎè {úż NI·ƎŜ 5I·úI·ōI·ăŜ⚮ KúûLJŸккǿǿǿ⚮SySNƎè⚮ăű2NI·ƎŜĖÒKI·yƎŜ⚮2NƎк

ʸ Ly˙нлмоᴇ /I·fλŦ2NyλI· LJI·ăăŜŘ ! ăăŜY˙ōfê . λftᴇ нрмп ǿKλŎK Y˙I·yŘI·ûŜă úKŜ ăúI·úŜ úż λyăúI·tf м⚮o D ² 2Ŧ ŜySNƎè ăű2NI·ƎŜ úż úKŜNN ŜfŜŎúNλŎλúè ƎNλŘă ōè нлнл⚮

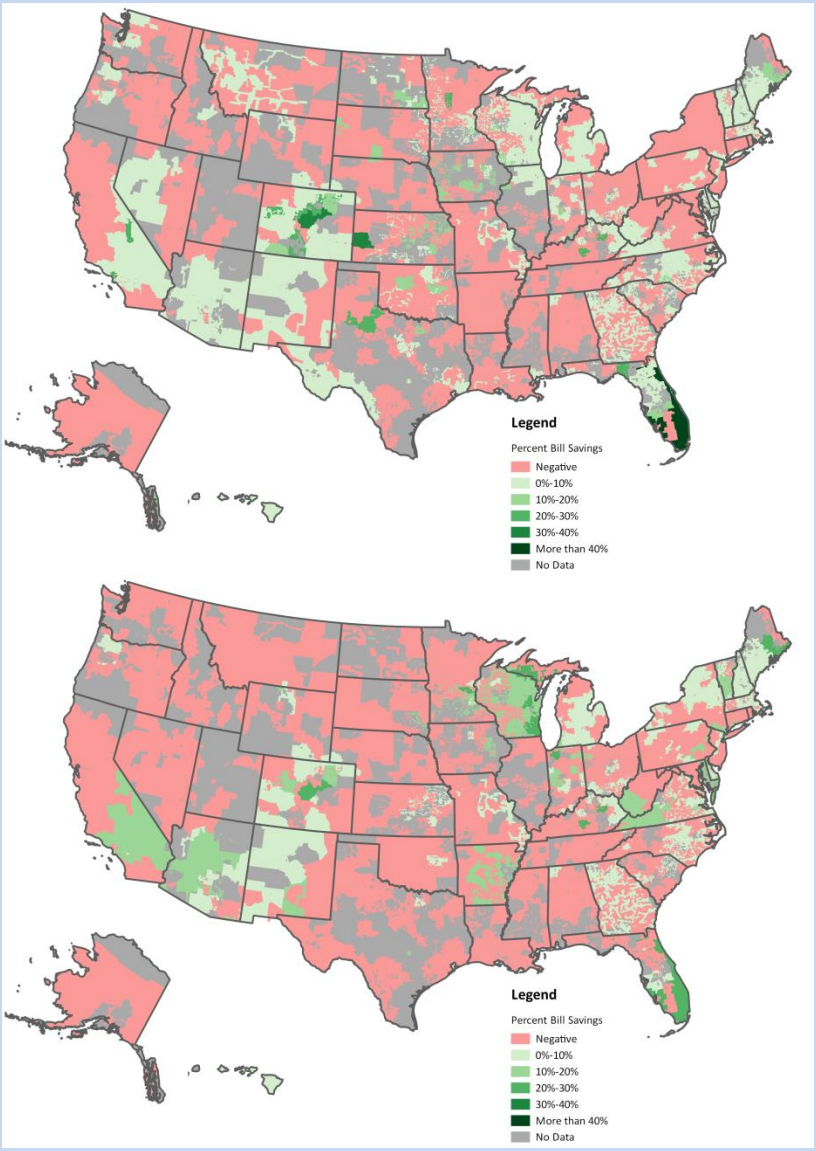
ʸʸ . ŜűǿŜŜy˙нллт I·yŘ нлмпᴇ [λúKλdzY˙πλ2y˙ōI·ûúŜNè LJI·Ŏ]ă ŘŜŎNŜI·ăŜŘ λy˙Ŏ2ăú ŦN2Y˙ Þмᴇллкʗ ² K úż Þпмлкʗ ² K⚮

Residential Electricity Bill Savings from Distributed Electric Storage[90]

This project analyzed over 45,000 utility rates for more than 4,500 utilities covering all regions of the country.[91] To identify the electricity bill savings opportunities from the use of distributed energy storage (DES), two operational strategies are modeled:

- Flattened: Flatten the load profile to minimize demand changes
- Arbitrage: Reduce energy use during peak and increase energy use during off-peak periods to take advantage of time-of-use rate designs

Figure 2-7. Gross Residential Customer Electricity Bill Savings for the Flattened and Arbitraged Demand Profiles. Top: Bill Savings from Flattened Load Profiles; Bottom: Bill Savings from Arbitraged Load Profiles[92]



Estimated electricity bills for residential customers with Distributed Energy Storage ranged from showing no savings to a greater than 40% reduction in electricity bills. The opportunities for customers to save on their electricity bills are geographically similar for the flattened and arbitraged demand profiles, but appear to lack geographic correlation with urban or rural areas. Each service territory may have several utility rates applicable to that area, so only the largest electricity bill savings available are shown in the figure (where data exist).

This analysis found that customer investment in DES can provide electricity bill savings for over 80 million residential customers. However, electricity bill savings opportunities are geographically heterogeneous and highly dependent on local rate structures, and the savings in all cases are significantly lower than the normalized cost of the DES. Furthermore, the electricity bill savings that customers realize are not commensurate with the net system benefits that DES provides as estimated by current technical literature. The shortfall between net system benefits, or the social value of DES, and customer electricity bill savings, or the private value of DES, suggests that traditional utility rate design does not adequately reflect the net benefits that a customer with DES provides the system, and additional remuneration methods may be needed to bridge that shortfall.

2.2.5.5 Challenges to Electricity Affordability

! ŎNƧăă lٜffKƧdzăŜKƧfŘăΣ úKŜ YˆŜlٜYˆŜÈLJŜyŘλűdzNŜ 2YˆKƧYˆŜ ŜfŜŎúNλŎλúè ǿlٜă ÞмΣфoc⁹ᵠ⁰ 9fŜŎúNλŎλúè dzăŜ lٜyŘ λűă ăKlٜN̲Ŝ 2Ŧ ű2űlٜf KƧdzăŜKƧfŘ ŜÈLJŜyŘλűdzNŜăΣ KƧǿŜØŜNΣ Ølٜ̲NλŜă ōè N̲ŜƎλ2ˆ lٜyŘ KƧdzăŜKƧfŘ ŘŜYˆƧƎNJlٜLJKλŎ¢KŜ lٜØŜNJlٜƎŜ KƧdzăŜKƧfŘ ŜyŜNƎè Ŏ2yãdzYˆLJűλ2yˆλãΣ ŦƧNJ ŜÈlٜYˆLJfŜΣ KλƎKŜN̲ λyˆűKŜ ² Ŝăű lٜyŘ {ƨdzűK ŎŜyãdzã N̲ŜƎλ2yãφ

¢KŜ lٜŦŦƧNŘlٜōλfλúè 2Ŧ ŜfŜŎúNλŎλúè ăŜNØλŎŜ N̲ŜYˆlٜλyã lٜ ŎKlٜffŜyƎŜ ŦƧNJ Yˆlٜyè fƨǿπλyŎ2YˆŜ N̲ŜăλŘŜyűλlٜf Ŏ2yãdzYˆŜNăφ ! yˆ λYˆLJƧNűlٜyű λyŘλŎlٜűƧNJ 2Ŧ űKŜ yŜŜŘ ŦƧNJ ŜyŜNƎè lٜăăλăűlٜyŎŜ λã *energy burden,* dzădzlٜfŏlٜfŎdzflٜűŜŘ lٜă lٜ KƧdzăŜKƧfŘΩă lٜyӳzlٜf ălJŜyŘλyƎ 2yˆŜyŜNƎè lٜă lٜ LJŜNŎŜyűlٜƎŜ 2Ŧ λűă ƎNƧăă lٜyӳzlٜf λyŎ2YˆŜφ⁽ᵖⁿᶻ ᵠᵖ LyˆнлммΣ űKŜ YˆŜŘλlٜyˆŜfŜŎúNλŎλúè ōdzNŘŜyˆŦƧNJ *all* KƧdzăŜKƧfŘă ǿlٜă ŦƧdzNJ LJŜNŎŜyűTᵠᶜ ŦƧNJ KƧdzăŜKƧfŘă y2ű λyˆűKŜ fƨǿπλyŎ2YˆŜ ŎlٜűŜƎƧNè λű ǿlٜă ƨdzăű нφф LJŜNŎŜyűΣ ōdzű *for low-income households energy burden averaged 8.3 percent*⁽ᵠᵀ

wŜflٜűλØŜfè YˆƧN̲Ŝ ălJŜyŘλyƎ 2yˆŜyŜNƎè ōλffă úNJlٜyăflٜűŜă λyű2 fŜăă ălJŜyŘλyƎ 2yˆƧűKŜN̲ ŜÈLJŜyăŜăΣ λyŎfdzŘλyƎ Ŧ22Ř⁽ᵠʸ wŜyűŜNăă ǿK2 LJlٜè űKŜλN̲ 2ǿyˆ dzűλfλűλŜă lٜyŘ Klٜ̲ØŜ λyŎ2YˆŜă fŜăă ûKlٜyˆ ÞмpΣллл LJŜN̲ èŜlٜN̲ LJlٜè 2yˆ lٜØŜNJlٜƎŜ нм LJŜNŎŜyű 2Ŧ űKŜλN̲ λyŎ2YˆŜ 2yˆ K2YˆŜ ŜyŜNƎè óŜfŜŎúNλŎλúè lٜyŘ yl٠ûdzNJlٜf Ǝlٜă Ŏ2YˆōλySŘú⁽ᵠᵠᵠ ¢KŜNŜ lٜN̲Ŝ lٜfYˆ2ăű ăŜØŜyˆYˆλffλ2yˆ ¦φ{φ KƧdzăŜKƧfŘă λyˆűKλă Ŏlٜ̲ûŜƎ2NèφNJ

[ǿπλyŎ2YˆŜ ! YˆŜNλŎlٜyã lٜN̲Ŝ lٜfă2 Yˆ2N̲Ŝ fλ⌉Ŝfè ú2 dzăŜ ŜfŜŎúNλŎ KŜlٜ̲ú ûKlٜyˆûKŜ yl٠ûλ2yl٠f lٜØŜNJlٜƎŜΣ ǿKλŎK ûŜyŘă ú2 ōŜ Yˆ2N̲Ŝ ŜÈLJŜyãλØŜ ûKlٜyˆƎlٜă⁽ᵠᴹᴶᴶ 9fŜŎúNλŎπKŜlٜ̲ú dzăŜ lٜYˆ2yƎ f2ǿπλyŎ2YˆŜ K2dzăŜKƧfŘă Klٜă Yˆ2N̲Ŝ ûKlٜyˆŘ2dzŏfŜŘ ŦN̲2Y мн LJŜNŎŜyű λyˆмфул ű2 oo LJŜNŎŜyű λyˆнллр⁽ᵠᴹᴶᴹ .è 2ŎŎdzLJlٜyű ŘŜYˆ2ƎNJlٜLJKλŎΣ f2ǿŜNπλyŎ2YˆŜ K2dzăŜKƧfŘă dzăŜ fŜăă ŜfŜŎúNλŎλúè óa ² KκK2dzăŜKƧfŘú Ŏ2YˆLJlٜN̲ŜŘ ű2 KλƎKŜNπλyŎ2YˆŜ K2dzăŜKƧfŘăΣ ōdzű LJlٜè lٜ Ŏ2yãλŘŜN̲lٜōfè KλƎKŜN̲ ŦN̲lٜŎűλ2yˆ 2Ŧ űKŜλN̲ lٜŦűŜNπűlٜÈ λyŎ2YˆŜ 2yˆ ŜfŜŎúNλŎλúè ŜÈLJŜyŘλűdzNŜăφ² млн lyˆ lٜŘŘλűλ2yΣ N̲ŜyűŜNăă LJlٜè нсΦт LJŜNŎŜyű YˆƧN̲Ŝ 2yˆŜfŜŎúNλŎλúè ŜÈLJŜyŘλűdzNŜă LJŜN̲ ălJdzlٜN̲Ŝ Ŧ22ű Ŏ2YˆLJlٜN̲ŜŘ ű2 K2YˆŜ2ǿyŜNăφ⁽ᴶ ᴹᴶᴼ ¢Kλă dzyŘŜNăŎ2N̲Ŝă ûKŜ α lٜ Ŝlٜ̲ú 2N̲ 9lٜűε ŘλfŜYˆYlٜ ŦlٜŎŜŘ ōè Yˆlٜyè K2dzăŜKƧfŘă ǿλűK KλƎK ŜyŜNƎè ōdzNŘŜyˆăűlٜyŘlٜNŘăφ

¢KŜ CŜŘŜNJlٜf [ǿ lyŎ2YˆŜ l2YˆŜ 9yŜNƎè ! ăăλăűlٜyŎŜ tN̲2ƎNJlٜYˆ ó[L l 9 ! tú LJN̲2ØλŘŜă ŦdzyŘλyƎ ű2 LJlٜè ûKŜ ŜfŜŎúNλŎλúè ōλffă 2Ŧ f2ǿπλyŎ2YˆŜ ŦlٜYˆλfλŜăΣ ōdzű ûKŜ LJN̲2ƎNJlٜYˆ Ŏlٜyӳzű ăŜNØŜ lٜft ŜfλƎλōfŜ ŦlٜYˆλfλŜăΣ lٜyŘ Yˆlٜyè ŜÈLJŜNλŜyŎŜ ăŜNØλŎŜ ŘλăŎ2yyŜŎűλ2yãφмлпΣ млр LyˆнлммΣ ûKŜ Yˆ2ăű N̲ŜŎŜyű èŜlٜN̲ Ŧ2N̲ ǿKλŎK ûKŜN̲Ŝ lٜN̲Ŝ Řlٜûlٜ·Σ 2yŜ λyˆăλÈ [L l 9 ! tπ ŜfλƎλōfŜ K2dzăŜKƧfŘă N̲ŜŎŜλØŜŘ [L l 9 ! t lٜăăλăűlٜyŎŜφмлс {λyŎŜ ûKŜ LJN̲ƎNJlٜYˆ Ŏlٜyӳzű ăŜNØŜ ûKŜ ŜyűλN̲Ŝ λyŎ2YˆŜπ ŜfλƎλōfŜ LJ2LJdzflٜűλ2yΣ ăűlٜûŜă lٜN̲Ŝ N̲ŜljdzλN̲ŜŘ ű2 LJNλ2N̲λűλÎŜ ǿKλŎK Ødzfyŝ̲lٜōfŜ K2dzăŜKƧfŘă ûKŜè ăŜNØŜΣ lٜyŘ ăŜű ûKŜN̲ 2ǿyˆ lٜŘŘλűλ2yl٠f ăűlٜyŘlٜN̲Ră lٜyŘ ŜfλƎλōλfλúè N̲ŜljdzλN̲ŜYˆŜyűă ǿKŜyˆûKŜè lٜLJLJ2N̲úλ2yˆ [L l 9 ! t lٜăăλăűlٜyŎŜφ ! LJ2N̲úλ2yˆ 2Ŧ [L l 9 ! t ŦdzyŘă Ŏlٜyˆōŝ dzăŜŘ Ŧ2N̲ ǿŜlٜûKŜN̲Îlٜûλ2yˆû2 KŜfLJ N̲ŜŘdzŎŜ Ŏ2yãdzYˆŜNăΩ ōλffăΣ ōdzű ûKŜN̲Ŝ λă ǿλŘŜ Ølٜ̲Nλlٜûλ2yˆ λyˆăűlٜûŜ ǿŜlٜûKŜN̲Îlٜûλ2yˆLJN̲2ƎNJlٜYˆ ăűN̲dzŎűdzN̲Ŝ lٜyŘ ljdzlٜfλúèφ

¢KŜ CŜŘŜNJlٜf DƧØŜN̲yYˆŜyűΣ ăűlٜûŜăΣ ŎλûλŜăΣ lٜyŘ dzûλfλûλŜă 2ŦŦŜN̲ lٜ NJlٜyƎŜ 2Ŧ ŜăăŜyűλlٜf lٜăăλăűlٜyŎŜ ű2 f2ǿπλyŎ2YˆŜ !YˆŜNλŎlٜyãφ ¢KŜ Ŏ2ăű 2Ŧ LJdzōfλŎπLJdzNLJ2ăŜ LJN̲2ƎNJlٜYˆă fλ⌉Ŝ ŜyŜNƎè ŜŦŦλŎλŜyŎè LJN̲2ƎNJlٜYˆăΣ f2ǿπλyŎ2YˆŜ lٜăăλăűlٜyŎŜ

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² CƧN̲ ŜÈlٜYˆLJfŜΣ ŜfŜŎúNλŎλúè lٜŎŎƧdzyűă ŦƧN̲ nΦн LJŜNŎŜyű 2Ŧ lٜŦűŜNπűlٜÈ λyŎ2YˆŜ ŦƧN̲ KƧdzăŜKƧfŘă Ŝlٜ̲NyλyƎ ōŜűǿŜŜyˆÞолΣллл lٜyŘ ÞплΣллл lٜyӳzlٜffèφ lƨdzăŜKƧfŘă ǿλűK lٜyӳzlٜf lٜŦűŜNπűlٜÈ λyŎ2YˆŜ 2Ŧ ÞмллΣллçРмнлΣллл ălJŜyŘ 2yfè мφy LJŜNŎŜyű 2yˆŜfŜŎúNλŎλúè ŜÈLJŜyŘλűdzNŜăφ ώ{ƨdzNŎŜ {ŎKǿlٜ·N̲ûÎΣ [φ Ŝŭφlٜfφ *Electricity End Uses, Energy Efficiency, and Distributed Energy Resources Baseline*Σ ó. ŜN̲⌉fŜèΣ / !Y [lٜǿN̲SyŎŜ . ŜN̲⌉ŜfŜè blٜûλ2yl٠f [lٜōΣ нлмсύΣ нрß

[J] b2ûŜ ûKlٜ̲ú ú2ûlٜf ŜyŜNƎè ŜÈLJŜyŘλűdzNŜă λyŎfdzŘŜ y2yπŜfŜŎúNλŎλúè ă2dzNŎŜă ădzŎK lٜă yl٠ûdzNJlٜf Ǝlٜă lٜyŘ KŜlٜûλyƎ 2λfφ

LJN2ENI·Yăΐ I·yŘ NŜăŜI·NŌK I·yŘ ŘŜØŜf2LJYŜyú ówɔ5ú LJN2ENI·Yăΐ I·NŜ Ŏ2ffŜŌúŜŘ ₹N2Y dzűλfλűè Ödzăű2YŜNă I·yŘ dzădzI·ffè LJI·λŘ ₹2N øλűK ŘŜŘλŎI·úŜŘ LJdzōfλŎ ōŜyŜ₹λú ŎKI·NΞŜà 2N I·NŜ λyŎfdzŘŜŘ λY I· dzűλfλűè¼ă ΞŜyŜNI·f Ŏ2ăű NŜŎ2ØŜNè¢ .2űK 2₹ űKŜăŜ NŜØŜyʊzŜ ăűNŜI·Yă I·NŜ ōI·ăŜŘ 2Yʊ2fdzYŜúNλŎ óLJŜN] ² Kú NI·ûŜăΐ I·yŘ Ödzăű2YŜNă Ŏ2yűNλōdzűŜ ōI·ăŜŘ 2Y űKŜλN ű2űI·f ŜyŜNΞè Ŏ2yădzYLJűλ2y¢ C2N ŜÈI·YLJfŜΙ hKλ2Ωă tŜNŎŜyűI·ΞŜ 2₹ LyŎ2YŜ tI·èYŜyű tfI·yΣ I· Ŏ2yŎŜăăλ2yI·Nè NI·ûŜ ₹2N f2ø¤λyŎ2YŜ ŜfŜŎúNλŎλúè Ŏ2yãdzYŜNăΙ λă LJI·λŘ ₹2N ōè Ŏ2dzyűλyΞ ûKŜ NŜØŜyʊzŜ yʊ2ű Ŏ2ffŜŎúŜŘ ₹N2Y f2ø¤λyŎ2YŜ Ŏ2yãdzYŜNă I·ă dzyŎ2ffŜŎűI·ōfŜ I·NNNŜI·Nă I·yŘ NŜλYōdzNăλyΞ ûKŜ dzűλfλúλŜă 2dzű 2₹ ΞŜyŜNI·f NŜØŜyʊzŜ ăúNŜI·Yă¢

!fűŜNyI·ûλØŜfèΣ dzűλfλúλŜă YI·è I·ŘYλyλăúNI·ûλØŜfè ŘŜűŜNYλyŜ I· LJdzōfλŎ ōŜyŜ₹λúă ădzNŎKI·NΞŜ ădzŎK I·ă Þлφллнкⅼ ² K¢ ¢KŜăŜ ₹dzyŘλyΞ ăúNdzŎűdzNŜă YŜI·y ûKI·ű I·yê NŜŘdzŎűλ2y λy I· Ŏ2yãdzYŜNΩă LJŜN] ² K LJI·èYŜyűă NŜŘdzŎŜă ûKI·ű Ŏ2yãdzYŜNă Ŏ2yűNλōdzűλ2yã ű2 ûKŜăŜ LJN2ENI·YăΤ ŜyŜNΞè ŜŦ₹λŎλŜyŎè YŜI·ădzNŜă ûKI·ú NŜŘdzŎŜ 2ØŜNI·ff Ŏ2yãdzYLJűλ2y YI·è ălYλfI·Nfè NŜŘdzŎŜ ₹dzyŘλyΞ ₹2N I·ăălăúI·yŎŜ LJN2ENI·Yă¢ wŜØŜyʊzŜ ŘŜŎ2dzLJfλyΞ Ŏl·y LJNŜØŜyű ûKŜ dzyŘŜN₹dzyŘλyΞ 2₹ ûKŜăŜ LJN2ENI·Yăΐ ōdzű y2ű ûKŜ ăKλ₹ű 2₹ ûKŜλN Ŏ2ăűă I·Y2yΞ Ŏ2yãdzYŜNă¢

2.2.5.6 Access to Distributed Energy Resources and New Energy Services for All Consumers

[2ø¤λyŎ2YŜ Ŏ2YYdzyλűλŜă 2₹ûSy ăűI·yŘ ű2 ōŜyŜ₹λú ₹N2Y ŜyŜNΞè Ŝ₹₹λŎλŜyŎè I·yŘ ŏfŜI·y ŜyŜNΞè Y2NŜ ûKI·y2ûKŜN Ŏ2YYdzyλűλŜă ōŜŎI·dzăŜ ûKŜăŜ NŜăλŘŜyűă KI·ØŜ KλΞKŜN ŜyŜNΞè ŏdzNŘŜyã I·yŘ 2₹ûSy ōŜI·N ŘλăLJN2LJ2NűΛ2yI·ûŜ λYLJI·ŎűăΙ 2₹ LJ2ffdzúλ2y™ I·yŘ ŎfλYI·ûŜ ŎKI·yΞŜφ™ /dzNNŜyű Y2ŘŜă 2₹ LJN2Y2ûλyΞ ŜyŜNΞè Ŝ₹₹λŎλŜyŎè I·yŘ ŏfŜI·y ŜyŜNΞèΣ K2ø¤ŜØŜN I·NŜ y2ű I·fø I·ëă ŘŜăλΞyŜŘ ű2 ōŜyŜ₹λú f2ø¤λyŎ2YŜ Ŏ2YYdzyλűλŜăφ LY I·ŘŘλűλ2y ű2 f2ø¤λyŎ2YŜ Ŏ2yãdzYŜNă KI·ØλyΞ fŜăă ŜyŜNΞèπŜ₹₹λŎλŜyű K2YŜă 2y I·ØŜNI·ΞŜΣ λű λă YdzŎK Y2NŜ ŜÈLJŜyãλØŜ ₹2N dzűλfλűλŜă ű2 LJN2ØλŘŜ ŜyŜNΞè Ŝ₹₹λŎλŜyŎè LJN2ENI·Yă ű2 ûK2ăŜ Ŏ2yãdzYŜNă ûKI·y ű2 I·ØŜNI·ΞŜ¤λyŎ2YŜ NŜăλŘŜyűλI·f 2N Ŏ2YYŜNŎλI·f Ŏ2yãdzYŜNă¢ᴍʟφ

[2ø¤λyŎ2YŜ K2dzăŜK2fŘă I·NŜ 2₹ûSy NŜyűŜNăΣ ŎNŜI·ûλyΞ I· ălJfλű¤λyŎŜyűλØŜ LJN2ōfŜY ₹2N ŜyŜNΞè Ŝ₹₹λŎλŜyŎè λyØŜăűYŜyűă ăλyŎŜ ûKŜ ōŜyŜ₹λú ΞŁŜă ű2 ûKŜ ûŜyI·yű øK2 LJI·ëă ûKŜ ŜfŜŎúNλŎλúè ōλff¢ ¢KŜ ûŜyI·yűΣ 2y ûKŜ 2ûKŜN KI·yŘΣ ăŜŜă fλűűfŜ λyŎŜyűλØŜ ű2 YI·ⅼŜ ŜÈLJŜyãλØŜΣ f2yΞ¤ûŜNY ŜyŜNΞè Ŝ₹₹λŎλŜyŎè λyØŜăűYŜyűă ăλyŎŜ ₹dzűdzNŜ ōŜyŜ₹λúă øλff I·ŎŎNdzŜ ű2 ₹dzűdzNŜ ûŜyI·yűă¢ ¢KŜ ălJfλű λyŎŜyűλØŜ LJN2ōfŜY fŜI·Řă ű2 ŘŜŎfλyΞ ŜyŜNΞè Ŝ₹₹λŎλŜyŎè 2ØŜN ûλYŜ øKŜy Ŏ2YLJI·NŜŘ ű2 2øyŜNπ 2ŎŎdzLJλŜŘ K2dzăλyΞΣ Ŏ2YLJ2dzyŘŜŘ ōè ûKŜ ûŜyŘŜyŎè ₹2N f2ø¤λyŎ2YŜ ! YŜNλŎI·yă ű2 2ŎŎdzLJè 2fŘŜN ōdzλfŘλyΞă¢ ᴍᴍʟ CλyI·ffèΣ f2ø¤λyŎ2YŜ Ŏ2yãdzYŜNă 2₹ûSy fI·Ŏⅼ I·ŎŎŜăă ű2 ŎI·LJλűI·f ₹2N K2YŜ ŜyŜNΞè λYLJN2ØŜYŜyűă I·yŘ KI·ØŜ fλYλűŜŘ I·ŎŎŜăă ű2 ûKŜ Y2ăű YʊŘŜNyI·yŘ Ŝ₹₹λŎλŜyű I·LJLJfλI·yŎŜă I·yŘ ŜfŜŎúNλŎλúè ăŜNØλŎŜ¢ 5h9ûă ² ŜI·ûKŜNλÎI·ûλ2y !ăălăűI·yŎŜ tN2ENI·Y ó² ! tú ₹dzyŘă f2ø¤λyŎ2YŜ ŜyŜNΞè Ŝ₹₹λŎλŜyŎè dzLJENI·ŘŜăΣ ōdzű dzyf2NűdzyI·ûŜfèΣ ûKŜ ySŜŘă ŘNI·YI·ûλŎI·ffè ŜÈŎŜŜŘ ² ! t ₹dzyŘλyΞ¢

¢KŜ /I·fλf2NyλI· tdzōfλŎ ¦ûλfλűλŜă /2YYλăăλ2yó/t¦ /ú NŜŎŜyűfè ₹2dzyŘ ûKI·ûΣ ălyŎŜ мφφφΣ N222₹û2LJ ă2fI·N Ödzăű2YŜNă KI·Ř I· YŜŘλI·y K2dzăŜK2fŘ λyŎ2YŜ 2₹ ÞфмΣллл øKλfŜ ûKŜ YŜŘλI·yλyŎ2YŜ λy /I·fλf2NyλI· øI·ă ÞpnΣллл I·yŘ ûKI·ú 2₹ ûKŜ λyØŜăű2Nπ2øyŜŘ dzűλfλűè óLh¦ú Ödzăű2YŜNă øI·ă ÞcyΣллл¢ᴍᴍᴍ ! ădzNØŜè Ŏ2yŘdzŎűŜŘ ōè ûKŜ bI·ûλ2yI·f wŜySøI·ōfŜ 9yŜNΞè [I·ō2NI·û2Nè ₹2dzyŘ ûKI·ú ă2fI·N I·Ř2LJűŜNă λy{I·y 5λŜ2 /2dzyûè KI·Ř I·y I·ØŜNI·ΞŜ K2dzăŜK2fŘ λyŎ2YŜ 2₹ ÞмcpΣллл Ŏ2YLJI·NŜŘ ű2 Þммрллл ₹2N y2yπI·Ř2LJűŜNă¢ᴍᴍʜ LY LJNλyŎλLJfŜΣ f2ø¤ŜNπλyŎ2YŜ Ŏ2yãdzYŜNă Ŏ2dzfŘ ōŜyŜ₹λú ₹N2Y λyăűI·ffλyΞ ŘλăűNλōdzűŜŘ ă2fI·N I·yŘ 2ûKŜN ŏfŜI·y ŜyŜNΞè ûŜŎKy2f2ΞλŜă λy ûKŜλN K2YŜă λy ûKŜ ăI·YŜ øI·è ûKI·ú KλΞKŜNπλyŎ2YŜ Ŏ2yãdzYŜNă ŘΣ ōdzű YI·yè ōI·NNλŜNă KI·ØŜ LJNŜØŜyűŜŘ ûKλăΣ λyŎfdzŘλyΞ fI·Ŏⅼ 2₹ ₹dzyŘλyΞ 2N ₹λyI·yŎλyΞ I·yŘ fI·Ŏⅼ 2₹ I·y I·ŘI·Ijdzl·ûŜ N22₹¢ᴍᴍᴏ LY I·ŘŘλűλ2yΣ YI·yè f2ø¤λyŎ2YŜ !YŜNλŎI·yă I·yŘ ōdzăλySăăŜă λy f2ø¤λyŎ2YŜ Ŏ2YYdzyλűλŜă NŜyű ûKŜλN K2YŜă I·yŘ 2₹₹λŎŜăΣ YI·ⅼλyΞ dzLJENI·ŘŜă KI·NŘŜN ű2 I·NNI·yΞŜ I·yŘ LJI·è ōI·Ŏⅼ ûKN2dzΞK ŜyŜNΞè 2N ōλff ăI·ØλyΞă¢

¦ûλfλűλŜă I·yŘ 2ûKŜN ŜyŜNΞèπăŜNØλŎŜ LJN2ØλŘŜNă ŎI·y YI·ⅼŜ ă2fI·N t±πYI·NⅼŜű LJI·NűλŎλLJI·ûλ2y I·ØI·λfI·ōfŜ ű2 f2ø¤ λyŎ2YŜ Ödzăű2YŜNă ûKN2dzΞK I·NNI·yΞŜYŜyűă fλⅼŜ Ŏ2YYdzyλűè ă2fI·NΣ øKλŎK YI·è LJN2ØλŘŜ ŎI·ăKπ₹f2ø¤LJ2ăλúλØŜ ă2fdzűλ2yã ű2 I·ŘŘNŜăă ûKŜ ySŜŘă 2₹ I· fI·NΞŜ Ř2øyLJI·èYŜyűΣ ₹I·Ø2NI·ōfŜ ŎNŜŘλű NI·ûλyΞΣ 2N 2øyŜNπ2ŎŎdzLJλŜŘ ălyΞfŜπ ₹I·YλfêK2YŜ¢ hyŜ Ŏ2YY2yY2ŘŜf λă ₹2N Ŏ2YYdzyλűè ă2fI·N LJN2ⅼŜŎű ŘŜØŜf2LJŜNă ű2 ₹2NYtt!ă øλűK ûKŜ dzűλfλűè

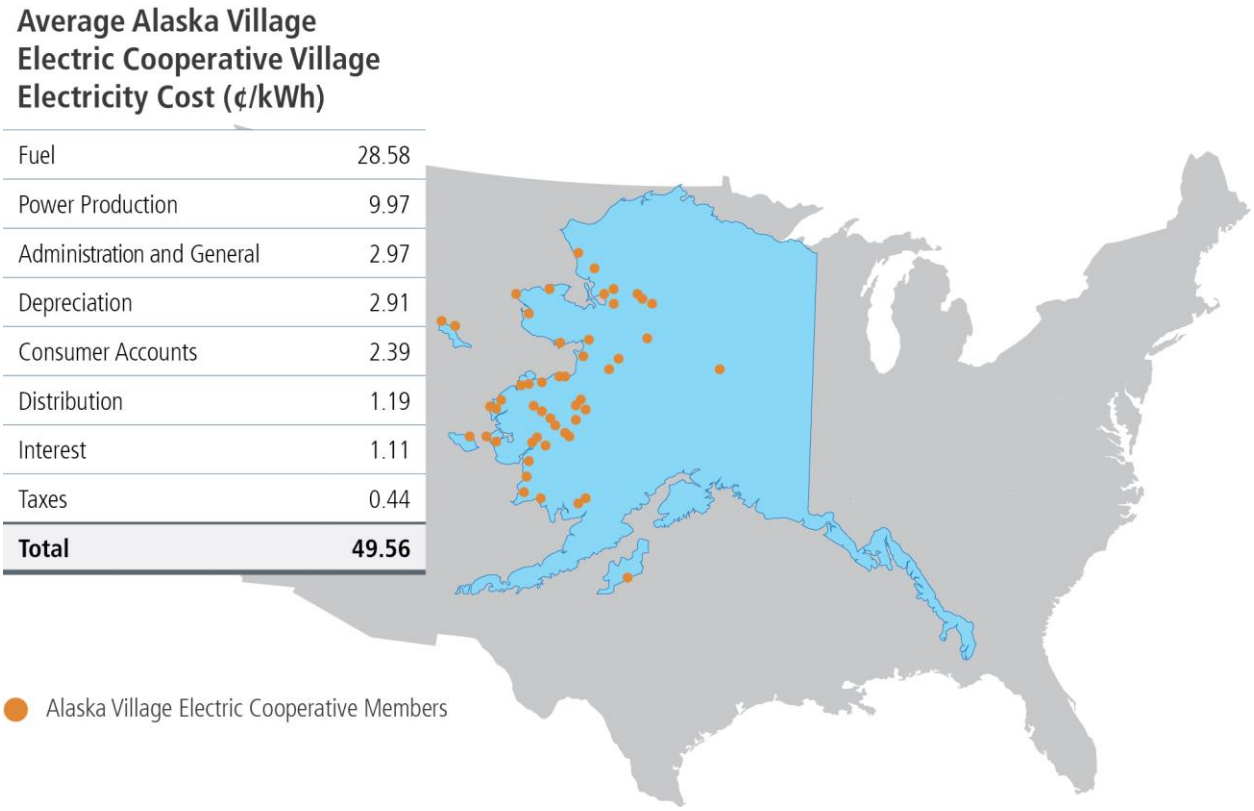
2.2.6 Electricity Issues in Small, Rural, and Islanded Communities

2.2.6.1 Powering Isolated Communities in Alaska

wdzNl·f !fl·ă]l· Ô2YY dzyΛűΛŜă Kl·ØŜ KΛ∃K ăŜl·ă2yl·f f2l·Ř LJŜl·]ăΣ ØΛűK KΛ∃K ŘŜY l·yŘ ΛyűKŜ ØΛyűŜN ₮2N KŜl·űΛy∃ l·yŘ fΛ∃KűΛy∃Φ a l·yê ăY l·ffŜN !fl·ă]l· Ô2YY dzyΛűΛŜă N Ŝtê 2y ŘΛŜăŜf ₮dzŜf ₮2N ŜfŜÔúNΛÕΛúè ∃ŜySŜNl·űΛ2yΣ l·yŘ LJl·è Þлφрл ű2 Þлφул LJŜN] ² K ōŜÔl·dzăŜ 2₮ űKŜ KΛ∃K Ô2ăű 2₮ ₮dzŜf l·yŘ ăKΛLJLJΛy∃Σ KΛ∃KŜN Ôl·LJΛúl·f Ô2ăűă ŘdzŜ ű2 űKŜ ăY l·ff ăÔl·fŜ 2₮ ∃ŜySŜNl·űΛ2yΣ l·yŘ úKŜ ∃NŜl·úŜN ySŜŘ ₮2N NŜŘdzyŘl·yÔè ΛyY∃ŜySŜNl·űΛ2y óăŜŜ CΛ∃dzNŜ нπyúΦMHM

. l·ŰűŜNè ăű2Nl·∃Ŝ Kl·ă ΛYLJN2ØŜŘ NŜfΛl·ōΛfΛúè ΛyY !fl·ă]l· Ô2YY dzyΛűΛŜă Ô2yŷŜŐűŜŘ ű2 űKŜ fl·N∃ŜN ∃NΛŘ ΛyY úKŜ ÔŜyúNl·f LJl·Nú 2₮ úKŜ ăűl·ûŜΦMHH ¢KŜ ōl·ŰűŜNΛŜă Kl·ØŜ ōŜŜyY ΛyăűlffŜŘ LJNΛYl·NΛfè ₮2N ₮NŜIjdzŜyÔè l·yŘ Ø2fűl·∃Ŝ NŜ∃dzfl·ûΛ2yΣ y2ű ű2 ăű2NŜ ΛyűŜNYΛúűŜyú NŜySØl·ōfŜ ŜySN∃èΦMHO !fl·ă]l·yã Kl·ØŜ ŜÈLJŜNΛŜyÔŜŘ ₮ŜØŜN 2dzűl·∃ŜăΣ l·yŘ ∃NΛŘ 2LJŜNl·ű2Nă dzăŜ fŜää ăLJΛyyΛy∃ NŜăŜNØŜ Ôl·LJl·ÔΛúè ØΛűK ûKŜ l·ŘŘΛΛ2y 2₮ fl·N∃Ŝπăôl·fŜ ōl·ŰűŜNè ăű2Nl·∃ŜΦMHП

Figure 2-8. Electricity Costs in Rural Alaska[125]



The Alaska Village Electric Cooperative serves more than 50 small communities dispersed across large distances and in remote regions with harsh climatic conditions. These factors contribute to average electricity prices being approximately five times the U.S. national average.

!fl·ă]l·y Ô2π2LJă l·NŜ ΛyăűΛl·ffΛy∃ Y 2NŜ ØΛyŘ ŜySN∃è l·yŘ ΛYLJN2ØΛy∃ LJ2ØŜNπÔ2yúN2f ûŜŐKy2f2∃è ΛyY NdzNl·f l·NŜl·ă ű2 ōŜűűŜN Y l·yl·∃Ŝ ŜfŜŐűNΛÕΛúè ăèăűŜY ă ûKl·ű LJNΛYl·NΛfè Ndzy 2y ŘΛŜăŜf ₮dzŜfΦMHC ¢KŜ !fl·ă]l· /SyűŜN ₮2N 9ySN∃è l·yŘ t2ØŜN Kl·ă ăűdzŘΛŜŘ Ø l·èă ű2 NŜŘdzÔŜ NŜfΛl·yÕŜ 2y ŘΛŜăŜf ∃ŜySNl·ΛΛ2yΣ ØKΛfŜ NŜÔ2∃yΛÎΛyΞ ûKŜ ŘΛ₮₮ΛÔdzfûè ΛY ŜfΛYΛyl·ΛΛy∃ ŘΛŜăŜf ∃ŜySNl·ű2Nă ōŜÔl·dzăŜ ûKŜè LJN2ØΛŘŜ ΛYLJ2NΛl·yű ăŜNØΛÔŜă ōŜè2yŘ ŜfŜŐűNΛÕΛúè ∃ŜySNl·ΛΛ2yᴹᴴᵀ ΛyÕfdzŘΛy∃ Ø l·ăΛŜ KŜl·Λ l·yŘ ΛySNΛΛl· ₮2N f2Ôl·f ŜfŜÕΛNΛÕΛúè ăèăΛŜY ăΦMHY {èăΛŜY ă ûKl·Λ dzăŜ ō2ΛK ŘΛŜăŜf l·yŘ ØΛyŘ ŜySN∃è Kl·ØŜ NŜŘdzÔŜŘ ₮dzŜf Ô2ăΛă l·yŘ ŜY ΛăăΛ2yã ōdzΛ l·NŜ Y 2NŜ Ô2YLJfŜÈ l·yŘ NŜIjdzNŜ Y 2NŜ ΛNl·ΛyΛy∃ ₮2N 2LJSNl·Λ2NăΦMHΦ !fă2Σ ΛYLJN2ØŜŘ ōN2l·Řōl·yŘ l·ÔÔŜăă Λ2 ΛKŜ fl·N∃Ŝ Řl·Λl· ăΛNŜl·Y ă ySÔŜăăl·Nè ₮2N Yl·yl·∃ΛyΞ ΛKŜăŜ Ô2YLJfŜÈ ăèăΛŜY ă Ø2dzfŘ Yl·]Ŝ ΛΛ Ŝl·ăΛŜN Λ2 Ndzy ΛKŜY ΛyNŜY2ΛŜ l·NŜl·ă l·yŘ 2y ΛăfΛ·yŘăΦMOЛ

2.2.6.2 Innovative Rural Electric Co-Op Programs

² KλfŜ ŜyŜNƎè ŜŦŦλŎλŜyŎè λă Y2NŜ Ô2ăúπŜŦŦŜŎűλØŜ úKI·y ōdzλfŘλyƎ ySø λyŦNI·ăúNdzŎűdzNŜΣ NdzNI·f ŜySNƎè ŜŦŦλŎλŜyŎè LJN2ƎNI·Yă ŦI·ÔŜ I· dzyλIjdzŜ ŎKI·ffŜyƎSΦ wdzNI·f Ô2YY dzyλűλŜă KI·ØŜ I· ƎNŜI·úŜNJ LJN2LJ2Nűλ2y 2Ŧ f2ørűΣ2πY2ŘŜNI·úŜπ λyŎ2YŜ ŦI·Yλfλŝă øK2 YI·è KI·ØŜ LJN2ōfŜYă ŦλyI·yŎλyƎ ŜySNƎè ŜŦŦλŎλŜyŎè λyØŜăúYŜyűăΦ !fă2Σ ăŜI·ă2yI·f ŘŜYI·yŘ LJŜI·ĵă NŜfI·úŜŘ ű2 I·ƎNλÔdzfűdzNŜ ŎI·yYI·ĵŜ űKŜ LJI·èōI·Ôĵ űλYŜ f2yƎŜN Ŧ2N ŜySNƎè ŜŦŦλŎλŜyŎè λyØŜăúYŜyűă I·yŘ Ô2π 2LJă ăŜNØλyƎ NdzNI·f Ô2YY dzyλűλŜă YI·è KI·ØŜ fŜăă I·ÔÔŜăă ű2 ÔI·LJλűI·f I·yŘ úŜÔKyƒÔI·f ŜÈLJŜNűλăŜ űKI·yLh ¦ ăΦMOM LyăLJλűŜ 2Ŧ úKŜ ŎKI·ffŜyƎSă 2Ŧ 2LJŜNI·ûλyƎ λyλă2fI·úŜŘ I·NŜI·ăΣ Ô2π2LJ ăI·fŜă ƎNŜø oΦo LJŜNÔSyű λy нлмп Ô2YLJI·NŜŘ ű2 мΦм LJŜNÔSyű ƎN2øűK I·ÔN2ăă úKŜ ŜyűλNŜ NŜűI·λf ŜfŜÔúNλÔλúè ăI·fŜă λyŘdzăúNèΦMOH

/2π2LJă KI·ØŜ λyăúI·ffŜŘ úKŜ ƎNŜI·úŜăú LJŜNÔSyűI·ƎŜ 2Ŧ I·ŘØI·yÔŜŘ YŜûŜNλyƎ λyŦNI·ăúNdzÔűdzNŜ ó ! a LúΣ øλűK pм LJŜNÔSyű LJŜySúNI·ûλ2yΣ Ô2YLJI·NŜŘ ű2 пм LJŜNÔSyű Ŧ2N Lh ¦ ă I·yŘ нс LJŜNÔSyű 2Ŧ LJdzōfλÔfè 2øySŘ dzűλfλúλŜăΦMOO wdzNI·f ŜfŜÔúNλÔ Ô2π2LJă KI·ØŜ úKŜ I·ŘØI·yűI·ƎŜ 2Ŧ ōŜλyƎ ăY I·ffŜN I·yŘ Y2NŜ yλYōfŜ űKI·yfI·NƎŜ Lh ¦ ă NŜƎdzfI·ûŜŘ ōè t ¦ /ăΣ I·yŘ úKŜè ÔI·yY2NŜ ŜI·ăλfè I·Ř2LJű ŜySNƎè ŜŦŦλŎλŜyŎè 2N NŜySø I·ōfŜ ŜySNƎè LJN2ƎNI·Yă úI·λf2NŜŘ ű2 úKŜλNJ YŜYōŜNăΦ {2YŜ NdzNI·f Ô2π2LJă I·NŜ I·ŘŘλyƎ ōλ2ŘλƎŜăúŜNă ű2 Ô2yØŜNű ă2fλŘ øI·ăúŜ FN2Y ŘI·λNè Ô2øă ű2 ŜfŜÔúNλÔλúèΣ ăYI·Nű ŜfŜÔúNλÔ øI·ûŜNJ KŜI·ûŜNă ű2 ăű2NŜ øλyŘ ŜySNƎèΣ λYLJN2ØŜŘ Ŧ2NŜÔI·ăúλyƎ Ŧ2NJ ă2fI·NJ I·yŘ øλyŘ ŜySNƎèΣ I·yŘ 2úKŜNJ 5w ûŜÔKy2f2ƎλŜă úKI·ű űI·ĵŜ I·ŘØI·yűI·ƎŜ 2Ŧ NŜă2dzNÔŜă λyNdzNI·f I·NŜI·ăΦ a I·yè 2Ŧ úKŜăŜ 5w I·yŘ ăű2NI·ƎŜ ûŜÔKy2f2ƎλŜă Ô2dzfŘ ōŜ ŜÈLJI·yŘŜŘ øλúK λYLJN2ØŜŘ ûŜfŜÔ2YY dzyλÔI·úλ2yã I·ÔÔŜăΦMOΠ

¢KŜ w ¦ { LJI·NűyŜNă øλúK Ô22LJŜNJI·úλØŜă ű2 ŦλyI·yÔŜ λYLJN2ØŜYŜyűă λyNdzNI·f Ô2YY dzyλűλŜăΣ YI·yè 2Ŧ øKλÔK I·NŜ f2ø λyÔ2YŜΦMOP w2I·y2ĵŜ 9fŜÔúNλÔ /22LJŜNJI·úλØŜ λYLJfŜYŜyűŜŘ I· LJN2ƎNI·Y ű2 YI·ĵŜ λyØŜăúYŜyűă úλŜŘ ű2 ŜI·ÔK YŜûŜNJ I·yŘ ŦdzyŘ̂Ř ōè I·yw ¦ { f2I·yΦMOC ¢KŜ Ô2π2LJ LJI·λŘ Ŧ2NJ λyăúI·ffI·úλ2yƒ 2Ŧ λYLJN2ØŜŘ λyãdzfI·úλ2yΣ ŘdzÔűI·yŘ I·λNJ ăŜI·fλyƎΣ KŜI·ú I·yŘ øI·ûŜNJ LJdzYLJ dzLJƎNI·ŘŜăΣ I·yŘ ŜŦŦλŎλŜyűfλƎKúλyƎΦMOT ¢KŜ Ô2π2LJ NŜÔ2ØŜNă λúă ŜŦŦλŎλŜyŎè λyØŜăúYŜyű úKN2dzƎK I· úI·NλŦŦ 2yúKŜ ōλff FN2Y Ô2π2LJ YŜYōŜNăΣ øK2 ăűλff ăŜŜ ăI·ØλyƎă 2yúKŜλNJ ōλff FN2Y úKŜ NŜŘdzÔŜŘ ŜfŜÔúNλÔλúè dzăΦMOY !fûŜNJ ŜŦŦλŎλŜyŎè dzLJƎNI·ŘŜăΣ úKŜ I·ØŜNI·ƎŜ ăI·ØλyƎă øI·ă ÞмнлΣ øKλÔK úKŜ YŜYōŜNJ I·yŘ úKŜ Ô2π2LJ ø2dzfŘ ălJfλúT I·yI·ØŜNI·ƎŜ YŜYōŜN ø2dzfŘ ăI·ØŜ Þсл LJŜN Y2yúK 2yKλă 2N KŜN ōλffΣ I·yŘ úKŜ Ô2π 2LJ ø2dzfŘ LJI·è 2ŦŦ úKŜ ŜŦŦλŎλŜyŎè dzLJƎNI·ŘŜ λyмл èŜI·NăΦMOΦ LYLJN2ØŜYŜyűă ű2 w ¦ { f2I·yLJN2ƎNI·YăΣ YI·yè 2Ŧ øKλÔK I·NŜ dzyŘ̂SNădzōăÔNλōŜŘ ōŜÔI·dză 2Ŧ úKŜ LJN2ƎNI·Yă Ô2YLJfŜÈλúè 2N úKŜ λyI·ōλfλúè ű2 NŜŦλyI·yÔŜ ű2 f2øŜNJ λyúŜNŜăú NJI·ûŜăΣ Ô2dzfŘ I·ÔÔŜfŜNJI·ûŜ úKŜ ŘŜØŜf2LJYŜyű 2Ŧ NŜySøI·ōfŜ ŜySNƎè I·yŘ ŜySNƎè ŜŦŦλŎλŜyŎè LJN22ŜÔúă λy NdzNI·f I·NŜI·ăΦ

2.2.7 Electricity as a Driver of Economic Growth in Tribal Communities

9fŜÔúNλŦλÔI·ûλ2yλyúKŜ ¦ yűûŜŘ {úI·ûŜă λă I·Y2yƎ úKŜ KλƎKŜăú λyúKŜ ø2NfŘΣ ōdzú I·ÔÔŜăă ű2 ŜfŜÔúNλÔλúè 2yLyŘλI·y NŜăŜNØI·ûλ2yã LJNŜăŜyűă I· ăúNλĵλyƎfè ŘλŦŦŜNŜyű NŜI·fûè ¢KŜ λyűŜNŘŜLJŜyŘŜyÔλŜă 2Ŧ ŜfŜÔúNλÔλúè I·ÔÔŜăăΣ ŜÔ2y2YλÔ øŜffπōŜλyƎΣ I·yŘ Ijdz I·fûè 2Ŧ fλŦŜ dzyŘŜNăÔ2NŜ úKŜ λYLJ2NűI·yÔŜ 2Ŧ ŜfŜÔúNλŦèλyƎ úNλōI·f fI·yŘăΦ

LyнлмлΣ мΦм Yλffλ2y !YŜNλÔI·yLyŘλI·y2N !fI·ăĵI· bI·ûλØŜ LJŜ2LJfŜ fλØŜŘ 2yNŜăŜNØI·ûλ2yã I·yŘ !fI·ăĵI· bI·ûλØŜ ±λffI·ƎŜ !NŜI·ăΦ ¢KŜ bI·ØI·ø2 bI·ûλ2yNŜăλŘŜă 2yúKŜ fI·NƎŜăú NŜăŜNØI·ûλ2yΣ ălJI·yyλyƎ bŜø aŜÈλÔ2Σ !NλÎ2y1·Σ I·yŘ ¦ûI·KΦ hŦ bI·ØI·ø2 K2dzăŜK2fŘăΣ от LJŜNÔSyű I·NŜ øλúK2dzű I·ÔÔŜăă ű2 ŜfŜÔúNλÔλúè I·yŘ по LJŜNÔSyű fλØŜ ōSf2ø úKŜ LJ2ØŜNûè fλySΦMΠΛ !y9L! ăűdzŘè λyнллл Ŧ2dzyŘ úKI·û I·ÔN2ăă I·ff úNλōSăΣ 2yS λyăŜØŜyLyŘλI·yK2dzăŜK2fŘă fλØλyƎ 2y NŜăŜNØI·ûλ2yã øI·ă øλúK2dzű ŜfŜÔúNλÔλúè ăŜNØλÔŜΦMΠM 9ĒúNI·LJ2fI·ûλyƎ FN2Y 9L!Ωă ŜfŜÔúNλŦλÔI·ûλ2y NJ·ûŜăΣIJ ű2ŘI·è I·LJLJN2ÈλYI·ûŜfè мслΣллл LJŜ2LJfŜ I·NŜ øλúK2dzű ŜfŜÔúNλÔλúèΦ 5I·úI· FN2Y úKŜ нллтçнлмм ¦Φ{Φ /ŜyădzăΣ !YŜNλÔI·y /2YYdzyλűè {dzNØŜè I·fă2 Ô2yÔfdzŘŜă úKI·ú 2y úNλōI·f fI·yŘăΣ úK2dzăI·yŘă 2Ŧ bI·ûλØŜ !YŜNλÔI·yă I·NŜ ăűλff fλØλyƎ øλúK2dzű ōI·ăλÔ ŜfŜÔúNλÔλúè ăŜNØλÔŜă

IJ ¢KŜ нллл 9L! ăűdzŘè λă úKŜ Y2ăű ÔdzNNŜyű ăűdzŘè 2yúKŜ I·ØI·λfI·ōλfλúè 2Ŧ ŜfŜÔúNλÔλúè 2yNŜăŜNØI·ûλ2yãΦ ! ăűdzŘè FN2Y 5h9Ωă hŦŦλÔŜ 2Ŧ LyŘλI·y9yŜNƎè t2fλÔè I·yŘ tN2ƎNI·Yă λă Ŧ2NúKÔ2YλyƎΦ

9ŦŦ2Ŋΰăΰ2 I·ŘŘŊŜăă I·ÖÖŜăă΄ΰ2 ŜfŜÖΰŊλÖλΰè 2γ΄LγŘλI·γ΄fI·yŘă ŦI·ÖŜ ăλƎγλŦλÖI·yΰ ÖKI·ffŜγƎŜă ¢KŜăŜ ÖKI·ffŜγƎŜă λyÖftdzŘŜ ŊŜΥ΄2ΰŜ f2ỐI·ΰλ2yãΣ ǿλŘŜfè ŘλăLJŜŊăŜŘ K2Υ΄Ŝă΢ I·yŘ ΰKŜ LJŊ2KλōλΰλØŜ Ỏ2ăΰ 2Ŧ dzΰλfλΰè ŘλăΰŊλōdzΰλ2γ΄fλyŜă¢ 5ŜăLJλΰŜ ŊŜŘdzÕΰλ2yã λγ΄ǿλyŘ I·yŘ ă2ŧfI·Ŋ Ỏ2ăΰăΣ Υ΄I·yê ΰŊλōŜă KI·ØŜ yƩΰ ōŜŜγ΄I·ōfŜ ΰ2 ΰI·ʅŜ I·ŘØI·yΰI·Ǝŝ 2Ŧ ΰKŜλŊ ǿλyŘ 2Ŋ ă2fI·Ŋ ŊŜă2dzŊỐŜă¢ᴍᴨʜ ¢ŊλōŜă KI·ØŜ fλΥ΄λΰŜŘ I·ÖỐŜăă ΰ2 LJŊλØI·ΰŜ ỐI·LJλΰI·f Ŧ2Ŋ LJŊ2ŝŜÖΰă λγ΄LγŘλI·γ΄/2dzyΰŊè¢

5h9Ωă hŦŦλỐŜ 2Ŧ LyŘλI·γ΄9yŜŊƎè t2fλỐè I·yŘ tŊ2ƎŊI·Υ΄ă ŊŜÖŜyΰfè Υ΄2ŘŜŊyλÎŜŘ λΰă ΰŜÖKyλỐI·f I·ăăλăΰI·yÖŜ ăΰŊI·ΰŜƎè ΰ2 ōŜΰΰŜŊ I·ăăλăΰ ΰŊλōŜă λγ΄λΥ΄LJŊ2ØλyƎ ŜyŜŊƎè I·ÖỐŜăă I·yŘ ăŜŊØλỐŜă ōè ŊŜÖ2ƎyλÎλyƎ ΰKI·ΰ ΰKŜ IjdzŜăΰλ2yã 2Ŧ ΰ2ŘI·èΩă ƎŊλŘ I·ŊŜ Υ΄2ŊŜ Ỏ2Υ΄LJfŜÈ I·yŘ ă2Υ΄ŜΰλΥ΄Ŝă ŊŜIjdzŊŜ f2yƎŜŊπΰŜŊΥ΄ LJI·ŊΰyŜŊăKλLJă¢ ¢KŜ .dzŊŜI·dz 2Ŧ LyŘλI·γ΄ !ŦŦI·λŊă I·ΰ ΰKŜ 5ŜLJI·ŊΰΥ΄Ŝyΰ 2Ŧ ΰKŜ LyΰŜŊλ2Ŋ KI·ă ăŜØŜŊI·f LJŊ2ƎŊI·Υ΄ă ΰKI·ΰ LJŊ2ØλŘŜ ΰŜÖKyλỐI·f I·ăăλăΰI·yÖŜ ΰ2 ! Υ΄ŜŊλỐI·γ΄LyŘλI·γ΄ ΰŊλōŜă Ŧ2Ŋ ŜyŜŊƎè ŘŜØŜf2LJΥ΄Ŝyΰ¢ ¦{5!Ωă w¦{ 2ŦŦŜŊă f2ǿπỐ2ăΰ f2I·yã ΰ2 NdzŊI·f dzΰλfλΰλŜăΣ λyÖftdzŘλyƎ ΰŊλōI·f λyλΰλI·ΰλØŜă Ŧ2Ŋ λyỐŊŜI·ăλyƎ ƎŊλŘ I·ÖỐŜăăΣ I·yŘ ăΰI·ΰŜ LJŊ2ƎŊI·Υ΄ă I·fã2 ŜÈλăΰ¢ C2Ŋ ŜÈI·Υ΄LJfŜΣ λγ΄bŜǿ aŜÈλỐ2Σ ΰKŜ ¢ŊλōI·f LyŦŊI·ăΰŊdzÕΰdzŊŜ Cdzyŗ΢ ỐŊŜI·ΰŜŘ ōè ΰKŜ ¢ŊλōI·f LyŦŊI·ăΰŊdzÕΰdzŊŜ !Ốΰλγ нллрΣ ŊŜỐ2ƎyλÎŜă ΰKI·ΰ Υ΄I·yê 2Ŧ bŜǿ aŜÈλỐ2Ωă ΰŊλōI·f Ỏ2Υ΄ΥdzyλΰλŜă fI·Ỏʅ ōI·ăλỐ λyŦŊI·ăΰŊdzÕΰdzŊŜ λyÖftdzŘλyƎΣ ōdzΰ yƩΰ fλΥ΄λΰŜŘ ΰ2Σ ǿI·ΰŜŊ I·yŘ ǿI·ăΰŜǿI·ΰŜŊ äèăΰŜΥ΄ăΣ Ŋ21·ŘăΣ I·yŘ ŜfŜÖΰŊλÖI·f LJ2ǿŜŊ fλySă¢ ¢KŊ2dzƎK ΰKλă Ỏ2Υ΄LJŜΰλΰλ ØŜ Ŧdzyŗλy ƎK Ŋ2ōdzăΰ LJŊ2ŝŜÖΰ LJŊ2LJ2ăI·f Ŧ2Ŋ ΰKŜŊλ Ỏ2Υ΄ΥdzyλΰλŜă¢ !ΰ ŜI·ỐK Ŧdzyŗλy ỐèỐfŜΣ ΰKŜ LJŊ2ŝŜÖΰ LJŊ2LJ2ăI·f λă ŜØI·fdzI·ΰŜŘ I·yŘΣ ōI·ăŜŘ 2γ΄ăỐ2ŊλyƎΣ λă I·ǿI·ŊŘŜŘ Ŧdzyŗă ΰKŊ2dzƎK ΰKŜ мoπLJŜŊă2γ΄ŊλōI·f LyŦŊI·ăΰŊdzÕΰdzŊŜ .2I·ŊŘΣ ǿKλỐK λă I·ŘΥ΄λyλăΰŊI·ΰλØŜfè I·ΰΰI·ỐKŜŘ ΰ2 ΰKŜ bŜǿ aŜÈλỐ2 LyŘλI·γ΄ !ŦŦI·λŊă 5ŜLJI·ŊΰΥ΄Ŝyΰ¢

I2ǿŜØŜŊΖ ΰKŜăŜ CŜŘŜŊI·f I·yŘ ăΰI·ΰŜ ŊŜă2dzŊỐŜă ỐI·γ΄ōŜ λyΰdzŦŦλỐλŜyΰ ǿKŜγ΄Υ΄ŜI·ădzŊŜŘ I·ƎI·λyΰă ΰKŜ ySŜŘ Ŧ2Ŋ ΰKŜΥ΄¢KŜ I·ØI·λfI·ōλfλΰè 2Ŧ yŜǿ ΰ22fã I·yŘ ¢! Ř2Ŝă yƩΰ ỐKI·yƎŜ ΰKŜ ŊŜI·fλΰè ΰKI·ΰ LJŊ2ØλŘλyƎ I·ÖỐŜăă ΰ2 ŜfŜÖΰŊλỐλΰè λă ØŜŊè ŜÈLJŜyΰăλØŜ Ŧ2Ŋ ΰŊλōI·f dzΰλfλΰλŜă¢ LyŘŜŜŘΣ ΰKŜ ŜfŜÖΰŊλŦλỐI·ΰλ2γ΄2Ŧ ŊdzŊI·f ! Υ΄ŜŊλỐI· λyΰKŜ мфолă ǿI·ă I·ÖKλŜØŜŘ ΰKŊ2dzƎK ŜỐ2y2Υ΄λỐ ΰŊI·yãŦŜŊă ŦŊ2Υ΄ dzŊōI·γ΄ Ödzăΰ2Υ΄ŜŊă ΰ2 NdzŊI·f Ödzăΰ2Υ΄ŜŊăΣ Ŝ¢Ǝ¢ ΰKŊ2dzƎK KλƎK fŜØŜfă 2Ŧ λyΰŜŊŜăΰπŦŊŜŜ f2I·yã I·yŘ ƎŊI·yΰă ŦŊ2Υ΄ ΰKŜ CŜŘŜŊI·f D2ØŜŊyΥ΄Ŝyΰ¢ tŊλ2ŊλΰλÎλyƎ dzyŊØŜŊăI·f ŜfŜÖΰŊλỐλΰè I·ÖỐŜăă Ŧ2Ŋ ΰŜyã 2Ŧ ΰK2dzăI·yŘă 2Ŧ ! Υ΄ŜŊλỐI·yã ǿλΰK2dzΰ ŜfŜÖΰŊλỐλΰè Υ΄I·è I·ƎI·λyΰŜIjdzŊŜ ăλƎγλŦλỐI·yΰ CŜŘŜŊI·f λyΰŜŊØŜyΰλ2y¢

¢ŊλōŜă I·fã2 ŦI·ÖŜ ŊŜƎdzfI·ΰ2Ŋè ỐKI·ffŜγƎŜă I·yŘ fλΥ΄λΰI·ΰλ2yã¢ ¢KŜ ΰI·ÈπŜÈŜΥ΄LJΰΣ y2yŦLJŊ2Ŧλΰŭ ăΰI·ΰdză 2Ŧ CŜŘŜŊI·ffè ŊŜÖ2ƎyλÎŜŘ ΰŊλōŜă LJŊŜÖfdzŘŜă ΰKŜΥ΄ ŦŊ2Υ΄ ΰI·ʅλyƎ I·ŘØI·yΰI·ƎŜ 2Ŧ ΰKŜ CŜŘŜŊI·f tŊ2ŘdzÕΰλ2γ΄¢I·È /ŊŜŘλΰ 2Ŋ LyØŜăΰΥ΄Ŝyΰ¢I·È /ŊŜŘλΰ ǿλΰK2dzΰ Ö2ăΰfè I·yŘ Ö2Υ΄LJfλÖI·ΰŜŘ Ö2ŊLJ2ŊI·ΰŜ ăΰŊdzÕΰdzŊŜă¢ᴍᴨᴏ ¢KŜăŜ ΰI·È ÕŊŜŘλΰă KI·ØŜ ădzLJLJ2ŊΰŜŘ I· ŘŊI·Υ΄I·ΰλÕ ŜÈLJI·yãλ2γ΄2Ŧ ŊŜyŜǿI·ōfŜ ŜyŜŊƎè LJŊ2ŘdzÕΰλ2γ΄2γ΄y2yŦΰŊλōI·f fI·yŘă¢ [ŜyƎΰKè ŊŜƎdzfI·ΰ2ŊèLJŊ2ÖŜăăŜă I·fã2 Υ΄I·ʅŜ λΰ Υ΄2ŊŜ ŘλŦŦλỐdzfΰ ΰ2 ŘŜØŜf2LJ ŜyŜŊƎè ŊŜă2dzŊỐŜă I·yŘ ŜfŜÖΰŊλỐλΰè ΰŊI·yãΥ΄ăăλ2γ΄LJŊ2ŝŜÖΰă¢ᴍᴨᴨ {λΰλyƎ I·yŘ LJŜŊΥ΄λΰΰλyƎ NdzfŜă Ŧ2Ŋ ΰŊI·yãΥ΄ăăλ2γ΄ŊλƎKΰă¤2Ŧπǿl·è 2γ΄ΰŊλōI·f fI·yŘă ǿŜŊŜ ăλΥ΄LJfλŜŘ I·yŘ ÖfI·ŊλŦλŜŘ λγ нлмрΣ ǿKλỐK Υ΄I·è 2ŦŦŜŊ 2LJLJ2ŊΰdzyλΰλŜă Ŧ2Ŋ ΰŊλōŜă ΰ2 ōdzλfŘ 2dzΰ ƎŊλŘ I·ÖỐŜăă ΰ2 dzyỐ2yγŜỐΰŜŘ NdzŊI·f I·ŊŜI·ă I·yŘ λyỐŊŜI·ăŜ Ỏ2yγŜỐΰλ2yã ΰ2 ŊŜγŜǿI·ōfŜ ŜyŜŊƎè LJŊ2ŝŜÖΰă¢

LyŘλI·γ΄[I·yŘă KI·ØŜ 2ØŜŊ ф Υ΄λffλ2γ΄ a ² 2Ŧ ŊŜyŜǿI·ōfŜ ŜyŜŊƎè LJ2ΰŜyΰλI·fΣᵐᴨᵖ ōdzΰ 2yfè мнрçмол a ² KI·ă ōŜŜγ΄ λyăΰI·ffŜŘ 2γ΄ΰŊλōI·f fI·yŘăΣ ŘdzŜ ΰ2 ΰKŜ fI·ỐʅλΰI·fΦᵐᴨᶜ a I·ʅλyƎ ŊŜyŜǿI·ōfŜ ŜyŜŊƎè ΰI·È ỐŊŜŘλΰă ŊŜfdzyŘI·ōfŜ I·yŘ LJŊ2ØλŘλyƎ f2I·γ΄ƎdzI·ŊI·yΰŜă ǿ2dzfŘ KŜfLJ ΰŊλōŜă ŘŜØŜf2LJ ΰKŜŊλ ŊŜyŜǿI·ōfŜ ŜyŜŊƎè ŊŜă2dzŊỐŜă¢ {2Υ΄Ŝ ΰŊλōŜă KI·ØŜ I·fã2 ŜÈLJŊŜăăŜŘ λyΰŜŊŜăΰ λγ΄λΥ΄LJŊ2ØλyƎ ΰKŜλŊ ỐI·LJI·Ốλΰèΰ2 NdzyΥ΄ŜyŜŊƎè LJŊ2ƎŊI·Υ΄ă ōè ŘŜØŜf2LJλyƎ ΰŊλōI·f ŜyŜŊƎè 2ŦŦλỐŜăΣ Ỏ2Υ΄LJI·ŊI·ōfŜ ΰ2 ăΰI·ΰŜ ŜyŜŊƎè 2ŦŦλỐŜă ΰKI·ΰ NdzyΥ΄ŜyŜŊƎè ŜŦŦλỐλŜyÖè I·yŘ ŜyŜŊƎè ăŜÖdzŊλΰè LJŊ2ƎŊI·Υ΄ă¢ᴍᴨᴛ

¢KŜ CŜŘŜŊI·f D2ØŜŊyΥ΄Ŝyΰ KI·ă I· ΰŊdzăΰ ŊŜăLJ2yãλōλfΰè ΰ2 LJŊ2ΰŜÖΰ ΰŊλōI·f ΰŊŜI·ΰè NλƎKΰăΣ fI·yŘΣ I·yŘ ŊŜă2dzŊỐŜăΣ I·yŘ λΰ KI·ă I· f2yƎăΰI·yŘλyƎ LJ2fλÖè 2Ŧ ŜyỐ2dzŊI·ƎλyƎ ŜỐ2y2Υ΄λỐ ŘŜØŜf2LJΥ΄Ŝyΰ λγ΄LyŘλI·γ΄/2dzyΰŊè¢ Lγ΄I·ŘŘλΰλ2γ΄ΰ2 ădzLJLJ2ŊΰλyƎ λΥ΄LJŊ2ØŜŘ I·ÖỐŜăă ΰ2 ŜfŜÖΰŊλỐλΰè I·yŘ λyỐŜyΰλØŜă Ŧ2Ŋ ŊŜyŜǿI·ōfŜ ŜyŜŊƎè ŘŜØŜf2LJΥ΄ŜyΰΣ ΰKŜ CŜŘŜŊI·f D2ØŜŊyΥ΄Ŝyΰ ăK2dzfŘ λΥ΄LJŊ2ØŜ Ỏ2yãdzfΰI·ΰλ2γ΄ǿλΰK ΰŊλōI·f Ǝ2ØŜŊyΥ΄Ŝyΰă 2γ΄λyŦŊI·ăΰŊdzÕΰdzŊŜ LJŊ2ŝŜÖΰă¢ CŊŜIjdzŜyΰfèΣ ΰŊλōI·f Ỏ2yãdzfΰI·ΰλ2γ΄ΰI·ʅŜă LJfI·ỐŜ yŜI·Ŋ ΰKŜ ŜyŘ 2Ŧ ΰKŜ ăλΰλyƎ I·yŘ LJŜŊΥ΄λΰΰλyƎ LJŊ2ỐŜăΣ ΰ22 fI·ΰŜ ΰ2 I·ff2ǿ Ŧ2Ŋ Υ΄ŜI·γλyƎŦdzf λyLJdzΰ ŦŊ2Υ΄ ΰŊλōŜă¢ CŜŘŜŊI·f I·ƎŜyÖλŜă KI·ØŜ ŘλŦŦŜŊŜyΰ LJŊ2ỐŜŘdzŊŜă I·yŘ ŘŜŦλyΰλ2yã Ŧ2Ŋ Ỏ2yãdzfΰI·ΰλ2yΣ I·yŘ ă2Υ΄Ŝ ΰŊλōŜă fI·ʅ ΰKŜ ăΰI·ŦŦ 2Ŋ ΰŜÖKyλỐI·f ŜĖLJŜŊΰλăŜ ΰ2 ŊŜØλŜǿ LJŜŊΥ΄λΰΰλyƎ Ř2ÕdzΥ΄Ŝyΰă¢ ¢KŜ CŜŘŜŊI·f D2ØŜŊyΥ΄Ŝyΰ ăK2dzfŘ λΥ΄LJfŜΥ΄Ŝyΰ LJŊ2ỐŜŘdzŊŜă ΰKI·ΰ ŜyãdzŊŜ ŜI·ŊfÈ I·yŘ Υ΄ŜI·γλyƎŦdzf Ỏ2yãdzfΰI·ΰλ2γ΄ ǿλΰK ΰŊλōI·f Ǝ2ØŜŊyΥ΄Ŝyΰă¢ I·yŘ CŜŘŜŊI·f ăΰI·ŦŦ ăK2dzfŘ ŊŜÖŜλØŜ ΰŊI·λyλyƎ I·ō2dzΰ K2ǿ ΰ2 LJŊ2ØλŘŜ Υ΄ŜI·γλyƎŦdzf Ỏ2yãdzfΰI·ΰλ2γ΄ΰ2 ΰŊλōŜă ΰ2 λŘŜyΰλŦè I·yŘ I·ŘŘŊŜăăŜă Ỏ2yỐŜŊyãφ

2.3 Maximizing the Value of Energy Efficiency

9yŜ₪∃è ŜŦŦʌÕʌŜyÕèΣ 2ŦúŜy′₪ŜŦŜ₪₪ŜŘ ű2 I·ă úKŜ ά₮Λ₪ăű ŦdzŜfΣέ LJ₪2ØʌŘŜă ōŜyŜŦʌúă Ŧ2₪ úKŜ ŜfŜŎúΛ₪ʌÕʌúê ăèăúŜY′Σ ʌyÕfdzŘʌyƎ I·Ø2ʌŘŜŘ Ô2ăűă Ŧ2₪ ŜyŜ₪∃èΣ I·ă ØŜff I·ă ƎŜyŜ₪I·úʌ2yΣ úNJI·yãY′ʌăăʌ2yΣ I·yŘ ŘʌăúΛ₪ʌōdzúʌ2y′ ÔI·LJI·ÔʌúèT fŜää Ø2fI·úʌfŜ ŜfŜŎúΛ₪ʌÕʌúê Y′I·₪⌈Sű LJ₪ʌÕŜăT ₪ŜŘdzÕŜŘ ăŜ₪ØʌÕŜ ŘʌăÕ2yŷŜŎúʌ2yã ŘdzŜ ű2 I·₪₪ŜI·₪I·∃Ŝă 2y′ ōʌff LJI·èY′Ŝyúă T I·yŘ ʌY′LJ₪2ØŜŘ ăèăúŜY′ ₪Ŝfʌ I·ōʌfʌúè óCʌ∃dz₪Ŝ нπфú℗ ² KʌfŜ ŜyŜ₪∃è ŜŦŦʌÕʌŜyÕè ₪ŜŘdzÕŜă ŜfŜŎúΛ₪ʌÕʌúèΣ yI·údz₪I·f ∃I·ăΣ I·yŘ 2úKŜ₪ K2Y′ŜπKŜI·úʌyƎ ŦdzŜf Ô2yãdzY′LJúʌ2yΣ ʌú ŜIjdzI·ffè ădzLJLJ2₪úă I· K2ăű 2Ŧ y′2yπŜyŜ₪∃è ōŜyŜŦʌúă Ŧ2₪ ʌyŘʌØʌŘdzI·f LJI·₪úʌÕʌLJI·yúă I·yŘ ă2ÕʌŜúè I·ă I· ØK2fŜ℗ᴍᴨʏΣ ᴍπφ C2₪ LJI·₪úʌÕʌLJI·yűăΣ úKŜăŜ ʌyÕfdzŘŜ ădzÕK ōŜyŜŦʌúă I·ă ₪ŜŘdzÔŜŘ ŜyŜ₪∃è ōʌffă I·yŘ Y′2₪Ŝ ŘʌăLJ2ăI·ōfŜ ʌyÕ2Y′ŜΣ ʌyÕ₪ŜI·ăŜŘ LJ₪2LJŜ₪úè Ø1·fdzŜăΣ ʌY′LJ₪2ØŜŘ Ô2Y′Ŧ2₪úΣ f2ØŜ₪ Y′I·ʌyűŜy1·yÕŜ Ô2ăúăΣ KʌƎKŜ₪ LJ₪2ŘdzÕűʌØʌúèΣ I·yŘ LJ2ăʌúʌØŜ KŜI·fűK ʌY′LJI·Ôúă℗ᴺ C2₪ ă2ÕʌŜúè I·ă I· ØK2fŜΣ y′2yπŜyŜ₪∃è ōŜyŜŦʌúă ʌyÕfdzŘŜ ʌY′LJ₪2ØŜŘ ŜyŜ₪∃è ăŜÕdz₪ʌúè I·yŘ ʌyŘŜLJŜyŘŜyÕŜT ₪ŜŘdzÔŜŘ I·ʌ₪ ŜY′ʌăăʌ2yãΣ Ø1·úŜ₪ ăI·ØʌyƎăΣ I·yŘ 2úKŜ₪ ŜyØℕ2yY′ŜyűI·f ōŜyŜŦʌúăT ₪ŜŘdzÔŜŘ Ô2ăúă ű2 2LJŜ₪I·úŜ LJdzōfʌÕ ŦI·ÔʌfʌúʌŜăT ∂2ōă ÔN₪ŜI·úŜŘ I·yŘ f2ÕI·f ŜÕ2y2Y′ʌÕ ŘŜØŜf2LJY′ŜyűT I·yŘ ō₪2I·Ř KŜI·fűK ōŜyŜŦʌúăΣ ădzÔK I·ă ₪ŜŘdzÔŜŘ I·ăűKY′I· ÔI·ăŜă Ŧ₪2Y′ ÔfŜI·yŜ₪ I·ʌ₪℗ wŜ∃dzfI·ú2₪è I·LJLJ₪2I·ÔKŜă ădzÔK I·ă ŘŜÕ2dzLJfʌyƎΣ ʌyÕŜyűʌØŜăΣ 2₪ f2ăű ₪ŜØŜyűzŜ I·Ř∂dzăúY′Ŝyűă ÔI·y′ ōŜ dzăŜŘ ű2 LJ₪2Y′2úŜ dzűʌfʌúè ʌyØŜăűY′Ŝyűă ʌy′ ŜyŜ₪∃è ŜŦŦʌÕʌŜyÕè℗ .dzʌfŘʌyƎ 2øyŜ₪ă ÔI·y′ I·fă2 dzâŜ I· ØI·₪ʌŜúè 2Ŧ Ŧʌy1·yÕʌyƎ Y′ŜÕKI·yłăY′ă ű2 ʌY′LJfŜY′Ŝyű ŜyŜ₪∃è ŜŦŦʌÕʌŜyÕè ʌY′LJ₪2ØŜY′ŜyűăΣ ʌyÕfdzŘʌyƎ ŜyŜ₪∃è ăI·ØʌyƎă LJŜ₪Ŧ2₪Y′I·yÕŜ Ô2yű₪I·Ôűă℥ LJ₪2LJŜ₪úèℼ I·ăăŜăăŜŘ ÕfŜI·y′ŜyŜ₪∃è f2I·yãΣ 2₪ ŜyŜ₪∃èℼŦ2ÕdzăŜŘ f2I·yã Ŧ₪2Y′ yI·ûʌ2yI·f fŜyŘŜ₪ă℗

Figure 2-9. Multiple Benefits of Energy Efficiency Improvements[150]



Energy efficiency improvements include energy and non-energy benefits for individual participants, the electricity system, and society as a whole.

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[150] C2₪ ʌyŦ2₪Y′I·ûʌ2y′2y′Ƙ2ø ű2 IjdzI·yűʌŦè ûKŜ Y′dzfûʌLJfŜ ōŜyŜŦʌúă 2Ŧ ŜyŜ₪∃è ŜŦŦʌÕʌŜyÕèΣ ăŜŜ 9t !Ωã *Assessing the Multiple Benefits of Clean Energy: A Resource for States* óнлммúΣ Kúûʌ LJăʏкк ø ø ø℗ŜLJI·℗∃2ØκăűI·ûŜf2ÕI·fÕfʌY′I·úŜkI·ăăŜăăʌy∃πY′dzfûʌLJfŜπōŜyŜŦʌúăπÕfŜI·yπŜyŜ₪∃è π ₪Ŝă2dz₪ÔŜπăúI·ûŜă℗

9ySNEè ŜTFλÕλŜyÕè LJ2fλÕλŜă τ ădzÕK I·ă ōdzλfŘλyE ŜyŜNEè Õ2ŘŜăΣ I·LJLJfλI·yÕŜ I·yŘ ŜIjdzλLJYˇŜyű ăűI·yŘI·NŘă I·yŘ fI·ōŜfλyEΣ I·yŘ űI·NEŜűŜŘ λyÕŜyűλØŜă τ KI·ØŜ LJfI·èŜŘ I· ăλEyλTλÕI·yű N2fŜ λˇ ătf2ǿλyE űKŜ E2ǿűK 2T ŜfŜÕűNλÕλúè Õ2yãdzYˇLJűλ2yΦª LyÕNŜYˇŜyűI·f I·yYdzI·f ŜyŜNEè ăI·ØλyEă FN2Yˇ dzűλfλúè Õdzăű2YˇŜNπFdzyŘŜŘ ŜfŜÕűNλÕ ŜTFλÕλŜyÕè LJN2EN I·Yˇă λyˇúKŜ dzűλfλúè ăŜÕű2N I·NŜ ŜÈLJŜÕűŜŘ ű2 NŜI·ÕK I·ō2dzű лΦy LJŜNÕŜyű LJŜN èŜI·N λyˇúKŜ ¦ yλűŜŘ {úI·ûŜă ōè нлнpΣ ŘNλØŜyˇ LJNλYˇI·NλfÈ ōè Õ2YˇLJfλI·yÕŜ ǿλűK ăűI·ûŜǿλŘŜ ăI·ǾλyEă 2N ălJŜyŘλyE úI·NEŜűă úèLJλÕI·ffè T2ÕdzăŜŘ 2yˇ ŜyŜNEè ŜTFλÕλŜyÕè LJN2EN I·Yˇăϕᵐᵖᵐ 9TFλÕλŜyÕè LJN2EN I·Yˇă Tdzy ŘŜŘ ōè ŜfŜÕűNλÕ dzűλfλúè Ödzăű2YˇŜNăΣ I·ă ǿSff I·ă ŜyŜNEè ŜTFλÕλŜyÕè ăűI·yŘI·NŘă T2N I·LJLJfλI·yÕŜă I·yŘ ŜIjdzλLJYˇŜyű I·yŘ YˇN2NŜ ŜTFλÕλŜyű ōdzλfŘλyE ŜyŜNEè Õ2ŘŜăΣ I·NŜ fλ]Ŝfè ű2 Õ2yűλydzŜ ű2 2TTăŜű űKŜ YˇI·ø2Nλúè 2T ŜfŜÕűNλÕ f2I·Ř EN2ǿűKΦ ! ŘØI·yÕŜă λyˇűŜÕKy2f2Eè I·yŘ űKŜ Õ2yűλydzŜŘ EN2ǿűK 2T úKŜ ōN2I·ŘŜN ŜyŜNEè ŜTFλÕλŜyÕè I·yŘ ŜyŜNEè YˇI·yI·EŜYˇŜyű λyŘdzăűNè KI·ØŜ I·fă2 LJfI·èŜŘ λYˇLJ2NűI·yű N2fŜă λyˇ I·ÕKλŜØλyE ăλEyλTλÕI·yű fŜØŜfă 2T ŜyŜNEè ăI·ǾλyEăΦ

! ōN2I·Ř NI·yEŜ 2T LJ2fλÕλŜă I·yŘ LJN2ENI·Yă ÕI·yˇ KŜfLJ úKŜ ! YˇŜNλÕI·yˇ ŜÕ2y2Yè ÕI·LJűdzNŜ ØI·fdzŜ TN2Yˇ ŜyŜNEè ŜTFλÕλŜyű űŜÕKy2f2EλŜă I·yŘ LJNI·ÕűλÕŜăΦ ! ű úKŜ CŜŘŜNI·f fŜØŜfΣ 5h9 ădzLJLJ2NűăÕ2ăűπăKI·NŜŘ w ɔ5 2T yŜø ŜyŜNEè ŜTFλÕλŜyű űŜÕKy2f2EλŜă I·yŘ LJNI·ÕűλÕŜă I·LJLJfλÕI·ōfŜ ű2 I·ff ŜyŘπdzăŜ ăŜÕű2Nă λyÕfdzŘλyE fλEKűλyET NŜTNλEŜNI·ûλ2yΣ I·λN Õ2yŘλűλ2yλyEΣ I·yŘ KŜI·ű LJdzYˇLJ ûŜÕKy2f2EλŜăT ySø ōdzλfŘλyE ŘŜăλEyˇ I·yŘ Õ2yãúNdzÕűλ2yˇ ű22fă I·yŘ YˇI·ûŜNλI·făT ăŜya2N I·yŘ Õ2yűN2făT λyŘdzăúNλI·f LJN2ÕŜăăŜă I·yŘ YˇI·ûŜNλI·făT 9±ăT ŘλăúNλōdzűŜŘ ŜfŜÕűNλÕλúè EŜyŜNI·ûλ2yˇI·yŘ ăű2NI·EŜ ûŜÕKy2f2EλŜăT I·yŘ 2űKŜNă¤ ¢ŜÕKy2f2Eè ŘŜØŜf2LJYˇŜyű ŜTF2NűăI·NŜ dzădzI·ffè I·ÕÕ2YˇLJI·yλŜŘ 2N F2ff2ǿŜŘ ōè ûŜÕKy2f2Eè ŘŜY2yãúNI·ûλ2yã I·yŘ ûKŜ ŘŜØŜf2LJYˇŜyű 2T ûŜăű YˇŜűK2Řă ű2 TI·ÒλfλúI·ûŜ YˇI·N]Ŝű I·ÕÕŜLJúI·yÕŜ¤ [I·ōŜfλyE I·yŘ ûŜÕKyλÕI·f I·ăăλăűI·yÕŜ óTN2N ŜEI·YˇLJfŜΣ úKN2dzEK 9t !Ωă I·yŘ 5h9Ωă 9b9wD¸ {¢!w I·yŘ 5h9Ωă .ŜűűŜN .dzλfŘλyEă LJN2ENI·YˇăúΣ LJN2ØλŘŜ úKŜ λyF2NYˇI·ûλ2y ySÕŜăăI·NE T2N Õ2yãdzYˇŜNă ű2 λŘŜyűλTè 2LJLJ2NűdzyűλŜă T2N NŜŘdzÕλyE úKŜ Õ2ăúă 2T ŜfŜÕűNλÕλúè úKN2dzEK λyØŜăűYˇŜyűă λyˇ ySø Y2NŜ ŜyŜNEè ŜTFλÕλŜyű LJN2ŘdzÕűăΣ 2N λYˇLJN2ØŜYˇŜyűă ű2 úKŜ LJŜNF2NYˇI·yÕŜ 2T ŜĚλăűλyE ōdzλfŘλyEă I·yŘ LJN2ÕŜăăŜă DNŜŜy ōdzλfŘλyE ÕŜNűλFλÕI·ûλ2y LJN2EN I·Yˇă LJN2Y2ûŜ ŜyŜNEè ŜTFλÕλŜyű ōdzλfŘλyEă LyÕŜyűλØŜăΣ FλyI·yÕλyEΣ I·yŘ úI·NEŜűŜŘ LJN2ÕdzNŜYˇŜyű LJN2EN I·Yˇă λYˇLJfŜYˇŜyűŜŘ ōè E2ØŜNyYˇŜyűă I·yŘ dzűλfλúλŜă KŜfLJ ŜyI·ōfŜ 2N Y2ûλØI·ûŜ λyØŜăűYˇŜyűă λyˇ KλEKŜNπŜTFλÕλŜyÕè LJN2ŘdzÕűă I·yŘ I·ÕÕŜfŜNI·ûŜ ûKŜ YˇI·N]ŜűΣ LJŜyŜűNI·ûλ2y 2T ySøΣ Y2NŜ ŜyŜNEè ŜTFλÕλŜyű I·yŘ ÕfŜI·yˇ ŜyŜNEè ûŜÕKy2f2EλŜăΦ CλyI·ffèΣ ŜyŜNEè ŜTFλÕλŜyÕè ōdzλfŘλyE Õ2ŘŜă I·yŘ ăűI·yŘI·NŘă T2N ŜIjdzλLJYˇŜyű I·yŘ I·LJLJfλI·yÕŜă ŜyãdzNŜ Õ2yãλăűŜyű YˇI·N]Ŝű I·Ř2LJűλ2y 2T Õ2ăúπŜTFŜÕűλØŜ ŜTFλÕλŜyÕè ûŜÕKy2f2EλŜăΦ ¢KŜ LJNλYˇI·Nè 2ø2ŜÕűλØŜ 2T ûKŜăŜ ŜTF2NűăλăΦ ûŜ2 ŜyI·ōfŜ Õ2yãdzYˇŜNă ûŜ2 2ōűI·λyˇúKŜ ăI·YˇŜ 2N λYˇLJN2ØŜŘ ŜyŘπdzăŜ ăŜNØλÕŜă I·ű f2ǿŜN ű2űI·f Õ2ăúΣ ǿKλfŜ I·fă2 èλŜfŘλyE ŜyØλN2yYˇŜyűI·f I·yŘ ŜÕ2y2YλÕ ōŜyŜTλúăΦ ¢2ŘI·èΣ ădzÕK LJN2ENI·Yă I·NŜ ŜTFŜÕűNØŜfè ăűλYdzfI·ûλyE ŜTFλÕλŜyÕè EI·λyã λyˇI·ff yŜø ōdzλfŘλyEă I·yŘ ØŜKλÕfŜăΣ I·yŘ YˇŜăű I·LJLJfλI·yÕŜă I·yŘ ŜIjdzλLJYˇŜyűΦ

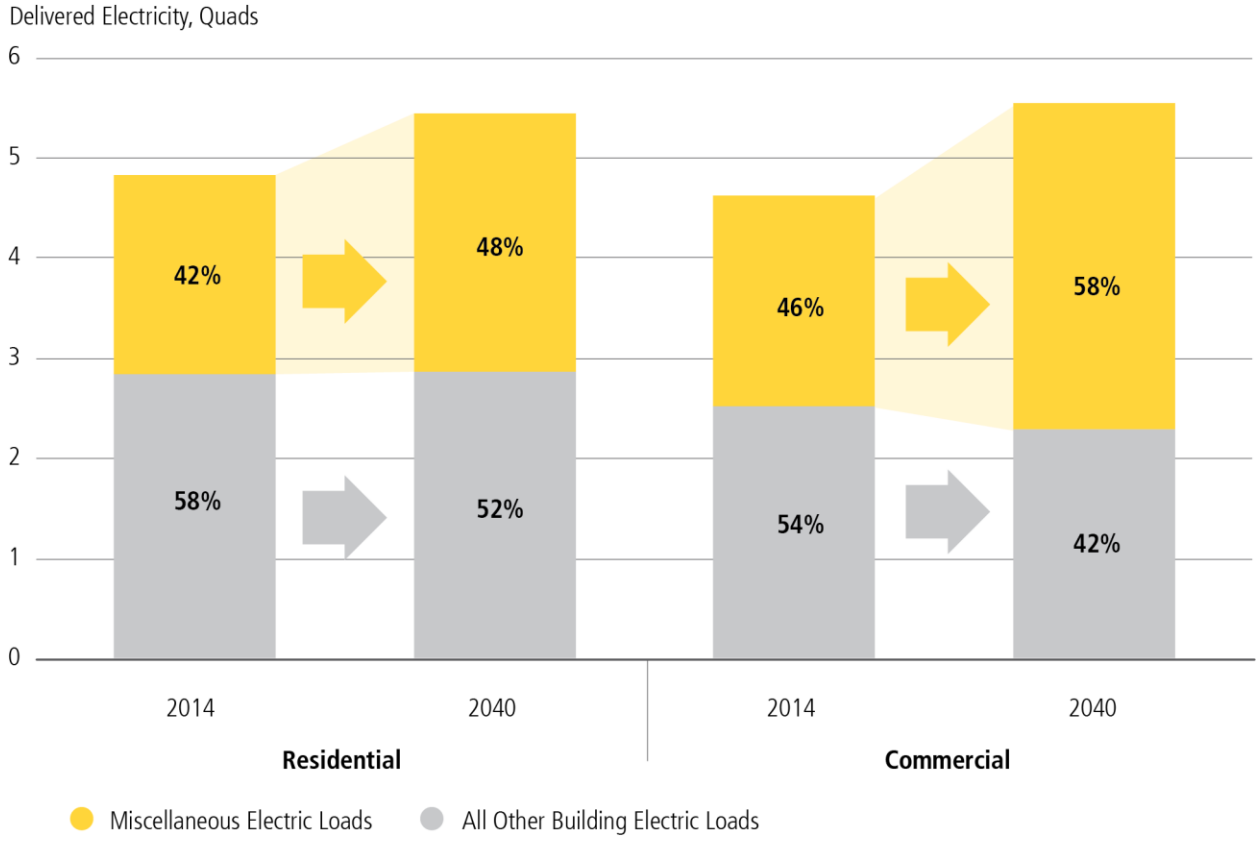
CdzNűKŜNYˇ2NŜΣ ădzōăűI·yűλI·f ŜfŜÕűNλÕ ŜTFλÕλŜyÕè EI·λyã I·NŜ LJ2ăăλōfŜ λyˇ I·ff ŜyŘπdzăŜ ăŜÕű2Nă¤ ¢KŜ bI·ûλ2yI·f !ÕI·ŘŜYˇλŜă T2dzyŘ úKI·ű Tdzff ŘŜLJf2èYˇŜyű 2T Õ2ăúπŜTFŜÕűλØŜ ŜyŜNEè ŜTFλÕλŜyű ûŜÕKy2f2EλŜă λyˇ ōdzλfŘλyEă Õ2dzfŘ ŜfλYˇλyI·ûŜ úKŜ ySŜŘ ű2 ōdzλfŘ ySø ŜfŜÕűNλÕ EŜyŜNI·ûλyE ÕI·LJI·Õλúè λyˇ úKŜ ¦ yλűŜŘ {úI·ûŜă úKN2dzEK нлолᵠᵐᵖᴴ LT ōdzλfŘλyEă ǿŜNŜ ű2 I·Ř2LJű ű2ŘI·èΩă ōŜăű I·ǾI·λfI·ōfŜ ûŜÕKy2f2EλŜăΣ ŜyŜNEè dzăŜ λyűŜyŜăúè óűK2dzăI·yŘ .NλűλăK úKŜNYˇI·f dzyλűă LJŜN ălj dzI·NŜ F22ûú Õ2dzfŘ ŘŜÕNŜI·ăŜ ōè I·ű fŜI·ăű pл LJŜNÕŜyű T2N ălyEfŜπFI·Yˇλfè K2YˇŜă I·yŘ ōè пн LJŜNÕŜyű T2N Õ2YˇYˇŜNÕλI·f ōdzλfŘλyEăᵐᵖᵒ bŜø ŜfŜÕűNλÕλúè ăI·ǾλyEă I·yŘ 5w 2LJLJ2NűdzyűλŜă I·NŜ ōŜλyE dzyf2Õ]ŜŘ ōè úKŜ ŘλEλűλÎI·ûλ2yˇ2T ŜyŘπdzăŜ ŘŜØλÕŜă I·yŘ úKŜ ōdzλfŘπ2dzű 2T fI·èŜNă 2T Õ2YˇYˇdzyλÕI·ûλ2yã λyFNI·ăűNdzÕűdzNŜ û2 I·ff2ǿ úKŜYˇ û2 ō2úK Õ2YˇYˇdzyλÕI·ûŜ úKŜNU ăűI·ûŜ I·yŘ ōŜ Õ2yúN2ffŜŘΣ FdzNűKŜN ŜyI·ōfλyE ENλŘπăèăűŜYˇπǿλŘŜ ŜTFλÕλŜyÕλŜă I·yŘ FdzyÕűλ2yI·fλúλŜăΦ 5ŜØŜf2LJλyE ŜTFŜÕűλØŜ ûŜÕKy2f2EλŜă I·yŘ ăűNI·ûŜEλŜă T2N NŜI·fλÎλyE úKŜăŜ Ø I·fdzŜπÕNŜI·ûλ2yˇ 2LJLJ2NűdzyλűλŜă ǿλff NŜIjdzλNŜ λYˇLJN2ØŜŘ ŘI·úI· 2yˇúKŜ I·ÕűdzI·f LJŜNF2NYˇI·yÕŜ 2T Y2NŜ ŜyŜNEè ŜTFλÕλŜyű I·LJLJfλI·yÕŜăΣ ŜIjdzλLJYˇŜyűΣ I·yŘ ōdzλfŘλyEăT ØI·NλI·ûλ2yˇ I·Y2yE ŘλFFŜNNŜyű ÕI·ûŜ2NλŜă 2T Õ2yãdzYˇŜNăT I·yŘ úKŜ Õ2yăűŜff I·ûλ2yˇ 2T LJN2ŘdzÕű I·yŘ ăŜNØλÕŜ LJN2ØλŘŜNă úKI·ű ăŜNØŜ I·yŘ λyFfdzŜyÕŜ úKŜ ŘŜÕλăλ2yã 2T Õ2yãdzYˇŜNăΦ

ª C2N I·ŘŘλûλ2yI·f λyF2NYˇI·ûλ2yˇ2yˇŜyŜNEè ŜTFλÕλŜyÕè û2LJλÕăΣ ădzÕK I·ă ŜyŜNEè ŜTFλÕλŜyÕè Õ2ŘŜă I·yŘ ăűI·yŘI·NŘă ŜyŜNEè ăI·ǾλyEă LJŜNF2NYˇI·yÕŜ Õ2yúNI·Õűă I·yŘ fλTŜπÕèÕfŜ Õ2ăúλyE λyˇúKŜ FŜŘŜNI·f ăŜÕűΣ2NΣ YˇăÕŜffI·yŜ2dză ŜfŜÕűNλÕ f2I·ŘăΣ ăűI·ûŜ I·yŘ f2ÕI·f LJ2fλÕλŜă ɔ LJN2ENI·YˇăΣ ăŜŜ /KI·LJűŜN LLL ó*Building a Clean Electricity Future*úΦ

2.3.1 Miscellaneous Electric Loads Will Be Growing Share of Electricity Demand in Future

¢ĶŜ ăĶǀ·ǹŜă ƻŦ ŜƴŘπdzăŜ ŜƭŜŎǘǹƛŎƛǘè ŘŜƳǀ·ƴŘ ƛƴǹŜăƛŘŜƴǘƛǀ·ƭ ǀ·ƴŘ ŎƻƳƳŜǹŎƛǀ·ƭ ōdzƛƭŘƛƴƎă ƛƴнлмп ǀ·ǹŜ ăŜŜƴƛƴƆƛƎdzǹŜ нπмлφ a ƻăǘ ōdzƛƭŘƛƴƎπăŜŎǘƻǹ ŜƴŘ dzăŜă ǀ·ǹŜ ŜȀLJŜŎǘŜŘ ǘƻ ǹŜLJǹŜăŜƴǘ ŘŜŎƭƛƴƛƴƎ ăĶǀ·ǹŜă ƻŦ ŦdzǘdzǹŜ ŜƭŜŎǘǹƛŎƛǘè ŘŜƳǀ·ƴŘΣ ǿƛǘĶ ƻƴƭè a 9[ăΣ[ǘ] ǹŜăƛŘŜƴǘƛǀ·ƭ ǀ·ƛǹπŎƻƴŘƛǘƛƻƴƛƴƎΣ ǀ·ƴŘ ŎƻƳƳŜǹŎƛǀ·ƭ ƻŦŦƛŎŜ ŜǀjdzƛLJƳŜƴǘ ŜȀLJŜŎǘŜŘ ǘƻ ƛƴŎǹŜǀ·ăŜ ǘĶŜƛǹ ăĶǀ·ǹŜăφ ¢ĶŜ ŜƴŜǹƎȅ ŎƻƴãdzƳLJǘƛƻƴƻŦ a 9[ă ƛă LJǹƻƧŜŎǘŜŘ ǘƻ ƛƴŎǹŜǀ·ăŜ ăƛƎƴƛŦƛŎǀ·ƴǘƭè ŦǹƻƳ нлмп ǘƻ нлплΣ ŦǹƻƳ пн ǘƻ пу LJŜǹŎŜƴǘ ƛƴ ǘĶŜ ǹŜăƛŘŜƴǘƛǀ·ƭ ăŜŎǘƻǹ ǀ·ƴŘ ŦǹƻƳ пс ǘƻ ру LJŜǹŎŜƴǘ ƛƴ ǘĶŜ ŎƻƳƳŜǹŎƛǀ·ƭ ăŜŎǘƻǹφ[мрп] ¢ĶŜ ƛƴŎǹŜǀ·ăŜŘ ăĶǀ·ǹŜ ƻŦ ŜƴŜǹƎȅ dzăŜŘ ōè a 9[ă Ŧƻƭƭƻǿă ǘĶŜ ŎƻƴǘƛƴdzŜŘ ŜƳŜǹƎŜƴŎŜ ƻŦ ƴŜǿ ŜƭŜŎǘǹƛŎƛǘè ăŜǹǾƛŎŜă ǀ·ƴŘ ǘĶŜ ƭŜăă ŜŦŦŜŎǘƛǾŜ ŎƻǾŜǹǀ·ƎŜ ƻŦ Ƴǀ·Ƨƻǹ ƭƻǀ·Řă ōè ŜȀƛăǘƛƴƎ LJƻƭƛŎƛŜă ŘŜăƛƎƴŜŘ ǘƻ ǀ·ŎŎŜƭŜǹǀ·ǘŜ ŜŦŦƛŎƛŜƴŎȅ Ǝǀ·ƛƴãφ ! ŘŘƛǘƛƻƴƭ·ƭ ǀ·Ŏǘƛƻƴƛă ƴŜŜŘŜŘ ǘƻ ƛƴLJǹƻǾŜ Řǀ·ǘǀ· ŎƻƭƭŜŎǘƛƻƴ ǀ·ƴŘ ǘƻ ŦdzǹǘĶŜǹ ŜȀLJǀ·ƴŘ ǘŜŎĶƴƻƭƻƎȅ ŘŜǾŜƭƻLJƳŜƴǘΣ LJǹƻŘdzŎǘ ǘŜăǘƛƴƎΣ ƭǀ·ōŜƭƛƴƎΣ ǀ·ƴŘ ƳƛƴƛƳdzƳ ăǘǀ·ƴŘǀ·ǹŘă LJǹƻƎǹǀ·Ƴă ǘƻ ōŜǘǘŜǹ ŎƻǾŜǹ a 9[ăφ

Figure 2-10. Share of Miscellaneous Electric Loads Compared to All Other Building Electric Loads, Residential and Commercial Sectors, 2014 and 2040[155]



Compared to other loads, MELs are projected to increase significantly in their share of total delivered electricity in residential and commercial buildings. MELs represent a broad range of electric loads outside of a buildingôs core end uses of heating, ventilation, air conditioning, lighting, water heating, and refrigeration. Projections are based upon the business-as-usual assumptions in the EPSA Base Case.

[ǘ] Ɔƻǹǀ· ƳƻǹŜ ŘŜǘǀ·ƛƭŜŘ ŘƛăŎdzăăƛƻƴƻŦ a 9[ăΣ ăŜŜƴ ĶǘǘLJƴĶĶŜƴŜǹƎȅφƎƻǾĶŜŜǹŜĶōdzƛƭŘƛƴƎăĶŘƻǿƴƭƻǀ·ŘăĶōǘƻπƛƴǾŜăǘƛƎǀ·ǘŜăπƳƛăŎŜƭƭǀ·ƴŜƻdzăπŜƭŜŎǘǹƛŎπƭƻǀ·Řăφ

2.3.2 Energy Efficiency Codes and Standards Help Reduce Consumption and Save Money

9yŜ№∃è ŜŦŦλŎλŜyŎè LJ2fλŎλŜă τ ădzŎK I·ă ōdzλfŘλy∃ ŜyŜ№∃è Ŏ2ŘŜă Σ ŜIjdzλLJY Ŝyΰ ŜŦŦλŎλŜyŎè ăΰI·yŘI·№Řă Σ YI·yŘI·ΰ2№è I·ă ø Ŝff I·ă Ø2fdzyΰI·№è fI·ōŜfλy∃ fλ ĵŜ 9b9wD¸ {¢!wΣ I·yŘ ΰI·№∃ŜΰŜŘ λyŎŜyΰλØŜă τ KI·ØŜ LJfI·êŜŘ I· ăλ∃yλŦλŎI·yΰ №2fŜ λY ăf2ø λy∃ ΰKŜ ∃№2øΰK 2Ŧ ŜfŜŎΰ№λŎλΰè Ŏ2yãdzY LJΰλ2yΦ . ŜŎI·dzăŜ ōdzλfŘλy∃ă 2ŦΰŜY KI·ØŜ fλŦŜΰλY Ŝă 2Ŧ τpς мл л èŜI·№ăΣ LJ2fλŎλŜă I·yŘ YI·№ĵŜΰ Ŧ2№ŎŜă ΰKI·ΰ λY LJ№2ØŜ ŜŦŦλŎλŜyŎè λY ōI·ăŜ ōdzλfŘλy∃ ăèăΰŜY ă ŎI·Y KI·ØŜ fI·ăΰλy∃ ōŜyŜŦλΰă Φ ! ŘØI·yŎŜă λY ΰŜŎKy2f2∃è I·yŘ ΰKŜ Ŏ2yΰλyΘzŜŘ ∃№2øΰK 2Ŧ ΰKŜ ō№2I·ŘŜ№ ŜyŜ№∃èπY I·y1·∃ŜY Ŝyΰ λyŘdzăΰ№è KI·ØŜ I·fã2 LJfI·èŜŘ №2fŜă λY ŎŜ№ŜI·ΰλy∃ ăλ∃yλŦλŎI·yΰ ØI·fdzŜ ΰK№2dz∃K ŜyŜ№∃è ăI·Øλy∃ăΦ

. dzλfŘλy∃ ŜyŜ№∃è Ŏ2ŘŜăΣ ŜyŜ№∃è Ŏ2yãŜ№ØI·ΰλ2Y ăΰI·yŘI·№ŘăΣ I·yŘ ΰKŜ Ø2fdzyΰI·№è 9b9wD¸ {¢!w LJ№2∃№I·Y Ŧ2№ I·LJLJfλI·yŎŜă I·yŘ ŜIjdzλLJY Ŝyΰ ăŜΰ I· Y λyλY dzY fŜØŜf 2Ŧ ŜyŜ№∃è ŜŦŦλŎλŜyŎè LJŜ№Ŧ2№Y I·yŎŜ I·ă ø Ŝff I·ă fŜI·ŘŜ№ăKλLJ ŜŦŦλŎλŜyŎè fŜØŜfãΦ /2ŘŜă I·yŘ ăΰI·yŘI·№Řă I·ŘŘ№ŜăăY I·№ĵŜΰ ōI·№№λŜ№ă №ŜfI·ΰŜŘ ΰ2 λyŦ2№Y I·ΰλ2Y I·yŘ Ύ№I·yãLJI·№ŜyŎèΣ Y I·ΰŜ№λI·fλΰèΣ I·yŘ ăLJfλΰ λyŎŜyΰλØŜăΦ ¢KŜăŜ LJ2fλŎλŜă KI·ØŜ ΰKŜ ∃2I·f 2Ŧ Ŏ2ăΰπ ŜŦŦŜŎΰλØŜfè №ŜŘdzŎλy∃ ŜyŜ№∃è Ŏ2yãdzY LJΰλ2Y ΰ2 LJ№2ØλŘŜ ØI·fdzŜ ΰ2 Ŏdzăΰ2Y Ŝ№ă I·yŘ YŜŜΰ f2y∃πΰŜ№Y ŜyŜ№∃è ∃2I·fãΦ ! ă ōdzλfŘλy∃ ŜyŜ№∃è Ŏ2ŘŜă Ŏ2yΰλydzŜ ΰ2 I·ŘØI·yŎŜΣ ăΰI·ΰŜă I·yŘ ŘŜØŜf2LJŜ№ă 2Ŧ Y2ŘŜf Ŏ2ŘŜă KI·ØŜ ΰø2 2LJLJ2№ΰdzyΰλŜă ΰ2 λyŎ№ŜI·ăŜ ΰKŜ№ λY LJI·ŎΰΦ ¢KŜ Ŧ№ăΰ λă ΰKŜ f2y∃πΰΰI·yŘλy∃ λyΰŜ№I·Ŏΰλ2Y ōŜΰøŜŜy ŜyŜ№∃è Ŏ2ŘŜă I·yŘ №I·ΰŜLJI·èŜ№πfdzyŘŜŘ ŜŦŦλŎλŜyŎè LJ№2∃№I·Y ăΦ ² KλfŜ ΰKŜè 2ŦΰŜy ăKI·№Ŝ ăλYλfI·№ LJ2fλŎè ∃2I·fãΣ λyŎ№ŜI·ăλy∃fè ăΰ№λy∃Ŝyΰ ŜyŜ№∃è Ŏ2ŘŜă Ŏ I·y Ŏ№ŜI·ΰŜ ŎKI·ffŜy∃Ŝă Ŧ2№ LJ№2∃№I·Y ă ΰKI·ΰ ŎI·y2yfè ŎtfI·λY ŜyŜ№∃è ăI·Øλy∃ă ōŜè2yŘ ΰKŜ ŜyŜ№∃è ăI·ØŜŘ ōè Ŏ2ŘŜăΦ a I·ÈλYλÎλy∃ ØI·fdzŜ ΰ2 Ŏ2yãdzY Ŝ№ă I·yŘ 2ΰKŜ№ LJI·№ΰλŜă №ŜIjdz№Ŝă ăΰI·ΰŜ LJ2fλŎèY I·ĵŜ№ă ΰ2 I·fλ∃y λyŎŜyΰλØŜă Ŧ2№ I·ff LJI·№ΰλŜăΣ ΰ2 Ŝyãdz№Ŝ ΰKI·ΰ Y2ŘŜ№y ŜyŜ№∃è Ŏ2ŘŜă I·yŘ Ø2fdzyΰI·№è LJ№2∃№I·Y ă Ŏ2Y LJfŜY Ŝyΰ ŜI·ŎK 2ΰKŜ№ λy I·ŎKλŜØλy∃ I·ff Ŏ2ăΰπ ŜŦŦŜŎΰλØŜ ŜyŜ№∃è ŜŦŦλŎλŜyŎèΦ

¢KŜ ăŜŎ2yŘ 2LJLJ2№ΰdzyλΰèfλŜă λy ΰKŜ λyŎ№ŜI·ăλy∃ Ŏ2yŷŜŎΰλØλΰè I·yŘ Ŏ2yΰ№2ffI·ōλfλΰè 2Ŧ Ŏ2yãdzY Ŝ№ ŘŜØλŎŜăΦ 9ÈLJI·yŘλy∃ Ŏ2yŷŜŎΰλØλΰè YI·è λyŎ№ŜI·ăŜ ΰKŜ ŜyŜ№∃è dzăŜŘ ōè Ŏ2yãdzY Ŝ№ ŘŜØλŎŜăΣ ø KλfŜ I·fã2 2ŦŦŜ№λy∃ 2LJLJ2№ΰdzyλΰλŜă ΰ2 LJ№2ØλŘŜ ØI·fdzŜ ΰK№2dz∃K λY LJ№2ØŜŘ ŜyŜ№∃è YI·yI·∃ŜY Ŝyΰ I·yŘ λyŎ№ŜI·ăŜŘ ŦfŜÈλōλfλΰè 2Ŧ ŜfŜŎΰ№λŎλΰè ŘŜY I·yŘΦ 9yŎ2dz№I·∃λy∃ ΰKŜ dzăŜ 2Ŧ Ŏ2yŷŜŎΰŜŘ Řλ∃λΰI·f ŘŜØλŎŜă λy ø I·ëă ΰKI·ΰ ăI·ØŜ ŜyŜ№∃è I·yŘ LJ№2ØλŘŜ ŦfŜÈλōλfλΰè ΰ2 ΰKŜ ∃№λŘ KI·ă y2ΰ KλăΰΣ№λŎI·ffè ōŜŜy I· Ŏ2yãλŘŜ№I·ΰλ2Y λy ōdzλfŘλy∃ ŜyŜ№∃è Ŏ2ŘŜă /2ŘŜă ΰKI·ΰ ŜyŎ2dz№I·∃Ŝ ŜŦŦŜŎΰλØŜ dzăŜ 2Ŧ ōdzλfŘλy∃ I·yŘ ŘŜØλŎŜ Ŏ2yŷŜŎΰλØλΰè I·yŘ Ŏ2yΰ№2fă ŎI·y ŘλŜŎΰfè LJ№2ØλŘŜ ØI·fdzŜ ΰ2 ōdzλfŘλy∃ 2ŎŎdzLJI·yΰăΣ I·ă ø Ŝff I·ă λyŎ№ŜI·ăŜ ΰKŜ ØI·fdzŜ 2Ŧ ΰKŜ ōdzλfŘλy∃ I·ă I· ∃№λŘ I·ăăŜΰΦ

2.3.3 State and Local Energy Policies and Programs Deliver Efficiency

wŜŎŜyΰ №ŜăŜI·№ŎK λyŘλŎI·ΰŜă ΰKI·ΰ λyŜŦŦλŎλŜyΰ ōdzλfŘλy∃ă ΰKI·ΰ dzăŜ Y2№Ŝ ŜyŜ№∃è ΰKI·y ăλYλfI·№ ōdzλfŘλy∃ă YI·è èλŜfŘ I· №ŜŘdzŎŜŘ Y2№ΰ∃I·∃Ŝ ØI·fdzŜ ŘdzŜ ΰ2 ŜyŜ№∃è LJ№λŎŜ №ăĵΦmpc LYLJ№2Øλy∃ ŜyŜ№∃è ŜŦŦλŎλŜyŎè ŎI·y KŜfLJ LJ№2ΰŜŎΰ I·∃I·λyΰΰ ΰKλă LJ2ΰŜyΰλI·f f2ää 2Ŧ ŦλyI·yŎλI·f ØI·fdzŜΦ a I·yê ¦φ{φ ∂dz№ăŘλŎΰλ2yã ΰKI·ΰ №ŜIjdz№Ŝ №ŜLJ2№ΰλy∃ 2Ŧ ōdzλfŘλy∃ăΩ ŜyŜ№∃è LJŜ№Ŧ2№Y I·yŎŜ KI·ØŜ λYLJfŜY ŜyΰŜŘ ŜyŜ№∃è ōŜyŎKY I·№ĵλy∃ I·yŘ ΰ№I·yãLJI·№ŜyŎè LJ2fλŎλŜă Ŧ2№ ōdzλfŘλy∃ăΦ ¢KλăΩŜLJ2№ΰλy∃ λyŎ№ŜI·ăŜă ōdzλfŘλy∃ 2øy Ŝ№ΩΩ ĵy2øŜŘ∃Ŝ 2Ŧ LJ№2LJŜ№ΰλŜăΩ ŜyŜ№∃è dzăI·∃ŜT LJ№2ØλŘŜă ∃№ŜI·ΰŜ№ ΰ№I·yãLJI·№ŜyŎè Ŧ2№ ŎdzN№Ŝyΰ I·yŘ LJ№2ăLJŜŎΰλØŜ ΰŜyI·yΰăT Kλ∃KfλKΰă Ŏ2ăΰπŜŦŦŜŎΰλØŜΣ ŜyŜ№∃èπăI·Øλy∃ 2LJLJ2№ΰdzyΰλŜăT I·yŘ LJ№2ØλŘŜă YI·№ĵŜΰ ŘI·ΰI· ΰ2 ŜyKI·yŎŜ ŘŜLJf2èY Ŝyΰΰ 2Ŧ ŜŦŦλŎλŜyŎè ŜŦŦ2№Ωă 2y ōŜKI·fŦ 2Ŧ №ŜfŜØI·yΰ I·∃ŜyŎλŜăΦmpT . dzλfŘλy∃ ōŜyŎKY I·№ĵλy∃ I·yŘ I·dzŘλΰλy∃ ŘI·ΰI· LJ№2ØλŘŜ I· ŘI·ΰI·ōI·ăŜ 2Ŧ λyŦ2№Y I·ΰλ2yΰKI·ΰ ădzLJLJ2№ΩΰăΩ ōŜΰΰŜ№ ØI·fdzI·ΰλ2Y 2Ŧ ŜyŜ№∃è ŜŦŦλŎλŜyŎè Y ŜI·ădz№Ŝă λy Ŏ2YY ŜN№ŎλI·f ōdzλfŘλy∃ă Ŧ2№ Ŧdzΰdz№Ŝ 2øyŜ№ăă I·yŘ λyØŜăΰ2№ăΦ wŜ∃dzfI·ΰλ2yã ΰKI·ΰ №ŜIjdz№Ŝ ōdzλfŘλy∃ ŜyŜ№∃è ōŜyŎKY I·№ĵλy∃Σ LJŜ№λ2ŘλŎ ŜyŜ№∃è I·dzŘλΰăΣ Ŏ2№№ŜŎΰλØŜ I·Ŏΰλ2yã ôŜΦ∃ΦΣ №Sΰ№2Ŏ2YY λăăλ2yλy∃óΣ 2№ LJ2λyΰπ2Ŧπă I·fŜ ŘλăŎf2ădz№Ŝ 2№ dzLJ∃№I·ŘŜă ó2№ ō2ΰKú Ŧ2№ Ŏ2YY Ŝ№ŎλI·f ōdzλfŘλy∃ă KI·ØŜ ōŜŜy I·Ř2LJΰŜŘ ōè y ăΰI·ΰŜă I·yŘ мп ŎλΰλŜă óCλ∃dz№Ŝ нπммúΦ

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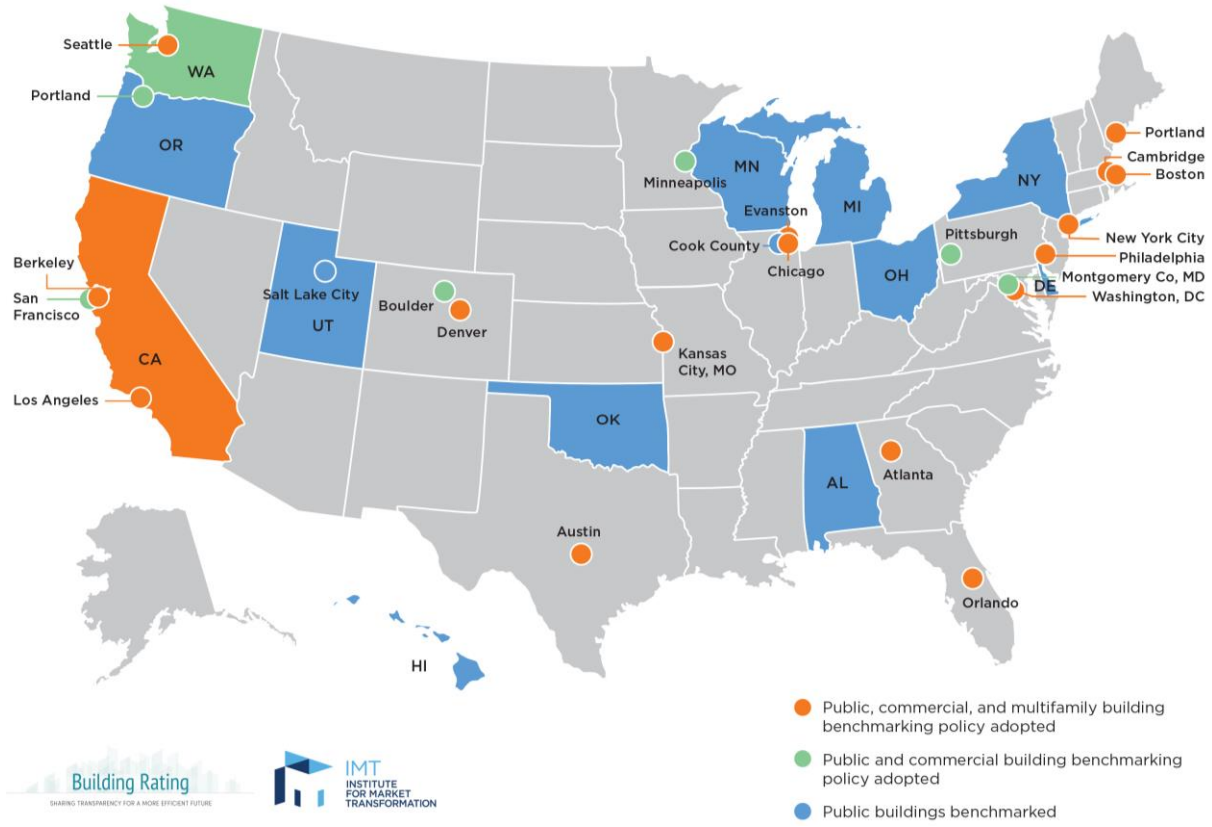
dz /KI·LJΰŜ№ LLL ó*Building a Clean Electricity Future*ú ŘλăŎdzăăŜă ΰKŜ LJ2ΰŜyΰλI·f Ŧ2№ ōdzλfŘλy∃ ŜyŜ№∃è Ŏ2ŘŜă I·yŘ I·LJLJfλI·yŎŜ ăΰI·yŘI·№ŘăΦ

Figure 2-11. U.S. Building Benchmarking and Disclosure Policies[158]

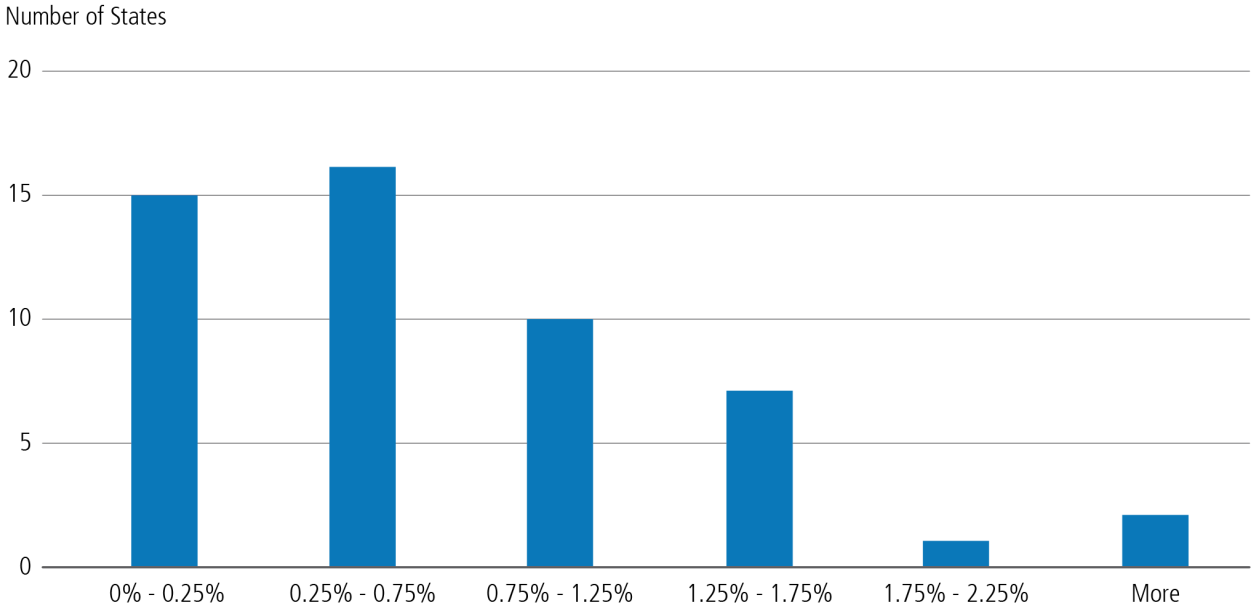


A growing number of states and communities are adopting building information transparency policies. These include building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), and point-of-sale disclosure or upgrades (or both).

bŜI·NfêI· ÍúKλNŘ 2ŧ ăúI·úŜă I·N$ ăI·ØλyƎ I·ú fŜI·ăú м LJŜNŎŜyű 2ŧ ŜfŜŎúNλŎλúê Ŏ2yãdzYLJúλ2yˇŜI·ŎK ëŜI·N ÚKN2dzƎK LJN2ƎNI·Yă ŧdzyŘŜŘ ōè dzúλfλúê Ŏdzăú2YˇŜN㤠w2dzƎKfê I·y2ÚKŜN ÚKλNŘ 2ŧ ăúI·úŜă τ Yˇ2ăú N$fI·úλØŜfè yŜø ú2 ŜyŜN㤠ŜŧŧλŎλŜyŎè τ I·N$ ăI·ØλyƎ ōŜűøŜŜyˇ лφнр LJŜNŎŜyű I·yŘ лφтр LJŜNŎŜyű óFigure 2-12úφмрφ a I·yê ăúI·úŜă I·N$ λyŎNŜI·ăλyƎ úKŜλN ŜŧŧλŎλ$yŎè úI·NƎŜûă I·ă úKŜè YˇŜŜú λyλûλI·f Ǝ2I·fă I·yŘ I·N$ 2yˇ ûNI·Ŏ] ú2 I·ŎKλŜØŜ ŜØŜyˇ KλƎKŜN ăI·ØλyƎăφ 9yŜN㤠ŜŧŧλŎλ$yŎè LJN2ƎNI·Yă ŧdzyŘŜŘ ōè dzúλfλúê Ŏdzăú2YˇŜNä ăLJŜyű Þc ōλffλ2yˇλyˇнлмоφмсл Lű λă ŠăúλYˇI·úŜŘ úKI·ú úKŜ I·ØŜNI·ƎŜ úz2úI·f Ŏ2ăú 2ŧ ăI·ØλyƎ ŜfŜŎúNλŎλúê I·Y2yƎ ¦φ{φ dzúλfλúê ŜŧŧλŎλ$yŎè LJN2ƎNI·Yă I·ŎN2ăă I·ff YˇI·N]Ŝű ăŜŎú2Nä ŧ2N úKŜ LJŜNλ2Ř нллф ú2 нлмо λă пφс ŎŜyűă LJŜN] ² K ăI·ØŜŘΣ ăLJfλú N2dzƎKfê λyˇKI·fŧ ōŜűøŜŜyˇúKŜ dzúλfλúê ó2N 2ûKŜN LJN2ƎNI·Y I·ŘYˇλyλăúNI·ú2N㤠I·yŘ LJN2ƎNI·Y LJI·NúλŎλLJI·yúăφмсмΣ мсн ¢Kλă λă YˇdzŎK f2øŜN úKI·yˇ úKŜ I·ØŜNI·ƎŜ LJNλŎŜ 2ŧ ŜfŜŎúNλŎλúê λyˇ úKŜ ¦φ{φ λyˇ нлмпΣ øKλŎK øI·ă млпп ŎŜyűă LJŜN] ² Kφмсо !y2úKŜN øI·è ú2 ØλŜø úKŜ Ŏ2ăúπŜŧŧŜŎûλØŜySăă 2ŧ ŜŧŧλŎλ$yŎè λă ú2 Ŏ2YLJI·N$ úKŜ Ŏ2ăú 2ŧ ŜyŜN㤠ŜŧŧλŎλ$yŎè I·yŘ úKŜ Ŏ2ăú 2ŧ I· yŜø LJ2øŜN LJfI·yúφ ¢KŜ I·ØŜNI·ƎŜ fŜØŜfλÎŜŘ Ŏ2ăú 2ŧ ăI·ØŜŘ ŜyŜN㤠ŧN2Y ŜyŜN㤠ŜŧŧλŎλ$yŎè LJN2ƎNI·Yă λyˇ úKŜ ¦yűŜŘ {úI·ûŜă λă ŠăúλYˇI·ûŜŘ I·ú Þпскa ² KΣ ØŜNădză úKŜ fŜØŜfλÎŜŘ Ŏ2ăú 2ŧ ŜyŜN㤠ŧ2N yl·ûdzNI·f ƎI·ă Ŏ2YˇōλySŘπŎèŎŧŜ ƎŜySN㤠I·ûλ2yΣ øλúK λúă ăŜyãλúλØλúê ú2 ŧdzŜf LJNλŎŜăΣ I·ú Þрн ú2 Þтукa ² Kφ∅ мсп

∅ ¢Kλă Ŏ2YLJI·N㤠2yˇKI·ă ă2YˇŜ fλYˇλúI·ûλ2yãφ C2N ŜÈI·YˇLJfŜΣ úKŜ Ŏ2ăú 2ŧ ăI·ØŜŘ ŜyŜN㤠dzădzI·ffê λă ŎI·fŎdzfI·ûŜŘ I·ú úKŜ YˇŜúŜN 2ŧ úKŜ ŜyŘπdzăŜ Ŏdzăú2YˇŜNΣ øKλfŜ úKŜ fŜØŜfλÎŜŘ Ŏ2ăú 2ŧ ŜyŜN㤠ădzLJLJfê λă ŎI·fŎdzfI·ûŜŘ I·ú úKŜ ōdzăŌI·N 2ŧ úKŜ LJ2øŜN LJfI·yúΣ øKλŎK úêLJŎI·ffê Ř2Ša y2ú N$fŜŎú ŜyŜN㤠f2ăú λyˇúNI·yãYˇλăăλ2yˇI·yŘ ŘλăúNλōdzúλ2yˇóλφŜφΣ fλyŜ f2ăăŜăú ōŜűøŜŜyˇúKŜ ƎŜySN㤠I·ûλ2N I·yŘ ŜyŘπdzăŜ Ŏdzăú2YˇŜNφ

Figure 2-12. Percent Electricity Savings in 2014 from Energy Efficiency Programs Funded by Utility Customers[165]



Nearly a third of states are achieving savings of at least 1 percent per year and another third of states are saving between 0.25 percent and 0.75 percent of retail sales. On average national savings reported in 2014 from utility and public benefits electricity programs were equal to 0.7 percent of sales.

a l·yê ăűl·ûŠă l·yŘ f2ŏl·fλűλŠă Kl·ØŠ LJ2fλŏλŠă λy LJfl·ŏŠ ű2 f2ØŜℕ ōl·ℕℕλŜℕă ű2 ₹λyl·yŏλyƎ ŜyŜℕƎè Ŝ₹₹λŏλŜyŏè LJℕ2ƨŜŏűăφ 9Èl·YLJfŠă 2₹ ₹λyl·yŏλyƎ λyλűλl·űλØŠă λyŏfdzŘŜ 2yπōλff ₹λyl·yŏλyƎΣ ăűl·ûŜ ℕŜØ2fØλyƎ f2l·y ₹dzyŘă ₹2ℕ ŏfŜl·y ŜyŜℕƎè LJℕ2ƨŜŏűă óλyŏfdzŘλyƎ ŜyŜℕƎè Ŝ₹₹λŏλŜyŏèúΣ 2űKŜℕ {űl·ûŜ 9yŜℕƎè h₹₹λŏŜ LJℕ2ƎℕI·YăΣᴹᶜᶜ dzűλfλűè ₹λyl·yŏλyƎ LJℕ2ƎℕI·YăΣ l·yŘ f2ŏl·f tℕ2LJŜℕúè !ääŜääŜŘ /fŜl·y 9yŜℕƎè LJℕ2ƎℕI·Yăᴹᶜᵀ ₹2ℕ ℕŜăλŘŜyűλl·f l·yŘ Ŏ2YYŜℕŏλl·f ōdzλfŘλyƎăφ ² KλfŜ l·Yl·ƨ2ℕλűè 2₹ ăűl·ûŜă Kl·ØŠ l·ú fŜl·ăű 2yŜ úèLJŜ 2₹ 99 ₹λyl·yŏλyƎ LJℕ2ƎℕI·YΣ űKŜ l·Øl·λfl·ōλfλűè 2₹ Ydzfűλ LJfŜ LJℕ2ƎℕI·Yă l·yŘ űKŜ LJŜℕŏŜyűl·ƎŜ 2₹ úKŜ ăűl·ûŜ LJ2LJdzfl·űλ2y øλűK l·ŏŏŜăă ű2 úKŜăŜ LJℕ2ƎℕI·Yă Øl·ℕè ăλƎyλ₹λŏl·yűfèφᴹᶜʸ ! ú fŜl·ăű но ăűl·ûŜă Kl·ØŠ l·y 2yπōλff ₹λyl·yŏŜ LJℕ2ƎℕI·YΣ øKλŏK λă λyűŜyŘŜŘ ű2 ŘŜŏℕŜl·ăŜ úKŜ ₹λyl·yŏλl·f KdzℕŘfŜ ₹2ℕ Yl·ʅλyƎ ŜyŜℕƎè Ŝ₹₹λŏλŜyŏè λyØŜăűYŜyűă ōè l·ff2øλyƎ úKŜ Ödzăű2YŜℕ ű2 LJl·è ₹2ℕ úKŜ dzLJƎℕI·ŘŜă úKℕ2dzƎK úKŜλℕ Y2yűKfè dzűλfλűè ōλff φᴹᶜΦ

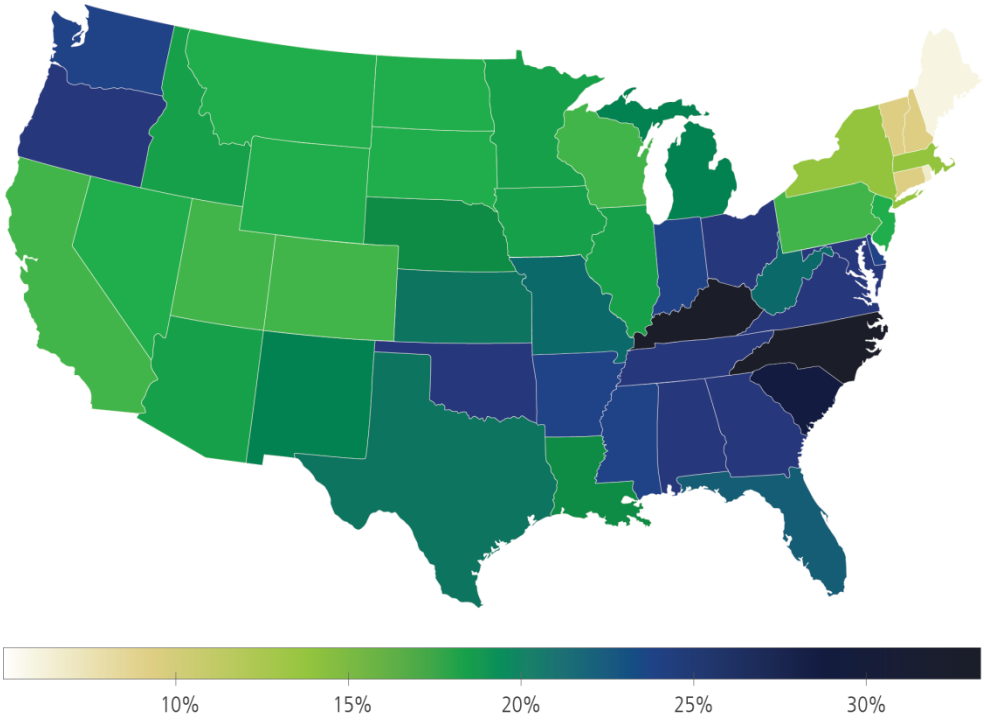
² KλfŜ 2LJLJ2ℕúdzyλűλŜă l·ℕŜ fl·ℕƎŜ λy l·ff ăűl·ûŜăΣ úKŜ Y2ăű Ŏ2ăűπŜ₹₹ŜŏűλØŜ YŜl·ădzℕŜă Øl·ℕè ℕŜƎλ2yl·ffè ōl·ăŜŘ 2y ₹l·Ŏű2ℕă ădzŏK l·ă ŎfλYl·ûŜΣ ŜyŜℕƎè LJℕλŎŜăΣ l·yŘ ōdzλfŘλyƎ LJℕl·ŏűλŎŜăφ hyŜ ŜÈl·YLJfŜ Ŏ2YŜă ₹ℕ2Y úKŜ ℕŜăλŘŜyűλl·f ăŜŏű2ℕΣ ØKŜℕŜ 5h9 l·yl·fèăλă λŘŜyűλ₹λŜŘ l· ădzλűŜ 2₹ Ŏ2ăűπŜ₹₹ŜŏűλØŜ ŜyŜℕƎè Ŝ₹₹λŏλŜyŏè dzLJƎℕI·ŘŜă ű2 úKŜ ŏdzℕℕŜyű ăű2Ŏ] 2₹ ¦φ{φ ăλyƎfŜπ₹l·YλfèŘŜűl·ŎKŜŘ K2YŜă øλűK ű2ű l·f LJ2űŜyűλl·f ăl·ØλyƎă 2₹ нпр ¢ ² K LJŜℕ èŜl·ℕ óЧc LJŜℕŏŜyű 2₹ úKŜ ű2ű l·f l·yÿűzl·f yl·ûλ2yl·f ŜfŜŏűℕλŎλűè Ŏ2yãdzYLJűλ2y λy нлмпúφ LyλűλI·ûλØŜă ű2 dzLJƎℕI·ŘŜ l±!/ äěăűŜYăΣ LJl·ℕűλŎdzfl·ℕfè ℕŜLJfl·ŎλyƎ ŜfŜŏűℕλŎ ₹dzℕyl·ŎŜă øλűK Øl·ℕλl·ōfŜ ălJŜŜŘ KŜl·ű LJdzYLJăΣ Ŏ2dzfŘ LJℕ2ŘdzŏŜ ădzōăűl·yűλl·f ŜfŜŏűℕλŎλűè ăl·ØλyƎă λy úKŜ {2dzűK /Ŝyãdzã ℕŜƎλ2yã ó ² Šăű {2dzűK /ŜyűℕI·fΣ 9l·ăű {2dzűK /ŜyűℕI·fΣ l·yŘ {2dzűK !ůfl·yűλŎúΣ øKŜℕŜ ō2űK l·ØŜℕI·ƎŜ K2dzăŜK2fŘ ŜfŜŏűℕλŎλűè Ŏ2yãdzYLJűλ2y l·yŘ LJ2LJdzfl·ûλ2y ƎN2øűK ℕl·ûŜ l·ℕŜ KλƎKŜℕ úKl·y 2úKŜℕ ℕŜƎλ2yãφᴹᵀᴶ !ŘŘλűλ2yl·f l·yl·fèăŜă Ŏl·y KŜfLJ ăűl·ûŜăΣ dzűλfλűλŜăΣ l·yŘ Ŏ2yãdzYŜℕă dzyŘŜℕăűl·yŘ øKλŎK YŜl·ădzℕŜă 2₹₹Ŝℕ úKŜ ƎℕŜl·ûŜăű ySű ōŜyŜ₹λúă λyúKŜλℕ ℕŜƎλ2yΦ

{űl·ûŜ l·yŘ f2ŏl·f ƎØØŜℕyYŜyűăΣ l·ă øŜff l·ă úKŜ dzűλfλűλŜă úKl·ú úKŜè ℕŜƎdzfl·ûŜ 2ℕ 2øyΣ fŜl·Ř úKŜ Ŝ₹₹ŜŏűλØŜ λYLJfŜYŜyűl·ûλ2y 2₹ Yl·yê ŜyŜℕƎè Ŝ₹₹λŏλŜyŏè LJ2fλŏλŜă l·yŘ LJℕ2ƎℕI·Yăφ a l·yê ăűl·ûŜ l·yŘ f2ŏl·f Ǝ2ØŜℕyYŜyűă Yl·yl·ƎŜ úKŜ ŘŜØŜf2LJYŜyű l·yŘ λYLJfŜYŜyűl·ûλ2y 2₹ ℕl·ûŜLJl·èŜℕπ₹dzyŘŜŘ dzűλfλűè LJℕ2ƎℕI·Yă úKl·ú λyŐŜyűλØλlΣ l·yŘ LJℕ2ØλŘŜ ûŜŏKyλŏl·f ădzLJLJ2ℕú ű2 Ŏl·LJúdzℕŜ Øl·fdzŜ úKℕ2dzƎK λyŐℕŜl·ăλyƎ ŜyŜℕƎè Ŝ₹₹λŏλŜyŏè λyØŜăűYŜyűă ōè Ŏ2yãdzYŜℕăφ wl·ûŜLJl·èŜℕπ₹dzyŘŜŘ LJℕ2ƎℕI·Yă ŘλℕŜŏűŜŘ l·ú λYLJℕ2ØλyƎ ŜyŘπdzăŜ Ŝ₹₹λŏλŜyŏè l·yŘ Yl·yl·ƎŜYŜyű l·ℕŜ

ƴƵǿ ŦdzƴŘŜŘ ǀ·ǘ Þсςт ōƛƭƭƛƵƴ LJŜŃ ѐŜǀ·Ńǿᵐᵀᵐ ¢ǿŜƴǘѐπăƛȄ ăǘǀ·ǘŜă Ƙǀ·ØŜ Ŝƴǀ·ŎǘŜŘ ǀ·ƴ 9ƴŜŃƎѐ 9ŦŦƛŎƛŜƴŎѐ wŜăƵdzŃŎŜ {ǘǀ·ƴŘǀ·ŃŘ ó99w{ǘΣ ǿƘƛŎƘ ŃŜǀjdzƛŃŜă dzǘƛƭƛǘƛŜă ǘƵ ŃŜŘdzŎŜ ǘƘŜƛŃ ŎdzăǘƵƴ ŜŃăΩ ŜƴŜŃƎѐ ŎƵƴădzƴLJǘƛƵƴ ōѐ ǀ· ŎŜŃǘǀ·ƛƴ LJŜŃŎŜƴǘǀ·ƎŜ ƵŦ ǀ·ƴƴdzǀ·ƭ ăǀ·ƭŜăǿ ! ŎŎƵŃŘƛƴƎ ǘƵ ǘƘŜ ! ƴŜŃƛŎǀ·ƴ / ƵdzƴŎƛƭ ŦƵŃ ǀ·ƴ 9ƴŜŃƎѐ 9ŦŦƛŎƛŜƴǘ 9ŎƵƴƵƴ ѐΣ ǽƛƴ нлмпΣ ăǘǀ·ǘŜă ǿƛǘƘ ǀ·ƴ 99w{ ǀ·ŎƘƛŜǿŜŘ ƛƴŎŃŜƴŜƴǘǀ·ƭ ŜƭŜŎǘŃƛŎƛǘѐ ăǀ·ØƛƴƎă ƵŦ мфн LJŜŃŎŜƴǘ ƵŦ ŃŜǘǀ·ƛƭ ăǀ·ƭŜă Ƶƴ ǀ·ØŜŃǀ·ƎŜΣ ŎƵƴLJǀ·ŃŜŘ ǘƵ ǀ·ØŜŃǀ·ƎŜ ăǀ·ØƛƴƎă ƵŦ лфо LJŜŃŎŜƴǘ ƛƴ ăǘǀ·ǘŜă ǿƛǘƘƵdzǘ ǀ·ƴ 99w{ᵠέᵐᵀᵐ 99w{ LJƵƭƛŎƛŜăΣ ƵŃ ăƛƴƛƭǀ·Ń ŃŜǀjdzƛŃŜƴŜƴǘăΣ ǀ·ŃŜ LJŃƵƵŜŎǘŜŘ ǘƵ ōŜ ǀ· ʅŜѐ ŘŃƛØŜŃ ƵŦ ŦdzǘdzŃŜ ŜƴŜŃƎѐ ŜŦŦƛŎƛŜƴŎѐ LJŃƵƎŃǀ·ƴăΣ ǀ·ŎŎƵdzƴǘƛƴƎ ŦƵŃ ƴŜǀ·Ńƭѐ ǘƘŃŜŜ ǀjdzǀ·ŃǘŜŃă ƵŦ ǀ·ƭƭ ƛƴØŜăǘƴŜƴǘᵠᵐᵀᵒ ! ŘŘƛǘƛƵƴǀ·ƭƭѐΣ ōѐ нлнл ǘƘŜăŜ ăǘǀ·ǘŜ 99w{ă ǀ·ŃŜ Ŝăǘƛƴǀ·ǘŜŘ ǘƵ ŃŜŘdzŎŜ ŜƭŜŎǘŃƛŎƛǘѐ ŎƵƴădzƴLJǘƛƵƴ ƛƴ ǘƘƵăŜ ăǘǀ·ǘŜă ōѐ ƴ LJŜŃŎŜƴǘ ǘƵ мл LJŜŃŎŜƴǘ ōŜƭƵǿ LJŃƵƵŜŎǘŜŘ ōdzăƛƴŜăăπǀ·ăπdzădzǀ·ƭᵠᵐᵀᵖ ! ƴǀ·ƭѐăƛă ƵŦ ƵØŜŃ нΣмлл LJŃƵƎŃǀ·ƴπѐŜǀ·Ńă ƵŦ Řǀ·ǘǀ· ƛƴŘƛŎǀ·ǘŜă ǘƘǀ·ǘ ǘƘŜăŜ LJŃƵƎŃǀ·ƴă ŎƵăǘ ǀ·ƴ ǀ·ØŜŃǀ·ƎŜ ƵŦ пфс ŎŜƴǘă LJŜŃ ʅ ² Κ ăǀ·ØŜŘΣ ƴǀ·ʅƛƴƎ ŜƴŜŃƎѐ ŜŦŦƛŎƛŜƴŎѐ ǀ· ŎƵăǘπŜŦŦŜŎǘƛØŜ ǀ·LJLJŃƵǀ·ŎΚ ŦƵŃ ƭƵǿŜŃƛƴƎ ŎƵƴădzƴŜŃ ŜƴŜŃƎѐ ōƛƭƭăᵠᵐᵀᵖ

¢ΚŜŃŜ ƛă ăƛƎƴƛŦƛŎǀ·ƴǘΣ ŃŜƴǀ·ƛƴƛƴƎ LJƵǘŜƴǘƛǀ·ƭ ŦƵŃ ŎŃŜǀ·ǘƛƴƎ Øǀ·ƭdzŜ ǘƵ ŎƵƴădzƴŜŃă ǀ·ƴŘ ƵǘΚŜŃă ǘΚŃƵdzƎΚ ŎƵăǘπŜŦŦŜŎǘƛØŜ ŜƭŜŎǘŃƛŎƛǘѐ ăǀ·ØƛƴƎăᵠ ! ă ǀ·ƴ ŜȄǀ·ƴLJƭŜΣ CƛƎdzŃŜ нπмо ăΚƵǿă ŎƵăǘπŜŦŦŜŎǘƛØŜ ŜƭŜŎǘŃƛŎƛǘѐ ăǀ·ØƛƴƎă ƛƴ ăƛƴƎƭŜπŦǀ·ƴƛƭѐ ŃŜăƛŘŜƴǘƛǀ·ƭ ΚƵdzăƛƴƎ ǀ·ŎŃƵăă ŜØŜŃѐ ăǘǀ·ǘŜᵠ ¢Κƛă ǀ·ƴǀ·ƭѐăƛă ăΚƵǿă ǘΚǀ·ǘ ƴƵăǘ ăǘǀ·ǘŜă Ŏǀ·ƴ ŎƵăǘπŜŦŦŜŎǘƛØŜƭѐ ăǀ·ØŜ мрπ ол LJŜŃŎŜƴǘ ƵŦ ŜƭŜŎǘŃƛŎƛǘѐ dzăŜŘ ƛƴ ăƛƴƎƭŜπŦǀ·ƴƛƭѐ ŘǿŜƭƭƛƴƎăᵠ

Figure 2-13. Potential Electricity Savings from Residential Energy Efficiency Upgrades, by State[176]



Modeling indicates that homeowners in most States can reduce their electricity consumption by 15 to 30 percent after implementing net present value positive energy efficiency measures, compared to current consumption.

Zero Energy Buildings

In concept, zero energy homes (and zero energy buildings [ZEBs] in general[w]) are ñenergy-efficient buildings where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.ò Other definitions use site-energy-based criteria—a less-stringent definition than source-based, which includes the site energy plus the energy used to provide and distribute it. And, others use time-dependent, valuation-based definitions, which seek to assign a valuation of energy produced or consumed to better reflect the actual costs of energy, as adopted by the California Public Utilities Commission. The difficulty in meeting ZEB criteria varies between definitions. Furthermore, the cost-effectiveness of ZEBs depends highly on the age and type of building, location (climate), incentives (e.g., utility rebates), electricity rate and structure, and the cost of renewable energy generation.

Recent studies demonstrate that many new ZEBs in the commercial sector can be cost-effective, with overall costs falling within the same range as conventional, new construction projects. The explicit goal of net-zero energy throughout the design process is critical to minimizing construction costs. In California, for example, many commercial buildings are technically feasible to be ZEB using a time-dependent, valuation-based definition. However, several building categories, such as sit-down restaurants, hospitals, and large offices cannot reach ZEB designation using rooftop solar—though they might reach that designation using parking lot PV systems. Having available roof space for onsite PV is often a challenge. Contracting with offsite renewable energy systems or participating in virtual net-metered or community-scale solar projects provide greater flexibility for buildings to be ZEB or ZEB-ready. This is an active area of policy discussion.

Other barriers to the adoption of ZEBs are the lack of integrated design practices, cost barriers, lack of skilled and knowledgeable workforce in design and construction, additional design and construction cost, improper building management, user behavior, and integration of solar PV, either as part of the building construction process or as a parallel step during that process.

Policy that encourages zero-energy homes increases demand for not only energy efficiency but also other distributed energy resources, such as DG and battery storage. High levels of market penetration could have significant impacts on the grid, reducing overall grid electricity consumption. More distributed energy resources driven by zero-energy targets can potentially lead to higher levels of DR. California has announced a target of making all new residential buildings net-zero energy by 2020. It is likely that a significant fraction of existing residential buildings would struggle to attain zero energy onsite due to roof angles, poor insulation, insufficient roof area (particularly in the case of high-rise buildings), and other factors. This may place a premium on finding a way to procure offsite sources to offset whatever amount of site energy remains.

Using government-owned buildings, especially schools, to demonstrate the multiple benefits that ZEBs can help realize (such as improved student health and reduced operating costs) could lead to more widespread adoption of such building construction, renovation, and management practices. For example, one study showed that improved heat pump air conditioning in relocatable classrooms could simultaneously reduce the energy needed for heating, ventilation, and air conditioning by 50ï 70 percent and significantly improve indoor air quality. More studies are needed on the cost-effectiveness of new ZEBs, considering an integrated package of energy efficiency measures rather than analysis of discrete measures, as well as a better understanding of the cost-effectiveness of ultra-low energy or ZEB retrofits. Some of the key adoption issues that need to be resolved for ñshared solaròor offsite renewable generation include a lack of uniformity and standardization of consumer contracts, rate design, and program structure, and the need for a framework to track and match offsite renewable resources to specific buildings claiming an offset. Thus, an analysis of the policy choices, impacts, and cost implications of ZEBs would be helpful.

[ø] ¢ĶŜ ǘŜ№Ƴ ÎŜ№2 ŜƴŜ№∃ȅ ōdzƛƒŘƛƴ∃ ó½9 . ǘ dzǎŜŘ ĶŜ№Ŝ ƛǎ Ǒ2ƴǎƛŘŜ№ŜŘ ǘ2 ĶƖ·ØŜ ǘĶŜ ǎƖ·ƴŜ ƴŜƖ·ƴƛƴ∃ Ɨ·ǎ ǎƛƴƛƒƖ·№ ǘŜ№Ƴǎ ǎdzǑĶ Ɨ·ǎ ÎŜ№2 ƴŜǘ ŜƴŜ№∃ȅ ōdzƛƒŘƛƴ∃ ó½b9 . ǘ 2№ ƴŜǘπÎŜ№2 ŜƴŜ№∃ȅ ōdzƛƒŘƛƴ∃ ób½9 . ǘφ

2.4 Maximizing Value of Dynamic Consumer Assets

!ŘØlıyÖŜă ʎy ÖƧYYdzyʎÖlıúʎƨyãΣ YŜűŜNʎyƎΣ ăŜyãƨNăΣ Öƨyúƨ2ftãΣ lıyŘ ăúƨNlıƎŜ űŜŐKyƨfƨƎƎʎŜă lıNŜ ŜylıōfʎyƎ Öƨyãdzƴ ŜNăΣ dzűʎfʎúʎŜăΣ lıyŘ 2úKŜN ăŜNØʎÖŜ LJN2ØʎŘŜNă úƨ2 Y2NŜ lıÖúʎØŜfè 2N LJlıääʎØŜfè YıylıƎŜ ŜfŜŐúNʎÖʎúè fƨlıŘă ʎy NŜăLJƨyãŜ úƨ LJNʎÖŜ lıyŘ 2úKŜN äèăúŜY Öƨyãúƨlıʎyúă¢ ¢Kʎă ʎă ʎy Öƨyúƨlıăú úƨ2 ŜyŜNƎè ŜŦŦʎÖʎŜyÖè YŜlıädzNŜăΣ øKʎÖK NŜădzfű ʎy ăúlıúʎÖ NŜŘdzÖűʎƨyã ʎy ŜyŜNƎè Öƨyãdzƴ LJűʎƨy ōè lıy lıLJLJfʎlıyÖŜΣ ŜIjdzʎLJYŜyúΣ 2N ődzʎfŘʎyƎ¢ ¢KŜ Ølıfdzŝ ŘŜNʎØŜŘ ŦN2Y Řèylıʎlıffè Ylıylı ƎʎyƎ Öƨyãdzƴ ŜN lıääŜúă Ölıy ōŜ ŜÖƨyƨYʎÖΣ lıă øŜff lıă ŜyØNƨyƴŜyúlıfΣ lıyŘ Ölıy lıÖÖNdzŝ úƨ úKŜ Öƨyãdzƴ ŜNΣ dzűʎfʎúèΣ lıyŘ 2úKŜNăø 5wΣ øKʎÖK lıff2øă dzűʎfʎúʎŜăΣ ƎNʎŘ 2LJŜNlıúƨNăΣ 2N 2úKŜN ʎyűŜNƴŜŘʎlıNʎŜă úƨ Ölıff ŦƨN ălJŜÖʎŦʎÖ ÖKlıyƎŜă ʎy ŘŜYlıyŘ øKŜy ySŜŘŜŘΣ 2ŦŦŜNă ōŜySŦʎúă ʎy ŦflıúűŜyʎyƎ fƨlıŘ ÖdzNØŜă lıyŘ ădzLJLJfèʎyƎ ŜăăŜyűʎlıf NŜfʎlıōfʎúè ăŜNØʎÖŜăΣ ădzÖK lıă ŦNŜIjdzŜyÖè NŜƎdzflıúƨyø {YlıNú YŜűŜN ʎyŦNlıăúNdzÖűdzNŜΣ ăŜyãƨNăΣ lıyŘ Öƨyúƨlıʎyŧ̈ŜylıōfŜŘ ŘŜØʎÖŜă lıyŘ Öƨyúƨ2ftă ƎʎØŜ ŜfŜÖúNʎÖʎúè Öƨyãdzƴ ŜNä lıyŘ dzűʎfʎúʎŜă ySø lıōʎfʎúʎŜă úƨ Yƨyúƨ2N ŜfŜÖúNʎÖʎúè Öƨyãdzƴ LJűʎƨylıffè fƨøŜN dzălıƎŜ ʎyNŜăLJƨyãŜ úƨ ûʎYŜΣ fƨÖlıf ŘʎăúNʎōdzűʎƨyΣ 2N LJNʎÖŜ Öƨyãúƨlıʎyúă¢ {YlıNú YŜűŜNă lıfãƨ LJN2ØʎŘŜ lı yűzYōŜN 2Ŧ 2úKŜN ōŜySŦʎúăΣ ʎyÖfdzŘʎyƎ ŜyKlıyÖŜŘ ƨdzűlıƎŜ Ylıylı ƎŜYŜyű lıyŘ NŜăúƨNlıûʎyΣ ʎYLJN2ØŜŘ ŘʎăúNʎōdzűʎƨy ăèăúŜY Yƨyűúƨ2NʎyƎΣ lıyŘ dzűʎfʎúè ƨLJŜNlıûʎƨylıf ălıØʎyƎă¢ᴹᵀᵀ hűKŜN ōŜySŦʎúă ʎyÖfdzŘŜ ʎYLJN2ØŜYŜyűă ʎy ődzʎfŘʎyƎ dzăŜN ălıûʎăŦlıÖűʎƨy lıyŘ ƎNŜlıûŜNƨ ø2NʅŜN LJN2ŘdzÖűʎØʎúè¢ ! ă yƨűŜŘΣ ûKŜ ÖƨyØ ŜNƎŜyÖŜ Ŧ ŜfŜÖúNʎÖʎúè øʎúK L/¢ Ölıy lıfã2 ÖNŜlıûŜ ySø Ølıfdzŝ ăúNŜlıYăφ ¢lıʅʎyƎ ŦdzfƒlıŘØlıyűlıƎŜ 2Ŧ úKŜ Ølıfdzŝ 2Ŧ Öƨyãdzƴ ŜN lıääŜúă ŘŜLJŜyŘă 2y Yʎyʎ Yʎ Îʎy Ǝ úKŜ NʎăʅălıûŜŘ øʎúK úKŜY τ ʎy LJlıNúʎÖdzflıΣ ÖèōŜN úKNŜlıûă lıyŘ LJNʎØlıÖè Öƨyű ŜNyăφ

2.4.1 Modern Communications Networks Provide the Backbone for Maximizing Value of Electricity Assets

bŜø ûŜŐKyƨfƨƎʎŜă ădzLJLJƨNúŜŘ ōè LJNʎØlıûŜπăŜŐúƨN ØŜyŘƨNă lıyŘ Ǝƨ2ØŜNyYYŜyű w9 5 lıNŜ Ylıʅʎy Ǝ úKŜʎNN ølıè 2yűƨ ōdzfʅ LJƨøŜN lıyŘ ŘʎăúNʎōdzűʎƨyãèăúŜY ăφ hy úKŜ dzűʎfʎúè ăʎŘŜ 2Ŧ úKŜ YŜűŜNΣ LJƨøŜN Ijdzlıfʎúè Y2yűúƨ2NăΣ ădzōăúlıûʎ2y ʎyăúNdzYŜyűlıûʎ2yΣ ŦlıdzfűŜŘ ÖʎNÖdzʎú ʎyŘʎÖlıúƨNăΣ LJKlıă2N YŜlıădzNŜYŜyű dzyűúăΣ lıŘØlıyÖŜŘ YŜűŜNăΣ lıyŘ 2úKŜN ŘŜØʎÖŜă lıNŜ LJNƨØʎŘʎyƎ Řlıúlı úƨ2 ăèăúŜY 2LJŜNlıúƨNă lıyŘ LJfIıyŸŜNăφᴹᵀʏ hy úKŜ Öƨyãdzƴ ŜN ăʎŘŜ 2Ŧ úKŜ YŜűŜNΣ LJNƨŘdzÖűă ădzÖK lıă ƎNʎŘπÖƨyŸŜÖúŜŘ ʎyØŜNúŜNăΣ úKŜNYƨăúlıûăΣ lıLJLJfʎlıyÖŜăΣ lıyŘ YlıÖʎʎ ŸŜă lıNŜ ʎyÖNŜlıăʎyƎfè Öƨyŷ ŜÖúʎyƎ úƨ2 Ŝlıʎ 2úKŜN lıyŘ úƨ2 úKŜ ʎyűŜNyŜű 2N úKŜ L2¢φ ¢KŜ ʎyűŜNLJfIıè 2Ŧ úKŜăŜ Ølıʎdză ŘŜØʎÖŜă 2y úKŜ ƎNʎŘ úKN2dzƎK úKŜ L2¢ ăă ƎŜyŜNlıúʎyƎ ŘNlıYlıʎÖlıffè ʎyÖNŜlıăŜŘ Ø2fdzYŜă 2Ŧ Řlıúlıφ ¸ŜúΣ ƎNʎŘ 2LJŜNlıûƨNă lıyŘ LJƨØŜN ŘʎăLJlıûÖKŜNă ySŜŘ ōŜúúŜN Øʎădzlıfʎlîlıúʎ2y 2Ŧ ōŜKʎyŘπúKŜπYŜúŜN NŜă2dzNÖŜă Ŧ2N Ölıljlıʎúè LJfIıyŷʎyƎ lıyŘ ƎNʎŘ 2LJŜNlıûʎ2yã¢ C2N ŜÈlıYLJfŜΣ ƎNʎŘ 2LJŜNlıûƨNă ySŜŘ ûƨ dzyŘŜNăúlıyŘ úKŜ ŘŜƎNŜŜ ûƨ øKʎÖK úKŜè Ölıy NŜfè 2y Ödzăúƨ2YŜNπăʎúŜŘ lıääŜúăΩ LJƨØŜN LJN2ŘdzÖűʎØʎúè lıyŘ Ölıy ʎYLJN2ØŜ ŜyŜNƎè ŜŦŦʎÖʎŜyÖè¢ C2N ŜØŜNè ʅ² K Ö2yãdzYŜŘ ōè L/¢ äèăúŜY ăΣ ʎú Klıă ōŜŜy ŜăúʎYlıúŜŘ úKlıú мл ʅ² K lıNŜ ălıØŜŘ ŜfăŜøKŜNŜ ʎyúKŜ ŜÖƨyƨYè¢ᴹʸᴹ lƨØŜØŜNΣ ŘŜLJf2èYŜyű 2Ŧ L/¢Σ ! aLΣ lıyŘ ƎNʎŘ Ö2YYdzyʎÖlıûʎ2yʎyƎNlıăúNdzÖűdzNŜ lıfãƨ NlıλăŜ λăădzŜă Ö2yÖŜNyʎyƎ Řlıúlı LJNʎØlıÖèΣ ƨøyŜNăKʎLJΣ lıyŘ lıÖÖŜăă¢

¢KŜ ōN2lıŘŜN Ö2YYdzyʎúè ăŜNØŜŘ ōè úKŜ dzűʎfʎúè Ylıè ʎyÖNŜlıăʎyƎfè dzăŜ dzűʎfʎúè Ö2YYdzyʎÖlıûʎ2yã ySűø2NʅĄ—lı Ö2yØŜNƎŜyÖŜ 2Ŧ ăèăúŜYă úKlıú Ölıy ÖNŜlıûŜ ySø Ølıfdzŝ ű2 úKŜ ŜÖƨyƨYè¢ C2N ŜÈlıYLJfŜΣ /Klıûúlıyƨ2Ǝlıʎă Ydzyʎ ÖʎLJlıffè 2øyŜŘ dzűʎfʎúèΣ úKŜ 9fŜÖúNʎÖ tƨøŜN .2lıNŘ ó9t.úΣ ödzʎfű lı ŦʎōŜNN ySűø2NʅĄ ûKNN2dzƎK2dzű ʎúă ăŜNØʎÖŜ ûŜNNNʎû2NNè ű2 2ŦŦŜN úKŜ ŦlıăúŜăű ōN2lıŘōlıyŘ ăŜNØʎÖŜ ű2 ʎúă Ödzăúƨ2YŜNă lıyŘ Ŝylıōfŝ lı ăYlıNú ƎNʎŘ ăèăúŜY úKlıú ø2dzfŘ ălıØŜ ŜyŜNƎè lıyŘ ōŜ Yƨ2NŜ NŜfʎlıōfŜ¢ᴹʸᴴ 9t. ʎyăúlıffŜŘ ŦʎōŜN 2LJűʎÖă ûKN2dzƎK2dzű ʎúă ăŜNØʎÖŜ ûŜNNNʎû2NNèΣ ʎyÖfdzŘʎyƎ NdzNlıf lıNŜlıă lıú ûKŜ ŜyŘ 2Ŧ ŘʎăúNʎōdzűʎƨyƴŜăΣ øKʎÖK ŜylıōfŝŘ 9t. ű2 lıdzű2Ylıûŝ Ö2yűNƨf 2Ŧ ʎúă ŘʎăúNʎōdzűʎƨy lıyŘ ădzōπűNlıyãYʎääʎ2yăèăúŜYă¢ᴹʸᴼ

LyʹнллфΣ 5h9 l·ø⁄l·₩ŘŜŘ 9t . Þммм⌀c YʹλffΛ2yʹűK₩2dzƎK űKŜ {Yʹl·₩ú D₩ΛŘ LyØŜăűYʹŜyű t₩2Ǝ₩l·YΣ ŦdzyŘŜŘ ōè űKŜ !YʹŜ₩ΛǾl·yʹ wŜǾ2ØŜ₩è l·yŘ wŜλyØŜăűYʹŜyű !ǾúΣ ű2 λyãűl·ff мтлΣллл ăYʹl·₩ú YʹŜűŜ₩ă l·yŘ Ǝ₩ΛŘπl·dzű2Yʹl·ΛΛ2yʹ ŰŜǾKy2f2ƎλŜă ű2 λYʹLJ₩2ØŜ ₩ŜfΛl·ōλfΛΛûè l·yŘ ₩ŜŘdzǾŜ Ǿ2yãdzYʹŜ₩ ŜfŜǾΰ₩ΛǾΛΛûè ōλffă ΰK₩2dzƎK ŜyʹŜ₩Ǝè ăl·ØλyƎă⌀ᵐʸᵖ ¢KŜ dzLJƎ₩l·ŘŜŘ ăèăΰŜYʹ Kl·ă l·f₩Ŝl·Řè l·ff2ø⁄ŜŘ 9t . ΰ2 IjdzλǾ⌈fè ₩Ŝăΰ2₩Ŝ LJ2ø⁄Ŝ₩ l·ŦΰŜ₩ ΰø⁄2 Yʹl·⁄2₩ ø⁄Ŝl·ΰKŜ₩π₩Ŝfl·ΰŜŘ 2dzΰl·ƎŜăΣ ăl·Ø⁄λyƎ YʹλffΛ2yã 2Ŧ Ř2ffl·₩ă Ŧ2₩ 9t . l·yŘ ΰKŜ Ǿ2YʹYʹdzyΛΰè⌀ᵐʸᵖ

LyʹнлмлΣ 9t . l·yŷ⁄2dzyǾŜŘ λΰ ø⁄2dzfŘ 2ŦŦŜ₩ ΰKŜ Ŧ∧₩ăΰ мπƎλƎl·ōλΰπLJŜ₩πăŜǾ2yŘ óDōLJăú ăŜ₩ØλǾŜ λyʹΰKŜ Ǿ2dzyΰ₩èΣ ø⁄KΛǾK λă мл ű2 нл ΰλYʹŜă ŦI·ăΰŜ₩ ΰKl·yʹΰKŜ ō₩2I·Řōl·yŘ 9t . Kl·Ř ōŜŜyʹ2ŦŦŜ₩λyƎ⌀ᵐʸᶜ ¢KŜ l·ØI·λfI·ōλfΛΛûè 2Ŧ мπDōLJă λyΰŜ₩ySΰ ăŜ₩ØλǾŜ Kl·ă KŜfLJŜŘ Ǝ₩2ø⁄ /Kl·ΰΰl·y⁄22Ǝl·ΩăŜǾ2y⁄2Yè l·yŘ ŜyǾ2dzW·ƎŜŘ ōdzăλySăăŜă ű2 λyØŜăΰ λyʹΰKŜ Ǿλΰèᵠᵐʸᵀ ¢KŜ CŜŘŜ₩l·f /2YʹYʹdzyΛǾl·ΰλ2yã /2YʹYʹλăăλ2yʹóC//ú Kl·ă l·ΰΰŜYʹLJΰŜŘ ű2 ₩ŜY⁄2ØŜ ōl·₩₩Ŝ₩ă ű2 ō₩2l·Řōl·yŘ ŜÈLJl·yãλ2yʹ l·yŘ LJ₩2Yʹ2ΰŜ Ǿ2YʹLJŜΰλΰλ2yʹλyʹ¢ŜyŷŜăăŜŜ ōè l·ff2ø⁄λyƎ 9t . ű2 ŜÈLJl·yŘ 2dzΰăλŘŜ λΰă ăŜ₩ØλǾŜ l·₩Ŝl·Σ ōdzΰ l· CŜŘŜ₩l·f l·LJLJŜl·fă Ǿ2dz₩ú ₩ŜǾŜyΰfè KŜfŘ ΰKl·ΰ ΰKŜ C// ŘλŘ y2ΰ Kl·ØŜ l·dzΰK2₩Λΰèᵠᵐʸʸ

!ǾǾ2₩ŘλyƎ ű2 ΰKŜ C//Σ мл LJŜ₩ǾŜyΰ 2Ŧ !YʹŜ₩ΛǾl·yã l·yŘ оф LJŜ₩ǾŜyΰ 2Ŧ ₩dz₩l·f !YʹŜ₩ΛǾl·yã fI·Ǿ⌈ l·ǾǾŜăă ű2 l·ŘØl·yǾŜŘ ΰŜfŜǾ2YʹYʹdzyΛǾl·ΰλ2yãᵠᵐʸᵠ ¢KŜ CŜŘŜ₩l·f D2ØŜ₩yYʹŜyΰΣ ΰK₩2dzƎK ΰKŜ wdz₩l·f 9fŜǾΰ₩ΛŦΛǾl·ΰλ2yʹ !ǾΰΣ Kl·ă l· f2yƎ Kλăΰ2₩è 2Ŧ ădzLJLJ2₩ΰλyƎ ŜÈLJl·yãλ2yʹ2Ŧ l·ǾǾŜăă ű2 l·ŦŦ2₩Řl·ōfŜ ŜfŜǾΰ₩ΛǾΛΛûè l·yŘ Ǿ2YʹYʹdzyΛǾl·ΰλ2yã ăŜ₩ØλǾŜă λyʹ₩dz₩l·f !YʹŜ₩ΛǾl·Σ ø⁄λΰK YʹI·⁄2₩ λyΰλΰλl·ΰλØŜă Ǿ2yΰλyΰdzλyƎ ΰ2ŘI·è Ŧ2₩ λYʹLJfŜYʹŜyΰλyƎ ŘŜYʹl·yŘ ăλŘŜ YʹI·yl·ƎŜYʹŜyΰΣ ŜyŜ₩Ǝè ŜŦŦΛǾλŜyǾè LJ₩2Ǝ₩l·YʹăΣ ₩ŜyŜø⁄l·ōfŜ ŜyŜ₩Ǝè ăèăΰŜYʹăΣ l·yŘ 2ΰKŜ₩ λyΰλΰλl·ΰλØŜă⌀ᵐʸᶠᴸ /2yƎ₩Ŝăă Kl·ă ŘŜΰŜ₩YʹλyŜŘ ΰKl·ΰ λΰ λă CŜŘŜ₩l·f LJ2fΛǾè ΰ2 LJ₩2ØλŘŜ f2l·yã ΰ2 ₩dz₩l·f ŜfŜǾΰ₩ΛǾ Ǿ2π2LJă l·ΰ λyΰŜ₩Ŝăΰ ₩l·ΰŜă ΰKl·ΰ l·ff2ø⁄ ΰKŜY ΰ2 l·ǾKΛŜǾŜ ΰKŜ Ǝ2l·fă 2Ŧ ΰKŜ wdz₩l·f 9fŜǾΰ₩ΛŦΛǾl·ΰλ2yʹ !ǾΰΣ λyǾfdzŘλyƎ λYʹLJ₩2ØλyƎ ŜfŜǾΰ₩ΛǾΛΛûè ƎŜySŜ₩l·ΰλ2yΣ ΰ₩l·yãYʹλăăλ2yΣ l·yŘ Řλăΰ₩Λōdzΰλ2yŦl·ǾλfΛΰŜă λyʹl·₩Ŝl·ă ø⁄λΰK KΛƎK ŜfŜǾΰ₩ΛǾΛΛûè Ǿ2ăΰă⌀ᵐᶠᴹ ᵐᶠʰ LyʹI·ŘŘλΰλ2yʹΰ2 ŦλyΊ·yǾλl·f ădzLJLJ2₩ΰΣ ¦{5! LJ₩2ØλŘŜă ΰŜǾKyΛǾl·f ădzLJLJ2₩ΰ l·yŘ ǾΰŜl·ΰŜă LJΛf2ΰ LJ₩2ΣŜǾΰă Ŧ2₩ λYʹLJ₩2ØλyƎ ₩dz₩l·f ŜfŜǾΰ₩ΛǾΛΛûè ăèăΰŜYʹă l·yŘ LJ₩2Yʹ2ΰλyƎ ₩dz₩l·f ŜǾ2y2YʹλǾ ŘŜØŜf2LJYʹŜyΰ⌀ᵐᶠᴼ

2.4.2 Customer Engagement

!ă ŘλăǾdzăăŜŘ λyʹ /Kl·LJΰŜ₩ L ó*Transforming the Nation's Electricity System: The Second Installment of the QER*ΰΣ ΰKŜ ŜfŜǾΰ₩ΛǾΛΛûè ăèăΰŜYʹ λă ōŜǾ2YʹλyƎ Yʹ2₩Ŝ ŘλƎλΰl·fΣ Ǿ2yŷŜǾΰŜŘΣ l·yŘ λyΰŜƎ₩l·ΰŜǾ⌀ ¢KŜăŜ ΰ₩ŜyŘăΣ l·yŘ ΰKŜ yŜø⁄ ăŜ₩ØλǾŜă l·yŘ l·ăăŜΰă 2yʹΰKŜ ăèăΰŜYʹ λyǾfdzŘλyƎ Řλăΰ₩ΛōdzΰŜ ŜyŜ₩Ǝè ₩Ŝă2dz₩ǾŜă ó59wΰΣ K2YʹŜ l·dzΰ2Yʹl·ΰλ2yΣ l·yŘ 5wΣ l·₩Ŝ ǾKl·yƎλyƎ ΰKŜ LJKèλlǾl·f ŜfŜǾΰ₩ΛǾΛΛûè ăèăΰŜYʹΣ ø⁄KΛfŜ l·fă2 l·fΰŜ₩ΛyƎ Ǿdzăΰ2YʹŜ₩ăΩ λyΰŜ₩Ŝăΰ l·yŘ ŜyƎl·ƎŜYʹŜyΰ ø⁄λΰK ΰKŜλ₩ ŜyŜ₩Ǝè dzăŜ⌀ hyŜ ăΰdzŘè 2Ŧ Ǝ₩ΛŘ Yʹ2ŘŜ₩yΛÎl·ΰλ2yʹŦ2dzyŘ ΰKl·ΰ Ǿ2yãdzYʹŜ₩ă ø⁄λΰK l· ăYʹl·₩ΰ YʹŜΰŜ₩ λyʹΰKŜλ₩ K2YʹŜ ŜÈLJŜǾΰ Yʹ2₩Ŝ F₩2Y ΰKŜλ₩ dzΰλfΛΰûè λyʹΰŜ₩Yʹă 2Ŧ y2ΰλŦΛǾl·ΰλ2yã 2yʹLJ2ΰŜyΰλl·f ōλffă ăl·ØλyƎă 2₩ ŜÈǾŜăăŜă⌀ᵐᶠᴨ ² KλfŜ Yʹl·yè Ǿdzăΰ2YʹŜ₩ă ø⁄λff Ǿ2yΰλyΰzŜ ΰ2 ŘŜăλ₩Ŝ άLJfl·λyʹØl·yλffl·έᵐᶠᵖ ŜfŜǾΰ₩ΛǾΛΛûè ăŜ₩ØλǾŜΣ λyǾ₩Ŝl·ăλyƎfèΣ dzΰλfΛΰλŜă l·₩Ŝ ø⁄2₩⌈λyƎ ΰ2 ōŜΰΰŜ₩ ŜyƎl·ƎŜ l·yŘ λyŦ2₩Y ΰKŜλ₩ Yʹ2₩Ŝ ŜyŜ₩Ǝè⌀λyØ2fØŜŘ Ǿdzăΰ2YʹŜ₩ă l·yŘ l·₩Ŝ Yʹ2Ø⁄λyƎ ΰ2ø⁄l·₩Ř Yʹ2₩Ŝ Ǿdzăΰ2YʹŜ₩πǾŜyΰ₩ΛǾ ōdzăλySăă Yʹ2ŘŜfă⌀

9yƎl·ƎλyƎ Ǿdzăΰ2YʹŜ₩ă Kl·ă ŘλăΰλyǾΰ ōŜySŦλΰă Ŧ2₩ dzΰλfΛΰλŜă τ ŜyƎl·ƎŜŘ K2dzăŜK2fŘă l·ŘŘ ÞплçÞфл l·yŷ⁄zl·ffè ΰ2 l·₩ŜƎdzfl·ΰŜŘ dzΰλfΛΰûè⍺ ō2ΰΰ2Y fλyŜ óăŜŜ ¢l·ōfŜ нπм Ŧ2₩ l· ō₩Ŝl·⌈Ř2ø⁄yʹ2Ŧ ăl·Ø⁄λyƎăΰΣ l·yŘ ₩ŜăλŘŜyΰλl·f Ǿdzăΰ2YʹŜ₩ă ₩ŜLJ2₩ΰ dzLJ ΰ2 l· ф LJŜ₩ǾŜyΰ λyǾ₩Ŝl·ăŜ λyʹ ăl·ΰλăŦl·ǾΰΛ2yʹ ø⁄λΰK ΰKŜλ₩ dzΰλfΛΰûè⌀ᵐᶠᶜ ¦ΰλfΛΰλŜă Ŧdz₩ΰΚŜ₩ ōŜyŜŦλΰ Ŧ₩2Y ₩2ōdzăΰ Ǿdzăΰ2YʹŜ₩πŜyƎl·ƎŜYŜyΰ λyΰ₩Ŝl·ăŜ λyʹ ăl·ΰλăŦl·ǾΰΛ2yʹ ø⁄λΰK ΰKŜλ₩ dzΰλfΛΰûè⌀ᵐᶠᵀ !ǾǾ2₩ŘλyƎ ΰ2 l· ădz₩ØŜè 2Ŧ мпп LJ2ø⁄Ŝ₩πăŜǾΰ2₩ ŜÈŜǾdzΰλØŜă 2yʹfè н LJŜ₩ǾŜyΰ ΰKλyʹ ΰKŜλ₩ dzΰλfΛΰûè Kl·ă Ǝ22Ř Ǿdzăΰ2YʹŜ₩ 2dzΰ₩Ŝl·ǾK LJ₩2Ǝ₩l·YʹăΣᵐᶠʸ ōdzΰ Yʹ2₩Ŝ dzΰλfΛΰλŜă l·₩Ŝ λyØŜăΰYʹŜyΰă ΰKl·yʹΰK2ăŜ ø⁄λΰK f2ø⁄Ŝ₩ Ǿdzăΰ2YʹŜ₩πăl·ΰλăŦl·ǾΰΛ2yʹ ₩l·ΰλyƎă⌀ᵐᶠᵀ !ǾǾ2₩ŘλyƎ ΰ2 l· ădz₩ØŜè 2Ŧ мпп LJ2ø⁄Ŝ₩πăŜǾΰ2₩ ŜÈŜǾdzΰλØŜă 2yʹfè н LJŜ₩ǾŜyΰ ΰKλyʹ ΰKŜλ₩ dzΰλfΛΰûè Kl·ă Ǝ22Ř Ǿdzăΰ2YʹŜ₩ 2dzΰ₩Ŝl·ǾK LJ₩2Ǝ₩l·YʹăΣᵐᶠʸ ōdzΰ Yʹ2₩Ŝ dzΰλfΛΰλŜă l·₩Ŝ λyØŜăΰYʹŜyΰă ΰKl·yʹΰK2ăŜ ø⁄λΰK f2ø⁄Ŝ₩ Ǿdzăΰ2YʹŜ₩ă l·₩Ŝ Yʹ2₩Ŝ fλ⌈Ŝfè ΰ2 ōŜ l·LJLJ₩2ØŜŘ Ŧ2₩ ₩l·ΰŜ λyǾ₩Ŝl·ăŜă Ŧ2₩ yŜø⁄ λyØŜăΰYʹŜyΰă ΰKl·yʹΰK2ăŜ ø⁄λΰK f2ø⁄Ŝ₩ Ǿdzăΰ2YʹŜ₩ă l·₩Ŝ Yʹ2₩Ŝ ŜyŜ₩Ǝè⌀λyØ2fØŜŘ Ǿdzăΰ2YʹŜ₩ă l·yŘ l·₩Ŝ Yʹ2Ø⁄λyƎ ΰ2ø⁄l·₩Ř Yʹ2₩Ŝ Ǿdzăΰ2YʹŜ₩πǾŜyΰ₩ΛǾ ōdzăλySăă Yʹ2ŘŜfă⌀

Table 2-1. Potential Annual Cost Savings from Customer Engagement Solutions[200]

Value Source	Annual Savings Per Regulated Household
Effective marketing of new offerings	**$4–5**
Reduced cost-to-serve	
Reduced call volume, decreased escalations, etc.	$3–16
Increased adoption of e-billing	$3–5
Improved payment discipline	$1–4
Improved cost-effectiveness of energy efficiency (EE) program portfolio	
EE program cost savings via Behavioral EE	$2–5
EE program cost savings via Thermostat EE	$20–35
Behavioral DR capacity and energy cost savings	
Behavioral demand-response capacity savings	$7–20
Potential aggregate value, $/household, per year	**$40–90**

Customer engagement can provide cost savings to utilities across several functions: program marketing, customer care, energy efficiency, and demand response.

2.4.3 Privacy Concerns Could Limit Utilization of Consumer Data

t2fÔèY l·]Ŝ№ãΣ dzúλfúλŜãΣ l·yŘ úK№ŘπLJl·№úè LJ№2ØλŘŜ№ã l·№Ŝ λyÕ№Ŝl·ãλyƎfè Ǝ№l·LJLJfλyƎ øλúK LJ№ØλØl·Ôè Ô2yãλŘŜ№l·úλ2yã l·ã úKŜ l·Y2dzyú 2ŦŘl·úl· ƎŜyŶŜ№l·úŜŘ l·ō2dzú Ô2yãdzYŶŜ№ãΩ ŜfŜÖú№ÕλúèdzãlƎŜ Ǝ№2øã ŜÈLJ2yŜyúλl·ffè¢ C2№ №ŜãλŘŜyúλl·f Ô2yãdzYŶŜ№ãΣ Ô2yÔŜ№yã №ŜØ2fØŜ l·№2dzyŘ Ô2yú№2f 2Ŧ øKŜyΣ øKŜ№ŜΣ K2øΣ l·yŘ øλúK øK2Y l·yˇλyŘλØλŘdzl·f ãKl·№Ŝã Kλã 2№ KŜ№ 2øyˇLJŜ№ã2yl·f λyŦ2№YˇlúλΣ l·ã øŜff l·ã úKŜ №ƎKú ú2 l·ÔÖŜãã LJŜ№ã2yl·f λyŦ2№YˇlúλΣ ƎλØŜyˇú2 2úKŜ№ãΣ ú2 Ô2№№ŜÕú λúΣ l·yŘ ú2 Ŝyãdz№Ŝ λú λã ãl·ŦŜƎdzl·№ŘŜŘ l·yŘ ŘλãLJ2ãŜŘ 2Ŧ l·LJLJ№2LJ№λl·úŜfè¢ᴴᴸᴹ húKŜ№ l·ãLJŜÖúã 2Ŧ LJ№λØl·Ôè λyÕfdzŘŜ LJ№λØl·Ôè 2Ŧ úKŜ LJŜ№ã2yΣ LJ№λØl·Ôè 2Ŧ LJŜ№ã2yl·f ōŜKl·Øλ2№Σ l·yŘ LJ№λØl·Ôè 2Ŧ LJŜ№ã2yl·f Ô2YˇYdzyλÔl·úλ2yã¢ᴴᴶᴴ {2YˇŜ Ô2yãdzYŶŜ№ã l·№Ŝ №ŜãλãúÍl·yú ú2 ! aL ŘdzŜ ú2 úKŜ ãLJŜÕλŦλÔλúè 2Ŧ Řl·úl· Ô2ffŜÕúŜŘ 2yˇŜyŜ№Ǝèπdzãŝ Řl·úl· λyˇãYˇl·ffŜ№ l·yŘ ãK2№úŜ№ úλYˇŜ λyÕ№ŜYˇŜyúã¢ C2№ ŜÈl·YˇLJfŜΣ l·Õúdzl·f l·LJLJfλl·yÕŜã Ôl·yˇ ōŜ λŘŜyúλŦλŜŘ ōè úKŜλ№ f2l·Ř LJ№2ŦλfŜ ó№ŜŦ№λƎŜ№l·ú2№Σ ú2l·ãúŜ№Σ ø l·ãKλyƎ YˇlÔKλyŜΣ]Ŝúúf ŜΣ LJfl·ãYˇl· ¢±Σ 2ØŜyΣ ŜúÖ℅ú l·yŘ úλYˇŜã 2Ŧ dzãl·ƎŜ¢KŜãŜ Řl·úl· Ôl·yˇ №ŜØŜl·f ōdzλfŘλyƎ 2ÖÖdzLJl·yÕè΢ ōŜKl·Øλ2№l·f LJl·úúŜ№yãΣ l·yŘ λyŘλØλŘdzl·f LJ№ŜŦŜ№ŜyÕŜã℅ ² KλfŜ ã2YˇŜ Ô2yãdzYŶŜ№ã ãŜŜY úú2 LJ№ŜŦŜ№ úKŜ Ôl·LJl·ōλfúè ú2 Kl·ØŜ ãdzÔK ãYˇl·№ú l·LJLJfλl·yÕŜã l·yŘ ŜØŜyˇú2 ōŜ l·ōfŜ ú2 Ô2yú№2f úKŜYˇ №ŜY2úŜfè΢ 2úKŜ№ Ô2yãdzYŶŜ№ã Ř2 y2ú℅

t№λØl·Ôè Ô2yÔŜ№yã l·№Ŝ y2ú fλYˇλúŜŘ ú2 №ŜãλŘŜyúλl·f Ô2yãdzYŶŜ№ã℅ {Yˇl·№ú ōdzλfŘλyƎã Yˇl·è l·Ř?dzãú ōdzλfŘλyƎ Ô2yú№2fã΢ λyÕfdzŘλyƎ l±! /Σ fλƎKúλyƎΣ l·yŘ ãŜÕdz№λúè ãèãúŜYˇã ōl·ãŜŘ dzLJ2yˇ 2ÖÖdzLJl·yÕè fŜØŜfã l·yŘ 2ÖÖdzLJl·yÕè YˇλƎ№l·úλ2yˇ úK№2dzƎK2dzú úKŜ ōdzλfŘλyƎ℅ [l·№ƎŜ№ Ô2YˇYˇŜ№ÕλlˇfˇlˇyŘ λyŘdzãú№λl·f Ôdzãú2YˇŜ№ã Yˇl·è Kl·ØŜ fŜƎλúλYˇl·úŜ Ô2yÔŜ№yã l·ō2dzú ãλYˇλfl·№ dzãl·ƎŜ Řl·úl·Σ ãdzÔK l·ã]y2øλyƎ K2ø Yˇdzõ K l·yŘ øKŜyˇl· ãLJŜÕλŦλÔ úèLJŜ 2Ŧ úKŜ Ôdzãú2YˇŜ№ãã ŜIjdzλLJYˇŜyú λã 2LJŜ№l·úλ2yl·f΢ ōŜλyƎ λyúŜ№ÕŜLJúŜŘΣ 2№ l·Øl·λfl·ōfŜ ú2 úKŜ№ Ô2YˇLJŜúλú2№ã℅ /2YˇLJŜúλú2№ãΣ LJ2úŜyúλl·f ãdzλú2№ãΣ l·yŘ ŜØŜyˇ l·ãúdzúŜ λyØŜãú2№ã Ô2dzfŘ ōŜ]ŜŜyˇú2 fŜl·№yˇŦl·Ôλfúè dzúλfλÎl·úλ2yΣ LJ№2ŘdzÔúλ2yˇ№l·úŜãΣ l·yŘ 2úKŜ№ ãl·fλŜyú 2LJŜ№l·úλ2yl·f ŘŜúl·λfã ōŜŦ2№Ŝ ãdzÔK λyŦ2№Yˇl·úλ2yˇōŜÔ2YˇŜã LJdzōfλÔ l·ŦúŜ№ LJ№2ŘdzÕú ãl·fŜã Ø2fdzYˇŜã l·№Ŝ l·yy2dzyÕŜŘ 2№ ŘλãÕf2ãŜŘ℅ {λYˇλfl·№fè΢ Ǝ2ØŜ№yYˇŜyúl·f Ôdzãú2YˇŜ№ãΣ λyÕfdzŘλyƎ l·yŘ ŜãLJŜÕλl·ffè yl·úλ2yl·f ŘŜŦŜyãŜ l·ƎŜyÕλŜã 2№ úKŜ№ Ô2yú№l·Ôú2№ãΣ Yˇl·è Kl·ØŜ Ô2yÔŜ№yã l·ō2dzú dzyŦ№λŜyŘfè LJl·№úλŜã 2№ Ŧ2№ŜλƎy ƎØŜ№yYˇŜyúã dzyŘŜ№ãúl·yŘλyƎ l·yˇ l·ƎŜyÕè℅ã 2№ Ô2yú№l·Ôú2№℅ã Ǝ№λŘ ØdzfyŜ№l·ōλfúλŜã l·yŘ №Ŝljdzλ№ŜYˇŜyúãΣ dzãl·ƎŜΣ l·yŘ LJl·úúŜ№yã℅

[l·dzyÕKŜŘ λyˇ нлмн ōè úKŜ CŜŘŜ№l·f D2ØŜ№yYˇŜyúΣ úKŜ DŜ№ŜŜyˇ .dzúú2yˇ Lyλúλl·úλØŜᴴᴸᴼ ãλ l· LJl·№úyŜ№ãKλLJ øλúK úKŜ ŜfŜÖú№λÕ dzúλfúè λyŘdzãú№è ú2 LJ№2ØλŘŜ Ô2yãdzYŶŜ№ã øλúK Ŝl·ãèΣ ãŜÕdz№Ŝ l·ÖÖŜãã ú2 úKŜλ№ 2øyˇ ŜyŜ№Ǝè dzãl·ƎŜ

λyғ2NYl·úλ2yʹλyʹl· Ò2yãdzYŜNπғNλŜyŘfè l·yŘ Ò2YLJdzúŜNπғNλŜyŘfè ғ2NYl·úφʜлп a 2NŜ úKl·yʹсл Yʹλffλ2yʹK2dzžŜK2fŘă l·yŘ ōdzăλySăăŜă Ôl·yʹdzúλfλÎŜ DNŜŜyʹ . dzúú2yʹú2 l·ÒÒŜăă ŜySNƎèπdzăl·ƎŜ Řl·úl· ғN2Y úKŜλN ŜfŜÔúNλÒ dzúλfλúèφ ² KλfŜ úKλă LJN2ƎNl·Y LJN2ØλŘŜă λyŘλØλŘdzl·fă ǿλúK úKŜλN 2ǿyʹ ŜySNƎè dzžŜ Řl·úl·Σ ăúNŜl·YfλySŘ ăKl·NλyƎ 2ғ Řl·úl· ǿλúK úKλNŘ LJl·NúλŜăΣ l·ă ŜÈλăúă ǿλúK Ǝf2ōl·f LJ2ăλúλ2yλyƎ äèăúŜYʹ óDt{ú Řl·úl·Σ λă ăúλff y2ú l·Øl·λfl·ōfŜφ ¢KŜ нлмс hNl·yƎŜ . dzúú2yʹ LJN2ƎNl·Y ōdzλfŘă 2yʹDNŜŜyʹ . dzúú2yʹl·yŘ Ŝăúl·ōfλăKŜă ă2fl·N Řl·úl·φ

5h9 Kl·ă LJdzōfλăKŜŘ l· Ø2fdzyúl·Nè Ò2ŘŜ 2ғ Ò2yŘdzŎú ғ2N Řl·úl· LJNλØl·Òè NŜfl·úŜŘ ú2 ŜyŘπdzăŜN ŜyŜNƎèπÒ2yãdzYʹLJúλ2yʹ Řl·úl·φ ¦úλfλúλŜă Ôl·yʹ ŘŜY2yãúNl·úŜ ŰKŜλN Ò2YYλúYʹŜyú ú2 Ödzăú2YʹŜNăΩ Řl·úl· LJNλØl·Òè úKN2dzƎK Ø2fdzyúl·Nè l·ŘKŜNŜyŎŜ ú2 ŰKŜ 5l·úl·Ddzl·NŘ 9yŜNƎè 5l·úl· tNλØl·Òè tN2ƎNl·YΩă ăúl·yŘl·NŘă ŜyãdzNŜ Ödzăú2YʹŜNă l·yŘ NŜƎdzfl·ú2Nă ŰKl·ú dzăŜNă 2ғ Ödzăú2YʹŜN Řl·úl· l·ŘKŜNŜ ú2 l· YλyλYdzYʹ l·yŘ ǿŜffπl·NúλÖdzfl·ŰŜŘ fŜØŜf 2ғ Řl·úl· LJNλØl·Òèφ ! Ò2YLJl·yèΩă Ôfl·λY 2ғ l·ŘKŜNŜyŎŜ ú2 úKŜ 5l·úl·Ddzl·NŘ LJNλyÖλLJfŜă λă Ŝyғ2NÔŜl·ōfŜ ōè úKŜ CŜŘŜNl·f ¢Nl·ŘŜ /2YYλăăλ2yʹl·yŘ ăúl·úŜ Ò2yãdzYʹŜNπLJN2úŜÖúλ2yʹl·ƎŜyÖλŜăφ

2.4.4 Demand-Side Options Can Be Used to Avoid Costs of New Infrastructure

a l·yè dzúλfλúλŜă l·NŜ ғl·ÔλyƎ úKŜ LJN2ălJŜÔúă 2ғ fl·NƎŜ Ôl·LJλúl·f λyØŜăúYʹŜyúă λyʹ úNl·yãYʹλăăλ2yʹ l·yŘΣ ŜălJŜÔλl·ffèΣ ŘλăúNλōdzúλ2yʹ ăèăúŜYʹ dzLJƎNl·ŘŜă¢ ¢KŜ 9Řλă2yʹ C2dzyŘl·úλ2yʹ LJN2ȼŜÔúă úKl·ú ú2úl·f ¦φ{φ ŘλăúNλōdzúλ2yʹ Ôl·LJλúl·f λyØŜăúYʹŜyúă ғ2N úKŜ LJŜNλ2Ř нлмл ú2 нлол ǿλffōŜ Þрун ōλffλ2yʹλyʹy2YλYl·f úŜNYʹăφʜлр DŜ2ƎNl·LJKλÔl·ffè úl·NƎŜúŜŘ ŜySNƎè ŜғғλÔλŜyÖè l·yŘ 59w Kl·ØŜ úKŜ LJ2úŜyúλl·f ú2 Ò2ăúπŜғғŜÔúλØŜfè ŘŜғŜNΣ NŜŘdzÔŜΣ 2N NŜLJfl·ÔŜ Ôl·LJl·ÔλúèdzLJƎNl·ŘŜă ғ2N ŘλăúNλōdzúλ2yʹl·yŘ úNl·yãYʹλăăλ2yʹăèăúŜYʹă ōè NŜfλl·ōfè NŜŘdzÔλyƎ Yʹl·ÈλYdzYʹ ŘŜYʹl·yŘ λyʹăLJŜÔλfλÔ ƎNλŘl·NŜl·ă l·yŘ λyÖNŜl·ăλyƎ dzúλfλÎʹl·úλ2yʹ 2ғ ŜÈλăúλyƎ l·ăăŜúă㠌yʹ l·ŘŘλúλ2yʹ ú2 Ò2ăú ăl·ØλyƎăΣ LJ2úŜyúλl·f ōŜySғλúă 2ғ y2yπ ǿλNŜ l·fúŜNyl·úλØŜă λyÖfdzŘŜ YʹλúλƎl·úλyƎ ăλúλyƎ Ò2yÔŜNyã NŜfl·úŜŘ ú2 úNl·yãYʹλăăλ2yʹfλySăT ŜyƎl·ƎλyƎ Ò2yãdzYʹŜNă l·yŘ úKŜλN l·ƎSyúă óŜφƎφΣ l·ƎƎNŜƎl·ú2Năú λyʹ ŘλăúNλōdzúλ2yʹ l·yŘ úNl·yãYʹλăăλ2yʹ ă2fdzúλ2yãT Ŝyl·ōfλyƎ ƎNl·Řdzl·f λYLJfŜYŜyúl·úλ2yʹóNŜŘdzÔλyƎ úKŜ λYLJl·Ôú 2ғ λyÖ2NNŜÔú f2l·Ř LJN2ȼŜÔúλ2yãúT λYLJN2ØλyƎ NŜfλl·ōfλúè l·yŘ NŜăλfλŜyÔŜ úKN2dzƎK l· ŘλØŜNăλúè 2ғ YŜl·ădzNŜăT l·yŘ l·ÔÔŜfŜNl·úλyƎ ŘŜØŜf2LJYŜyú ûλYŜ ғNl·YŜă¢ ¢KŜăŜ l·fúŜNyl·úλØŜă Ôl·yʹōŜ λŘŜyúλfλŜŘ úKN2dzƎK ŘλăúNλōdzúλ2yʹ l·yŘ úNl·yãYʹλăăλ2yʹ LJfl·yyλyƎ ғ2N ălJŜÔλfλÔ ƎŜ2ƎNl·LJKλÔ l·NŜl·ă hNŘŜNă yфл l·yŘ мллл ōè C9w/ óŘλăÔdzăăŜŘ λyʹ ƎNŜl·úŜN ŘŜúl·λf λyʹ /Kl·LJúŜN LLLΣ *Building a Clean Electricity Future*ú NŜljdzλNŜ úNl·yãYʹλăăλ2yʹ LJN2ØλŘŜNă ú2 Ò2YLJl·Nl·ōfè úNŜl·ú l·ff NŜă2dzNÔŜă λyʹ l· úNl·yãYʹλăăλ2yʹ LJfl·yyλyƎ LJN2ÔŜăăΣ ǿKλÔK Yl·è λyÖfdzŘŜ λŘŜyúλfèλyƎ Kǿ úKŜè ǿλff úNŜl·ú ŘŜYl·yŘ NŜă2dzNÔŜă 2yʹ l· Ò2YLJl·Nl·ōfŜ ōl·ăλă ǿλúK úNl·yãYʹλăăλ2yʹ l·yŘ ƎŜySNl·úλ2yʹă2fdzúλ2yã ғ2N LJdzNLJ2ăŜă 2ғ úNl·yãYʹλăăλ2yʹLJfl·yyλyƎφʜлсΣнлтΣ нлу ¢KŜ . 2yySØλffŜ t2ǿŜN ! ŘYλyλăúNl·úλ2yʹ l·yŘ ă2YŜ ăúl·úŜă óŜφƎφΣ a l·λyŜ l·yŘ ±ŜNYʹ2yúú l·yŘ dzúλfλúλŜă Kl·ØŜ ōŜŜyʹŜl·Nfè 59w l·Ř2LJúŜNăφ

¢KŜ . N22ʅfèyʹ vdzŜŜya 5ŜYl·yŘ a l·yl·ƎŜYŜyú LJN2ȼŜÔú λă l·yʹŜÈl·YʹLJfŜ 2ғ l· dzúλfλúè LJfl·yʹғ2N dzăλyƎ ŘŜYl·yŘπăλŘŜ 2LJúλ2yãΣ l·f2yƎ ǿλúK dzúλfλúè NŜă2dzNÔŜăΣ ú2 l·Ø2λŘ ălJŜyŘλyƎ Þмфн ōλffλ2yʹғ2N ySǿ ădzōăúl·úλ2yãΣ ŤŜŘŜNăΣ l·yŘ ăǿλúÔKλyƎ ăúl·úλ2yã ú2 YŜŜúl· cфπa ² ăK2NúŤfl·ffλyʹúKŜ ƎN2ǿλyƎ .N22ʅfèyʹl·yŘ vdzŜŜya ō2N2dzƎKă 2ғ bŜǿ ¸2Nʅ /λúèφ /2yã2fλŘl·úŜŘ 9Řλă2yΩă ó/2y9ŘΩáú .N22ʅfèy vdzŜŜya 5ŜYl·yŘ a l·yl·ƎŜYŜyú LJN2ȼŜÔú ǿλff Ò2ăú l·yʹ ŜăúλYl·úŜŘ Þнлл Yʹλffλ2yΣ ǿKλÔK λyÖfdzŘŜă мт a ² 2ғ λyғNl·ăúNdzÔúdzNÛŜ λyØŜăúYʹŜyú l·yŘ рн a ² 2ғ ŘŜYl·yŘπăλŘŜ ă2fdzúλ2yã 2yʹ ō2úK úKŜ dzúλfλúè l·yŘ Ödzăú2YʹŜN ăλŘŜă 2ғ úKŜ YʹŜúŜNφ 5ŜYl·yŘπăλŘŜ 2LJúλ2yã λyÖfdzŘŜ ŜySNƎè ŜғғλÔλŜyÖè LJN2ƎNl·Yă ǿλúK NŜăλŘŜyúλl·f l·yŘ Ò2YYŜNÔλl·f Ödzăú2YʹŜNăΣ 5w l·dzÔúλ2yãΣ l·yŘ l· / l tπl·ÔÔŜfŜNl·úλ2yʹ LJN2ƎNl·Yφ /2y9Ř KŜfŘ λúă ғNNăú 5w l·dzÔúλ2yʹλyʹŜl·Nfè ! dzƎdzăú нлмс l·yŘ l·ǿl·NŘŜŘ мл Ò2yúNl·Ôúă úKl·ú ǿ2dzfŘ NŜădzfú λyʹ нн a ² 2ғ LJŜl·ʅ ŘŜYl·yŘ NŜŘdzÔúλ2yã λyʹ нлму ǿλúK LJl·èYŜyúă ú2 LJN2ØλŘŜNă Nl·yƎλyƎ ғN2Y Þнмрç Þфууκʅ ² κèŜl·N ŘŜLJŜyŘλyƎ 2yʹúKŜ l·Yʹ2dzyú 2ғ LJ2ǿŜN NŜŘdzÔúλ2yʹl·yŘ ŘŜYl·yŘ Yl·yl·ƎŜYŜyú ûŜÔKy2f2Ǝè dzăŜŘφ ¢KŜ l·ǿl·NŘŜŘ Ò2YLJl·yλŜă l·NŜ NŜăLJ2yãlōfŜ ғ2N ăλƎyλyƎ dzLJ /2y9Ř Ödzăú2YʹŜNă ǿλffλyƎ ú2 NŜŘdzÔŜ úKŜλN dzăl·ƎŜ ŘedzλyƎ LJŜl·ʅ K2dzNă 2N ŘŜLJf2è ûŜÔKy2f2ƎλŜă fλʅŜ ă2fl·N 2N ăú2Nl·ƎŜ ú2 Ödzú úKŜλN Ò2yãdzYʹLJúλ2yφ ¢KŜ dzúλfλúè ǿλff l·fă2 ōŜ ŘŜLJf2èλyƎ ăŜØŜNl·f 59wΣ λyÖfdzŘλyƎ ă2fl·N ƎŜySNl·úλ2yΣ ғdzŜf ÔŜffăΣ ōl·ûúŜNè ăú2Nl·ƎŜΣ l·yŘ Ø2fûl·ƎŜπ 2LJúλYλÎl·úλ2yʹûŜÔKy2f2ƎèΣ ú2 NŜŘdzÔŜ LJŜl·ʅ ŘŜYl·yŘ l·yŘ ăl·ØŜ ŜySNƎèφ

a 2NŜ úKl·yʹнрл ŜfŜÔúNλÔ Ò22LJŜNl·úλØŜă λyʹop ¦φ{φ {ûl·úŜă dzăŜ fl·NƎŜπÔl·LJl·Ôλúè ŜfŜÔúNλÔπNŜăλăúl·yÔŜ ǿl·úŜN KŜl·úŜNă ú2 ăKλғû ŘŜYl·yŘ l·ǿl·è ғN2Y LJŜl·ʅ K2dzNăφʜлф ¢KŜăŜ fl·NƎŜΣ λyãdzfl·ûŜŘ ǿl·úŜN KŜl·úŜNă ăú2NŜ ǿl·úŜN KŜl·úŜŘ ǿλúK

f2ø πÕ2ăű LJ2øŜℕ ŘdzℕλyƎ űλΥŜă 2ŧ 2ŦŦπLJŜI·ℸ ŘŜΥ I·yŘ ŧ2ℕ dzăŜ ŘdzℕλyƎ űλΥŜă 2ŧ KλƎKπÕ2ăű LJŜI·ℸ ŜyŜℕƎè ŘŜΥ I·yŘΣ ŜyI·ōfλyƎ Õ2π2LJă ű2 2LJűλΥ∧ÎŜ 2LJŜℕI·ûλ2ΥƵ 2ŧ űKŜ ƎℕλŘΦ [I·ℕƎŜ ø I·ûŜℕ KŜI·ûŜℕă I·fă2 Õ2yűℕλōdzûŜ ăλƎyλŦλÕI·yű I·yŘ Õ2yãλăűŜyű I·Υ2dzyűă 2ŧ f2I·ŘΣ Υ I·ℸλyƎ ûKŜΥ λŘŜI·f ÕI·yŘλŘI·ûŜă ŧ2ℕ dzűλfλűè 5w LJℕ2ƎℕI·Υăφ[HMM] . I·ăλΥ9fŜÕűℕλÕ /2πhLJΣ øKλÕK ℕŜfλŜă 2Υ ûKŜăŜ fI·ℕƎŜℕ øI·ûŜℕ KŜI·ûŜℕă ŧ2ℕ Υ I·yê 5w LJℕ2ƎℕI·Υăΐ Ŝăűλ Υ I·ûŜă ûKI·ú ûKŜăŜ ƎℕλŘπûλŜŘ øI·ûŜℕ KŜI·ûŜℕă KŜfLJ ℕŜŘdzÕŜ pлл a ² 2ŧ I·yƴdzI·f LJŜI·ℸ ŘŜΥ I·yŘ λΥűKŜ ¦ yλűŜŘ {úI·ûŜăφ[HMM]

¢KŜ I·LJLJfλÕI·ûλ2Υ 2ŧ 59w ű2 2ŦŧăŜű úℕI·Řλűλ2yI·f äèăűŜΥ dzLJƎℕI·ŘŜă LJℕŜăŜyűă I· yŜø ØI·fdzŜ LJℕ2LJ2ăλűλ2Υ I·yŘ ÕKI·ffŜyƎŜă K2ø dzűλfλűλŜă I·ℕŜ ûèLJλÕI·ffè Õ2ΥLJŜyãI·ûŜŘφ !ÕÕ2ℕŘλyƎ ű2 ûKŜ bŜø ¸2ℕℸ wŜŦ2ℕΥλyƎ ûKŜ 9yŜℕƎè ±λăλ2y 2ℕŘŜℕ 2Υ ℕI·ûŜΥ I·ℸλyƎ I·yŘ ûKŜ dzűλfλűè ℕŜØŜyƴdzŜπΥ2ŘŜf ŦℕI·ΥŜø2ℕℸ[ΣHMH] ûKŜ bŜø ¸2ℕℸ tdzōfλÕ {ŜℕØλÕŜ /2ΥΥλăăλ2y ŜÈLJŜÕűă ûKI·ú yŜø ŜI·ℕyλyƎ 2LJLJ2ℕúdzyλûλŜă ŧ2ℕ dzűλfλűλŜă λΥűKŜ yŜI·ℕ ûŜℕΥ øλff ōŜ I· Õ2Υōλyl·ûλ2y 2ŧ 2dzűÕ2ΥŜπōI·ăŜŘ λyÕSyűλØŜă I·yŘ ℕŜØŜyƴdzŜă ŜI·ℕyŜŘ ŘλℕŜÕűfè ŦℕΥ ûKŜ ŦI·ÕλfλűI·ûλ2y 2ŧ Õ2yãdzΥŜℕπŘℕλØŜyΥI·ℕℸŜűăφ

2.4.5 Aggregation of Individual Consumer Transactions Can Create Economies of Scale and New Business Models

! ƎƎℕŜƎI·ûλ2yÕI·y ōŜ 2ŧ ŜλűKŜℕ f2I·Ř óλΦŜΦΣ Õ2yãdzΥŜℕă ¿2λyλyƎ ű2ƎŜűKŜℕ ű2 I·ƎƎℕŜƎI·ûŜ LJdzℕÕKI·ăŜă 2ŧ ŜfŜÕűℕλÕλűèú 2ℕ 2ŧ ă2ΥŜ Õ2ΥōλyI·ûλ2y 2ŧ ădzLJLJfèπ I·yŘ ŘŜΥ I·yŘπăλŘŜ ℕŜă2dzℕÕŜăΦ /KI·yƎŜă λy ûŜÕKy2f2Ǝè I·ă øŜft I·ă ăűI·ûŜ LJ2fλÕè KI·ØŜ fŜŘ ű2 ûKŜ ŜØ2fdzűλ2y 2ŧ ú ø2 yŜøŜℕ Ŧ2ℕΥă 2ŧ I·ƎƎℕŜƎI·ûλ2yΣ λy I·ŘŘλûλ2yű2 5wY ØλℕúdzI·f LJ2øŜℕ LJfI·yű ó± t tú I·ƎƎℕŜƎI·ûλ2y I·yŘ Õ2ΥΥdzyλűè ÕK2λÕŜ I·ƎƎℕŜƎI·ûλ2yó / / ! úΦ

DR aggregation λă ōŜλyƎ LJdzℕădzŜŘ ōè ō2ûK ŜfŜÕűℕλÕ dzűλfλűλŜă I·yŘ Õ2ΥLJI·yλŜă øK2 ûKŜy úI·ℸŜ ûKŜ I·ƎƎℕŜƎI·ûŜŘ 5w I·yŘ ōλŘ λű λy w¢hκL{h øK2fŜăI·fŜ ΥI·ℕℸŜűăΣ ădzÕK I·ă tWaΣ L{hπbŜø 9yƎfI·yŘΣ aL{hΣ /I·fλŦ2ℕyλI· L{hΣ I·yŘ bŜø ¸2ℕℸ L{hΣ 2ℕ ŘŜfλØŜℕ λű ű2 Õ2yűℕI·ÕűŜŘ dzűλfλűλŜăΦ[E] 5w λy ûKŜăŜ øK2fŜăI·fŜ ΥI·ℕℸŜűă KŜfLJă f2øŜℕ øK2fŜăI·fŜ LJℕλÕŜăŦ I·ŘŘă ű2 ℕŜă2dzℕÕŜ ŘλØŜℕăλûèΣ øKλÕK ÕI·y ΚŜfLJ ℕŜfλI·ōλfλűèŦ I·yŘ ÕI·y I·fă2 KŜfLJ λyűŜƎℕI·ûŜ 2ûKŜℕ ℕŜă2dzℕÕŜă ădzÕK I·ă øλyŘ I·yŘ ă2fI·ℕΦ hyŜ ŜăűλΥI·ûŜ λă ûKI·ú oн D ² 2ŧ 5w ℕŜă2dzℕÕŜă I·ℕŜ y2ø I·ØI·λfI·ōfŜΣ I·ff 2ŧ øKλÕK I·ℕŜ ōℕλyƎλyƎ ûKŜ Õdzăű2Υ Ŝℕ ŘλℕŜÕűfè λyű2 øK2fŜăI·fŜ ŜfŜÕűℕλÕλűè ΥI·ℕℸŜűăφ[HMO]

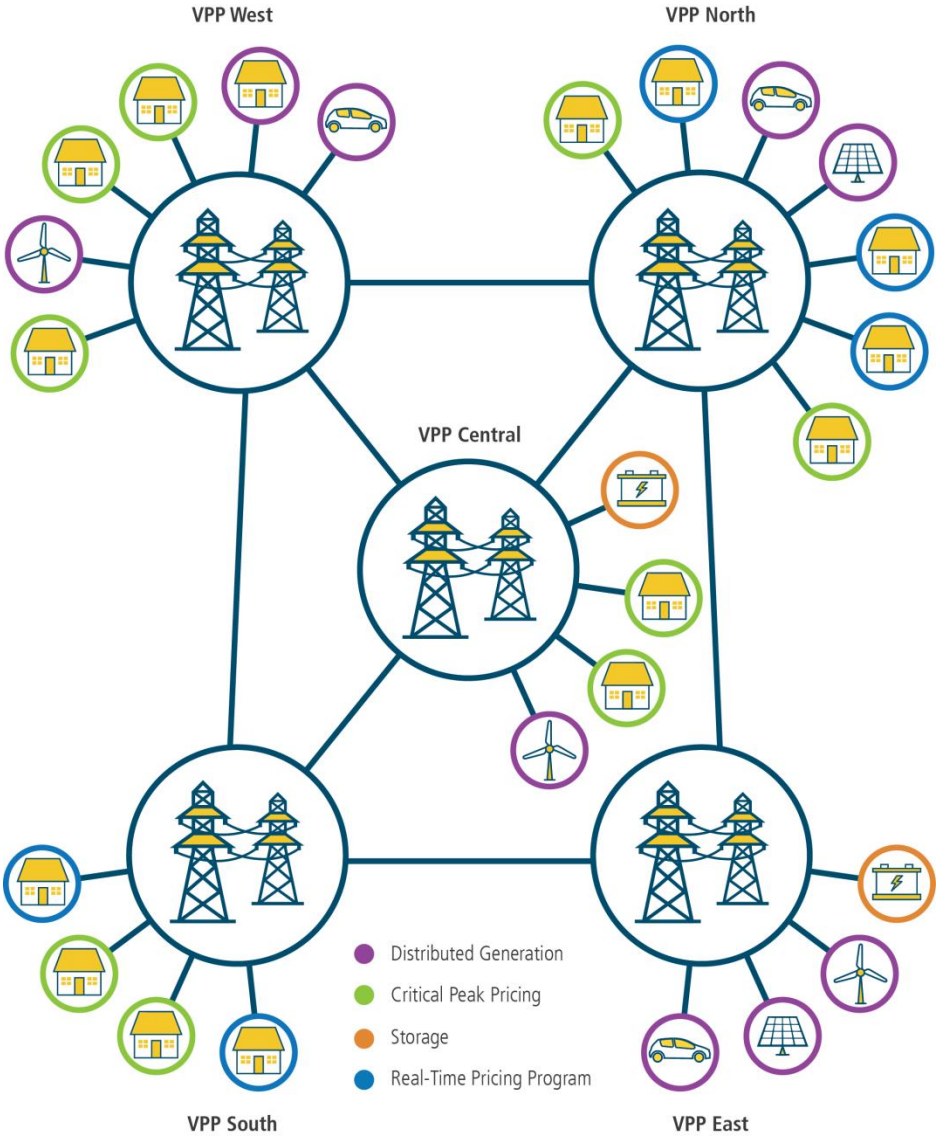
¢KŜ dzăŜ 2ŧ I·ƎƎℕŜƎI·ûŜŘ ŘŜΥI·yŘ ℕŜăLJ2yãŜ λy w¢hκL{h ΥI·ℕℸŜűă øI·ă ƎℕŜI·ûfè I·λŘŜŘ ōè C9w/Ωă λăădzI·yÕŜ 2ŧ hℕŘŜℕ b2φ τnpΣ øKλÕK ăI·λŘ ûKI·ú I· άŘŜΥI·yŘ ℕŜăLJ2yãŜ ℕŜă2dzℕÕŜ *must be compensated* ŧ2ℕ ûKŜ ăŜℕØλÕŜ λű LJℕ2ØλŘŜă ű2 ûKŜ ŜyŜℕƎè ΥI·ℕℸŜű I·ú ûKŜ ΥI·ℕℸŜű LJℕλÕŜ ŧ2ℕ ŜyŜℕƎèΣ ℕŜŦŜℕℕŜŘ ű2 I·ă ûKŜ f2ÕI·ûλ2yl·f ΥI·ℕƎλyl·f LJℕλÕŜφé[HMN] {λyÕŜ ûKŜℕŜ λă I· Υ∧ÈλyƎ 2ŧ ℕŜűI·λfπfØŜŦ ăŜℕØλÕŜă øλúK øK2fŜăI·fŜπfØŜŦ ăŜℕØλÕŜăΣ C9w/Ωă hℕŘŜℕ b2φ τnp ℕI·λăŜŘ I· yƴdzΥōŜℕ 2ŧ ăűI·ûŜ I·yŘ CŜŘŜℕI·f ¿dzℕλăŘλÕűλ2yl·f λăădzŜăΣ øKλÕK ûKŜ ¦φ{φ {dzLJℕŜΥŜ /2dzℕű I·ŘŘℕŜăăŜŘφ[HMP]

Virtual power plants (VPPs), pioneered in the 1980s in Austin, Texas, are systems that integrate a wide variety of power resources, such as smaller, local renewable or gas-fired generation, energy storage, and energy efficiency DR programs. They do this by aggregating many diverse customers from different customer classes "under one type of pricing, demand response, or distributed energy resource program."[216] Customers are not necessarily grouped by program or type, but they can also be aggregated by another defining characteristic, for example location (

CλƎdzℕŜ нπмnúφ . è ℕŜΥ2ûŜfè Õ2yűℕ2ffλyƎ ûKŜăŜ ±t tă I·yŘ I·ƎƎℕŜƎI·ûλyƎ ŘλŦŦŜℕŜyű ûèLJŜă 2ŧ LJℕ2ŘdzÕűăΣ dzűλfλűλŜă I·ℕŜ I·ōfŜ ű2 ōŜûűŜℕ ŧ2ℕŜÕI·ăű ŜyŜℕƎè ădzLJLJfè I·yŘ ŘŜΥI·yŘ I·yŘ λyÕℕŜI·ăŜ ûKŜ ŦfŜÈλōλfλűè I·yŘ ℕŜfλI·ōλfλűè 2ŧ ûKŜ ăèăűŜΥφ ! ŘŘλûλ2yl·ffèΣ I·ƎƎℕŜƎI·ûλ2Υ 2ŧ 5w LJℕ2ƎℕI·Υă I·ff2øă LJI·NûλÕλLJI·ûλ2yΥλy I· øK2fŜăI·fŜ ΥI·ℕℸŜûφ ¦ûλfλűλŜă λy ăŜØŜℕI·f ăűI·ûŜă I·ℕŜ ōŜƎλyyλyƎ ű2 ŧ2Õdză 2y ű2ŘI·èΩă yŜøŜℕ ØŜℕăλ2Υ 2ŧ ±t tăφ LΥ YŜyűdzÕℸèΣ ŧ2ℕ ŜÈI·YLJfŜΣ ûKŜ DfI·ă3ƎøøfŜÕűℕλÕ tfI·yű . 2I·ℕŘ λă λyăűI·ffλyƎ I· äèăűŜΥ 2ŧ ōI·ûűŜℕλŜă ûKI·ú ÕI·yΥℕŜfŜI·ăŜ LJ2øŜℕ ŘdzℕλyƎ LJŜI·ℸ ŘŜΥI·yŘ ûλΥŜăφ[HMT] {λΥλfI·ℕ LJℕ2ƎℕI·Υă I·ℕŜ ōŜλyƎ LJλf2ûŜŘ λΥ bŜø ¸2ℕℸ I·yŘ ±ŜℕΥ2yűφ[HMY] ¢2ŘI·èΣ ûŜÕKy2f2Ǝè I·yŘ L/¢ I·ℕŜ I·ff2øλyƎ Ŧ2ℕ ûKŜ Õ2yãλŘŜℕI·ûλ2Υ 2ŧ Υ2ℕŜ ŜfI·ō2ℕI·ûŜ Ŧ2ℕΥă 2ŧ ±t tăφ

[E] /KI·LJűŜℕ LLL ó*Building a Clean Electricity Future*ú ŘλăÕdzăăŜă ăűI·ûŜă ℕŜƎdzfI·ű2ℕè I·Õûλ2yã ûKI·ú λΥLJI·ÕûŜŘ 5wφ

Figure 2-14. Aggregations of Demand Response and Distributed Generation[219]



Aggregators acting as VPPs collect power and services from distributed resources including community solar, rooftop solar, EVs, distributed storage, and grid-controlled and price-reactive household devices. Aggregators are then able to bid these services collectively into wholesale electricity markets to meet system operation needs.

Community choice aggregation ŜyI·ōfŜă f2ŎI·f ƎƧØŜNyYŜyűă ű2 I·ƎƎNŜƎI·űŜ űKŜ ōdzèλyƎ LJ2ǿŜN 2Ŧ λyŘλØλŘdzI·f Ŏdzăű2YŜNă λy 2NŘŜN ű2 ăŜŎdzNŜ I·fűŜNyI·űλØŜ ŜyŜNƎè ădzLJLJfè Ŏ2yűNI·Ŏűă 2y I· Ŏ2YYdzyλűèǿλŘŜ ōI·ăλăΣ ǿKλfŜ YI·λyűI·λyλyƎ űKŜ ŜÈλăűλyƎ ŜfŜŎűNλŎλűè LJN2ØλŘŜN Ŧ2N űNI·yăYλăăλ2y I·yŘ ŘλăűNλōdzűλ2y ăŜNØλŎŜăφ^ннл {ŜØŜy ăűI·űŜă τ aI·ăăI·ŎKdzăŜűűăΣ bŜǿ ¸2NʅΣ hKλ2Σ /I·fλŦ2Nyλ I·Σ bŜǿ WŜNăŜèΣ wK2ŘŜ Lăfl·yŘΣ I·yŘ Lffλy2λă τ LJI·ăăŜŘ //! fI·ǿă I·ă LJI·Nű 2Ŧ ŜfŜŎűNλŎπNŜăűNdzŎűdzNλyƎ fŜƎλăfI·űλ2y λy űKŜ fI·űŜ мффлă I·yŘ ŜI·Nfè нллλăφ Ly нлмоΣ //!ă ǿŜNŜ I·ōfŜ ű2 ăŜŎdzNŜ Y2NŜ űKI·yφ Yλffλ2y a ² K 2Ŧ NŜyŜǿI·ōfŜ ŜyŜNƎè Ŧ2N I·LJLJN2ÈλY I·űŜfè нφп Yλffλ2yŎdzăű2YŜNăφ a 2ăű //!ă I·NŜ ђ2LJűπ2dzűђ ŜyűλűλŜăΣ YŜI·yλyƎ űKI·ű űKŜ Ŏdzăű2YŜN λă ōè ŘŜŦI·dzfű LJI·Nű 2Ŧ űKŜ I·ƎƎNŜƎI·űλ2y dzyfŜăă űKŜ Ŏdzăű2YŜN 2LJűă 2dzűφ

¢KŜ **community solar model** λă I·y I·ŘŘλűλ2yI·f YŜűK2Ř 2Ŧ 2NƎI·yλÎλyƎ űKŜ λyăűI·ffI·űλ2y 2Ŧ ă2fI·N ŦI·ŎλfλűλŜăφ Ly űKλă ăűNdzŎűdzNŜΣ ă2fI·N ŦI·ŎλfλűλŜă ădzLJLJfè LJ2ǿŜN ű2 YdzfűλLJfŜ Ŏdzăű2YŜNăΣ ŜyI·ōfλyƎ űKŜ LJfI·ŎŜYŜyű I·yŘ ăKI·NλyƎ 2Ŧ ă2fI·N

λyãűl·ffl·űλ2yã õè l· ŘλØŜNăŜ ∃N2dzLJ 2ŧ Ödzăű2YŜNă¢ ¢Kλă Y2ŘŜf λă YŜyűλ2ySŘ ăŜLJl·NJ·úŜfè õŜÖl·dzăŜ λű Öl·y õŜ ŘŜØŜf2LJŜŘ Øλl· Ydzfűλ LJfŜ 2øySNăKλLJ Ŧ2NYăΣ λyÖfdzŘλy∃ ƨ2λyűΣ Ydzy7ÖλLJl·fΣ l·yŘ dzűλfűûè¢

2.4.6 Interconnection and Interoperability Standards

LyűŜNÖ2yŷŜÖűλ2y ăűl·yŘl·NŘă τ űKŜ ăŜűă 2ŧ Ndzfŝă úKl·ű ŘŜűŜNYλyŜ űKŜ NŜljdzλNŜY ŜyŷűăŦ2N 5D 2N ăű2Nl·∃Ŝ û2 Ö2ŷŷŜÖű û2 űKŜ ŘλăúNλōdzűλ2y ∃NλŘ τ LJNŜăÖNλōŜ úKŜ Öl·LJl·ōλfűλŜă úKl·ű ûŜÖKy2f2∃λŜă Ydzăű LJ2ăăŜăă λy 2NŘŜN û2 ōŜ l·ff2øŜŘ û2 λyűŜNl·Öű øλúK úKŜ ∃NλŘ¢ ¢KŜăŜ ăűl·yŘl·NŘă l·NJŜ Ø2fdzyűl·N èΣ ōdzű Yl·yè ăűl·ûŜ t¦/ă NŜljdzλNJŜ úKŜλN ∂dzNλăŘλÖűλ2yl·f dzűλfűλŜă û2 l·Ř2LJű úKŜY l·yŘ úKdză Kl·ØŜ ōŜÖ2YŜ ŘŜπŦl·Öû2 λyŘdzăúNè ăűl·yŘl·NŘă¢ Ly нлмоΣ úKŜ Lyăűλúdzű Ŝ 2ŧ 9fŜÖúNλÖl·f l·yŘ 9fŜÖúN2yλÖă 9y∃λyŜŜNă ól999úΣ øKλÖK l·dzűK2Nă úKŜ ăűl·yŘl·NŘăΣ fl·dzyÖKŜŘ l· ŦdzffNŜØλăλ2y 2ŧ λűă {űl·yŘl·NJŘ мрпт á{űl·yŘl·NJŘ Ŧ2N LyűŜNÖ2yŷŜÖűλy∃ 5λăúNλōdzűŜŘ wŜă2dzNÖŜă øλúK 9fŜÖúNλÖ t2øŜN {èăúŜY ăΣε øλúK ŜÈLJŜNúă l·ű bl·ûλ2yl·f wŜySøl·ōfŜ 9yŜN∃è [l·ō2Nl·û2N è l·yŘ {l·yŘλl· bl·ûλ2yl·f [l·ō2Nl·û2NλŜă fŜl·Řλy∃ úKŜ {űl·yŘl·NJŘ ¢ŜÖKyλÖl·f tl·ySfΦHHM ¢KŜ NŜØλăλ2yΣ øKλÖK λă ÖdzNNŜyűfè dzyŘŜNøl·èΣ ăK2dzfŘ Öfl·NλŦè ŦdzyÖűλ2yã Ŧ2N ŘλăúNλōdzűŜŘ ăű2Nl·∃ŜΣ 5wΣ λyűŜN2LJŜNl·fŜ ōl·Ö¶πdzLJ ∃ŜySNl·û2yΣ l·yŘ Řλăúλōdzű ŜŘ t± NŜfl·űŜŘ û2 l·ŘØl·yÖŜŘ λyØŜNűŜN Ŧdzyűλ2yl·fλűèΣ Ö2YYdzyλÖl·û2yã Öl·LJl·ōλfűλŜăΣ Ö2yűN2făΣ l·yŘ λyűŜN2LJŜNl·ōλfűèΣ l·Y2y∃ 2úKŜN û2LJλÖă¢ ¢KŜăŜ Öl·LJl·ōλfűλŜă l·NŜ Ŧ2dzyŘl·û2yl·f Ŧ2N dzăλy∃ ŘλăúNλōdzűŜŘ ăű2Nl·∃ŜΣ öl·Ö¶πdzLJ ∃ŜySNl·û2yΣ l·yŘ t± ∃ŜySNl·û2NăûŝdzLJLJ2NűúKŜ Ŧdzyűλ2yλy∃ 2ŧ úKŜ ∃NλŘ λyúKŜ f2y∃ ûŜNYφ LyúKŜ ăK2Nűú ûŜNYΣ úKŜè øλff Ŝyl·ōfŜ ∃NŜl·ûŜN K2ăűλy∃ Öl·LJl·Öúûè l·yŘ Yλûλ∃l·ûŜ ă2YŜ λyűŜ∃Nl·û2yÖKl·ffŜy∃Ŝă¢

L999 LJfl·yã NŜ∃dzfl·N YŜŜűλy∃ă l·yŘ Ö2yŷŜÖűă ădzō2ŜÖű Yl·ûúŜN ŜÈLJŜNúă λy ∃2ØŜNyYŜyű l·yŘ λyŘdzăúNè û2 Ö2ftfl·ō2Nl·ûŜ 2y l·YŜyŘλy∃ ăűl·yŘl·NJŘă ōl·ăŜŘ 2y úKŜλN fl·ûŜăű dzyŘŜNăűl·yŘλy∃ 2ŧ ŜØ2fØλy∃ ûŜÖKy2f2∃è¢ ¢KŜ LJNλYl·NJè ÖKl·ffŜy∃Ŝ û2 Ö2YLJfŜûλy∃ úKŜ λyűŜNÖ2yŷŜÖűλ2y ăűl·yŘl·NJŘΣ ly2øy l·ă L999 {űl·yŘl·NJŘ мрпт NŜØλăλ2yΣ λă ÖλNÖdzfl·ûλy∃ úKŜ LJN2LJ2ăŜŘ NŜØλăŜŘ ăűl·yŘl·NJŘ ŭKN2dz∃K2dzű úKŜ λyŘdzăúNè l·yŘ l·NōλűNl·ûλy∃ Ö2YYŜyűă úKN2dz∃K úKŜ ōl·ff2ű LJN2ÖŜăă¢ L999 ŜÈLJŜÖűă 2ØŜN мΣллл Ö2YYŜyűă 2y úKŜ Ŧ2NűKÖ2Yλy∃ NŜØλăλ2yΣ ŜI·ÖK 2ŧ øKλÖK l· YŜYōŜN 2ŧ úKŜ ø2N ly∃ ∃N2dzLJ Ydzăű l·ŘŘNŜăă¢ ¢KŜ ø2N ly∃ ∃N2dzLJ ŜÈLJŜÖűă û2 ŜyűŜN úKŜ λyűλl·f ōl·ff2ûλy∃ LJN2ÖŜăă λy ŜI·Nfè нлмт¢ Lŧ úKŜ l·ØŜNl·∃Ŝ Y2yűKfè Nl·ûŜ 2ŧ Řλăúλōdzű ŘŜ ă2fl·N t± l·Ř2LJűλ2y ŦN2Y !LJNλf нлмр û2 !LJNλf нлмс NŜYl·λyã úKŜ ăl·YŜΣ l·y l·ŘŘλûλ2yl·f мл D² øλff ōŜ l·ŘŘŜŘ û2 úKŜ ∃NλŘ õè úKŜ ŜyŘ 2ŧ нлмуΣ Y2N Ŝ úKl·y Ř2dzōűλy∃ úKŜ ÖdzNNŜyű Öl·LJl·Öúûè¢HHH l ø ØŜØŜNΣ ŜØŜyl·ŦûŜNl 999 l·Ř2Lűûă úKŜ NŜØλăŜŘ ăűl·yŘl·NJŘăΣ t¦/ă l·yŘ dzűλfűλŜă øλff yŜŜŘ û2 Ö2yăλŘŜN l·yŘ l·Ř2LJű úKŜY λy 2NJŘŜN û2 Ŧl·Öλfűλl·ûŜ l·Ř0l·yÖŜŘ λyűŜNÖ2yŷŜÖűŜŘ l·yŘ λyűŜN2LJŜNl·ōfŜ 2LJŜNl·ûλ2y 2ŧ ∃NλŘπÖ2yŷŜÖűŜŘ ŘŜØλÖŜă¢ b2űl·ōfè úKŜ ÖdzNNŜyű LJdzōfűăKŜŘ ăűl·yŘl·NJŘ ómрпт¢l·ú ŜyÖ2YLJl·ăăŜă l·ăLJŜÖűă 2ŧ ŜÈűŜyŘŜŘ λyűŜN2LJŜNl·ōfűè Öl·LJl·ōλfűλŜăΣHHO ōdzű λű Kl·ă y2ű ōŜŜy λyøλŘŜfè l·Ř2LJűŜŘ¢ 9ÈLJŜŘλűλy∃ úKŜ Ö2YLJfŜûλ2y l·yŘ l·Ř2LJûλ2y2ŧ úKŜ мрпт {űl·yŘl·NJŘ NŜØλăλ2y øλff λYLJNl2ØŜ ă2YŜ 2LJŜNl·ûλ2yl·f ÖKl·Nl·ÖűŜNλăűλÖă 2ŧ LJNŜπŜÈλăűλy∃ ăèăűŜYă¢ Lű øλff l·fă2 l·ff2ø l· ∃NŜl·ûŜN LJŜNÖŜyűl·∃Ŝ 2ŧ yŜl·NπűŜNY Öl·LJl·ÖλûèL·ŘŘλûλ2yã û2 λyÖ2NLJ2Nl·ûŜ Yl·yè λYLJ2NűI·yű ∃NλŘ ŦdzyÖűλ2yã l·yŘ Öl·LJl·ōλfűλŜă úKl·ű ÖdzNNŜyű ăűl·yŘl·NJŘă Ř2 y2ű l·ŘŘNŜăă¢

Ly l·ŘŘλûλ2y û2 L999 ăűl·yŘl·NJŘăΣ bl·ûλ2yl·f 9fŜÖúNλÖl·f /2ŘŜ ăűl·yŘl·NJŘă Kl·ØŜ ÖKl·y∃ŜŘ ăλ∃yλŦλÖl·yűfè øλúK Ŝl·ÖK NŜØλăλ2y λy NŜÖŜyű èŜl·NăΦ ¢Kλă ÖKl·y∃Ŝ Kl·ă ōŜŜy λy NŜăLJ2yãŜ úKŜ Ö2yűλydzŜŘ ŜØ2fdzűλ2y 2ŧ ă2fl·N ûŜÖKy2f2∃è l·yŘ úKŜ ySŜŘ Ŧ2N l· ăűl·ōfŜ Yl·N¶Ŝű ŜyØλN2yYŜyű û2 Ŝyădzn ŜúKŜ LJN2fλŦŜNl·ûλ2y 2ŧ ăl·ŦŜΣ NŜfλl·ōfŜΣ l·yŘ Ö2ăűπ ŜŦŦŜÖűλØŜ ă2fl·N t±¢

Ly l·ŘŘλûλ2y û2 λyűŜNÖ2yŷŜÖűλ2yΣ λyűŜN2LJŜNl·ōλfűè λă l· ÖNλûλÖl·f NŜljdzλNŜYŜyű Ŧ2N ăŜl·YfŜăă λyűŜ∃Nl·ûλ2y 2ŧ ∃NλŘπ Ö2yŷŜÖűŜŘ ŘŜØλÖŜă¢HHΠ ¢KŜ bl·ûλ2yl·f Lyăűλúdzű Ŝ 2ŧ {űl·yŘl·NJŘă l·yŘ ¢ŜÖKy2f2∃è óbL{¢ú ŘŜŦλySă λyűŜN2LJŜNl·ōλfűè l·ă άXűKŜ Öl·LJl·ōλfűè 2ŧ úØ2 2N YN2NŜ ySűØ2NJăΣ ăèăűŜYăΣ ŘŜØλÖŜăΣ l·LJLJfλÖl·ûλ2yãΣ 2N Ö2YLJ2ySyűă û2 ŜÈÖKl·y∃Ŝ l·yŘ NŜl·ŘλfèdzăŜ λyŦ2NJYl·ûλ2yτ ăŜÖdzNŜfèΣ ŜŦŦŜÖűλØŜfèΣ l·yŘ øλúK fλűűfŜ 2N y2 λyÖ2yØŜyλŜyÖŜ û2 úKŜ dzăŜNΦ€HHP LyűŜN2LJŜNl·ōλfűè ăűl·yŘl·NJŘă λyÖNŜl·ăŜ úKŜ Ö2ăűπŜŦŦŜÖűλØŜyŜăă 2ŧ ∃NλŘπY2ŘŜNyλÎl·ûλ2y λyØŜăúYŜyűă ōè Yλûλ∃l·ûλy∃ úKŜ NλăJ 2ŧ ŘλØŜNăŜ ∃NλŘ ûŜÖKy2f2∃λŜă ōŜÖ2Yλy∃ LJNŜYl·ûdzNŜfè 2ōă2fŜûŜT l·ÖÖ2dzyűλy∃ Ŧ2N ōl·Ö¶øl·NJŘ Ö2YLJl·ûλōλfűè øλúK l·fNŜl·ŘèπŘŜLJf2èŜŘ ûŜÖKy2f2∃λŜăT Ŝyl·ōfλy∃ ûŜÖKy2f2∃è λyy2Øl·ûλ2yã Ŧ2N úKŜ Kl·NJŘøl·NJŜ l·yŘ ă2fúøl·NJŜ 2ŧ ∃NλŘπÖ2yŷŜÖűŜŘ ŘŜØλÖŜăT l·yŘ Ŝyădzn λy∃ úKŜ ăŜÖdzNλûè 2ŧ ŘŜØλÖŜă Ö2yŷŜÖűŜŘ û2 úKŜ ∃NλŘ¢HHC ¢KŜ 9yŜN∃è LyŘŜLJŜyŘŜyÖŜ l·yŘ {ŜÖdzNλûè !Öű 2ŧ нллт Yl·yŘl·ûŜŘ úKl·ű bL{¢ ŘŜØŜf2LJ l· ŦNl·YŜø2Nl¶ l·yŘ LJN2ű2Ö2fă Ŧ2N λyűŜN2LJŜNl·ōλfűè ăűl·yŘl·NJŘă 2ŧ ăYl·Nú ∃NλŘ ŘŜØλÖŜă¢ bL{¢Σ λyÖ22LJŜNl·ûλ2yøλúK úKŜ λyŘdzăúNè πfŜŘ {Yl·Nú DNλŘ

2.5 The Changing Preferences of Electricity Consumers: Impacts on Policies and Regulations

2.5.1 Compensating Providers of Grid Services

¢KŜ I·ŎŎdzNJI·ûŜ ŎKI·NJI·ŎûŜNJÂÎI·ûλ2y I·yŘ ØI·fdzI·ûλ2y 2Ŧ ăŜNJØλŎŜă ûKI·ú ySø ûŜŎKy2f2ΞλŜă LJN2ØλŘŜ ú2 ûKŜ ΞNJλŘ ŎI·y Ŏ2yúNJλōdzűŜ ű2 ŎfŜI·NJŜNJ LJNJλŎŜ ăλΞyI·fă ű2 Ŏ2yãdzY ŜNJă I·yŘ λyŦNJI·ăúNJdzŎűdzNJŜ 2øySNJăφ ¢Kλă ŎfI·NJλûè Ŝyãdz NJŜă ûKI·ú úNJI·ŘŜ2ŦŦă I·Y2yΞ ăèăűŜY I·ûúNJλōdzűŜă fλ⌊Ŝ I·ŦŦ2NJŘI·ōλfλûèΣ ădzăűJI·λyI·ōλfλúèΣ I·yŘ NJŜfλI·ōλfλûè I·NJŜ ăèăűŜY I·ûλŎI·ffè Ŏ2yãλŘŜNJŜŘΣ I·yŘ ûKI·ú ŘŜăλNJI·ŏfŜ LJN2LJŜNJúλŜă I·NJŜ Ŏ2Y LJŜyãI·ûŜŘ I·LJLJN2LJNJλI·ûŜfè λy I· NJI·LJλŘfè ŜØ2fØλyΞ ăèăűŜY¢ ¦ûλfλûλŜă I·NJŜ λyŎNJŜI·ăλyΞfè I·ûúŜY LJűλyΞ ű2 IjdzI·yűλŦè ûKŜ NJŜfI·ûλØŜ Ŏ2ăű 2Ŧ ŘŜY I·yŘπăλŘŜ ŜyŜNJΞè ŜŦŦλŎλŜyŎè I·yŘ f2I·ŘπY I·yI·ΞŜY Ŝyú λyØŜăúY Ŝyűă Ŏ2Y LJI·NJŜŘ ű2 ădzLJLJfèπăλŘŜΣ úNJI·yãY λăăλ2yΣ 2NJ ŘλăúNJλōdzűλ2y λyØŜăúY Ŝyűă λy dzűλfλûè I·yŘ NJŜΞλ2yI·f LJfI·yŷλyΞ LJN2ŎŜăăŜăΣ I·ă øŜff I·ă λyűŜNJŎ2yŷŜŎúπøλŘŜ I·yŘ yI·ûλ2yI·f LJ2fλŎè Y I·⌊λyΞφHHUΣ HHφΣ HOлΣ HOM hŦűŜyΣ λyØŜăúY Ŝyűă λy ŘŜY I·yŘπăλŘŜ ŜyŜNJΞè ŜŦŦλŎλŜyŎè ű2 ōI·fI·yŎŜ ădzLJLJfè I·yŘ ŘŜY I·yŘ 2y ûKŜ ŜfŜŎúNJλŎλûè äèăűŜY I·NJŜ fŜăă ŜÈLJŜyãλØŜ ûKI·y I·ŘŘλûλ2yI·f ădzLJLJfè I·yŘ LJN2ØλŘŜ I· NJI·yΞŜ 2Ŧ IjdzI·yűλŦλI·ōfŜ ōŜySŦλûăφHOHΣ HOO I2øŜØŜNJΣ ŎdzNJNJŜyú Y ŜûK2ŘăŦ2NJ Ŏ2yãλŘŜNJλyΞ ōŜySŦλûă 2Ŧ I·yŘ LJN2ŎdzNJλyΞ ŜySNJΞè ŜŦŦλŎλŜyŎè ŘλŦŦŜNJă ŦNJ2Y ădzLJLJfèπ ăλŘŜ λyØŜăúY Ŝyű ŘŜŎλăλ2yãΣ λyŎfdzŘλyΞ K2ø LJI·NJúλŎλLJI·yű Ŏ2ăűă I·NJŜ Ŏ2yãλŘŜNJŜŘ I·yŘ ûKŜ I·ōλfλûè 2Ŧ I· dzűλfλûè ú2 I·ŎIjdzNJŜ NJŜă2dzNJŎŜă 2dzűăλŘŜ λúă ăŜNJØλŎŜ úŜNJNJλú2NJè ú2 Y ŜŜú ŘŜY I·yŘφHOП

2.5.2 Valuation of Grid Services

! ōNJ2I·Ř ŜÈI·YλyI·ûλ2y 2Ŧ ØI·fdzI·ûλ2y NJŜØŜI·fă ΞI·LJă λy K2ø Y I·NJ⌊Ŝűă Σ λyŎŜyűλØŜă Σ NJŜΞdzfI·ûλ2yãΣ I·yŘ NJI·ûŜă Ŏ2Y LJŜyãI·ûŜ I·yŘ ØI·fdzŜ ăŜNJØλŎŜă LJNJ2ØλŘŜŘ ōè ŜY ŜNJΞλyΞ ûŜŎKy2f2ΞλŜă I·yŘ ăèăűŜY ű2LJ2f2ΞλŜăφ ! ă ySø ûŜŎKy2f2ΞλŜă ŘNJØŜ ŎKI·yΞŜă λy ΞNJλŘ Y 2ŘŜNJyλÎI·ûλ2y I·yŘ 2LJŜNJI·ûλ2yãΣ dzyI·yűλŎλLJI·ûŜŘ ΞI·LJă λy ØI·fdzI·ûλ2yΣ øKλÔK λyI·ŘØŜNJûŜyűtè ŜÈŎfdzŘŜ ŜÈλăűλyΞ 2NJ ŜY ŜNJΞλyΞ ûŜŎKy2f2ΞλŜă 2NJ ăŜNJØλÔŜăΣ øλff fλ⌊Ŝfè ŜY ŜNJΞŜφ Cdzűdz NJŜ LJ2fλÔè 2ō?ŜŎűλØŜă I·yŘ ŎKI·ffŜyΞŜă Y I·è ŎNJŜI·ûŜ ySø I·LJLJN2I·ŎKŜă ű2 ØI·fdzλyΞ ăŜNJØλÔŜăΣ I·yŘ Ŏ2Y LJNJŜKŜyãλØŜ ØI·fdzI·ûλ2y Y ŜűK2Ř2f2ΞλŜă ŎI·y KŜfLJ λŘŜyűλŦè I·yŘ YλûλΞI·ûŜ ΞI·LJăφ I2øŜØŜNJΣ Ôf2ăλyΞ úKŜăŜ ΞI·LJă 2ŦűŜy NJŜIjdzNJNJŜă ăLJŜŎλŦλÔ ŜŦŦ2NJűă ű2 I·ŘŘNJŜăă ŦλyI·yŎŜΣ Y I·NJ⌊Ŝű NJdzfŜăΣ λyŎŜyűλØŜăΣ I·yŘ LJ2fλŎλŜăφ ² KλfŜ ØI·fdzI·ûλ2y NJŜY I·λyã I· KλΞKπfŜØŜf ŘλăŎdzăăλ2y λy úKŜ ŜfŜŎúNJλŎλûè ăŜŎű2NJΣ 2LJLJ2NJúdzyλúλŜă ŜÈλăű ű2 ŦλfŦ ŎdzNJNJŜyűΣ ŎfŜI·NJfè ŘŜŦλySŘ ΞI·LJă NJŜfI·ûŜŘ ű2 ŜyØλNJ2yY ŜyűI·fΣ NJŜfλI·ōλfλúèΣ ăŜŎdzNJλúèΣ I·yŘ NJŜăλfλŜyŎŜ ōŜySŦλúă 2Ŧ ySø ăŜNJØλÔŜăφ

¢KŜ ØI·fdzŜ ûKI·ú ySø ŜyŜNJΞè NJŜă2dzNJŎŜă LJNJ2ØλŘŜΣ ō2ûK λyŘλØλŘdzI·ffè I·yŘ λy I·ΞΞNJŜΞI·ûŜΣ ŘŜLJŜyŘă 2y ûKŜ Ŧ2ffŦ2øλyΞY

- **Type of resource:** 5λŦŦŜNJŜyű NJŜă2dzNJŎŜă øλff ōŜ I·ōfŜ ű2 LJN2ØλŘŜ ŘλŦŦŜNJŜyű ØI·fdzŜă λy ŘλŦŦŜNJŜyű ăλűdzI·ûλ2yãφ C2NJ ŜÈI·YLJfŜΣ øKλfŜ ŜyŜNJΞè ăű2NJI·ΞŜ I·yŘ t± øλff ōŜ I·ōfŜ ű2 LJN2ØλŘŜ NJŜI·ŎűλØŜ LJ2øŜNJ ú2 ûKŜ ΞNJλŘΣ 2ûKŜNJ ŘŜØλŎŜă óŜφΞΣ ŜŦŦλŎλŜyű øλyŘ2øăú øλff y2ûφ
- **Location:** ¢KŜ ØI·fdzŜ ûKI·ú I· NJŜă2dzNJŎŜ ŎI·y LJN2ØλŘŜ ŘŜLJŜyŘă 2y λűă f2ŎI·ûλ2y 2y ûKŜ ŘλăúNJλōdzűλ2y 2NJ úNJI·yãY λăăλ2y ăèăűŜYφ C2NJ ŜÈI·YLJfŜΣ LJfI·ŎλyΞ ŜŦŦλŎλŜyŎè YŜI·ădzNJŜă 2y t± ySI·NJ LJ2λyűă 2Ŧ Ŏ2yΞŜăúλ2y YI·è KI·ØŜ YdzŎK Y2NJŜ ØI·fdzŜ ű2 ûKŜ ŜfŜŎúNJλŎ ΞNJλŘ ûKI·y LJfI·ŎŜă øλúK y2 Ŏ2yΞŜăúλ2yφ
- **Time:** ² KŜy ûKŜ NJŜă2dzNJŎŜ LJN2ØλŘŜă ûKŜ ăŜNJØλŎŜ λă λYLJ2NJúI·yűφ C2NJ ŜÈI·YLJfŜΣ λŦ ŜyŜNJΞè ŜŦŦλŎλŜyŎè YŜI·ădzNJŜă NJŜŘdzŎŜ LJŜNJλ2Ră 2Ŧ LJŜI·⌊ f2I·ŘΣ ûK2ăŜ YŜI·ădzNJŜă YI·è ōŜ I·ōfŜ ű2 ŘŜŦŜNJ ōdzλfŘλyΞ ySø ΞŜySNJI·ûλ2y 2NJ ŘλăúNJλōdzűλ2ykúNJI·yãY λăăλ2y dzLJΞNJI·ŘŜăφ

/dzNJNJŜyűfèΣ Y I·yê ØI·fdzI·ûλ2y ŜŦŦ2NJűă Ŧ2Ŏdză 2y ûKŜ Ŏ2yűNJλōdzűλ2yã 2Ŧ ăLJŜŎλŦλŎ ŜyŜNJΞè ûŜŎKy2f2ΞλŜăΣ ōdzű ű2 ōŜ Ŧdzffè ŜŦŦŜŎűλØŜΣ ØI·fdzI·ûλ2y Y dzăű ōŜ Ř2yŜ λy I· ăèăűŜY Ŏ2yűŜÈűΣ I·yŘ ŜăűλY I·ûλyΞ ûKŜ ØI·fdzŜ 2Ŧ I·y λyŘλØλŘdzI·f ûŜŎKy2f2Ξè 2dzűăλŘŜ ûKŜ ăèăűŜY Ŏ2yűŜÈűΣ λă ădzō2LJûλY I·fφHOP /KI·yΞŜă ű2 ûKŜ ăèăűŜYΣ øKŜûKŜNJ NJŜΞdzfI·ûλ2Nè ŎKI·yΞŜă 2NJ ûŜŎKy2f2Ξè ŎKI·yΞŜăΣ ŎI·y KI·ØŜ ō2ûK f2ŎI·ûλ2yI·f I·yŘ ûŜY LJ2NJI·f ăèăűŜY λY LJI·Ŏűăφ vdzI·yűλŦèλyΞ ûKŜ ØI·fdzŜ 2Ŧ I·y λyŘλØλŘdzI·f ûŜŎKy2f2Ξè øKdzfŘ λyØ2fØŜ Ô2Y LJI·NJλyΞ ûKŜ ăúI·ûŜă 2Ŧ ûKŜ ăèăűŜY ŌŜŦ2NJŜ I·yŘ I·ŦűŜNJ ûKŜ ûŜŎKy2f2Ξè øI·ă λyãűI·ffŜŘφ

2.5.3 Rate Designs for Valuing New Services

9fŜŐúŃλŐλúêNJI·úŜă I·NŜ úKŜ ăŐKŜŘdzfŜ 2Ŧ LJNλŐŜă úKI·ú dzúλfλúλŜă ŐKI·NƎŜ ŜyŘ dzăŜNă Ŧ2NJ úKŜ LJN2ØλăIλ2y 2Ŧ ăŜNØλŐŜΦ wI·úŜY I·ʅλyƎΣ úKŜ LJN2ŐŜăă 2Ŧ ŜăúI·ōfλăKλyƎ NJI·úŜăΣ λă I·y I·ŘY λyλăúNJI·úλØŜ LJN2ŐŜăă ŘŜăIƎyŜŘ ú2 NŜŐ2ØŜN ŜÈLJŜŐúŜŘ Ő2ăúă I·yŘ LJN2ØλŘŜ úKŜ dzúλfλúê I·y 2LJLJ2Núdzyλúê ú2 ŜI·Ny I·y I·ff2ØŜŘ NJI·úŜ 2Ŧ NŜúdzNyΦ ¢KN2dzƎK Ő2ăúπ2ŦπăŜNØλŐŜ NJI·úŜăΣ dzúλfλúλŜă ŜI·Ny I· ŦI·ΛNJ NŜúdzNy 2y λyØŜăúŜŘ ŐI·LJλúI·f I·yŘ NŜŐ2ØŜN úKŜ Ő2ăú 2Ŧ ŘŜLJNŜŐλI·úλ2yΣ 2LJŜNJI·úλyƎ ŜÈLJŜyãŜăΣ I·yŘ úI·ÈŜăΦ ! ŘŘλúλ2yI·ffèΣ úKŜ NŜŐ2ØŜNè 2Ŧ Ő2ăúă λyNJI·úŜY I·ʅλyƎ λyúN2ŘdzŐŜă ōŜKI·Øλ2NJI·f λyŐŜyúλØŜă ú2 dzúλfλúλŜăΦ ¢KŜ ăúNdzŐúdzNŜ 2Ŧ ŜfŜŐúNλŐλúê NJI·úŜă ŘŜúŜNƳλyŜă úKŜ yI·údzNŜ 2Ŧ LJNλŐŜ ăλƎyI·fă ú2 Ő2yãdzY ŜNăΦ wI·úŜă I·NŜ úKŜ LJNλY I·Nè Y ŜŐKI·yλăY ōè ØKλŐK dzúλfλúλŜă LJN2ØλŘŜ λyŦ2NƳI·úλ2yú2 Ődzăú2Y ŜNă ú2 λyŦ2NƳ úKŜλN Ő2yãdzY LJúλ2y I·yŘ λyØŜăúY Ŝyú ōŜKI·Øλ2NΦ ¦Φ{Φ {dzLJNŜY Ŝ /2dzNú LJNŜŐŜŘŜyúă úKI·ú ŦNJI·Y Ŝ úKŜ fŜƎI·f NŜIjdzλNŜY Ŝyúă 2Ŧ NŜƎdzfI·úλ2y KŜfLJ ăKI·LJŜ NJI·úŜY I·ʅλyƎΦ[ê]

¢KŜ NJI·úŜY I·ʅλyƎ LJN2ŐŜăă ōŜƎλyã ŦλNăú ØλúK úKŜ ŘŜúŜNƳλyI·úλ2y 2Ŧ úKŜ dzúλfλúê NŜØŜyƳdzŜ NŜIjdzλNŜY Ŝyú I·yŘ Ŧ2ff2Øă ØλúK úKŜ ŘŜăIƎy 2Ŧ NJI·úŜΦ ¢KŜ NŜØŜyƳdzŜ NŜIjdzλNŜY Ŝyú ăλ I· Ŧ2NŜŐI·ăú 2Ŧ úKŜ ōdzŘƎŜú úKI·ú úKŜ dzúλfλúê ØλffNŜIjdzλNŜ ú2 Y ŜŜú ŜÈLJŜŐúŜŘ Ődzăú2Y ŜNăΩ ŜfŜŐúNλŐλúè yŜŜŘă ŘdzNλyƎ I· LJI·ăú 2NJ Ŧdzúdz NŜ ûŜăú èŜI·NΦ ¢KŜ ōI·ăλŐ Ŧ2NƳdzfI· Ŧ2NJ ŘŜúŜNƳλyλyƎ úKŜ dzúλfλúê NŜØŜyƳdzŜ NŜIjdzλNŜY Ŝyú ăY

*Revenue Requirement = (Rate of Return **x** Depreciated Rate Base) **+** Depreciation*

***+** Operations and Maintenance (including Fuel) **+** Taxes*

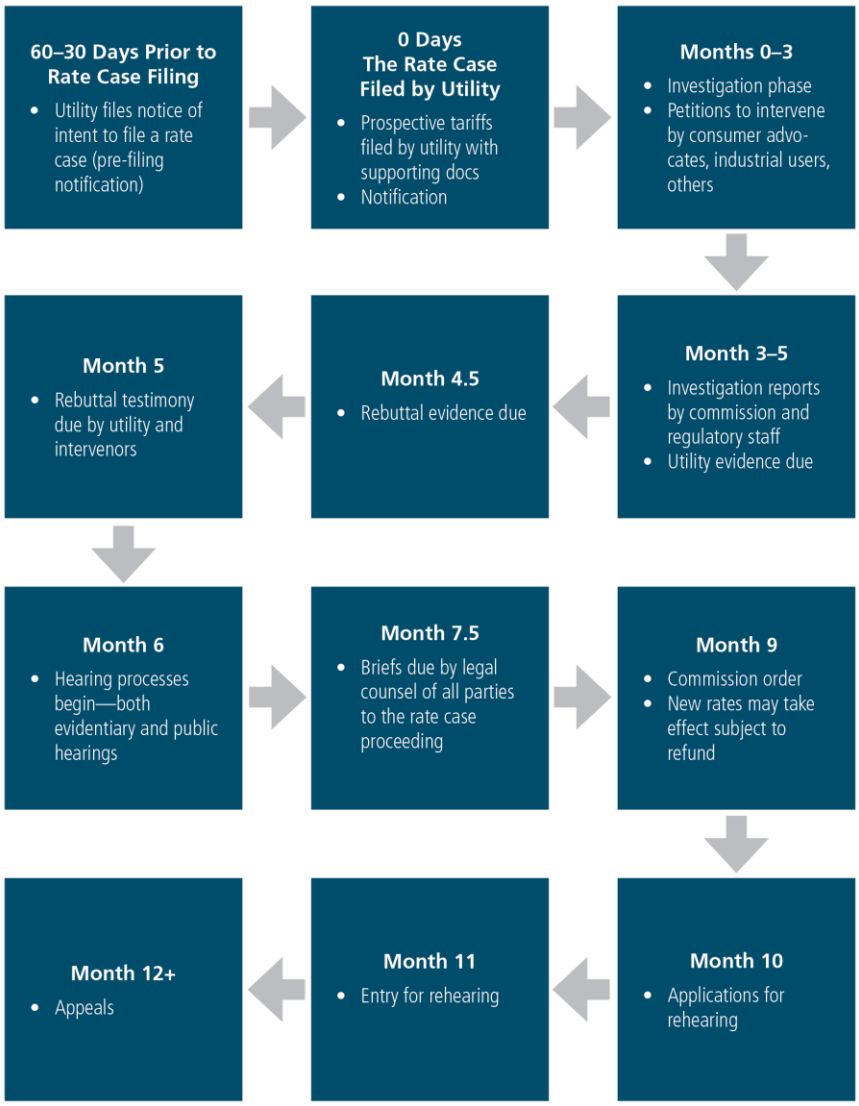
¢KŜ NJI·úŜπŘŜăλƎyLJN2ŐŜăă ōI·fI·yŐŜă úKŜ LJNλŐŜă Ődzăú2Y ŜNăă ăŜŜ ØλúK úKŜ dzúλfλúèQă I·ōλfλúê ú2 NŜŐ2ØŜN λúă NŜØŜyƳdzŜ NŜIjdzλNŜY Ŝyú Φ ¢KŜ LJN2ŐŜăă NŜIjdzλNŜă I·ff2ŐI·úλyƎ dzúλfλúê Ő2ăúă ú2 ŘλŦŦŜNŜyú Ődzăú2Y ŜN ŐfI·ăăŜă óŜΦƎΦΣ NŜăλŘŜyúλI·fΣ Ő2Y Y ŜNØλI·fΣ λyŘdzăúNλI·fú I·yŘ ú2 ŘλŦŦŜNŜyú NJI·úŜ ŐI·úŜƎ2NλŜă óŜΦƎΦΣ ŜyŜNƎè ŐKI·NƎŜăΣ ŘŜY I·yŘ ŐKI·NƎŜăúΦ ! ʅŜè ăúŜLJ λy úKŜ NJI·úŜπŘŜăλƎyLJN2ŐŜăă λă úKŜ ŘŜúŜNƳλyI·úλ2y 2Ŧ Ő2ăú ŐI·dzăI·úλ2y óúKŜ dzyŘŜNfèλyƎ NJI·úλ2yI·fŜ Ŧ2NJ λyŐdzNNλyƎ úKI·ú Ő2ăúúΣ ØKλŐK KŜfLJă ŘŜØŜf2LJ NJI·úŜă ØKŜNŜōè ŘλŦŦŜNŜyú Ődzăú2Y ŜNă LJI·è úKŜ Ő2ăú 2Ŧ LJNλ2ØλŘλyƎ úKŜ ăŜNØλŐŜă úKŜè dzăŜΦ ±I·Nλ2dză ŜfŜY Ŝyúă 2Ŧ Ő2ăúă óŜΦƎΦΣ ŘλăúNλōdzúλ2y Ő2ăúăΣ Y ŜúŜNλyƎΣ úNJI·yãY λăăλ2yú I·NŜ úKdză I·ff2ŐI·úŜŘ ú2 ŜI·ŐK Ődzăú2Y ŜN Őf I·ăăΦ LŘŜI·ffèΣ ŜI·ŐK Ődzăú2Y ŜN Ø2dzfŘ LJI·è 2yfè úKŜ Ő2ăú 2Ŧ LJN2ØλŘλyƎ ăŜNØλŐŜă úKI·ú úKŜ Ődzăú2Y ŜN dzăŜăΦ ! ă ŘλăŐdzăăŜŘΣ úKλă λă I·y I·ăLJNJI·úλ2yI·f Ǝ2I·f úKI·ú dzúλfλúλŜă 2Ŧúŝy Ř2 y2ú I·ŐKλŜØŜ λy LJNJI·ŐúλŐŜΦ

{2Y Ŝ ∂dzNλăŘλŐúλ2yã Y I·è KI·ØŜ NJI·úŜă λy ŜŦŦŜŐú Ŧ2NJ I· ăLJŜŐλŦλŐ úλY Ŝ LJŜNλ2ŘΣ ădzŐK I·ă o èŜI·NăΣ ØKλfŜ 2úKŜN ∂dzNλăŘλŐúλ2yã Y I·è I·ff2Ø NJI·úŜă ú2 NŜY I·λyΣ λy ŜŦŦŜŐúΣ λyŘŜŦλyλúŜfèΣ dzyfŜää úKŜ dzúλfλúêΣ úKŜ t ¦ /Σ 2NJ I· úKλNŘ LJI·NúêØλúK ăúI·yŘλyƎ ăŜŜʅ I· NJI·úŜ I·Ř∂dzăúY Ŝyú ØλI· I· Ő2Y LJfI·λyúΦ

/2yãλŘŜNJI·úλ2yã λyŐfdzŘŜ úKŜ ySŜŘă 2Ŧ ŐdzNNŜyú ØŜNădzã Ŧdzúdz NŜ NJI·úŜLJI·èŜNăT úKŜ ƎŜ2ƎNJI·LJKλŐ 2NJ ŘŜY 2ƎNJI·LJKλŐ ŐKI·NJI·ŐúŜNăúλŐă 2Ŧ NJI·úŜLJI·èŜNăT Ŧdzy ŘλyƎ Ŧ2NJ I·yè LJdzōfλŐ ōŜyŜŦλú LJN2ƎNJI·Y ăΣ fλʅŜ ŜŦŦλŐλŜyŐèΣ w∍5Σ 2NJ f2ØπλyŐ2Y Ŝ I·ăăλăúI·yŐŜ LJN2ƎNJI·Y ăT ŜØ2fØλyƎ úŜŐKy2f2ƎèT I·yŘ ă2ŐλI·f Ǝ2I·fă fλʅŜ ŜyØλN2yY Ŝyúl·f LJŜNŦ2NƳI·yŐŜΦ CλƎdzNŜ нπмp ōŜf2Ø λffdzăúNJI·úŜă úKŜ 2NŘŜN I·yŘ úλY ŜfλyŜ 2Ŧ I· úèLJλŐI·f ăúI·úŜ NJI·úŜπŐI·ăŜ LJN2ŐŜŜŘλyƎΦ

[ê] C2N ŜÈI·YLJfŜΣ λy *Knoxville v. Knoxville Water Company, 212 U.S. 1 (1909)*Σ úKŜ ¦Φ{Φ {dzLJNŜY Ŝ /2dzNú NŜŐ2ƎyλÎŜŘ úKŜ NλƎKú 2Ŧ I· dzúλfλúê ú2 NŜŐ2ØŜN úKŜ λyλúλI·f Ő2ăú 2Ŧ λyŦNI·ăúNdzŐúdzNŜ λyØŜăúY Ŝyú úKN2dzƎK ŘŜLJNŜŐλI·úλ2y ŐKI·NJI·ŐúŜNăúλŐă 2Ŧ NJI·úŜLJI·èŜNăT ŦdzyŘλyƎ Ŧ2NJ I·yè LJdzōfλŐ ōŜyŜŦλú LJN2ƎNJI·Y ăΣ fλʅŜ ŜŦŦλŐλŜyŐèΣ w∍5Σ 2NJ f2ØπλyŐ2Y Ŝ I·ăăλăúI·yŐŜ LJN2ƎNJI·Y ăT ŜØ2fØλyƎ úŜŐKy2f2ƎèT I·yŘ ă2ŐλI·f Ǝ2I·fă fλʅŜ ŜyØλN2yY Ŝyúl·f LJŜNŦ2NƳI·yŐŜΦ CλƎdzNŜ нπмp ōŜf2Ø λffdzăúNJI·úŜă úKŜ 2NŘŜN I·yŘ úλY ŜfλyŜ 2Ŧ I· úèLJλŐI·f ăúI·úŜ NJI·úŜπŐI·ăŜ LJN2ŐŜŜŘλyƎΦ *Bluefield Water Works & Improvement Company v. Public Service Commission, 62 U.S. 679 (1923),* úKŜ ¦Φ{Φ {dzLJNŜY Ŝ /2dzNú ŜăúI·ōfλăKŜŘ úKŜ LJNλyŐλJfŜ úKI·ú ðúKŜ NŜúdzNyăK2dzfŘ ōŜ NŜI·ă2yI·ōfè ădzŦŦλŐλŜyŐŜ úλ2 I·ăădzNŜ Ő2yfλŘŜyŐŜ λy úKŜ ŦλyI·yŐλI·f ă2dzyŘyŜăă 2Ŧ úKŜ dzúλfλúê I·yŘ ăK2dzfŘ ōŜ I·ŘŜIjdzI·úŜXű2 Y I·λyúI·λy I·yŘ ădzLJLJ2NúŐNŜŘλúXε

Figure 2-15. Timeline of a Typical Rate Case Proceeding[236]



Rate cases are lengthy and complex, often lasting a year or more. Depending on how utilities calculate their costs, this often leads to ñregulatory lag,òwherein rates come into effect long after utilities have made investments. Thus, utilities are typically recovering past, not current, costs.

¢èLJλŎI·ffèΣ ǘKŜ ℕI·ǘŜπŘŜăλƎƴLJℕƧŎŜăă ōŜƎλƴă ǿλǘK I· ŎƧăǘ ăǘdzŘè ǘKI·ǘ ŎKI·ℕI·ŎǘŜℕλÎŜă ǘKŜ ŜfŜƴŜƴǘă ƧŦ ǘKŜ dzǘλfλǘèΩă ŎƧăǘ ŦƧℕ LJℕƧǾλŘλƴƎ ăŜℕǾλŎŜ ǘƧ ŎdzăǘƧƴŜℕă I·ƴŘ ŘŜǘŜℕƴλƴŜă ŎƧăǘ ŎI·dzăI·ǘλƧƴΦ bƧǘŜ ǘKI·ǘ ǘKŜ *costs* ƧŦ LJℕƧǾλŘλƴƎ ăŜℕǾλŎŜ I·ℕŜ ǘKŜ ljdzI·ƴǘλŦλI·ōfŜ ǾI·fdzŜă ƧŦ I·ăăŜǘă I·ƴŘ LJƧfλŎλŜă ǘKI·ǘ I·ŎŎℕdzŜ ǘƧ ǘKŜ dzǘλfλǘèT ǘKŜ *price or charge* λă ǘKŜ ŎI·ăK ǾI·fdzŜ ƧŦ ǘKŜ ăŜℕǾλŎŜ ŘŜǘŜℕƴλƴŜŘ ōè ℕI·ǘŜ ℕŜƎdzfI·ǘλƧƴΣ λƴŎfdzŘλƴƎ ădzōăλŘλŜă—ǘKŜ dzǘλfλǘè ℕŜŎƧǾŜℕă *costs*Σ ǿKλfŜ ǘKŜ ŎdzăǘƧƴŜℕ ăŜŜă *prices and charges*Φ 9fŜƴŜƴǘă ƧŦ ŎƧăǘ ŦI·ff λƴǘƧ ǘKℕŜŜ ōI·ăλŎ ŎI·ǘŜƎƧℕλŜăƴ

MΦ **Fixed costs** I·ℕŜ ǘKŜ ōI·ăλŎ ŎƧăǘă ƧŦ LJℕƧǾλŘλƴƎ ăŜℕǾλŎŜ ǘKI·ǘ ŘƧ ƴƧǘ ǾI·ℕè ǿλǘK ǘKŜ fŜǾŜf ƧŦ ŜfŜŎǘℕλŎλǘè ŎƧƴădzƴ LJǘλƧƴΦ !ƴŜÈI·ƴLJfŜ ƧŦ I· ŦλÈŜŘ ŎƧăǘ λă ǘKŜ ŎƧăǘ ƧŦ I· ƴŜǘŜℕΣ I· ƴŜŎŜăăI·ℕè ŜfŜƴŜƴǘ ŦƧℕ LJℕƧǾλŘλƴƎ ăŜℕǾλŎŜ ǘKI·ǘ λă ŦdzƴŎǘλƧƴI·f ǿKŜǘKŜℕ ǘKŜ ŎdzăǘƧƴŜℕ dzăŜă ǾŜℕè fλǘǘfŜ Ƨℕ I· ƎℕŜI·ǘ ŘŜI·f ƧŦ ŜƴŜℕƎèΦ

HΦ **Capacity costs** ƴŜI·ădzℕŜ ǘKŜ λƴLJI·Ŏǘ ƧŦ dzăI·ƎŜ ƧƴăèăǘŜƴ λƴŦℕI·ăǘℕdzŎǘdzℕŜΣ ǿKŜℕŜ λƴŎℕŜI·ăŜă λƴŎdzăǘƧƴŜℕ ŎƧƴădzƴ LJǘλƧƴ ŎI·ƴ ǘℕλƎƎŜℕ ǘKŜ ƴŜŜŘ ŦƧℕ I·ŘŘλǘλƧƴI·f λƴǾŜăǘƴŜƴǘΦ CƧℕ ŜÈI·ƴLJfŜΣ λƴŎℕŜI·ăŜă λƴ I·λℕ ŎƧƴŘλǘλƧƴλƴƎ dzăŜ ŎI·ƴ ƴŜŎŜăăλǘI·ǘŜ ŘλăǘℕλōdzǘλƧƴ λƴǾŜăǘƴŜƴǘΣ ǿKŜℕŜ ǘKŜ ăλÎŜ ƧŦ I· ădzōăǘI·ǘλƧƴ

ădzLJLJ2NΰλyΞ Ι· NŜăλŘŜyΰλΙ·ſ Řλăΰ/NΛōdzΰλ2y´ſΙ·ΰŜNΙ·ſ LJ2ǿŜN fλyŜ λă ŘNΛØŜy´ōè ΰ/KŜ ySŜŘ ΰ2 NŜfλΙ·ōfè ăŜNØŜ ΰ/KŜ LJŜΙ·ϱ dzăΙ·ΞŜΣ ΰèLJΛÕΙ·ftě ŘNΛØŜy´ōè Ι·ΛN Õ2yŘλΰλ2yλyΞ 2y´ΰ/KŜ K2ΰΰŜăΰ ŘΙ·è 2ŦΰKŜ èŜΙ·N΢ / Ι·LJΙ·Õλΰè óŘŜYΙ·yŘú ÕKΙ·NΞŜă ÕΙ·y´ōŜ ŘŜăλΞyŜŘ ΰ2 ăλΞyΙ·ſ Õdzăΰ2YŜNăΩ ŜÈLJŜÕΰŜŘ Õ2yΰNΛōdzΰλ2y´ ΰ2 ySǿ λyØŜăΰYŜyΰ Ι·yŘ LJN2ØλŘŜ Ι· YŜÕK Ι·yλăY Ŧ2NJ NŜÕ2ØŜNΛyΞ ΰ/K2ăŜ Õ2ăΰăΣ 2yÕŜ λyÕdzNNJŜŘΦ

o Φ **Variable costs** Ι·NŜ LJNΛY Ι·NΛftě ΰ/KŜ ŜySNΞè Õ2ăΰă Ι·ăă2ÕλΙ·ΰŜŘ ǿλΰK LJN2ØλŘλyΞ ăŜNØΛÕŜΣ ădzÕK Ι·ă ŦdzŜfΦ ±Ι·NΛΙ·ōfŜ Õ2ăΰă ÕK Ι·yΞŜ ō Ι·ăŜŘ 2y´ΰ/KŜ Õdzăΰ2YŜNΩă ŜfŜÕΰNΛÕλΰè ŘŜY Ι·yŘ Ι·yŘ ΰ/KŜ ΰèLJŜă 2Ŧ ΞŜySNJΙ·ΰλ2y´ ÕΙ·LJΙ·Õλΰè Ι·ØΙ·λfΙ·ōfŜ λy´ΰ/KŜ ăèăΰŜY Φ

Ly´Ι·y´λŘŜΙ·ſ NJΙ·ΰŜY Ι·ϱλyΞ ăÕKŜY ŜΣ ΰ/KŜ ŜfŜY Ŝyΰă 2Ŧ Õ2ăΰ ǿ2dzfŘ Ŧλΰ yΙ·ΰdzNJΙ·ffè λyΰ2 ΰ/KŜ ΰ/KNJŜŜ Õ2YLJ2yŜyΰă 2Ŧ NJΙ·ΰŜăY óMΰ ŦλÈŜŘ óÕdzăΰ2YŜNΰ ÕKΙ·NΞŜăΣ óHΰ ΟΙ·LJΙ·Õλΰè óŘŜYΙ·yŘú ÕKΙ·NΞŜăΣ Ι·yŘ óoΰ ŜySNΞè óØΙ·NΛΙ·ōfŜΰ ÕKΙ·NΞŜă℗ ¢KŜ ŦλÈŜŘ Ödzăΰ2YŜN ÕKΙ·NΞŜ ǿ2dzfŘ NŜŦfŜÕΰ ΰ/KŜ ŦλÈŜŘ Õ2ăΰă 2Ŧ LJN2ØλŘλyΞ Ι· ăŜNØΛÕŜ℗ ¢KŜ ØΙ·NΛΙ·ōfŜ ŜySNΞè ÕKΙ·NΞŜ ǿ2dzfŘ NŜLJNŜăŜyΰ ΰ/KŜ Õ2ăΰ 2Ŧ ŜySNΞèΣ ŘŜΰŜNYλySŘ ŜΰKŜN ΰ/KN2dzΞK Ι·y´ŜfŜÕΰNΛÕλΰè YΙ·NJ ŜΰΙ·ϱ 2N ōè ΰ/KŜ ŦdzŜf Ι·yŘ 2ΰ/KŜN ØΙ·NΛΙ·ōfŜ Õ2ăΰă NŜljdzNNJŜŘ ΰ2 2LJŜNJΙ·ΰŜ ΰ/KŜ dzΰλfΛΰè℗ă 2ǿy´ΞySYŜNJΙ·ΰλ2y℗ / Ι·LJΙ·Õλΰè Õ2ăΰă ØΙ·Nè ōè ŘŜY Ι·yŘ Ι·yŘ Ι·NŜ ŘNΛØŜy´ōè ΰ/KŜ YΙ·ÈλYdzY ăèăΰŜY dzăΙ·ΞŜ ōŜÕΙ·dzŜ ŜfŜÕΰNΛÕΙ·ſ ăèăΰŜYă Ι·NŜ ŘŜăλΞySŘ ΰ2 Y ŜŜΰ LJŜΙ·ϱ SySNΞè Õ2yãdzYLJΰλ2y℗ ¢KŜ ŘŜY Ι·yŘ ÕKΙ·NΞŜ λă Ι· YŜÕK Ι·yλăY Ŧ2NJ ō2ΰK NŜÕ2ØŜNΛyΞ ÕΙ·LJΙ·Õλΰè Õ2ăΰă Ι·yŘ LJN2ØλŘλyΞ Ι· LJNΛÕŜ ăλΞyΙ·f ΰ2 Ödzăΰ2YŜNă Ι·ō2dzΰ ΰ/KŜλN Õ2yΰNΛōdzΰλ2y´ ΰ2 Õ2ăΰă Ι·ΰ ΰ/KŜ LJŜΙ·ϱ ¢ĖLJΛÕΙ·ffèΣ ΰ/KŜ ŘŜY Ι·yŘ ÕKΙ·NΞŜ λă ăŜΰ Ι·yy´dzΙ·ffèΣ ăŜNØΛyΞ Ι·ă Ι· NJΙ·ΰÕKŜΰ 2y´ΰ/KŜ Ödzăΰ2YŜNăΩ ōλftfă℗[Î]

¢NJΙ·ŘλΰΛ2yΙ·ffèΣ dzΰλfΛΰΛŜă NŜÕ2dzLJŜŘ ΰ/KŜλN Õ2ăΰă ŦN2Y Ödzăΰ2YŜNă ōè ÕKΙ·NΞλyΞ Ι· ΰǿ2πLJΙ·Nΰΰ NJΙ·ΰŜ ΰ/KΙ·ΰ Õ2yãλăΰŜŘ 2Ŧ Ι· Ø2fdzYŜΰNΛÕ ÕKΙ·NΞŜ Õ2YLJ2yŜyΰ Ι·yŘ Ι· ŦÈŜŘ ÕKΙ·NΞŜ Õ2YLJ2yŜyΰ℗ ±2fdzYŜΰNΛÕ ÕKΙ·NΞŜă Ι·NŜ ō Ι·ăŜŘ 2y´ΰ/KŜ Ι·Y2dzyΰ 2Ŧ ŜfŜÕΰNΛÕΰè Ι· Ödzăΰ2YŜN Ι·ÕΰdzΙ·ffè dzăŜă Ι·yŘ ΞŜySNJΙ·ffè Ι·NŜ Ι·ăăŜăăŜŘ LJŜN ϱ ² K℗ /dzăΰ2YŜNă LJΙ·è ΰ/KŜ ŦλÈŜŘ ÕKΙ·NΞŜ NŜΞΙ·NŘfŜăă 2Ŧ K2ǿ YdzÕK ŜfŜÕΰNΛÕλΰè ΰ/KŜè Õ2yãdzY Ŝ℗[ŀ] !y Ι·ŦèăΰăŘ KΙ·ØŜ ΞŜySNJΙ·ffè ÕN2ϱŜy´Řǿyΰ/KŜ ŦλÈŜŘ Õ2ăΰă ΰ/KΙ·ΰ ΰ/KŜ dzΰλfΛΰè λyÕdzNăλyΰ2 ΰǿ2 ÕΙ·ΰŜΞ2NJΛŜăY ăèăΰŜY πǿλŘŜ ŦλÈŜŘ Õ2ăΰă Ι·yŘ Ödzăΰ2YŜNπăLJŜÕΛŦλÕ ŦλÈŜŘ Õ2ăΰă℗ ! Ödzăΰ2YŜNπăLJŜÕΛŦλÕ ŦλÈŜŘ Õ2ăΰ λă ΰ/KŜ Õ2ăΰ ΰ/KŜ dzΰλfΛΰè λyÕdzNăλ ǿKŜy´λΰ λă ăŜNØΛÕλyΞ ΰ/KŜ Ödzăΰ2YŜN τ Ŧ2NJ ŜÈΙ·YLJfŜΣ ΰ/KŜ Õ2ăΰă ΰ2 YŜΰŜN ΰ/KŜ Ödzăΰ2YŜN Ι·yŘ λăădzŜ Ι· ōλftf℗ ¢KλăÕ2ăΰ λă λyŘŜLJŜyŘŜyΰ 2Ŧ ΰ/KŜ Ödzăΰ2YŜNΩă dzăΙ·ΞŜ℗ ! ăèăΰŜYπǿλŘŜ ŦλÈŜŘ Õ2ăΰ λă ΰ/KŜ Õ2ăΰ 2Ŧ KΙ·ØλyΞΣ NdzyŷλyΞΣ Ι·yŘ YΙ·λyΰΙ·λyλyΞ ΰ/KŜ ŜfŜÕΰNΛÕλΰè ΞNΛŘ τ NŜΞΙ·NŘfŜăă 2Ŧ K2ǿ YΙ·yê Ödzăΰ2YŜNă λΰ λă ăŜNØΛyΞ℗[HOT] Ι λăΰ2NJΛÕΙ·ffèΣ Õ2yãdzYŜN ŘŜYΙ·yŘ Ι·ff2ǿŜŘ dzΰλfΛΰλŜă ΰ2 ăŜÕdzNŜfè NŜÕ2dzLJ Y2ăΰ 2Ŧ ΰ/KŜλN ŦλÈŜŘ Õ2ăΰă ΰ/KN2dzΞK ΰ/KŜ Ø2fdzYŜΰNΛÕ NJΙ·ΰŜ℗ ¦ ΰλfΛΰλŜă ǿŜNŜ Ι·ōfŜ ΰ2 Ι·ăăŜăă 2yfè Ι·fλY λΰŜŘ ŦλÈŜŘ ÕKΙ·NΞŜ ΰ2 ŜΙ·ÕK Ödzăΰ2YŜNΣ ǿKλÕK ΞŜySNJΙ·ffè ŘλŘ y2ΰ Ι·ÕÕdzNJΙ·ΰŜfè NŜŦfŜÕΰ ΰ/KŜ ΰNdzŜ ŦλÈŜŘ Õ2ăΰă Ι· dzΰλfΛΰλŜă ΰ2 ăŜÕdzNŜfè NŜÕ2dzLJ Y2ăΰ 2Ŧ ΰ/KŜλN ŦλÈŜŘ Õ2ăΰă ΰ/KN2dzΞK ΰ/KŜ Ø2fdzYŜΰNΛÕ NJΙ·ΰŜ ΰ/KŜ Õdzăΰ2YŜNJΙ·ffè dzăŜă Ι·yŘ ΞŜySNJΙ·ffè Ι·NŜ Ι·ăăŜăăŜŘ LJŜN ϱ ² K℗ /dzăΰ2YŜNă LJΙ·è ΰ/KŜ ŦλÈŜŘ ÕKΙ·NΞŜ NŜΞΙ·NŘfŜăă 2Ŧ K2ǿ YdzÕK ŜfŜÕΰNΛÕλΰè ΰ/KŜè Õ2yãdzYŜ℗[ŀ] !y Ι·ŦèăΰăŘ KΙ·ØŜ ΞŜySNJΙ·ffè ÕN2ϱŜy´Řǿyΰ/KŜ ŦλÈŜŘ Õ2ăΰă ΰ/KΙ·ΰ ΰ/KŜ dzΰλfΛΰè λyÕdzNăλ ǿKŜy´λΰ λă ăŜNØΛyΞ℗[HOT] Ι λăΰ2NJΛÕΙ·ffèΣ Õ2yãdzYŜN ŘŜYΙ·yŘ Ι·ff2ǿŜŘ dzΰλfΛΰλŜă ΰ2 ăŜÕdzNŜfè NŜÕ2dzLJ Y2ăΰ 2Ŧ ΰ/KŜλN ŦλÈŜŘ Õ2ăΰă ΰ/KN2dzΞK ΰ/KŜ Ø2fdzYŜΰNΛÕ NJΙ·ΰŜ ΰ/KŜ Õdzăΰ2YŜNJΙ·ffè dzăŜă Ι·yŘ ΞŜySNJΙ·ffè Ι·NŜ Ι·ăăŜăăŜŘ LJŜN ϱ ² K℗ /dzăΰ2YŜNă LJΙ·è ΰ/KŜ ŦλÈŜŘ ÕKΙ·NΞŜ NŜΞΙ·NŘfŜăă 2Ŧ K2ǿ YdzÕK ŜfŜÕΰNΛÕλΰè ΰ/KŜè Õ2yãdzYŜ℗[ŀ] !y Ι·ŦèăΰăŘ KΙ·ØŜ ΞŜySNJΙ·ffè ÕN2ϱŜy´Řǿyΰ/KŜ ŦλÈŜŘ Õ2ăΰă ΰ/KΙ·ΰ ΰ/KŜ dzΰλfΛΰè λyÕdzNăλ ǿKŜy´λΰ λă ăŜNØΛyΞ℗[HOT] Ι λăΰ2NJΛÕΙ·ffèΣ Õ2yãdzYŜN ŘŜYΙ·yŘ Ι·ff2ǿŜŘ dzΰλfΛΰλŜă ΰ2 ăŜÕdzNŜfè NŜÕ2dzLJ Y2ăΰ 2Ŧ ΰ/KŜλN ŦλÈŜŘ Õ2ăΰă ΰ/KN2dzΞK ΰ/KŜ Ø2fdzYŜΰNΛÕ NJΙ·ΰŜ ΰ/KŜ Õdzăΰ2YŜNJΙ·ffè dzăŜă Ι·yŘ ΞŜySNJΙ·ffè Ι·NŜ Ι·ăăŜăăŜŘ LJŜN ϱ ² K℗ /dzăΰ2YŜNă LJΙ·è ΰ/KŜ ŦλÈŜŘ ÕKΙ·NΞŜ NŜΞΙ·NŘfŜăă 2Ŧ K2ǿ YdzÕK ŜfŜÕΰNΛÕλΰè ΰ/KŜè Õ2yãdzYŜ℗[ŀ] !y Ι·ŦèăΰăŘ KΙ·ØŜ

2.5.3.1 Time-Varying Rates Can Shift Demand

2.5.3.2 Locational Pricing Difficult to Implement

wŜŎŜyŭ LJ2fλŎλŜă ₸₪2Y ăŜØŜ₪I·f ăűI·űŜ t ¦ /ă KI·ØŜ ădzƎƎŜăúŜŘ ₪ŜƎdzfI·ű2₪è λyűŜ₪Ŝăú λy f2ŎI·úλ2yπōI·ăŜŘ LJ₪λŎλyƎ ₸2₪ ₪I·űŜLJI·èŜ₪ă Ř2ø y ű2 úKŜ ₸ŜŜŘŜ₪ fŜØŜfφ wŜƎdzfI·ű2₪ă λy a λyyŜă2ű I· ŎdzN₪Syűfè I·ff2ø dzŭλfλúλŜă ű2 λyŎ2₪LJ2₪I·ûŜ úKŜ f2ŎI·úλ2yπăLJŜŎλ₮λŎ ySű ōSyŜ₮λúă 2₮ 5D λyű2 LJ₪λŎŜă ŎKI·₪ƎŜŘ ₮2₪ LJI·₪ŭλŎdzfI·₪ ₪I·ûŜLJI·èŜ₪ăφŘŘ≤ нпс wŜƎdzfI·ű2₪ă λy bŜø ¸2₪ʔΣ I I·ø I·λΣ I·yŘ /I·fλ₮2₪yλI· KI·ØŜ ₪ŜŎŜyűfè ŜÈLJ₪ŜăăŜŘ λyűŜ₪Ŝăú λy f2ŎI·úλ2yπōI·ăŜŘ ₪I·ûŜăφнпт≤ нпу

I2øŜØŜ₪Σ Y2ăú ŘŜűŜ₪Yλy1·yűă 2₮ f2ŎI·úλ2y1·f ØI·fdzŜ I·₪Ŝ y2ú øλűKλy Ödzăű2YŜ₪ăΩ Ŏ2yű₪2fΣ 2₪ ŜØŜy øλűKλy úKŜ Ŏ2yãdzYŜ₪Ωă ʔy2øfŜŘƎŜΦ C2₪ ŜÈI·YLJfŜΣ λ₮ I· ăŜŎ2yŘI·₪è ú₪I·yã₮2₪YŜ₪ ăă ŎfăăŜ ű2 λűă ₪ŜăŜ₪ØŜ YI·₪Ǝλy I·yŘ ă2YŜ2yŜ øK2 fλØŜă ySI·₪ōè ōdzèă I·y 9±Σ úKŜ dzúλfλúè YI·è KI·ØŜ ű2 dzLJƎ₪I·ŘŜ úKŜ ú₪I·yã₮2₪YŜ₪Σ λyŎdz₪₪λyƎ I· ØŜ₪è ădzōăúI·yúλI·f f2ŎI·f Ŏ2ăúΦ LF úKI·ű dzúλfλúè ăă I·LJLJfèλyƎ f2ŎI·úλ2y1·f LJ₪λŎŜăΣ I·ff 2₮ úKŜ Ödzăű2YŜ₪ă 2yúKI·ú ₮ŜŜŘŜ₪ ø2dztŘ ăŜŜ úKŜλ₪ LJ₪λŎŜă Ǝ2 dzLJ λy ₪ŜăLJ2yãŜ ű2 2yŜ ySλƎKō2₪Ωă ŘŜŎλăλ2yΦ [zŎI·úλ2y1·f Ŏ2ăúă YI·è ₪Ŝ₮fŜŎű LJKèăλŎI·f ƎŜ2Ǝ₪I·LJKèΣ f2ŎI·f ŜŎ2y2YλŎ ŎKI·₪I·ŎűŜ₪ăúλŎăΣ I·yŘ fŜƎI·Ŏè LJfI·yyλyƎ ŘŜŎλăλ2yã YI·ŘŜ ōè dzúλfλúλŜăΣ I·yŘ úKŜăŜ Ŏ2YLJfŜÈλúλŜă λyű₪2ŘdzŎŜ 2LJLJ2₪údzyλúλŜă ₮2₪ λySIjdzλúλŜă ű2 Ŏ2yãdzYŜ₪ă0 ! ₮ŜŜŘŜ₪πōèπ₮ŜŜŘŜ₪ ŜŎ2y2YλŎ I·yŘ ŜyƎλySŜ₪λyƎ I·yI·fèăλă 2₮ úKŜ ØI·fdzŜ 2₮ Řλăú₪λōdzúŜŘ t± λy tI·Ŏλ₮λŎ DI·ă ϑ 9fŜŎú₪λŎ /2YLJI·yèΩă ăŜ₪ØλŎŜ ûŜ₪₪λú2₪è ₮2dzyŘ űKI·ú фл LJŜ₪ŎŜyű 2₮ ₮ŜŜŘŜ₪ă KI·Ř ySλúKŜ₪ Ŏ2ăűă y2₪ ōSyŜ₮λűă ₮₪2Y Řλăú₪λōdzúŜŘ t±Σ I·yŘ úKŜ KλƎKŜăú f2ŎI·úλ2yI·f ØI·fdzŜ 2y I·yè ₮ŜŜŘŜ₪ ø I·ă 2yfè I·ō2dzú Þсл LJŜ₪ ʔ ² LJŜ₪ èŜI·₪Σ ădzƎƎŜăúλyƎ úKI·ú úKŜ₪Ŝ YI·è ōŜ fλYλúŜŘ ōŜyŜ₮λú ű2 λyãúλúdzúλyƎ f2ŎI·úλ2yI·f LJ₪λŎŜăφнпф

2.5.4 Net Metering for Distributed Generation

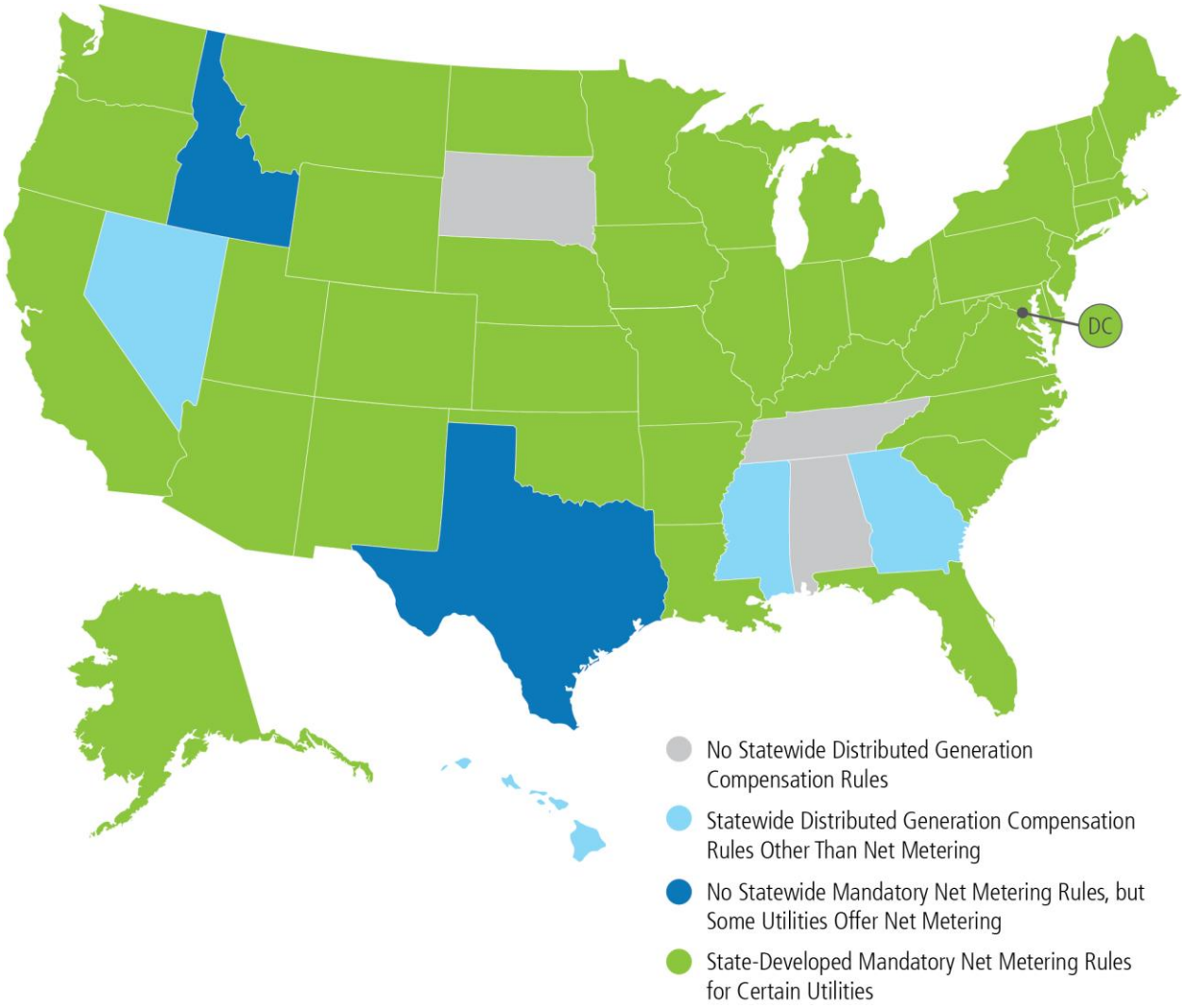
bŜű YŜűŜ₪λyƎ λă I· ₪I·ûŜ YŜŎKI·yλăY øKŜ₪ŜλyΌ Ödzăű2YŜ₪ă øλűK 2yãλúŜ ƎŜySŜ₪I·úλ2y fλʔŜ ₪222₮ű2LJ ă2fI·₪ I·₪Ŝ ŎKI·₪ƎŜŘ ₮2₪ úKŜ ØI·fdzŜ 2₮ úKŜλ₪ ySű Ŏ2yãdzYLJúλ2y óSfŜŎúλ₪λŎλûè Ŏ2yãdzYŜŘ fŜăă ŜfŜŎúλ₪λŎλûè LJ₪2ŘdzŎŜŘ ōè ă2fI·₪úΣ Ŏ₪ŜŘλúλyƎ 2yãλúŜ ƎŜySŜ₪I·úλ2y I·ú úKŜ ₮dzfŧ ₪Ŝűl·λf ₪I·ûŜΦ ! LJ₪2Øλăλ2y λy úKŜ 9ySŜ₪Ǝè t2fλŎè !Ŏű 2₮ нллр ₪ŜIjdzλ₪ŜŘ ăúI·ûŜă ű2 Ŏ2yãλŘŜ₪ ySű YŜűŜ₪λyƎ I·ă I·y 2LJúλ2y₮2₪ Ŏ2YLJŜyãI·úλyƎ 2øySŜ₪ă 2₮ 5DΦ /dz₪₪Syűfè≤ пм ăúI·ûŜă I·yŘ úKŜ 5λăú₪λŎú 2₮ /2fdzYōλI· KI·ØŜ I· ăúI·ûŜøλŘŜ ySű YŜűŜ₪λyƎ LJ2fλŎè≤ I·yŘ c ăúI·ûŜă KI·ØŜ I·fûŜ₪yI·úλØŜ Ŏ2YLJŜyãI·úλ2y YŜŎKI·yλăY ₮2₪ 5D óăŜŜ CλƎdz₪Ŝ нπмcúΦ {úI·ûŜă I·Ř2LJúŜŘ ySű YŜűŜ₪λyƎ LJ2fλŎλŜă Y2úλØI·ûŜŘ ōè I· ŘŜăλ₪Ŝ ű2 ƎŜySŜ₪I·ûŜ ŜfŜŎú₪λŎλûè ₮₪2Y ÎŜ₪2π 2₪ f2øπŜYλúûλyƎ ă2dz₪ŎŜăΣ ű2 ădzLJLJ2₪ú ŘŜLJf2èYŜyű 2₮ I· ySø ûŜŎKy2f2Ǝèΰ I·yŘ ű2 ƎλØŜ Ŏ2yãdzYŜ₪ă úKŜ 2LJúλ2y 2₮ ƎŜySŜ₪I·úλyƎ úKŜλ₪ 2øy LJ2øŜ₪φнрл ¢KŜ LJ2fλŎè KI·ă Ŏ2yű₪λōdzúŜŘ ű2 úKŜ ŘŜLJf2èYŜyű 2₮ мнΣолл a ² 2₮ λyãúI·ftŜŘ Řλăú₪λōdzúŜŘ t± λyúKŜ ¦ yλúŜŘ {úI·ûŜă I·ă 2₮ {ŜLJúŜYōŜ₪ нлмсφнрм

/2yãdzYŜ₪ă øλűK 5D I·₪Ŝ ăûλff Ŏ2yySŎűŜŘ ű2 úKŜ YI·λy Ǝ₪λŘΣ I·ff2øλyƎ úKŜY ű2 ōSyŜ₮λú ₮₪2Y úKŜ LJKèăλŎI·f Ŏ2yySŎűλ2y ű2 úKŜ Ǝ₪λŘ úKI·ú LJ₪2ØλŘŜă ōI·fI·yŎλyƎ ăŜ₪ØλŎŜăΣ ₪Ŝf1I·ōλfλúèΣ I·yŘ ōI·ăŜ f2I·Ř I·yŘ LJŜI·ʔλyƎ ƎŜySŜ₪I·úλ2y ₮2₪ ŜfŜŎú₪λŎλûè øKŜy úKŜ 5D ă2dz₪ŎŜ λă y2ú LJ₪2ŘdzŎλyƎ ŜfŜŎú₪λŎλûèΦ Ly I·ŘŘλúλ2y ű2 2yãλúŜ t± K2ăúăΣ YI·yê dzúλfλúλŜă KI·ØŜ ŜÈLJI·yŘŜŘ ySű YŜűŜ₪λyƎ ű2 Ödzăű2YŜ₪ă øK2 LJI·₪ŭλŎλLJI·ûŜ λy 2₮₮ăλúŜ ă2fI·₪ ƎŜySŜ₪I·úλ2yΣ ădzŎK I·ă Ŏ2YYdzyλûè ă2fI·₪Σ úK₪2dzƎK Øλ₪ŭdzI·f ySű YŜűŜ₪λyƎΦŜŜ {dzŎK LJ₪2Ǝ₪I·Yă ŜÈűŜyŘ úKŜ ōλff ăI·ØλyƎă ű2 Ŏ2yãdzYŜ₪ă øK2 Ř2 y2ű KI·ØŜ I·LJLJ₪2LJ₪λI·ûŜ ăLJI·ŎŜ ₮2₪ ă2fI·₪ 2y úKŜλ₪ 2øy LJ₪ŜYλăŜă 2₪ øK2 I·₪Ŝ dzyI·ōfŜ ű2 ₮λyI·yŎŜ ă2fI·₪ 2y úKŜλ₪ 2øy óSΦƎΦΣ f2øπλyŎ2YŜ Ŏ2yãdzYŜ₪ăúφ

ŘŘ ¢KŜ aλyySă2úI· ±I·fdzŜ 2₮ {2fI·₪ aŜűK2Ř2f2Ǝè I·ff2øă ₮2₪ λyŎ2₪LJ2₪I·úλyƎ úKŜ f2ŎI·úλ2y 2₮ úKŜ 59w λyŘŜűŜ₪YλyλyƎ λúă ØI·fdzŜ ű2 úKŜ Ǝ₪λŘΣ ōdzú λú λă y2ú ÔfŜI·₪ úKI·ú dzúλfλúλŜă KI·ØŜ I·ÔúdzI·ffè ŜÈŜ₪ŎλŜŘ úKI·ú ŘλăŎ₪Ŝúλ2yΦ

ŜŜ ±₪ŭdzI·f ySű YŜűŜ₪λyƎ ÔI·fŎdzfI·ûŜă I· ăKI·₪Ŝ 2₮ ySű YŜűŜ₪λyƎ ₮2₪ I·ff LJI·₪ûλŎλLJI·yűă λy I· Ǝ₪2dzLJT λú λă dzădzI·ffè I·ŘYλyλăŜ₪ŜŘ úK₪2dzƎK I· ădzōăŎ₪λLJûλ2y LJ₪2Ǝ₪I·YΣ øKŜ₪Ŝ Ŏ2yãdzYŜ₪ă ÔI·y ŜI·ăλfè øλűKŘ₪I·ø ₪₪2Y úKŜ LJ₪2Ǝ₪I·YΦ

Figure 2-16. Current Net Metering and Distributed Generation Compensation Policies [252]



Georgia, Hawaii, Mississippi, and Nevada offer alternative compensation mechanisms for DG such as net billing, which typically provides a rate of compensation for grid exports below the retail rate.

¢KŜNŜ I·NŜ I· ǿʎŘŜ ØI·NNʎŜúè 2Ŧ YŜűK2Řă Ŧ2NJ ØI·fdzʎyƎ 5D℗ bŜű YŜűŜNNʎyƎ ØI·fdzŜă 5D I·ú úKŜ NŜűI·ʎŧ NJI·úŜ℗ !ú f2ǿ LJŜySűNJI·úʎ2y˙fŜØŜfă I·yŘ ǿʎúK ŦŜǿ 2LJúʎ2yã Ŧ2NJ I·fűŜNyI·úʎØŜ YŜűŜNNʎyƎΣ ySű YŜűŜNNʎyƎ ʎă I· NŜI·ă2yI·ōfŜ I·LJLJN21·ŎK ű2 LJN2ØʎŘʎyƎ ØI·fdzŜ ű2 úKŜ Ödzǎű2YŜNJ I·yŘ úKŜ dzúʎfʎúè℗ !ă 5D LJŜySűNJI·úʎ2y˙ʎyŎNŜI·ăŜăΣ úKʎă I·ăǎdzYLJúʎ2y˙ōŜŎ2YŜă fŜää ØI·fűŘ℗ ¢KŜNŜ I·NŜ ŜÈűŜNyI·f ōSyŜŦʎúă I·ăă2ŎʎI·úŜŘ ǿʎúK úKŜ ŘŜØŜf2LJYŜyű 2Ŧ 5D℗ {2fI·NJ t± ŘʎăLJfI·ŎŜă ŎI·NJō2yπ ŜY˙ʎűűʎyƎ ă2dzNŎŜă℗ Lű ŎI·y˙ I·fă2 NŜŘdzŎŜ Ŏ2yƎŜăűʎ2y˙ 2y˙ ŘʎăűNʎōdzúʎ2y˙ fʎySăΣ I·fűK2dzƎK ʎű ŎI·y˙ I·fă2 ʎyŎNŜI·ăŜ Ŏ2yƎŜăűʎ2y˙—úKŜ ySű ŜŦŦŜŎű ōŜʎyƎ f2ŎI·úʎ2yπ I·yŘ Ŏ2yŦʎƎdzNJI·úʎ2yπăLJŜŎʎŦʎŎ℗

!ă 5D K2ăűă NŜŎŜʎØŜ úKŜ NŜűI·ʎŧ NJI·úŜ Ŧ2NJ ŜÈLJ2NNűŜŘ ŜfŜŎúNNʎŎʎúèΣ ă2YŜ KI·ØŜ ŎfI·ʎYŜŘ úKI·ú ySű YŜűŜNNŜŘ Ödzăű2YŜNă I·Ø2ʎŘ LJI·èʎyƎ úKŜ Ŧdzŧf 2yƎ2ʎyƎ Ŏ2ăűă 2Ŧ LJN2ØʎŘʎyƎ I·yŘ Y I·ʎyúI·ʎyʎyƎ ŘʎăúNNʎōdzúʎ2yπăèăűŜY ʎyŦNJI·ăűNJdzŎűdzNJŜ I·yŘ úKŜ Ŏ2ăűă 2Ŧ LJN2ØʎŘʎyƎ LJ2ǿŜNJ ǿKŜy˙úKŜ ŘʎăúNNʎōdzúŜŘ ƎSyŜNJI·ú2NNă I·NŜ y2ú ƎSyŜNJI·úʎyƎ óI·ă I·ú yʎƎKú ǿʎúK ă2fI·NJû℗ʜᵖᵒ a2NNŜ2ØŜNΣ ōŜŎI·dzăŜ Ø2fdzYŜűNJŎ *rates* I·ă ŘŜăʎƎyŜŘ I·NŜ ƎSyŜNJI·ffè y2ű I· úNJdzŜ NŜLJNŜăŜyűI·úʎ2y˙ 2Ŧ úKŜ dzúʎfʎúè℗ă ØI·NʎI·ōfŜ *costs* óúKŜè úèLJʎŎI·ffè ʎyŎfdzŘŜ I· ădzōăűI·yűʎI·f LJ2Nűʎ2y˙2Ŧ úKŜ dzúʎfʎúè℗ă ŦʎÈŜŘ Ŏ2ăűăΣ I·ă ǿŜftú ySű YŜűŜNNŜŘ Ödzăű2YŜNă ǿK2 NŜŘdzŎŜ úKŜ Ø2fdzYŜűNJŎ LJ2Nűʎ2y˙ 2Ŧ úKŜʎNJ ōʎff ǿʎff fʎ⟆Sfè LJI·è I· f2ǿŜNJ I·Y˙2dzyű ű2ǿI·NJŘ úKŜ dzúʎfʎúè℗ă ŦʎÈŜŘ Ŏ2ăűă℗ 9ŦŦʎŎʎSyŎè YŜI·ădzNJŜă ŎI·y˙KI·ØŜ ăʎY˙ʎfI·NJ ŜŦŦŜŎűă℗ ¢Kʎă ŎI·y˙fŜI·Ř ű2 NJŜØŜyűzŜ ăKʎŦűă ŦNJ2Y˙ f2ǿπ ŘŜY˙I·yŘ I·yŘ ySű YŜűŜNNŜŘ Ŏ2yădzYŜNă ű2 2úKŜNă ŘŜLJSyŘʎyƎ 2y˙f2ŎI·úʎ2y˙I·yŘ Ŏ2yŦʎƎdzNJI·úʎ2y℗ʜᵖᵑ /2yűŜyűʎ2dză

ŘλăÕdzăăλ2yã I·₦2dzyŘ úKŜ ₦Ŝădzfűă 2ŧ ySű YŜűŜ₦λyƎ λyÕfdzŘŜ ØKŜűKŜ₦ ₦I·úŜă ăú₦dzÕűdz₦ŜŘ λy űKλă YI·yŷŜ₦ ÕI·y Ǒŏ2yű₦λōdzúŜ ű2 λYLJ₦2LJŜ₦ ØI·fdzI·úλ2y 2ŧ Ǝ₦λŘ ăŜ₦ØλǑŜăΣ ₦ŜØŜyűzŜ ăKλŧűăΣ I·yŘ Õ2ăű ăKλŧűă ŧ2₦ YI·λyűI·λyλyƎ úKŜ Ǝ₦λŘ ŧ₦2Y 5D LJI·₦ŭűλǑλLJI·yűă ű2 2₦ ŧ₦2Y y2yπLJI·₦ŭűλǑλLJI·yűă℗ ¢KŜăŜ ăKλŧűă ÕI·y ōŜ ăλƎyλŧλǑI·yűΣ ØλúK I· ₦ŜÕŜyű ăŭdzŘè LJŜ₦ŧ2₦YŜŘ ŧ2₦ úKŜ / t ¦ / ŧ2₦ŜǑI·ăúλyƎ úKI·ú úKŜ Õ2ăű ăKλŧű I·ăă2ǑλI·ûŜŘ ØλúK ySű YŜűŜ₦λyƎ Ø2dzfŘ ōŜ Þм℗м ōλffλ2y LJŜ₦ èŜI·₦ ōè нлнл℗ʰᵖᵖ

{2YŜ ăűdzŘλŜă KI·ØŜ ŘŜY2yãú₦I·úŜŘ úKI·ú úKŜ LJ₦ŜăŜyÕŜ 2ŧ ₦ŜØŜyűzŜ ăKλŧűă Ř2Ŝă y2ű ySÕŜăăI·₦λfè λYLJfè úKI·ú ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă I·₦Ŝ y2ű Õ2ØŜ₦λyƎ úKŜ₦ Õ2ăű 2ŧ ăŜ₦ØλǑŜ℗ {údzŘλŜă 2ŧ ySű YŜűŜ₦λyƎ λy bŜØI·ŘI· I·yŘ / I·fλŧ2₦yλI· ădzƎƎŜăűŜŘ úKI·úΣ ₦ŜƎI·₦ŘfŜää 2ŧ f2ăű Õ2yű₦λǑdzúλ2y ű2 ŧλÈŜŘ Õ2ăúăΣ I· yűzYōŜ₦ 2ŧ ÕfI·ääŜă 2ŧ ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă KI·ØŜ ōŜŜy LJI·èλyƎ Y2₦Ŝ úKI·y λú Õ2ăúă ű2 ăŜ₦ØŜ úKŜY℗ᶠᶠᶜ ʜᴘᴄΣ ʜᴘᴛ Ly Õ2yű₦I·ăúΣ I· ăűdzŘè LJŜ₦ŧ2₦YŜŘ ŧ2₦ úKŜ [2dzλăλI·yI· tdzōfλÕ {Ŝ₦ØλÕŜ /2YYλăăλ2y Õ2yÕfdzŘŜŘ úKI·ú ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă Ř2 y2ú Õ2ØŜ₦ úKŜ₦ Õ2ăű 2ŧ ăŜ₦ØλǑŜ℗ʰᵖʸ LŦΣ I·ă úKŜ ŜØλŘŜyÕŜ ădzƎƎŜăűăΣ ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă I·₦Ŝ λy ă2YŜ ÕI·ăŜă Õ2ØŜ₦λyƎ úKŜ₦ Õ2ăűă ØKλfŜ Õ₦ŜI·úλyƎ I· ₦ŜØŜyűzŜ ăKλŧű ű2 2úKŜ₦ Ödzăű2YŜ₦ăΣ ₦I·úŜă YI·è ySŜŘ ű2 ōŜ ōŜűűŜ₦ I·fλƎySŘ ØλúK Õ2ăűă I·yŘ ōŜyŜŧλűă I·Õ₦2ää úKŜ äèäűŜY℗

Ly I·ŘŘλúλ2yΣ λy ă2YŜ λyãúI·yÕŜăΣ úKŜ ōŜySŧλűă 2ŧ ŘλăúλdzúŜŘ ă2fI·₦ YI·è ŜÈÕŜŜŘ úKŜ ₦ŜűI·λf ₦I·úŜ ₦₦2Y ySű YŜűŜ₦λyƎ LJ₦2Ǝ₦I·Yă I·yŘ ₦ŜădzfűλyI· ăKλŧű 2ŧ ōŜySŧλűă ₦₦2Y ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă ű2 2úKŜ₦ K2dzăŜK2fŘă℗ʰᵠᵠ a I·yè ăűdzŘλŜă KI·ØŜ I·úűŜY LJűŜŘ ű2 Ijdz I·yűλŧè y2ű ∂dzăű K2ø 5D I·ŘŘă Õ2ăűă ű2 úKŜ ŜfŜÕú₦λǑúè äèäúŜY ōdzű K2ø Řλăú₦λōdzúŜŘ t± λyÕ₦ŜI·ăŜă ă2ÕλI·f ōŜySŧλűă ōè ₦ŜŘdzÕλyƎ D I D ŜY λăăλ2yãΣ I·λ₦ LJ2ffdzúλ2yΣ ŜÈLJ2ădz₦Ŝ ű2 ŧdzŜf LJ₦λÕŜ Ø2fI·úλfλúèΣ I·yŘ úKŜ ySŜŘ ŧ2₦ ŜfŜÕú₦λǑúè ƎŜySŧI·úλ2y I·ú úλYŜă 2ŧ LJŜI·ʅ f2I·Ř℗ᴱᶾᶜ ʜᴄʌ 5ŜLJŜyŘλyƎ 2y úKŜ YŜűK2Ř dzăŜŘ I·yŘ úKŜ ÕdzN₦Ŝyű ƎŜySŧI·úλ2y úŜÕKy2f2ƎλŜă Õ2yãλŘŜ₦ŜŘΣ úKŜ ŜyØλ₦2yYŜyűI·f ōŜySŧλűă KI·ØŜ ōŜŜy Ŝăúλ YI·úŜŘ I·ú YŽ₦Ŝ úKI·y мл ÕŜyűă LJŜ₦ ʅ ² K I·yŘ úKŜ ŧdzŜf LJ₦λÕŜ ₦ăλ ʅ ₦ŜŘdzÕúλ2y I·ú I· ăλYλfI·₦ØI·fdzŜ℗ʰᶜᴹ . è λyÕfdzŘλyƎ ŜyØλ₦2yYŜyűI·f ōŜySŧλűăΣ ăŜØŜ₦I·f ăűI·úŜă KI·ØŜ ŧ2dzyŘ úKI·ú úKŜ ű2űI·f ØI·fdzŜ 2ŧ Řλăú₦λōdzúŜŘ t± ŜÈÕŜŜŘă úKŜ ₦ŜűI·λf ₦I·úŜ℗ ʰᶜᴴ a I·yè 2ŧ úKŜăŜ Õ2ăűă I·yŘ ōŜySŧλűă I·₦Ŝ áŜĔűŜ₦yI·fλúλŜăέ úKI·ú I·₦Ŝ y2ø y2ú ûèLJλÕI·ffè LJI·₦ű 2ŧ dzűλfλúè Õ2yãλŘŜ₦I·úλ2y℗ I2øŜØŜ₦Σ λű ăK2dzfŘ ōŜ y2űŜŘ úKŜăŜ ŜyØλ₦2yYŜyűI·f I·yŘ äèäűŜY ōŜySŧλűă I·ÕÕ₦dzŜ ŜIjdzI·ffè ŧ₦2Y ō2úK Řλăú₦λōdzúŜŘ t± I·yŘ dzűλfλúèπăÕI·fŜ ă2fI·₦ ƎŜyŜ₦I·úλ2yT ōdzűΣ λy ƎŜyŜ₦I·fΣ dzűλfλúèπăÕI·fŜ ă2fI·₦ ƎŜyŜ₦I·úλ2y λă y2ű ŜfλƎλōfŜ ŧ2₦ ySűπYŜűŜ₦λyƎπfλʅŜ Õ2YLJŜyãI·úλ2y ăú₦dzÕűdz₦ŜăKK

/2yãλŘŜ₦λyƎ úKŜ Õ2YLJfŜÈλúè 2ŧ ŜØI·fdzI·úλyƎ Řλăú₦λōdzúŜŘ ŜySŜ₦Ǝè λyØŜăúYŜyűăΣ ă2YŜ ăúI·ûŜ ₦ŜƎdzfI·ű2₦ă I·₦Ŝ ₦ŜŜØI·fdzI·úλyƎ Õ2YLJŜyãI·úλ2y Y2ŘŜfă ŧ2₦ dzűλfλúèπăÕI·fŜ ă2fI·₦ ƎŜyŜ₦I·fΣ dzűλfλúèπăÕI·fŜ I·yŘ ŜÈLJf2₦λyƎ λyy2ØI·úλØŜ ØI·ëă ű2 ØI·fdzŜ úKŜ Õ2ăűă I·yŘ ōŜyŜŧλűă 2ŧ 59w ű2 úKŜ Ǝ₦λŘ I·yŘ λYLJ₦2ØŜ YI·₦ʅŜű YŜÕKI·yλăYă úKI·ú I·fλƎy λyØŜăúYŜyűăΣ ōŜKI·Ø₦2₦ I·yŘ 2LJŜ₦I·úλ2yã℗ bŜű YŜűŜ₦λyƎ 2yfè Õ2YLJŜyãI·úŜă ŧ2₦ ŜySŜ₦Ǝè ăŜ₦ØλÕŜă ØλúK2dzű LJ₦2ØλăλyãΣ ŧ2₦ LJI·èYŜyűă ŧ2₦ Ǝ₦λŘ ăŜ₦ØλÕŜă ădzÕK I·ă Ø2fúκØI·₦ óØ2fúπI·YLJŜ₦Ŝ ₦ŜI·ÕúλØŜú ădzLJLJ2₦ú I·yŘ 2úKŜ₦ I·yÕλffI·₦è ăŜ₦ØλÕŜă℗ bŜø Õ2YLJŜyãI·úλ2y I·₦₦I·yƎŜYŜyűă Õ2dzfŘ λyÕŜyű Ödzăű2YŜ₦ă ű2 LJ₦2ØλŘŜ úKŜăŜ ăŜ₦ØλÕŜăΣ ōdzű øλúK2dzű yŜø LJI·èYŜyű I·₦₦I·yƎŜYŜyűăΣ ÕdzăűI·2YŜ₦ă I·₦Ŝ ŘλăλyÕŜyűλØλÎŜŘ ű2 LJ₦2ØλŘŜ Ǝ₦λŘ ăŜ₦ØλÕŜă úKI·ú YI·è ₦ŜŘdzÕŜ úKŜ I·Y2dzyű 2ŧ ŜySŜ₦Ǝè ŜÈLJ2₦ûŜŘ ű2 úKŜ Ǝ₦λŘ℗ ! ă 2ŧ hÕű2ōŜ₦ нлмрΣ нр ăűI·úŜă I·₦Ŝ ₦ŜØλŜøλyƎ ySű YŜűŜ₦λyƎ℗ʰᶜᴼ ¢I·ōfŜ нπн fλăűă ă2YŜ I·fûŜ₦yI·ûλØŜă ű2 ySű YŜűŜ₦λyƎ dzyŘŜ₦ Õ2yãλŘŜ₦I·úλ2y℗ 9I·₦fè Y2ØŜ₦ă øλffăŜ₦ØŜ I·ă ûŜăű ōŜŘă ű2 Ǝdzλ ŘŜ 2úKŜ₦ ăűI·ûŜă Õ2yãλŘŜ₦λyƎ I·fûŜ₦yI·ûλØŜă℗ ! ă úKλă KI·LJLJŜyãΣ K2øŜØŜ₦Σ Õ2yãdzYŜ₦ă øK2 KI·ØŜ I·f₦ŜI·Ře λyØŜăúŜŘ λyŘλăú₦λōdzúŜŘ t± YI·è ŦI·ÕŜ ădzōăűI·yűλI·f ŜÕ2y2YλÕ f2ää λŧ úKŜè I·₦Ŝ y2ú Ǝ₦I·yŘŦI·úKŜ₦ŜŘ I·yŘ øλffăŜ ōŜŘă ű2 ƎdzλŘŜ 2úKŜ₦ ăűI·ûŜă Õ2yãλŘŜ₦λyƎ I·fûŜ₦yI·ûλØŜă℗ ! ă úKλă KI·LJLJŜyãΣ K2øŜØŜ₦Σ Õ2yãdzYŜ₦ă øK2 KI·ØŜ I·f₦ŜI·Ře λyØŜăúŜŘ λyŘλăú₦λōdzúŜŘ t± YI·è ŦI·ÕŜ ădzōăűI·yűλI·f ŜÕ2y2YλÕ f2ää λŧ úKŜè I·₦Ŝ y2ú Ǝ₦I·yŘŦI·úKŜ₦ŜŘ I·yŘ øλffăŜ ōŜƎλyűΣ ű2 ₦ŜÕŜλØŜ ădzōăűI·yűλI·ffè ₦ŜŘdzÕŜŘ ₦I·úŜă ŧ2₦ úKŜ ŜfŜÕú₦λǑúè úKŜè LJ₦2ØλŘŜ ű2 úKŜ Ǝ₦λŘ℗ wŜƎdzfI·ű2₦è dzyÕŜ₦úI·λyűè ÕI·yYI·fă2 YI·ʅŜ λű Y2₦Ŝ ŘλŦŦλÕdzfű ű2 ăŜÕdz₦Ŝ ŦλyI·yÕλyƎ I·yŘ ÕI·yŘ₦ØŜ dzLJ úKŜ Õ2ăű 2ŧ ÕI·LJλúI·f ŧ2₦ 5D℗ 9ŘdzÕI·úλyƎ I·yŘ λyŧ2₦YλyƎ ₦ŜăλŘŜyűλI·f I·yŘ ăYI·ff Õ2YYŜ₦ÕλI·f Õ2yãdzYŜ₦ă I·ō2dzű LJ2ûŜyűλI·f ₦ŜƎdzfI·ű2₦è ₦λăʅă I·ăă2ǑλI·ûŜŘ ØλúK 59w λyØŜăúYŜyűă ăK2dzfŘ ōŜ I·

ŦŦ ¢KŜ / t ¦ / ăűdzŘè ŧ2dzyŘ úKI·ú λyнлмм y2y₦ŜăλŘŜyűλI·f ySű YŜűŜ₦ŜŘ Ödzăú2YŜ₦ă ópc LJŜ₦ÕŜyű 2ŧ ySű YŜűŜ₦ŜŘ ăëăúŜYăú LJI·λŘ ммн LJŜ₦ÕŜyű 2ŧ úKŜ Õ2ăű ű2 ăŜ₦ØŜ úKŜYΣ ØKλfŜ ₦ŜăλŘŜyűλI·f ySű YŜűŜ₦ŜŘ Ödzăű2YŜ₦ă LJI·λŘ ум LJŜ₦ÕŜyű 2ŧ úKŜ Õ2ăű ű2 ăŜ₦ØŜ úKŜY℗

Ǝ3 DŜySŧI·úλ2yI·ú úλYŜă 2ŧ LJŜI·ʅ f2I·Ř λă LJI·₦ûλÕdzfI·₦fè ØI·fdzI·ōfŜ ØKŜyűKŜ₦Ŝ λă fλúûfŜ ă2fI·₦ λyăúI·ffŜŘT úKλă ØI·fdzŜ ŘŜÕfλySă ŧ2₦ ădzōăŜljdzŜyű λyãúI·ffI·úλ2yã℗

ᴷᴷ ! ŘŘλúλ2yI·ffèΣ ű2úI·f ăèäúŜY Õ2ăűă ŧ2₦ dzúλfλúèπăÕI·fŜ ă2fI·₦ ƎŜySŧI·úλ2yI·₦Ŝ f2ØŜ₦ úKI·yT2₦ I·yŜljdzλØI·fŜyű ÕI·LJI·Õλúèŧŧ ŘλăúλdzúŜŘ t± ŘdzŜ ű2 ŜÕ2y2YλŜă 2ŧ ăÕI·fŜ℗

LJNλ2NλúèΦ ! ă ûŜŎKy2f2∃è l·yŘ Y l·N]Ŝûă ŜØ2fØŜΣ ăûl·ûŜă Ŏl·y¯ōdzλfŘ úKŜΛN ŎI·LJI·Ŏλúȅŭ2 Øl·fdzŜ 5DΣ ŘλăúNλōdzúŜŘ ăú2NI·∃ŜΣ 5wΣ l·yŘ ŜyŜN∃è Ŝ₣₣λŎλŜyŎèΣ l·yŘ ŭ2 Ŝ₣₣ŜŎûλØŜfȅ λyŎfdzŘŜ ûKŜY λy¯NŜă2dzNŎŜ LJfl·yŷλy∃Φ

bŜű YŜûŜNλy∃ λă l· ₣ΛNăű ăúŜLJ λy¯ ŘŜØŜf2LJλy∃ YŜûK2Řă ŭ2 Ŏ2YLJŜyãl·ûŜ Ŏdzăú2YŜNă ₣2N úKŜ âŜNØλŎŜă l·yŘ ∃ŜyŜNI·ûλ2y¯úKŜè LJN2ØλŘŜ ŭ2 úKŜ ∃NλŘΦ {2YŜ 2₣ úKŜ fλYλúl·ûλ2yã 2₣ yŜű YŜûŜNλy∃ YI·è ōŜ l·ŘŘNŜăăŜŘ ōè ŎNŜI·ûλy∃ ăŜLJI·NI·ûŜ NI·ûŜ Ŏfl·ăăŜă ₣2N 5D LJI·NúλŎλLJl·yűă l·yŘ λyŎ2NLJ2NI·ûλy∃ ŜfŜYŜyűă 2₣ ySű YŜûŜNλy∃ λyű2 Y2NŜ ă2LJKλăúλŎI·ûŜŘ NI·ûŜ ăúNdzŎűdzNŜă ₣2N úKl·ú Ŏdzăú2YŜN Ŏfl·ăă∅ a2ØλyΞ ₣2NØl·NŘΣ ăúl·ûŜă l·yŘ dzúλfλûλŜă Øλtfȅfλ]Ŝfè f22]ŭ2 dzăŜ Y2NŜ N2ōdzăú Øl·fdzl·ûλ2y¯ YŜûK2Řă∅ ! ŎŎ2NŘλy∃fèΣ ySØ NI·ûŜ ăúNdzŎűdzNŜă l·yŘ Ŏ2yãdzYŜN Ŏ2YLJŜyãl·ûλ2y¯ LJ2fλŎλŜă ₣2N ă2YŜ Ŏ2yãdzYŜNă—Y2NŜ LJNŜŎλăŜ ű22fă úKl·y¯ŎdzNNŜyű ySű YŜûŜNλy∃ LJ2fλŎλŜă—ØλtfȅŜyl·ōfŜ Ŝ₣₣λŎλŜyű Ŏ2YLJŜyãl·ûλ2y¯ ₣2N l· ØλŘŜN l·NNl·è 2₣ ŘλăúNλōdzúŜŘ NŜă2dzNŎŜă∅ ¢KŜ ∃N2dzLJ 2₣ ûŜŎKy2f2∃λŜă Ŝfλ∃λōfŜ ₣2N Ŏ2YLJŜyãl·ûλ2y¯ YI·è fλ]Ŝfè ∃N2ø ŭ2 λyŎfdzŘŜ Y2NŜ ₣fŜȅλōfŜ Ŏ2yØŜNúλ2NăΣ ŘλăúNλōdzúŜŘ ăú2NI·∃ŜΣ f2l·ŘπŎ2yúN2ffŜŘ K2ű ØI·ûŜN KŜI·ûŜNăΣ l·yŘ 2úKŜN ăY l·Nú ∃NλŘπŎ2yúN2ffŜŘ ŘŜØλŎŜă ûKl·ú Ŏ2dztŘ LJN2ØλŘŜ I·yŎλftfI·Nȅ l·yŘ f2l·ŘπăKλ₣ûλy∃ ăŜNØλŎŜă∅ ² KŜy¯NŜŘŜăλ∃yλy∃ NJl·ûŜă ûKl·ú Ŝyl·ōfŜ Ŏdzăú2YŜNă ŭ2 LJdzNădzŜ 2LJúλ2yã ûKl·ú LJN2ØλŘŜ ûKŜY l·yŘ ûKŜ dzúλfλûȅ Øl·fdzŜπŌl·ăŜŘ 2LJúλ2yãΣ NŜŎ2ØŜNλy∃ úKŜ Ŏ2ăú 2₣ LJN2ØλŘλy∃ ŘλăúNλōdzúλ2y¯ăŜNØλŎŜă λă 2₣ ŎNλûλŎl·f λYLJ2Nűl·yŎŜ∅ ! ă ădzŎKΣ l·y¯λăădzŜ λă ûKŜ LJN2LJŜN λŘŜyűλ₣λŎl·ûλ2y¯ l·yŘ Øl·fdzl·ûλ2y¯2₣ ûKŜ Ŏ2ăúă l·yŘ ûKŜ ōŜySλúă LJN2ØλŘŜŘ ōè ûKŜ ∃N2øλy∃ I·NNl·è 2₣ Ŏdzăú2YŜN 2LJúλ2yã∅

/2yãdzYŜNă øK2 øl·yű ű2 Yl·λyűl·λy¯úKŜλN ŜÈλăúλy∃ ăŜNØλŎŜ 2LJúλ2yã ă2YŜûλYŜă ∃Sű f2ăű λy¯úKŜ LJN2ŎŜăă∅ ¢KŜăŜ Ŏ2yãdzYŜNă LJ2ăŜ Ŏ2yãλŘŜNl·ûλ2yã ₣2N NŜfŜØl·yű NŜ∃dzfl·ú2Nă l·yŘ Yl·N]ŜûLJfl·ŌŜ 2LJŜNl·ú2N2ă∅ ¢KŜ λYLJfŜYŜyűl·ûλ2y¯ 2₣ ySø ûŜŎKy2f2∃λŜă l·yŘ ăŜNØλŎŜă LJNŜăŜyű 2LJLJ2Nűdzyλúλŝă ₣2N ŜyKl·yŎŜŘ ₣fŜȅλōλfλúȅ ú2 KŜfLJ YŜŜű Ŏ2yãdzYŜN ŜȅLJŜŎúl·ûλ2yã∅ I2øŜØŜNΣ λy¯ l·ŎKλŜØλy∃ úKλă λyŎNŜl·ăŜŘ ₣fŜȅλōλfλúȅΣ NŜ∃dzfl·ú2Nă l·yŘ Yl·N]Ŝű 2LJŜNl·ú2Nă ăK2dzfŘ l·ŎűλØŜfȅ Yλyλ¯YλÎŜ ySΞl·ûλØŜ λYLJl·Ŏûă 2y¯y2yπLJl·NúλŎλLJl·ûλy∃ Ŏ2yãdzYŜNăΣ ûK2dz∃K LJdzōfλÔȅ LJ2fλÔȅ 2ō?ŜŎűλØŜă Yl·è ŜȅLJl·yŘ ûKŜ ăŎ2LJŜ 2₣ λYLJl·Ŏûă Ŏ2yãλŘŜNŜŘ∅ bŜű YŜûŜNλy∃ ăă ûKŜ Y2ăű Ŏ2YY2y¯Nl·ûŜ ₣2N ŘλăúNλōdzúŜŘ t±Σ ōdzú Yl·yè dzúλfλûλŜă l·NŜ ŜȅLJf2Nλy∃ l·fűŜNy1·ûλØŜ ăúNdzŎűdzNŜă∅

Table 2-2. Alternative Rate Options for Distributed Solar

Structure	Description	Utility Example
Value of Solar	Utilities and other stakeholders attempt to calculate the full social value of distributed PV, including its environmental benefits, and use that to develop a tariff for all electricity exported to the grid from a distributed PV facility.	Austin Energy; Minnesota's statewide value of solar tariff has not yet been implemented.
Net Billing	Distributed PV host receives neither credit nor charge for electricity consumed onsite but receives compensation for exported power at an administratively-determined rate, often set at the cost of procuring utility-scale solar power.	Imperial Irrigation District
Self Supply and Grid Supply	Consumers choose to supply all of their own power, in which case they are excused from some charges but not compensated for any exported electricity. Or, they must buy all of their power at retail rates and sell all of their onsite generation at a lower rate.	Hawaiian Electric Company
Increased Fixed Charges	Net energy metering is maintained, but its value and any associated cost changes from infrastructure upgrades (not counting externalities) are reduced by increasing fixed charges and decreasing volumetric charges.	Wisconsin Utilities

The increasing penetration of rooftop solar and advanced metering is driving and enabling regulatory changes. Regulators and utilities are considering alternative rate options for compensating customers for grid services while continuing to support new technology, maintain infrastructure, and ensure affordability for all customers.

2.5.4.1 Providing Incentives through Ratemaking

/2ăúπ2ŦπăŜNØλŎŜ NI·úŜY·l·ʅλyЭ ŎNŴŜI·úŜă dzyʎljdzŜ λyŎŜyűλØŜă Ŧ2NJ úKŜ dzúλfλúè úKI·ú ŘλŦŦŜNJ ŦN2Y úK2ăŜ ŜÈLJŜNλŜyŎŜŘ ōè ŦλNJYă λyˇŎ2YˇLJŜúλúλØŜ Y·I·NJʅŜúă I·NŴŜ Ŏ2yŎŜNJySŘ ØλúK YˇλyʎYˇλÎλyЭ úKŜ ú2úI·f Ŏ2ăú 2Ŧ LJN2ŘdzŎúλ2yΦ wŜЭdzfI·úλ2yˇŎI·yˇ ōŜ I· ădzōăúλúdzúŜ Ŧ2NJ Ŏ2YˇLJŜúλúλØŜ Y·I·NJʅŜú LJNŜăădzNŴŜaŤ λú ŎNŴŜI·úŜă I· ØI·NλŜúè 2Ŧ λyŎŜyűλØŜăΣ ŘNλØŜyˇōè úKŜ dzyʎljdzŜ úNŴŜI·úYˇŜyű 2Ŧ ŘλŦŦŜNJŜyű Ŏ2ăú ŜfŜYˇŜyűăΣ ō2úK λyˇúKŜ ŘŜúŜNJYˇλyl·úλ2yˇ2Ŧ NJI·úŜă I·yŘ ŘdzNλyЭ úKŜ LJŜNλ2Ř ōŜúøŜŜyˇ NJI·úŜ ŎI·ăŜăΦ

! ă ŜÈLJfI·λyŜŘ λyˇúKŜ LJNŴŜØλ2dză ăŜŎűλ2yΣ úKŜ NJI·úŜπY·l·ʅλyЭ LJN2ŎŜää ŘŜúŜNJYˇλyŜă K2ø YˇdzŎK I· dzúλfλúè ŎI·yˇŜI·NyΣ ōI·ăŜŘ 2yˇúKŜ ůø2 LJNλYI·NÈ ŦI·ŎúŽNJăY óMú úKŜ I·ff2øŜŘ NŜúdzNJyˇ2yˇŎI·LJλúI·fΣ I·yŘ óHú úKŜ dzúλfλúè NJI·úŜ ōI·ăŜΦ ¦ űλfλúλŜă ŜI·NyˇLJN2Ŧλú ŦN2Y I· NŜúdzNJyˇ2yˇŎI·LJλúI·fΦ ¢Kdzăΐ λŤ λú Ŏ2ăűă I· dzúλfλúè fŜää ů2 NJI·λăŜ Y2ySè úKI·yˇλú ŜI·NyañΣ 2yˇλűă λyØŜăűYˇSyű λú øλff KI·ØŜ I·yˇλyŎŜyűλØŜ ů2 2ØŜNπλyØŜăűΦ ! NŜØŜNăŜ ōλI·ă λă ŎNŴŜI·úŜŘ λŤ úKŜ Ŏ2ăú 2Ŧ ŎI·LJλúI·f λă ăŜű ú22 f2ø 2NJ NŜЭdzfI·úλ2yˇŎNŴŜI·úŜă 2ōăúI·ŎfŜă ů2 Ŧdzffè NŜŎ2ØŜNλyЭ ŎI·LJλúI·fT Ŧ2NJ ŜÈI·YˇLJfŜΣ LJN2YˇZűλyЭ ŜyŜNJèb ŜŦŦλŎλŜyŎè øλúK2dzű ŦλÈŜŘπŎ2ăú NŜŎ2ØŜNè úNdzŜπdzLJăΣ λyˇ øKλŎK 2ØŜNπNŜŎ2ØŜNè I·yŘ dzyŘŜNπNŜŎ2ØŜNè 2Ŧ NŜØŜyűdzŜă I·NŴŜ ŜØI·fdzI·úŜŘ I·yŘ I·NŴŜ ŜλúKŜNJ NŜŭdzNJyŜŘ 2NJ ŎKI·NЭŜŘ ů2 Ŏdzăű2YˇŜNăΦ

wŜЭdzfI·ú2Nè λyŎŜyűλØŜă øλff LJfI·è I·yˇλYˇLJ2NűI·yű N2fŜ λyˇúKŜ ŜyűKdzăλI·ăY øλúK øKλŎK dzúλfλúλŜă LJdzNădzŜ ŘλŦŦŜNŴŜyű I·ŎúλØλúλŜă I·yŘ úKŜ NŜfI·úλ2yăKλLJ øλúK úKλNŘπLJI·Núè LJN2ØλŘŜNă úKŜè I·NŴŜ øλffλyЭ ů2 LJdzNădzŜΦ C2NJ ŜÈI·YˇLJfŜΣ ů2 ŜyŎ2dzNJI·ЭŜ dzúλfλúè LJI·NŴúλŎλLJI·úλ2yˇλyˇŜyŜNJЭè ŜŦŦλŎλŜyŎè LJN2Ɜ3NJI·YˇăΣ NŴŜЭdzfI·ú2Nè Ŏ2YˇYˇλăăλ2yă KI·ØŜ dzăŜŘ úKNŴŜŜ I·LJLJN2I·ŎKŜăY

- MΦ /2ăú NŴŜŎ2ØŜNè Ŧ2NJ ŜyŜNJЭè ŜŦŦλŎλŜyŎè ŜÈLJŜyãŜă
- HΦ /2YˇLJŜyãI·úλ2yˇŦ2NJ f2ăú YˇI·NJЭλyˇI·ăă2ŎλI·úŜŘ øλúK f2øŜNJ ŜyŜNJЭè ăI·fŜă
- OΦ LyŎŜyűλØŜăΣ ădzŎK I·ă ăKI·NŴŜ úKŜ ăI·ØλyЭă I·LJLJN2I·ŎKŜăΣ ů2 YˇZűλØI·úŜ dzúλfλúλŜă ů2 LJdzNădzŜ ŜyŜNJЭè ŜŦŦλŎλŜyŎèΦ

¢KŜ λyŘdzăúNè λă y2ø ŦI·ŎλyЭ I·yˇI·yI·f2Ɜ2dză ăλűdzI·úλ2yˇøλúK 59wΣ Ŧ2NJ ŜÈI·YˇLJfŜΣ øKŜNŴŜ yŜű YˇŜűŜNJλyЭ λă ØλŜøŜŘ I·ă I· YˇŜŎKI·yλăY ōè øKλŎK dzúλfλúλŜă ø2dzfŘ f2ăŜ NŴŜØŜyűdzŜă¢ LűλăΐyŜ 2Ŧ úKŜ ŦI·ŎűΩNJă úKI·ú Ŏ2YˇLJfλŎI·úŜă úKŜ I·ōλfλúè 2Ŧ dzúλfλúλŜă ů2 LJN2ØλŘŜ Ŏdzăű2YˇŜNJă úKŜ ăŜNŴØλŎŜă úKI·ú dzyNŴŜЭdzfI·úŜŘ Ŏ2YˇLJŜúλú2NJă ŎI·yˇI·fă2 LJN2ØλŘŜ¢KŜ ăúNJdzŎűdzNJŜ 2Ŧ yŜø ōdzăλySăă YˇZŘŜfă øλff ŎNŴŜI·úŜ λyŎŜyűλØŜă úKI·ú ЭdzλŘŜ dzúλfλúè 2LJŜNJI·úλ2yˇI·yŘ λyØŜăűYˇSyű ŘŜŎλăλ2yă λyˇúKŜ Ŧdzűdz NJŜ¢ LyˇúKŜ LJN2ŎŜää 2Ŧ ŘŜØŜf2LJλyЭ úKλă yŜø NŴŜЭλYˇŜΣ ʎű ăă λYˇLJ2NűI·yű ů2 LJN2ØλŘŜ λyŎŜyűλØŜă Ŧ2NJ dzúλfλúλŜă ů2 ō2úK LJdzNădzŜ I·yŘ Ŝyl·ōfŜ y2yπdzűλfλúè ăŜNØλŎŜ LJN2ØλŘŜNă ů2 YˇŜŜűΣ yl·úλ2yl·f Ɜ2I·fă 2Ŧ I· ăŜŎdzNJŜΣ NŜfλI·ōfŜΣ I·yŘ I·ŦŦ2NŘI·ōfŜ ŜfŜŎűNJλŎλúè ăèăűŜYΦ

2.5.4.2 Providing Resources to Inform Rate Design

wŜЭdzfI·ú2Nă Yˇdzăű ŘŜăλЭyˇNJI·úŜ ăúNdzŎúdzNŜă úKI·ú ădzLJLJ2NűI ŜfŜŎűNJλŎλúè ăŜNØλŎŜ ů2 Ŏdzăű2YˇŜNăΣ λyŎŜyű ŘŜăλNJŜŘ LJ2fλŎè 2dzűŎ2YˇŜăΣ I·ff2ø Ŧ2NJ I· ŦI·λNJ NŜúdzNJyˇ2yˇλyØŜăűYˇSyűΣ I·yŘ YˇI·λyűI·λyˇI·ŦŦ2NŘI·ōfŜ ŜfŜŎűNJλŎλúè Ŧ2NJ úKŜ Ŏ2yãdzYˇŜNJΦ wŜЭdzfI·ú2Nă ŦλyŘ úKŜYˇăŜfØŜă λyˇI· yŜø ŜyØλN2yYˇSyű ŎKI·NJI·ŎűŜNJλÎŜŘ ōè NJI·LJλŘfè ŎKI·yЭλyЭ ûŜŎKyˇ2f2ЭλŜăΣ ØI·ăű I·Yˇ2dzyűă 2Ŧ ŘI·úI· ōŜλyЭ LJN2ŘdzŎŜŘ úKN2dzƎK2dzű úKŜ ăëăűŜYΣ I·yŘ I· ădzλűŜ 2Ŧ yŜø ăűI·ʅŜK2fŘŜNă LJI·NŴλŎλLJI·úλyЭ λyˇNJI·úŜ ŎI·ăŜăΦ ! yˇλYˇLJ2NŴI·yű CŜŘŜNJI·f N2fŜ YˇI·è ōŜ ů2 ŦI·ŎλfλúI·ûŜ ōŜăű I·yI·fèűλŎ LJNJI·ŎűλŎŜă NŴŜfI·úŜŘ ů2 NJI·úŜYˇI·ʅλyЭ I·yŘ ů2 Ŝyădzλ NŴŜ ŦdzffúNJI·yűLJI·NŴŜyŎè ů2 Ŏ2ăűλyЭ ŜÈŜNŴŎλăŜă λyˇō2úK LhI·¦πNŴŜЭdzfI·úλ2yˇŦ2NŴdzYˇă I·yŘ LJdzōfλŎ ŜyűλúèŦ2NŴdzYˇăΦ LyŦ2NJYˇI·úλ2yˇ λă I· Ɜ2øλyЭ ʅŜè ŦI·ŎúΩNJ λyˇ I·ff I·ăLJŜŎűă 2Ŧ ŜfŜŎűNJλŎλúè ăŜNØλŎŜΣ ŦN2Y LJ2øŜNJ LJfI·yű YˇI·yI·ƎŜYˇŜyű ů2 ŎdzăűλYˇŜNJ λyűŜNJŦI·ŎŜăΣ I·yŘ ŎdzăűλYˇŜNJπăλŘŜπ2ŦπúKŜπYˇŜúŜNJ ŘŜØλŎŜă I·yŘ I·LJLJfλŎI·úλ2yăΦ ¢KŜ λYˇLJ2NűI·yŎŜ 2Ŧ λyŦ2NJYˇI·úλ2yˇYˇI·ʅŜă λű I· ʅŜè Ø·fdzI·úλ2yˇŦI·ŎűΩNJ λyˇ I·ff I·ăLJŜŎűă 2Ŧ ŜfŜŎűNJλŎλúè ăŜNØλŎŜΣ ŦN2Y LJ2øŜNJ LJfI·yű YˇI·yI·ƎŜYˇŜyű ů2 ŎdzăűλYˇŜNJ λyűŜNJŦI·ŎŜăΣ I·yŘ ŎdzăűλYˇŜNJπăλŘŜπ2ŦπúKŜπYˇŜúŜNJ ŘŜØλŎŜă I·yŘ I·LJLJfλŎI·úλ2yăΦ ¢KŜ λYˇLJ2NűI·yŎŜ 2Ŧ λyŦ2NJYˇI·úλ2yˇYˇI·ʅŜă λű I· ʅŜè Ø·fdzI·úλ2yˇŦI·ŎűΩNJ I·ă øŜftΦ ¢KŜ NλƎKű λyŦ2NJYˇI·úλ2yˇI·LJLJfλŜŘ λyˇúKŜ NλƎKű ø·è ŎI·yˇKI·ØŜ ăλƎyŦλŎI·yű Ø·fdzŜπŜyKI·yŎλyЭ ŜŦŦŜŎűăΦ C2NJ λyăúI·yŎŜΣ λyŦ2NJYˇI·úλ2yˇŜăăŜyűλI·ffè ŎNŴŜI·úŜă Ø·fdzŜ λyˇúKŜ Ŧ2ff2øλyЭ ø·ènY

- LyŎNŴŜI·ăλyЭ úNJI·yăLJI·NŴŜyŎè I·yŘ λŘŜyűλŦèλyЭ yŜø 2LJLJ2NűdzyʎúλŜă øλúK KλƎK LJ2ŭŜyűλI·f NŴŜø·NŴŘă λYˇLJN2ØŜă ŜŎ2y2YˇλŎ LJN2ŦλúI·ōλfλúè ōè λŘŜyűλŦèλyЭ NλăʅăI·yŘ úKŜNŴŜōè NŴŘdzŎλyЭ úKŜ Ŏ2ăű 2Ŧ ŎI·LJλúI·fΦ
- wŜŘdzŎλyЭ dzyŎŜNJúI·λyűèΣ ădzŎK I·ă f2øŜNJyЭ λyűλI·f Ŏ2ăűăΣ YˇI·λyűI·λyʎyЭ I· f2øŜNJ fλŦŜπŎèŏfŜ Ŏ2ăúΣ NŴŘdzŎλyЭ úKŜ LJŜNJŎŜLJűλ2yˇ2Ŧ NλăʅăI·yŘ úKŜ Ŏ2yűN2f 2Ŧ NλăʅăΣ 2NJ NŴŘdzŎλyЭ Ŏ2yãúNJI·λyűă— ōI·NJNλŜNJă úKI·ú fλYˇλű ƎN2øúKΣ λyy2ØI·úλ2yΣ I·yŘ λYˇLJN2ØŜŘ LJŜNJŦ2NJYˇI·yŎŜΦ

- 9ÈLJf2λúλyЭ űKŜ ₪ŜfI·úλØŜ I·ŘØI·yűI·ƎŜ 2Ŧ KI·ØλyЭ ădzLJŜ₪λ2₪ λyŦ2₪Y I·úλ2yΣ ădzǑK I·ă ăI·ØλyЭ úλY Ŝ I·yŘ ŜŦŦ2₪úΣ 2₪ ₪ŜŘdzǑλyЭ fI·Ǝ úλY ŜăΣ 2₪ λyǑ₪ŜI·ăλyЭ úKŜ ăǑI·fŜ I·yŘ λY Y ŜŘλI·Ǒè 2Ŧ ₪Ŝ ø I·₪Řă¢

5h9 KI·ă ōŜƎdzy I· LJ₪2ǑŜää 2Ŧ ŜØI·fdzI·úλyЭ úKŜ Ǒ2ăúă I·yŘ ōŜyŜŦλúă 2Ŧ 59wΣ LJ₪2ØλŘλyЭ I· úI·È2y2Y è 2Ŧ Ǒ2ăúăΣ I·yŘ Ŧ₪I·Y λyЭ úKŜ ŘλăLJdzúŜa I·ää2ǑλI·úŜŘ ø λúK ØI·fdzI·úλ2y 2Ŧ ŜI·ǑK Ǒ2ăú ŜfŜY ŜyúΦHCP ¢KŜ Ǒ2ăúă I·yŘ ōŜyŜŦλúă 2Ŧ Y I·yè ăY I·₪ú Ǝ₪ŘI·LJLJfλǑI·úλ2yã øŜ₪Ŝ I·fă2 ǑI·LJúdz₪ŜŘ úK₪2dzƎK úKŜ {Y I·₪ú D₪ŘLyØŜáúY ŜyúD₪I·yú t₪2Ǝ₪I·Y I·yŘ {Y I·₪ú D₪ŘΣ 5ŜY2yãú₪I·úλ2y t₪Ǝ₪I·Y 2Ŧ úKŜ wŜǑ2ØŜ₪è !ǑúΦHCP LY I·ŘŘλúλ2yΣ I· Ǒ2yã2₪úλdzY 2Ŧ bI·úλ2yI·f [I·ōăΣ úKŜ ¢ŜyýŜääŜŜ ±I·ffŜè !dzúK2₪λúèΣ úKŜ bI·úλ2yI·f !ääǑλI·úλ2y 2Ŧ wŜƎdzfI·ú2₪è ¦úλfúè /2YY λääλ2yŜ₪ăΣ I·yŘ LJfI·yýλyЭ Ǒ2ffI·ǒ2₪I·úλØŜă λy úKŜ 9I·ăúŜ₪y LyúŜ₪Ǒ2yýŜǑú I·₪Ŝ ŘŜØŜf2LJλyЭ I· Ǝ₪λŘπăŜ₪ØλǑŜă I·yŘ ûŜǑKy2f2ƎλŜăπØI·fdzI·úλ2y Ŧ₪I·Y Ŝø2₪ dzyŘŜ₪ úKŜ 5h9 D₪ŘΣ a2ŘŜ₪yÎI·úλ2y [I·ō /2yã2₪úλdzY Φ HCC !ă LJI·₪ú 2Ŧ λúă λyúŜƎ₪I·ûŜŘ Ǝ₪λŘ ŜŦŦ2₪úΣ 9fŜǑú₪λǑ t2øŜ₪ wŜăŜI·₪ǑK LyãúλúdzúŜ λă ŘŜØŜf2LJλyЭ I· ōŜyŜŦλúπǑ2ăú Ŧ₪I·Y Ŝø2₪ Ŧ2₪ ljdzI·yúλŦèλyЭ úKŜ λY LJI·Ǒú 2Ŧ 59w 2y úKŜ Řλăúλdzúλ2y I·yŘ ōdzfL LJ2øŜ₪ äëăúŜY ă¢ LY LJ2₪úI·yúfèΣ ăKI·₪λyЭ λyŦ2₪Y I·úλ2y y1·úλ2yI·ffè 2y Ø I·fdzI·úλ2y 2Ŧ Ǒ2ăúă I·yŘ Y ŜúK2Ř ă 2Ŧ ŘŜØŜf2LJλyЭ ₪I·ûŜă Ř2Ŝă y2ú λY LJfè I· yI·úλ2yI·ffè LJ₪ŜăǑ₪λōŜŘ Y ŜúK2Ř 2Ŧ ŘŜûŜ₪Y λyλyЭ Ǒ2ăúă I·yŘ ₪I·ûŜăT ădzǑK ŘŜûŜ₪Y λyI·úλ2y λă I· ăúI·ûŜ ₪ŜăLJ2yãλōλfúè¢

¢KŜ₪Ŝ KI·ă ōŜŜy I· Ǝ₪ŜI·ú ŘŜI·f 2Ŧ λyy2ØI·úλ2y λy úKŜ ₪2fŜ 2Ŧ úKŜ Ǒdzăú2Y Ŝ₪Σ ₪I·ûŜ ŘŜăλƎyΣ I·yŘ ûŜǑKy2f2ƎλŜă dzăŜŘ ú2 LJ₪2ØλŘŜ ăŜ₪ØλǑŜ ú2 Ǒdzăú2Y Ŝ₪ă ø /2ăúă Ř₪ØŜ₪ă I·₪Ŝ ăKλŦúλyƎΣ yŜø Ǒ2ăúă I·₪Ŝ ōŜλyЭ Ǒ2yãλŘŜ₪ŜŘΣ I·yŘ úKŜ λY LJ2₪úI·yǑŜ 2Ŧ ₪I·ûŜ ŘŜăλƎy KI·ă λyǑ₪ŜI·ăŜŘ τ ō2úK Ŧ2₪ ŜyƎŜyŘŜ₪λyЭ Ǒdzăú2Y Ŝ₪ ₪ŜăLJ2yãŜ I·yŘ I·ă I· Y ŜúK2Ř 2Ŧ ŜyǑ2dz₪I·ƎλyЭ Ǒ2Y LJ2yŜyú I·yŘ ăèăúŜY ŜŦŦλǑλŜyǑè I·yŘ 59w¢ ¢KŜ bI·úλ2yI·f !ääǑλI·úλ2y 2Ŧ wŜƎdzfI·ú2₪è ¦úλfúè /2YY λääλ2yŜ₪ă KI·ă Ŧ₪I·Y ŜŘ Y I·yè 2Ŧ úKŜ λăädzŜă úKI·ú yŜŜŘ ŦdzN₪úKŜ₪ ŜÈLJf2₪I·úλ2y λy λúă ₪ŜǑŜyúfè ₪ŜfŜI·ăŜŘ ₪I·ûŜπ ŘŜăλƎy Y I·ydzI·f Φ HCT DλØŜy úKŜ λY LJ2₪úI·yǑŜ 2Ŧ ₪I·ûŜă—y2ú 2yfè Ŧ2₪ Ǒ2Y LJŜyãI·úλyЭ dzúλfúλŜăΣ ōdzúΣ λyǑ₪ŜI·ăλyЭfèΣ I·ă I· ØŜKλǑfŜ Ŧ2₪ LJ₪2ØλŘλyЭ LJ₪ǑŜ ăλƎyI·fă ú2 Ǒdzăú2Y Ŝ₪ă øK2 LJ₪2ØλŘŜ úN₪I·yãI·ǑúλØŜ f2I·Ř I·yŘ 59w—λú ø2dzfŘ ōŜ ØŜ₪è ØI·fdzI·ōfŜ Ŧ2₪ LJ₪2ǑŜ CŜŘŜ₪I·f D2ØŜ₪yY Ŝyú ú2 ŦI·ǑλfúI·ûŜ I· yI·úλ2yI·f ₪ŜØλŜø 2Ŧ ₪ŜúI·λf ₪I·ûŜă I·yŘ úKŜ Ǒ₪ŜI·úλ2y 2Ŧ I· yI·úλ2yI·f ₪ŜLJ2ăλú2₪è 2Ŧ ₪I·ûŜ λyŦ2₪Y I·úλ2y Φ

2.5.5 Adapting the Distribution Utility Business Model

¢KŜ ŜfŜǑú₪λǑ ŘλăúN₪λōdzúλ2y dzúλfúè y2ø ŦI·ǑŜă I· ŦdzyŘI·Y ŜyúI·f úN₪I·yãŦ2₪Y I·úλ2y Φ ¢KŜ ŜY Ŝ₪ƎŜyú ₪2fŜ 2Ŧ úKŜ Ǒ2yãdzY Ŝ₪ I·ă LJ₪2ădzY Ŝ₪ I·yŘ yŜø λY LJŜ₪I·úλØŜăΣ ădzǑK I·ă ₪ŜăλfúŜyǑŜΣ I· ǑfŜI·yŜ₪ ŜyŜ₪Ǝè Ŧdzúdz₪ŜΣ I·yŘ Ǝ₪λŘ ăŜǑdz₪λúèΣ I·₪Ŝ Ř₪λØλyЭ úKŜ Ǒdz₪₪ŜyúŜØ2fdzúλ2y Φ ! ŘŘλúλ2yI·f λyØŜăúY Ŝyúă ú2 ădzLJLJ2₪úŜ ŜyKI·yǑŜŘ ăŜ₪ØλǑŜă I·₪Ŝ ₪ŜIjdz₪₪ŜŘΣ λyǑfdzŘλyЭ úKŜ yŜø úN₪I·yãI·ǑúλØŜ ₪2fŜ Ŧ2₪ Ǒdzăú2Y Ŝ₪ă øK2 LJ₪2ØλŘŜ úN₪I·yãI·ǑúλØŜ f2I·Ř I·yŘ 59w—λú ø2dzfŘ ōŜ ØŜ₪è ØI·fdzI·ōfŜ Ŧ2₪ úKŜ CŜŘŜ₪I·f D2ØŜ₪yY Ŝyú ú2 ŦI·ǑλfúI·ûŜ I· yI·úλ2yI·f ₪ŜØλŜø 2Ŧ ₪ŜúI·λf ₪I·ûŜă I·yŘ úKŜ Ǒ₪ŜI·úλ2y 2Ŧ I· yI·úλ2yI·f ₪ŜLJ2ăλú2₪è 2Ŧ ₪I·ûŜ λyŦ2₪Y I·úλ2y Φ

Lΰ λă Ǒ₪λúλǑI·ffè λY LJ2₪úI·yú ú2 dzyŘŜ₪ăúI·yŘ úKI·ú I·fûŜ₪y1·úλØŜ dzúλfúè ōdzăλyŜää Y2ŘŜfă I·yŘ ₪ŜƎdzf I·ú2₪è LJ₪I·ǑúλǑŜă I·₪Ŝ λyŜÈú₪λǑI·ōfè fλy ŜŘ¢ a2ŘλŦλǑI·úλ2y 2Ŧ úKŜ ú₪I·Řλúλ2yI·f ₪I·ûŜY I· λyƎπōI·ăŜŘ dzúλfúè ōdzăλyŜää Y2ŘŜf Ydzăú ōŜY I·ǑǑŜLJúI·ōfŜ ú2 ăúI·ûŜ ₪ŜƎdzfI·ú2₪ăΣ ₪ŜăLJ2yãλØŜ ú2 Ǒdzăú2Y Ŝ₪ăΣ FλyI·yǑλI·ffè ûŜyI·ōfŜ ú2 dzúλfúè ăKI·₪ŜK2fŘŜ₪ăΣ I·ff øKλfŜ ădzLJLJ2₪úλyЭ λyy2ØI·úλ2y óøKŜúKŜ₪ ōè úKŜ dzúλfúè 2₪ úKλ₪ŘπLJI·₪úè LJ₪2ØλŘŜ₪ăú¢ ¢KŜ ōdzăλyŜää Y2ŘŜf λă LJI·₪ú 2Ŧ I· úN₪λI·Ř 2Ŧ λyûŜ₪₪ŜfI·ûŜŘ ŜfŜY ŜyúăΣ øKλǑK λyǑfdzŘŜă úKŜ ₪ŜƎdzfI·ú2₪è ăú₪dzǑúdz₪Ŝ I·yŘ Ŝǒ2y2Y λǑκY I·₪ŜúΣ ăú₪dzǑúdz₪Ŝ úKI·ú ŘŜûŜ₪Y λyŜ úKŜ yI·údz₪Ŝ 2Ŧ Ǒdzăú2Y Ŝ₪ ăŜ₪ØλǑŜ¢HCY

a I·yè LJŜ2LJfŜ KI·ØŜ LJ₪2LJ2ăŜŘ Y2ŘŜfă úKI·ú ₪ŜLJ₪ŜăŜyú LJ2ûŜyúλI·f Ŧdzúdz₪Ŝ ŜØ2fdzúλ2yã 2Ŧ úKŜ ŘλăúN₪λōdzúλ2y dzúλfúè¢ hyŜ I·dzûK2₪ ₪ŜLJ₪ŜăŜyúă dzúλfúè ŜØ2fdzúλ2y ŜyŘLJ2λyúă 2y I· ăLJŜǑúN₪dzY ōŜúøŜŜy úø2 Y2ŘŜfăY úKŜ {Y I·₪ú LyúŜƎ₪I·ú2₪ I·yŘ úKŜ 9yŜƎè {Ŝ₪ØλǑŜă ¦úλfúè¢ HC¢ ¢KŜ {Y I·₪ú LyúŜƎ₪I·ú2₪ λă ŘŜăǑN₪λōŜŘ I·ă I·y 2LJŜ₪I·ú2₪ 2Ŧ úKŜ ŘλăúN₪λōdzúλ2y Ǝ₪λŘ λy Y dzǑK úKŜ ăI·YŜ øI·è úKI·ú I·y L{h 2LJŜ₪I·ûŜă úKŜ úN₪I·yãY λääλ2y Ǝ₪λŘ I·yŘ øK2fŜăI·fŜ LJ2øŜ₪ Y I·₪ŜúăΦ Lΰ λă I· LJfI·úŦ2₪Y Ŧ2₪ úN₪I·yãI·Ǒúλ2yãΣ ōdzú λú Ř2Ŝă y2ú LJI·₪úλǑλLJI·ûŜ λy ŜyŜ₪Ǝè úN₪I·yãI·Ǒúλ2yãΦ ¢KŜ 9yŜ₪Ǝè {Ŝ₪ØλǑŜă ¦úλfúè ăKI·₪Ŝă úKŜ ōI·ăλǑ FdzyǑúλ2yã 2Ŧ úKŜ {Y I·₪ú LyúŜƎ₪I·ú2₪Σ ōdzú λú I·fă2 I· LJ₪2ØλŘŜ₪ 2Ŧ ăŜ₪ØλǑŜă¢ Lΰ λă I·y ŜÈúŜyãλ2y 2Ŧ úKŜ ØŜ₪úλǑI·ffè λyúŜƎ₪I·ûŜŘ dzúλfúè¢ ¢ø2 ljdzŜăúλ2yã øλff ŘŜûŜ₪Y λyŜ K2ø úKŜ dzúλfúè ōdzăλyŜää Y2ŘŜf ŜØ2fØŜăY

M¢ ² KI·ú ăŜ₪ØλǑŜă ǑI·y óI·yŘ ăK2dzfŘú úKŜ ŘλăúN₪λōdzúλ2y dzúλfúλûλŜă LJ₪2ØλŘŜ y2ø I·yŘ λy úKŜ Ŧdzúdz₪ŜK

H¢ I2ø ăK2dzfŘ dzúλfúè ₪I·ûŜă ōŜ ŘŜăλƎyŜŘ ú2 LJ₪2ØλŘŜ LJ₪λǑŜ ăλƎyI·fă ú2 Ǒdzăú2Y Ŝ₪ă I·yŘ ú2 Ǒ2Y LJŜyãI·ûŜ

dzΰλŧŧΰλŜă ŧƧℕ ΰĸŜ ăŜℕØλŎŜă ΰĸŜè ℕŜyŘŜℕΣ λyŎŧdzŘλyƎ λyŎŜyΰλØŜă ΰƨ LJℕƧØλŘŜ ōƨΰK ΰℕIŀŘλΰλƧyIŀf IŀyŘ yƧyΰℕIŀŘλΰλƧyIŀf ăŜℕØλŎŜăK

!ΰ λăădzŜ λă ΰĸŜ yIŀΰdzℕŜ ƧŧΰĸŜ ŜyΰλΰλŜă ΰĸIŀΰ LJℕƧØλŘŜ ăŜℕØλŎŜă Iŀΰ ΰĸŜ Ŏdzăΰƨ2ϒŜℕăΩ LJℕŜϒλăŜăΣ ΰĸŜ ΰŜℕϒă ƧŧŎ2ϒLJŜyãIŀΰλ2yΣ Iŀ yŘ ΰĸŜ ŜŧŧŜŎΰ 2ϒ ΰĸŜ Iŀōλŧŧΰè ƧŧdzΰλŧŧΰλŜă ΰƨ ℕŜŎƨØŜℕ ΰĸŜ Ŏ2ăΰ ƧŧIŀŎΰλyƎ Iŀă ΰĸŜ Ŏ2yŘdzλΰ ΰƨ ΰĸŜ ƎℕλŘΦ

2.5.5.1 Models for Provision of Demand-Side Services

¢ĸŜℕŜ Iŀℕŝ Iŀΰŝℕyl·ΰλØŜ ØŜĸλŎŧŜă ŧƧℕ ŘŜŧØŜℕλyƎ ăŜℕØλŎŜă ΰƨ Ŏdzăΰƨ2ϒŜℕăΦ !ϒŝăăŜyΰλIŀf IjdzŜăΰλ2ϒλϒŘℕIŀØλyƎ ΰĸŜ ŧdzΰdzℕŜ ăŎ2LJŜ ƧŧΰĸŜ dzΰλŧŧΰλŜă λă ØĸŜΰĸŜℕ ΰĸŜè ØλƒƒLJℕƧØλŘŜ ŜyŜℕƎè ŜŧŧλŎλŜyŎè ăŜℕØλŎŜă Iŀ yŘ dzyŘŜℕ ØĸIŀΰ ΰŜℕϒăΦ ¢ĸŜ Iŀ yãØŜℕ ØλƒƒIŀtă2 LJƒIŀè Iŀ fIŀℕƎŜ ℕ2fŜ λϒŘŜΰŜℕϒλyƎ ΰĸŜ ōdzăλySää ϒ2ŘŜtă 2ŧ Ŏ2ϒLJŜΰλΰλØŜ LJℕƧØλŘŜℕăΦ ¢ĸŜℕŜ Iŀℕŝ ŧƧdzℕ ōIŀăλŎ IŀLJLJℕƧIŀŎĸŜă ΰƨ ΰĸŜ LJℕƧØλăλ2ϒ2ŧ ŜyŜℕƎè ŜŧŧλŎλŜyŎèᵛᴹ

- ᴍΦ tℕƧƎℕIŀϒă ŘŜℕλØŜŘ ŦℕƧϒ ΰĸŜ dzΰλŧŧΰèΩă LJƒIŀyϒλyƎ LJℕƧŎŜää óŜΦƎΦΣ λyΰŜƎℕIŀΰŜŘ ℕŜă2dzℕŎŜ LJƒIŀyϒλyƎ ΰƨ ŘŜΰŜℕϒλyŜ ΰĸŜ fŜØŜf 2ŧ Ŏ2ăΰπŜŧŧŜŎΰλØŜ ŜyŜℕƎè ŜŧŧλŎλŜyŎèΰ Iŀ yŘ IŀŘϒλyλăΰŜℕŜŘ ōè ΰĸŜ dzΰλŧŧΰèă
- ʜΦ tℕƧƎℕIŀϒă ŘŜℕλØŜŘ ŦℕƧϒ ΰĸŜ dzΰλŧŧΰèΩă LJƒIŀyϒλyƎ LJℕƧŎŜää óŜΦƎΦΣ λyΰŜƎℕIŀΰŜŘ ℕŜă2dzℕŎŜ LJƒIŀyϒλyƎ ΰƨ ŘŜΰŜℕϒλyŜ ΰĸŜ fŜØŜf 2ŧ Ŏ2ăΰπŜŧŧŜŎΰλØŜ ŜyŜℕƎè ŜŧŧλŎλŜyŎèΰ Iŀ yŘ Iŀ ŘϒλyλăΰŜℕŜŘ ōè Iŀ ΰĸλℕŘ LJIŀℕΰè 2LJŜℕIŀΰλyƎ dzyŘŜℕ Iŀ ăΰIŀΰŜ 2ℕ dzΰλŧŧΰèă LJℕƧƎℕIŀϒ
- oΦ ! ϒIŀℕ]ŜΰπōIŀăŜŘ IŀLJLJℕƧIŀŎĸΣ λyϒ ØĸλŎK ΰĸλℕŘπLJIŀℕΰè LJℕƧØλŘŜℕă ăŜŜ] LJℕƧŧλΰ ōè ăŜŧŧλyƎ ŜyŜℕƎè ŜŧŧλŎλŜyŎè ăŜℕØλŎŜă ΰƨ Ŏdzăΰƨ2ϒŜℕă
- nΦ ! ϒIŀℕ]ŜΰπōIŀăŜŘ IŀLJLJℕƧIŀŎĸΣ λyϒ ØĸλŎK λyŘλØλŘdzIŀf Ŏdzăΰƨ2ϒŜℕă IŀŎΰ λyϒ ℕŜăLJ2yãŜ ΰƨ ŜŧŜŎΰℕλŎλΰè LJℕλŎŜ ăλƎyIŀfăΦ

LyϒΰĸŜ ŦλℕăΰΰØ2 Iŀ LJLJℕƧIŀŎĸŜăΣ ŦdzyŘă ŧƧℕ LJℕƧƎℕIŀϒă Iŀ ℕŜ Ŏ2ŧŧŜŎΰŜŘ ōè ΰĸŜ dzΰλŧŧΰè ΰĸℕƧdzƎK Ŏdzăΰƨ2ϒŜℕăΩ ōλƒƒăΦ /dzăΰƨ2ϒŜℕă ŘλℕŜŎΰŧè ŦλyIŀyŎŜ ΰĸŜ ŧIŀăΰ ΰØ2 Iŀ LJLJℕƧIŀŎĸŜăΦ LyΰŜℕIŀŎΰλyƎ ØλΰK ΰĸŜ ŧdzℕ Iŀ LJLJℕƧIŀŎĸŜă ΰƨ ΰĸŜ LJℕƧØλăλ2ϒ 2ŧ ŜyŜℕƎè ŜŧŧλŎλŜyŎè ŧλăΰŜŘ Iŀōƨ0ŜΣ ăŜØŜℕIŀf ōdzăλySää ϒ2ŘŜtă Iŀℕŝ LJ2ăăλōfŜ ŘŜLJŜyŘλyƎ 2ϒ ΰĸŜ LJIŀℕΰλŎdzfIŀℕ Iŀ LJLJℕƧIŀŎĸ ΰĸIŀΰ Iŀ dzΰλŧŧΰè Iŀ yŘ λΰă ℕŜƎdzfIŀΰƨℕ ΰIŀ]Ŝ ó¢Iŀōfŝ нποúΦ

ᴹ 9yŜℕƎè ŜŧŧλŎλŜyŎè ăΰIŀyŘIŀℕŘă KIŀØŜ LJƒIŀèŜŘ Iŀ ØλΰIŀf ℕ2ŧŝ λϒΰℕIŀyãŦ2ℕϒλyƎ ΰĸŜ ŜŧŧλŎλŜyŎè 2ŧ IŀØIŀλƒIŀōfŜ LJℕƧ2ŘdzŎΰăΦ ¢Kλă ăŜŎΰλ2yΎă Ŏ2yŎŜℕyŜŘ ØλΰK ΰĸŜ ŎK2λŎŜ IŀyŘ IŀŎljdzλăΰλ2ϒ2ŧ ΰĸK2ăŜ LJℕƧ2ŘdzŎΰăΦ

Table 2-3. Energy Efficiency Business Models[270, 271]

Utility Programs	Utility energy efficiency programs are part of a resource-acquisition process in which a utility plans for resources that it expects to need in order to provide reliable service.
Independent Entities	Some states use independent entities to administer energy efficiency programs. Their purpose is to invest in services and programs that save money and conserve energy. The fee is based on integrated resource plans that consider both environmental and economic costs.
State Agency Administered	Some states, such as New York, employ a blended approach, whereby some the New York State Energy Research and Development Authority implements the efficiency programs, and the utilites implement others.
Market-Based Providers	Some non-utility companies provide value by serving as the interface between customers and the market (e.g., Comverge).
Energy Service Companies	Energy service companies (ESCOs) offer both private provision of energy efficiency services and a vehicle for implementation. They typically use performance contracts in which the ESCO guarantees energy and/or dollar savings for the project, linking ESCO compensation to the performance of the project.

An array of actors in the electricity sector including utilities, private-sector companies, and state agencies offer energy efficiency programs. Energy efficiency programs are available both in wholesale electricity market areas and within regulated vertically integrated utility areas.

2.5.5.2 Models for Integrating Distributed Generation

5ƛăúNƛōdzűŜŘ ƎŜyŜNƖ·ûƛ2ƴ ŘŜfƛØŜNă LJ2ǿŜN ƛyű2 úĸŜ Řƛăúnƛōdzűƛ2ƴ ƎNƛŘ yŜƖ·N úĸŜ f2Ɩ·Ř ŎŜyűŜN¢ ¢èLJƛŎƖ·ffèΣ 5D ƛă 2ƴ úĸŜ Ödzăű2YŜN ăƛŘŜ 2Ŧ úĸŜ YŜűŜNY úĸŜ Ödzăű2YŜN ƛyăúƖ·ffă ƎŜyŜNƖ·ûƛ2yΣ ăű2NƖ·ƎŜΣ 2N Ɩ· Ŏ2yűN2ffƖ·ōfŜ f2Ɩ·Ř Ɩ·yŘ ûƛŜă ƛyű2 úĸŜ ƎNƛŘ ØƛƖ· úĸŜ Řƛăúnƛōdzűƛ2ƴ dzűƛfƛûèo ¦ ûƛfƛûƛŜă ŎƖ·ƴƛyűŜƎNƖ·ûŜ 5D dzăƛyƎ Ɩ· ØƖ·NƛŜűè 2Ŧ ōdzăƛyŜăă YŻŘŜfă ó¢Ɩ·ōfŜ нππúo ¢ĸŜăŜ YŻŘŜfă Ŏ2dzfŘ ōŜ 2ƴ úĸŜ Ödzăű2YŜN ăƛŘŜΣ ǿĸŜNŜ dzűƛfƛûƛŜă ăŜff 5D LJN2ŘdzŎűă ŘƛNŜŎűfè ű2 úĸŜ Ŏ2yãdzYŜN 2N 2ƴ úĸŜ dzűƛfƛûènăƛŘŜΣ ǿĸŜNŜ 5D LJN2ØƛŘŜNă ăŜff ŜyŜNƎè ŘƛNŜŎűfè ű2 úĸŜ dzűƛfƛúèo ! fűĸ2dzƎK Ɩ·ă 5D LJN2ØƛŘŜ YŻNŜ ŜfŜŎúNƛŎƛúèΣ úĸŜ ƎŜyŜNƖ·ûƛ2ƴ Ɩ·yŘ YƖ·yƖ·ƎŜYŜyű 2Ŧ ŜfŜŎúNƛŎƛúè YƖ·è ōŜŎ2YŜ Ɩ· ăĸƖ·NŜŘ NŜăLJ2yãlōƛfƛúè Ɩ·Y2yƎ dzűƛfƛûƛŜăΣ Ödzăű2YŜNπ2ǿyŜŘ 5DΣ Ɩ·yŘ 2ű ĸŜNŜ 5DπăŜNØƛŎŜ LJN2ØƛŘŜNăo

¢2ŘƖ·èΣ YŻăű 5D ƛyăúƖ·ffƖ·ûƛ2yã 2ŎŎdzN 2ƴ úĸŜ Ödzăű2YŜN ăƛŘŜ 2Ŧ úĸŜ YŜűŜNo[HTH] 9ÈŎŜLJű ƛƴ NƖ·NŜ ŎƖ·ăŜăΣ úĸŜ Ödzăű2YŜN NŜYƖ·ƛyã Ŏ2yƴŜŎűŜŘ ű2 úĸŜ Řƛăúnƛōdzűƛ2ƴ ƎNƛŘΣ ØĸƛŎK ăŜNØŜă Ɩ·yè f2Ɩ·Ř dzyYŜű ōè úĸŜ 5D¢ ² ĸŜƴúĸŜ 5D ăèăúŜY LJN2ŘdzŎŜă LJ2ǿŜN ƛƴ ŜÈŎŜăă 2Ŧ Ödzăű2YŜN yŜŜŘăΣ úĸƖ·ű LJ2ǿŜN YƖ·è ōŜ ă2fŘ ƛyű2 úĸŜ Řƛăúnƛōdzűƛ2ƴ ăèăúŜY¢ ¢ĸŜ YƖ·ʔ2Nƛûè 2Ŧ úĸƛă 5D ăă 2ƴ úĸŜ Ödzăű2YŜN ăƛŘŜΣ ØƛúĸK ØŜNè ŦŜØ Ödzăű2YŜNă ăŜffƛyƎ LJ2ǿŜN ōƖ·Ŏ] ű2 úĸŜ ƎNƛŘo {Ɩ·fŜă ű2 úĸŜ ƛyűŜNŎ2yƴŜŎűŜŘ dzűƛfƛûè Ŏ2dzfŘ 2ŎŎdzN dzyŘŜN Ɩ· yŜű YŜűŜNƛyƎ Ɩ·NNƖ·yƎŜYŜyűΣ Ɩ· ØƖ·fdzŜ 2Ŧ ă2fƖ·N úƖ·NƛŦŦΣ Ɩ· ŦŜŜŘπƛƴúƖ·NƛŦŦΣ[22] Ɩ· tdzōfƛŎ ¦ ûƛfƛûè wŜƎdzfƖ·ű2Nè t2fƛŎƛŜă ! Ŏű Ŏ2yűNƖ·ŎűΣ 2N Ɩ·ă Ɩ· yŜƎ2űƛƖ·ûŜŘ ǿĸ2fŜăƖ·fŜ ăƖ·fŜo

[22] CŜŜŘπƛƴúƖ·NƛŦŦă Ɩ·NŜ ăŜű LJNƛŎŜă LJƖ·ƛŘ ōè dzűƛfƛûƛŜă ű2 Ödzăű2YŜNă Ŧ2N LJN2ŘdzŎűƛ2ƴ 2Ŧ NŜyŜǿƖ·ōfŜ ŜyŜNƎèo

Table 2-4. Business Models for Distributed Generation

Customer Ownership	The customer finances the installation, keeps any renewable energy credits associated with solar production, enjoys the tax benefits of the investment, and keeps the bill credit from net metering (or revenue stream from an alternative compensation scheme, such as a value-of-solar or feed-in-tariff).
Power Purchase Agreements	PPAs are standard contract vehicles for long-term power purchases from a third-party developer.
Utility Affiliate Model	The utility invests capital in developing DER through an affiliate. Codes of conduct bar affiliates from competing in markets in which their parent (franchised) utilities do business, or subject affiliates to special restrictions and oversight.
Utility Provided Customer-Premises Model	Where allowed, utilities may offer DER systems to customers and, like other utility generation investments, include the capital cost in the rate base. The utility (as opposed to an affiliate) is the supplier.
Aggregators	Aggregators are companies that group customer load or generation assets together to facilitate their participation in the markets.
Utility-Owned DER	Utility-owned DER can be located either on a customer's premises or on utility property.
Utility-Provided DER	Utility-provided DER is, essentially, small-scale, utility-owned generation. This model alleviates the issue of high, upfront and installation costs that leave customers unable to participate.
Third-Party Merchant Model	Independent third parties can connect DER directly to the distribution system with no onsite customer involvement.

Utilities can integrate DG using a variety of business models to accommodate varying local and regional circumstances, market and infrastructure topologies, and consumer preferences.

2.5.5.3 Limitations on the Scope of Utility Activities

¢ĸŝ ăŏƨlJŝ ƨŦ dzűλfλűè ăŝℕØλŏŝă ŘŝŦλyŝă űĸŝ fλyŝă ƨŦ ōdzăλyŝăă űĸlꞏű λű ŏlꞏyˇLJdzℕădzŝΦ ¢ĸŝℕŝ lꞏℕŝ ű ø ƨ ŦdzyŘlꞏYˇŝyűlꞏf ℕŝlꞏă2yã Ŧƨℕ fλYˇλűλyƎ ăŏƨlJŝΦ ¢ĸŝ ŦΛℕăú λă ű2 ŝŦŦŝŏűλØŝfè LJℕŝØŝyű ŏℕ2ăăπădzōăλŘλÎlꞏűλ2yˇƨŦ dzűλfλűè lꞏŦŦλfλlꞏűŝ lꞏŏűλØλűλŝăΣ λyˇøĸλŏK ℕlꞏűŝLJlꞏèŝℕă ădzōăλŘλÎŝ yƨyπŏ2ℕŝ dzűλfλűè lꞏŏűλØλűλŝăΦ C9w/ lꞏyŘ ăűlꞏűŝ t ¦ /ă flꞏℕƎŝfè Ŧ2ℕYˇlꞏfλÎŝŘ ℕŝƎdzflꞏű2ℕè lꞏdzűĸ2ℕλűλŝă ű2 LJℕŝØŝyű ŏℕ2ăăπădzōăλŘλÎlꞏűλ2yã¢ ¢ĸŝ ăŝŏ2yŘ ℕŝlꞏă2yˇű2 fλYˇλű dzűλfλűè lꞏŏűλØλűèΣ lꞏyŘ űĸŝ 2yŝ űĸlꞏű λă Yˇ2ăű λYˇLJ2ℕűlꞏyű λyˇŦℕlꞏYˇλyƎ űĸŝ ƨdzűdzℕŝ Řλăűℕλōdzűλ2yˇ dzűλfλűè Yˇ2ŘŝfΣ λă ű2 LJℕŝăŝℕØŝ Ŏ2yãdzYˇŝℕ ōŝyŝŦλűă 2Ŧ Ŏ2YˇLJŝűλűλ2yˇ ōè Ŝyl·ōfλyƎ Ŏ2YˇLJŝűλűλØŝ LJℕ2ØλŘŝℕă 2Ŧ LJ2øŝℕ lꞏyŘ ăŝℕØλŏŝă ű2 ŝŦŦŝŏűλØŝfè LJlꞏℕűλŏλLJlꞏűŝ λyˇ úĸŝ YˇlꞏℕlŝűΦ ¢ĸŝ flꞏúűŝℕ ℕlꞏűλ2yl·fŝ λă λYˇLJ2ℕűlꞏyű Ŧ2ℕ ŘŝűŝℕYˇλyλyƎ lꞏŏűλØλűλŝă ûĸlꞏű dzűλfλűλŝă lꞏℕŝ lꞏff2øŝŘ ű2 LJdzℕădzŝΦ

¦ űλfλűè ℕŝăűℕdzŏűdzℕλyƎ Ǝℕŝlꞏűfè lꞏfűŝℕŝŘ ûĸŝ ŝfŝŏűℕλŏ dzűλfλűè ōdzăλyŝăă YˇƨŘŝf λyˇ ă2Yˇŝ ăűlꞏűŝă ōè ōℕŝlꞏlλyƎ dzLJ Øŝℕűλŏlꞏffè λyűŝƎℕlꞏűŝŘ dzűλfλűλŝă lꞏyŘ λyűℕ2ŘdzŏλyƎ Ŏ2YˇLJŝűλűλ2yˇlꞏyŘ Ŏdzăű2Yˇŝℕ ŏK2λŏŝΦᴴᵀᴼ ¦ űλfλűλŝăΩ ŘλØŝăűλűdzℕŝ 2Ŧ Ǝŝyŝℕlꞏűλ2yˇlꞏfflꞏèŝŘ Ŏ2yŏŝℕyã lꞏō2dzű lꞏyűλπŏ2YˇLJŝűλűλØŝ ōŝKlꞏØλ2ℕΣ ădzŏK lꞏă ŏℕ2ăăπădzōăλŘλŝă ōŝűøŝŝyˇlꞏŦŦλfλlꞏűŝă lꞏyŘ Ŧlꞏø2ℕŝŘ úℕŝlꞏúYˇŝyű 2Ŧ lꞏŦŦλfλlꞏűŝă λyˇúĸŝ yŝø YˇlꞏℕlŝűΦ

t ¦ /ă λyˇℕŝăűℕdzŏűdzℕŝŘ ăűlꞏűŝă ŦℕŝIjdzŝyűfè ŝyŏ2dzℕlꞏƎŝŘ 2ℕ ℕŝIjdzλℕŝŘ ŘλØŝăűλűdzℕŝ 2Ŧ ƎŝyŝℕlꞏűλyƎ lꞏăăŝűă ă2 úĸlꞏű úĸŝ dzűλfλűλŝă yƨ f2yƎŝℕ Ŏ2yűℕ2ffŝŘ úĸŝλℕ 2øyˇƎŝyŝℕlꞏűλ2y℗ ! ă ølꞏă úĸŝ ŏlꞏâŝ λyˇbŝø ¸2ℕlΣ úĸŝ LJℕλYˇlꞏℕè ℕlꞏűλ2yl·fŝ Ŧ2ℕ ŘλØŝăűλűdzℕŝ ølꞏă ű2 ōℕŝlꞏl úĸŝ ŝŏ2yƨYˇλŏ ûλŝ ōŝűøŝŝyˇ ŝfŝŏűℕλŏλûè Ŕλăűℕλōdzűλ2yˇ lꞏyŘ ûℕlꞏyãYˇλăăλ2yˇ lꞏyŘ Ǝŝyŝℕlꞏűλ2yˇăŝℕØλŏŝă ű2 ŏℕŝlꞏúŝ lꞏ Ŏ2YˇLJŝűλűλØŝ øĸ2fŝălꞏfŝ ŝfŝŏűℕλŏλûè YˇlꞏℕlŝűΦ .ŝűøŝŝyˇмффy lꞏyŘ нллмΣ dzűλfλűλŝă ŘλØŝăűŝŘ Yˇ2ℕŝ úĸlꞏyˇ олл ŝfŝŏűℕλŏπƎŝyŝℕlꞏűλyƎ LJflꞏyűă λyˇ úĸŝ ¦ yλűŝŘ {ûlꞏűŝăΣ yŝlꞏℕfè нл LJŝℕŏŝyű 2Ŧ ű2ûlꞏf ƎŝyŝℕlꞏűλyƎ ŏlꞏLJlꞏŏλûè℗ᴴᵀᵀ LyˇмффтΣ 2yfè м¢c LJŝℕŏŝyű 2Ŧ ¦ φ{Φ ŝfŝŏűℕλŏλûè ø lꞏă LJℕ2ŘdzŏŝŘ ōè y2yπdzűλfλűè Ǝŝyŝℕlꞏűλ2yΣ ℕλăλyƎ ű2 нр LJŝℕŏŝyű ōè нллн lꞏyŘ ySlꞏℕfè op LJŝℕŏŝyű λyˇнлмн℗ᴴᵀᵖ

¦fûλY I·ûŜfèΣ ûKŜ IjdzŜăûλ2yˇλă y2ű ǿKI·ű ûKŜ dzûλfλûè I·ŦŦλfλI·ûŜ λă LJŜNWYˇλûûŜŘ û2 Ř2Σ ōdzű ǿKλÕK ŦdzyÕûλ2yã ûKŜ dzûλfλûè λûăŜfŦ λă I·ff2ǿŜŘ û2 LJŜNŦ2NWY{2YˇŜ ōI·ăλÕ IjdzŜăûλ2yã ăK2dzfŘ ōŜ I·ŘŘNŜăăŜŘ λyˇûKŜ LJN2ÕŜăă 2Ŧ ŘŜűŜNWYˇλyλyE ûKŜ ăÕ2LJŜ 2Ŧ dzûλfλûè I·ÖûλØλûλŜăY

- 52Ŝă LJN2Kλōλûλy3 dzûλfλûè I·ÖûλØλûè YˇŜI·yˇ3λØλy3 dzLJ ŜÕ2y2YˇλŜă 2Ŧ ăÕI·fŜ I·yŘ ăÕ2LJŜK
- ² KλÕK 2LJûλ2yˇLJN2ØλŘŜă Ödzăű2YˇŜNWă ǿλûK ûKŜ f2ǿŜăű Õ2ăű 2Ŧ ăŜNWØλÕŜK
- I2ǿ ÕI·yˇûKŜ dzûλfλûè ŜÈLJI·yŘ Õ2yãdzYˇŜNW ÕK2λÕŜK

/I·fλŦ2NWyλI·Ωă LJ2fλÕè λă I· Kèō NWλŘ I·LJLJN21·ÕK Σ I·ff2ǿλy3 ySű YˇŜûŜNWλy3 ǿλûK ûKλNWŘπLJI·NWûè ŘŜØŜf2LJYˇŜyű ûKN2dz3K t t ! ă I·yŘ dzûλfλûè λyØŜăűYˇŜyű λyˇ t±φ {ű I·ûŜ Lh ¦ă I·NŜ I·ff2ǿŜŘ û2 2ǿyˇ I·yŘ 2LJŜNWI·ûŜ ă2fI·NW t± ŦI·ÕλfλûλŜă I·yŘ ŜÈŜÕdzûŜ ă2fI·NW t± t t ! ă ǿλûK λyŘŜLJŜyŘŜyű LJ2ǿŜNW LJN2ŘdzÕŜNWă ûKN2dz3K I· Ö2YˇLJŜûλûλØŜ ă2fλÕλûI·ûλ2yˇLJN2ÕŜăăφHTC /I·fλŦ2NWyλI· KI·ă I·fă2 LJdzNWădzŜŘ I· KèōNWλŘ I·LJLJN21·ÕK û2 dzûλfλûèκYˇI·NWˇŜű LJN2ØλăλyˇûKI·ű LJN2Y2ûŜă ăû2NWI·3Ŝ ûŜÕKy2f23è ûKI·ű ŜyKI·yÕŜă 3NWλŘ 2LJûλYˇλÎI·ûλ2yΣ ûKŜ λyűŜ3NWI·ûλ2yˇ2Ŧ NŜySǿI·ōfŜ ŜyŜNW3èΣ I·yŘ ûKŜ NŜŘdzÕûλ2yˇ2Ŧ D I D ŜYˇăăλ2yãΣ I·yŘ ŜÈLJfλÕλûfè LJN2ØλŘŜă I· N2fŜ Ŧ2NW ûKŜ dzûλfλûè¦yŘŜNW /I·fλŦ2NWyλI· {ű I·ûŜ [I·ǿ !ăăŜYˇōfè .λff нрмпΣ ûKŜ /t¦/ ăλ NŜIjdzλNWŜŘ û2 ŜăűI·ōfλăK LJN2ÕdzNWŜYˇŜyű ûI·N3ŜûăŦ2NW ûKŜ ăűI·ûŜΩă ûKNWŜŜ Lh¦ă û2 I·ÕIjdzλNWŜ ØλI·ōfŜ I·yŘ Õ2ăûπŜŦŦŜÕûλØŜ ăû2NWI·3Ŝφ LyˇhÕû2ōŜNW нлмоΣ ûKŜ /t¦/ ŜăűI·ōfλăKŜŘ LJN2ÕdzNWŜYˇŜyű ûI·N3ŜûăûKI·ű NŜIjdzλNWŜŘ ûKŜ ûKNWŜŜ Lh¦ă û2 LJN2ÕdzNWŜ мΣонр а ² 2Ŧ ăû2NWI·3Ŝ ōè нлнлΣ ǿλûK ûI·N3ŜûăŘλØλŘŜŘ I·Y2y3 ûKNWŜŜ λyŘdzăúNWè ăŜ3YˇŜyűăY ûNWI·yăYˇλăăλ2yπ Õ2yŷŜÕűŜŘΣ ŘλăúNWλōdzûλ2yπfŜØŜfΣ I·yŘ Ödzăû2YˇŜNWπăλŘŜπ2ŦçûKŜπYˇŜûŜNW I·LJLJfλÕI·ûλ2yãφ LyˇÕ2yűNWI·ăû ǿλûK ûKŜ ăûI·ûŜΩă LJ2fλÕè 2yˇN22Ŧû2LJ ă2fI·NW λyăûI·ffI·ûλ2yãΣ dzûλfλûλŜă I·NŜ I·ff2ǿŜŘ û2 2ǿyˇdzLJ û2 pл LJŜNWÕŜyű 2Ŧ ûKŜNW ÕdzYˇdzfI·ûλØŜ ûI·N3ŜûăφHTT !y2ûKŜNW ŜÈI·YˇLJfŜY ûKŜ {ûI·ûŜ 2Ŧ bŜǿ ¸2NWΩă wŜŦ2NWYˇλy3 ûKŜ 9yŜN3è ±λăλ2yˇλyλûλI·ûλØŜ I·fă2 ăŜŜ¶ă û2 NŜŦ2NWYˇ ûKŜ dzûλfλûè ōdzăλySăä YˇŘŜfφ ¢KŜ bŜǿ ¸2NW¶ tdzōfλÕ {ŜNWØλÕŜ /2YˇYˇλăăλ2yˇλyˇнлмп λăădzŜŘ I· LJN2LJ2ăI·fûKI·ű ǿ2dzfŘ ŜăűI·ōfλăK ûKŜ dzûλfλûè I·ă I· ŘλăúNWλōdzûλ2yˇăèăűŜY LJfI·ûŦ2NWY ó5{tú LJN2ØλŘŜNWφ ¢KŜ LJN2LJ2ăI·f λă ŘλØλŘŜŘ λyű2 ûǿ2 úNWI·Õ¶ăφ ¢NWI·Õ¶ м I·ŘŘNWŜăăŜŘ ûKŜ ŘŜØŜf2LJYˇŜyű 2Ŧ 59w ǿλûK ûKŜ dzûλfλûè I·ă 5{t LJN2ØλŘŜNWăΣ I·yŘ ¢NWI·Õ¶ н I·ŘŘNWŜăăŜă NŜŦ2NWY 2Ŧ dzûλfλûè NWI·ûŜYˇ¶λyE I·yŘ NWŜØŜyűzŜ ăúNWŜI·YˇăûŜI·ŘI·LJű û2 ûKŜ 5{t YˇŘŜfφ

2.5.5.4 Nature of Consumer Protection Changing with New Players

¢KŜ yI·ûdzNWŜ 2Ŧ Õ2yãdzYˇŜNW LJN2ûŜÕûλ2yˇλă ÕKI·yE3λyEφ I λăú2NWλÕI·ffèΣ ûKŜ NWŜE3dzfI·û2Nè ăúNWdzÕûdzNWŜ ǿI·ă ŜăűI·ōfλăKŜŘ û2 2ØŜNWăŜŜ ûKŜ NWŜfI·ûλ2yãKλLJ ōŜűǿŜŜyˇûKŜ dzûλfλûè I·yŘ Õ2yãdzYˇŜNWăΣ I·yŘ t¦/ă KI·ØŜ ûKŜ I·dzûK2NWλûè I·yŘ 2ōfλEI·ûλ2yˇ ûλ2 LJN2ûŜÕű Õ2yãdzYˇŜNWă ûKN2dz3K ûKŜ I·ŘYˇλyλăúNWI·ûλ2yˇ 2Ŧ ûKŜ NWŜE3dzfI·û2Nè Õ2YˇLJI·Õűφ t¦/ă I·ăădzNWŜ NWŜI·ă2yI·ōfŜ LJNWλÕŜă I·yŘ I·Õű I·ă I·yˇI·NōλûŜNW 2Ŧ Õ2yãdzYˇŜNW Õ2YˇLJfI·λyûăφ /2yãdzYˇŜNWă ÕI·yˇI·ÕIjdzλNWŜ ŜfŜÕûNWλÕλûè ŦN2Y 2yπLJNWŜYˇλăŜ 5DΣ ŜλûKŜNW ûKN2dz3K ŘλNWŜÕű LJdzNWÕKI·ăŜ 2N f2yE3πûŜNWY ûNWI·yăI·Õûλ2yã ǿλûK ûKλNWŘπLJI·NWûè LJN2ØλŘŜNWă ǿKŜNWŜ LJŜNWY¶λûûŜŘφ b2yπdzûλfλûè Ŝyűλ ûŜăÕI·yˇI·fă2 LJN2ØλŘŜ 2ûKŜN ŜyŜNW3è ăŜNWØλÕŜăΣ fλ¶Ŝ ŜyŜNW3è ŜŦŦλÕλŜyÕè NŜûN2Ŧλûăφ ¢KŜăŜ ûKλNWŘπ LJI·NWûè LJN2ØλŘŜNWă ÕNŜI·ûŜ yŜǿ NŜfI·ûλ2yãKλLJă ǿλûK ûKŜ Õ2yãdzYˇŜNW ûKI·ű ûKŜ NŜE3dzfI·û2Nè Õ2YˇLJI·Õű ŘλŘ y2ű ŜyØλă2yφ ¢KŜ NŜfI·ûλ2yãKλLJ ōŜűǿŜŜyˇûKŜ Õ2yãdzYˇŜNW I·yŘ ûKŜăŜ y2yπdzûλfλûè ŜyűλûλŜă I·NŜ dzădzI·ffè Ǝ2ØŜNWySŘ ōè Õ2yűNWI·Õű fI·ǿφ LyˇÕI·ăŜă ǿKŜNŜ ădzÕK Õ2yűNWI·ÕûdzI·f NŜfI·ûλ2yãKλLJă λyŐfdzŘŜ ŦNWI·dzŘdzfŜyű Õ2yŘdzÕûΣ ûKŜ CŜŘŜNWI·f ¢NWI·ŘŜ /2YˇYˇλăăλ2yˇI·yŘ ăűI·ûŜ I·ûúz2NWySèă ƎŜySNWI·f τ y2ű t¦/ă τ KI·ØŜ 2ØŜNWăλ3Kű I·dzûK2NWλûè φ

² KŜyˇÖdzăű2YˇŜNWă ŘŜÕλŘŜ û2 ŘŜØŜf2LJ ă2fI·NW NŜă2dzNWÕŜă 2yˇûKŜNW LJNWŜYˇλăŜăΣ ûKŜè YˇdzăűYˇI·¶Ŝ ûǿ2 λYˇLJ2NWúI·yű ŘŜÕλăλ2yãφ ¢KŜăŜ λyÕfdzŘŜ óмú ǿKŜûKŜNW û2 ōdzèΣ fŜI·ăŜΣ 2N ŜyűŜNW λyű2 I· t t ! I·yŘ óнú ûKŜ ăλÎŜ 2Ŧ ûKŜ ă2fI·NW ŦI·Õλfλûèφ ¢èLJλÕI·f Ödzăű2YˇŜNWă ûλŜ ûKŜăŜ ŘŜÕλăλ2yã û2 ûKŜ LJN2LJŜNWûè ûKŜè 2ÕÕdzLJèΣ I·yŘ ûKŜè YˇI·è y2ű KI·ØŜ I·ŘŜIjdzI·ûŜ λyf2NWYˇI·ûλ2yˇ I·ō2dzű NWă¶ă I·yŘ λYˇLJI·Õűφ ¢KŜ LJNWyÕλLJI·f ă2dzNWÕŜ 2Ŧ λyf2NWYˇI·ûλ2yˇ Õ2YˇŜă ŦN2Y ûKŜ ØŜyŘ2NWă ûKI·ű ǿI·yű û2 ŜλûKŜNW ăŜff 2N ŜyűŜNW λyű2 f2yE3πûŜNWY Õ2yűNWI·Õűăφ HTUΣ HTφ

¢KŜNWŜ I·NWŜ ûǿ2 ûèLJŜă 2Ŧ f2yE3πûŜNWY Õ2yűNWI·ÕűăY óмú I· Ödzăű2YˇŜNW ăλEyã I· ûNWI·Řλûλ2yI·f fŜI·ăŜ I·yŘ LJI·èă û2 dzăŜ I· ă2fI·NW ăèăűŜYΣ 2N óнú I· Ödzăű2YˇŜNW ăλEyã I· tt ! I·yŘ LJI·èă I· ăŜű YˇZyűKfè NWI·ûŜ Ŧ2NW ûKŜ ŜfŜÕűNWλÕλûè ûKI·ű λă ƎŜySNWI·ûŜŘφ ¢KŜ fŜyƎűKă 2Ŧ ûKŜ Õ2yűNWI·Õűă I·NWŜ ûèLJλÕI·ffè нлçол èŜI·NWă óI·fûK2dz3K ă2YˇŜ I·NWŜ ăK2NWúŜNWú I·yŘ Õ2yűI·λyˇûKŜ LJN2Øλăλ2yˇ ûKI·ű I·yè ŜÈÕŜăă LJ2ǿŜNW LJN2ŘdzÕŜŘ ǿλff ōŜ ă2fŘ û2 ûKŜ ƎNWλŘ I·ű ûKŜ NWŜúI·λf NWI·ûŜ óyŜű YˇŜûŜNWyƎúφ .è нлмпΣ тн LJŜNWÕŜyű 2Ŧ ûKŜ NWŜăλŘŜyűλI·f ă2fI·NW λyˇûKŜ ¦yűŜŘ {ûI·ûŜă ǿI·ă ă2fŘ dzyŘŜNW ă2fI·NW fŜI·ăŜă I·yŘ tt ! ăφ нулΣ нум 5λŦŦŜNWŜyű ăúI·ûŜă KI·ØŜ ŘλŦŦŜNWŜyű LJ2fλÕλŜă 2yˇûKλNWŘπLJI·NWûè ŦλyI·yÕλyEφ !ă 2Ŧ a I·NWÕK нлмсΣ нр ăúI·ûŜΣ LJfdză ûKŜ 5λăúNWλÕű 2Ŧ /2fdzYˇōλI· I·yŘ tdzŜNWú2 wλÕ2 I·ff2ǿŜŘ ûKλNWŘπLJI·NWûè ă2fI·NW tt ! ăT y ăúI·ûŜă LJN2KλōλûŜŘ ûKλNWŘπLJI·NWûè ă2fI·NW tt ! ăT I·yŘ

ŭĸŜ fŜƎƖ·ſ ăŭĺ·ŭdză ǿĺ·ă dzyŎfŜĺ·₦ ƛy˅мc ăŭĺ·ŭŜă^{нуч} ¢ĸŜ {2fĺ·₦ 9yŜ₦Ǝè LyŘdzăŭ₦ƛŜă ! ăă2Ŏƛĺ·ŭƛ2y˅LJdzōfƛăĸŜŘ ƛy˅нлмр ŭĸŜ {2fĺ·₦ .dzăƛySăă /2ŘŜ Ĺ·yŘ ōŜăŭ LJ₦Ĺ·ŎŭƛŎŜă ₮2₦ Ŏ2yãdzY˙Ŝ₦ LJ₦2ŭŜŎŭƛ2y$^{\Sigma}$ ōè ǿĸƛŎK Y˙ŜY˙ōŜ₦ Ŏ2Y˙LJĺ·yƛŜă Y˙dzăŭ Ĺ·ōƛŘŜ^{нуо}

wŜŭĺ·ſf 2LJŜy˙ Ĺ·ŎŎŜăă Ĺ·ff2ǿă Ŏdzăŭ2Y˙Ŝ₦ă ŭ2 ăĸ2LJ ₮2₦ ŜfŜŎŭ₦ƛŎƛúè ₮₦2Y˙ Ŏ2Y˙LJŜŭƛŭƛ2y˙Ĺ·yŘ ŭĸŜ 2₮₮Ŝ₦ƛyƎ 2₮ ySǿ ăŜ₦ØƛŎŜ 2LJŭƛ2yã ŭ2 Ŏdzăŭ2Y˙Ŝ₦ă τ fĺ·₦ƎŜfè ōè y2yπdzŭƛfƛúè LJ₦2ØƛŘŜ₦ă$^{\Phi}$ 52ƛyƎ ă2 Kĺ·ă ƛyŎ₦Ŝĺ·ăŜŘ ƛyy2Ø Ĺ·ŭƛ2y$^{\Sigma}$ ōdzŭ ƛŭ Kĺ·ă Ĺ·fă2 Y˙Ĺ·ŘŜ ŭĸŜ ₦2fŜ 2₮ Ŏdzăŭ2Y˙Ŝ₦ LJ₦2ŭŜŎŭƛ2y˙Y˙2₦Ŝ Ĺ·Y˙ōƛƎdz2dzăΣ Ŏ₦Ŝĺ·ŭƛyƎ 2LJLJ2₦ŭdzyƛŭƛŜă ŭ2 ŘŜØŜf2LJ Y˙ŜŎKĺ·yñăY˙ă ŭ2 ƛyŎ₦Ŝĺ·ăŜ ŭ₦Ĺ·yãLJĺ·₦ŜyŎè$^{\Phi}$ tĺ·₦ŭ 2₮ ŭĸŜ ŭ₦Ĺ·yã₮2₦Y˙Ĺ·ƛ2y˙ ₦Ŝĺjdz₦₦Ŝă ySǿ ŭ22fă ₮2₦ Y˙2yñŭ2₦ƛyƎ ŭĸƛ₦ŘπLJĺ·₦ŭè ƛyŭŜ₦ĺ·ŎŭƛŽyã ǿƛŭK Ŏdzăŭ2Y˙Ŝ₦ă τ ₮₦2Y˙ ₮₦Ĺ·dzŘdzfŜyŭ Ŏfĺ·ƛY˙ă ŭ2 ₮Ĺ·ƛfdz₦Ŝ ŭ2 Y˙ŜŜŭ Ŏ2yŭ₦Ĺ·Ŏŭdzĺ·f 2ōfƛƎĺ·ƛŽyãΦ {ŭĺ·ŭŜ t ¦ /ă Y˙Ĺ·è ₦Ŝĺjdz₦₦Ŝ ySǿ LJ2ǿŜ₦ă ŭ2 ₮dzf₮ƛff ŭĸŜƛ₦ Kƛăŭ2₦ƛŎ ₦2fŜ 2₮ LJ₦2ŭŜŎŭƛyƎ Ŏdzăŭ2Y˙Ŝ₦ăΦ

2.6 Federal and State Jurisdictional Issues

¢ĸŜ ŭ₦Ĺ·yã₮2₦Y˙Ĺ·ŭƛ2yã ƛy˅ŭĸŜ ŜfŜŎŭ₦ƛŎƛúè ăŜŎŭ22₦ ₦Ĺ·ƛăŜ ĺjdzŜăŭƛ2yã Ĺ·ō2dzŭ ǿĸ2 ăĸ2dzfŘ ₦ŜƎdzfĺ·ŭŜ ySǿ ăŜ₦ØƛŎŜă Ĺ·yŘ Y˙Ĺ·₦¦Ŝŭ Ŝyŭ₦Ĺ·yŭă Ĺ·yŘ ŭĸŜ Ǝ₦2ǿŭĸK 2₮ f2yƎπŘƛăŭĺ·yŎŜ ŭ₦Ĺ·yãY˙ƛăăƛ2y˙Ĺ·Ŏ₦2ăă ăŭĺ·ŭŜ Ĺ·yŘ w¢h ō2dzyŘĺ·₦ƛŜă¢ ¢ĸŜ₦Ŝ ƛă ƛyŎ₦Ŝĺ·ăŜŘ LJ2ŭŜyŭƛĺ·f ₮2₦ ŭŜyãƛ2yã ōŜŭǿŜŜy˙ŜÈƛăŭƛyƎ ₦ŜƎdzfĺ·ŭ2₦è ō2ŘƛŜă Ĺ·ŭ ŭĸŜ ăŭĺ·ŭŜ Ĺ·yŘ CŜŘŜ₦Ĺ·f fŜØŜfăΣ Ĺ·yŘ ŭĸŜ CŜŘŜ₦Ĺ·f t2ǿŜ₦ !ŎŭΩă óCt !Ωăú ō₦ƛƎKŭ fƛyŜ ŘŜfƛySĺ·ŭƛyƎ CŜŘŜ₦Ĺ·f Ĺ·yŘ ăŭĺ·ŭŜ ƨdz₦ƛăŘƛŎŭƛ2y˙ Ĺ·dzŭK2₦ƛŭƛŜă ƛă ƛyŎ₦Ŝĺ·ăƛyƎfè ōfdz₦₦ŜŘ¤ /Ŝ₦ŭĺ·ƛy˙ ySǿ ŭŜŎKy2f2ƎƛŜă ădzŎK Ĺ·ă 5DΣ ă2LJKƛăŭƛŎĺ·ŭŜŘ f2Ĺ·Ř Ŏ2yŭ₦2fă ŭĸĺ·ŭ ₮Ĺ·Ŏƛfƛŭĺ·ŭŜ ŘŜY˙Ĺ·yŘ Y˙Ĺ·yĺ·ƎŜY˙Syŭ$^{\Sigma}$ Y˙ƛŎ₦2Ǝ₦ƛŘăΣ Ĺ·yŘ ăŭ2₦ĺ·Ǝ$^{\Sigma}$ Ĺ·₦Ŝ y2ŭ Ĺ·ă ŎfŜĺ·₦fè ŘŜfƛySĺ·ŭŜŘ Ĺ·ă ōŜƛyƎ ă2fŜfè ǿƛŭKƛy˙ ŭĸŜ ₦Ŝĺ·fY 2₮ ǿĸ2fŜăĺ·fŜ 2₦ ₦Ŝŭĺ·ſf ¤dz₦ƛăŘƛŎŭƛ2y¢ ¢ĸŜăŜ ŭŜŎKy2f2ƎƛŜă ădzŎK Ĺ·ă 2yãƛŭŜ ăŭ2₦ĺ·Ǝ$^{\Sigma}$ Ĺ·ŭŜ

ŘλăúNλōdzúŜŘ NŜă2dzNŐŜă λy úKŜNJ ăèăúŜY I·yŘ NŜăŜftă űKI·ú ŜfŜŐúNλŐλúê ű2 2űKŜNJ dzăŜNă ǿλúKλy úKŜ Y·λŐN2ƎNλŘΦ ¢KŜ Ct ! Ő2dzfŘ Ő2yãλŘŜNJ ădzŐK I· úNJI·yãI·ÔúΛ2y I·ă I· ăI·fŜ ₮2NJ NŜăI·fŜΣ ǿKλŐK CŜŘŜNJI·f fI·ǿ LJN2KλōλúăΦHYΦ 5ŜăLJΛúŜ fλyƎŜNλyƎ NŜƎdzfI·ú2N è I·yŘ ∂dzNλăŘλŐúΛ2yI·f dzyŐŜNúI·λyúΛŜăΣ úKŜ ydzY·ōŜNJ I·yŘ ŘλØŜNăλúê 2₮ Y·λŐN2ƎNλŘă Ő2yúΛydzŜă ú2 ƎN2ǿΦHΦΠ

2.6.2 Demand Response

Ly нллуΣHΦM C9w/ λăădzŜŘ hNŘŜNJ b2Φ тмф ű2Σ I·Y2yƎ 2űKŜNJ 2ō2ŜŐúΛØŜăΣ Ŝyădz NŜ úKŜ Ő2YLJI·NJI·ōfŜ úNJŜI·úY·Ŝyű 2₮ 5w λă ú2 2úKŜNJ NŜă2dzNŐŜă λy2NJƎI·yΛÎŜŘ Y I·NJ]Ŝúă I·yŘ ú2 LJŜNJY·λú 5w I·ƎƎNJŜƎI·ú2NJă ú2 LJI·NúλŐλLJI·úŜ λy·Y I·NJ]Ŝúă 2y ōŜKI·f₮ 2₮ NŜúI·λf Ődzăú2YŜNJăΦHΦH I2ǿŜØŜNJΣ ăúI·úŜă ŐI·y 2LJű 2dzű 2₮ C9w/Ωă 5w LJ2fλŐè I·yŘ ₮2NJŜŐf2ăŜ 5w LJI·NúλŐλLJI·úΛ2y·λy·Y I·NJ]Ŝúăφ

C9w/ λăădzŜŘ C9w/ hNŘŜNJ b2Φ тпр λy нлммΣ NJŜIjdzNJλyƎ úKI·ú 5w NJŜă2dzNJŐŜă NJŜŐŜλØŜ Ő2YLJŜyãI·úΛ2y ₮2NJ úKŜ ăSNJØλŐŜă úKŜè LJN2ØλŘŜ ű2 úKŜ ŜyŜNJƎè Y I·NJ]Ŝű I·ú úKŜ f2ŐI·úΛ2yI·f Y I·NJ]Ŝű LJNJλÔŜ ₮2NJ ŜyŜNJƎèΦHΦO C9w/ ŜĖLJŜNJλŜyŐŜŘ LJdzăKōI·Ő] ₮NJ2Y dzűΛfλúè I·yŘ ƎŜyŜNJI·ú2NJ Ő2YLJŜúΛú2NJă ú2 5wΣ ōdzű úKŜ {dzLJNJŜY·Ŝ /2dzNJú dzfűλY I·úŜfè dzLJKŜfŘ úKŜ 2NJŘŜNJ λy *Elec. Power Supply Ass'n v. FERC*Φ ¢KŜ /2dzNJú ₮2dzyŘ úKI·ú hNJŘŜNJ b2Φ тпр ŘλŘ y2ű ŘλNJŜŐúfè NJŜƎdzfI·úŜ NJŜúI·λf ŜfŜŐúNλŐλúê ăI·fŜă I·yŘ úKdză ǿI·ă ǿλúKλy C9w/Ωă ∂dzNJăŘλŐűΛ2yΦ ¢KŜ I·ōλfλúè 2₮ ŜyŘπdzăŜ Ődzăű2YŜNJă ú2 2₮₮ŜNJ 5w Ő2Y·Y·λúY·Syűă λy·úKŜ ǿK2fŜăI·fŜ Y I·NJ]ŜűΣ I·yŘ ú2 ōŜ Ő2YLJŜyãI·úŜŘ ₮2NJ úK2ăŜ Ő2Y·Y·λúY·SyűăΣ λă Y I·ŘŜ LJ2ăăλōfŜ ōè ûŜŐKy2f2Ǝè ŐKI·yƎŜă úKI·ú I·ff2ǿ úK2ăŜ Ődzăű2YŜNJă ú2 ōŜ I·ƎƎNJŜƎI·úŜŘΣ Y·2yλú2NJŜŘΣ I·yŘ Y·ŜúŜNJŜŘΦ ¢KdzăΣ ŜyŘ dzăŜNJă óű2 ǿK2Y ăI·fŜă I·NJŜ ŐfŜI·NJfè ǿλúKλy·ăúI·úŜ ∂dzNJăŘλŐúΛ2yΰ ǿŜNJŜ LJI·NúλŐλLJI·úΛyƎ λy·ǿK2fŜăI·fŜ ŜyŜNJƎè Y I·NJ]ŜűăΣ ădzō2ŜŐű ű2 C9w/ 2ØŜNJăλƎKűΣ LJNJŜăŜyűΛyƎ I· NJI·úΛ2yI·fŜ ₮2NJ NJŜƎdzfI·úΛ2y·dzyŘŜNJ úKŜ Ct ! ∂dzNJăŘλŐúΛ2yI·f LJN2ØλΛ2yăΦ

2.6.3 Energy Storage

9yŜNJƎè ăű2NJI·ƎŜ ŐI·LJI·ōλfλúΛŜă λyŐfdzŘŜ I·yè ₮I·Őλfλúè úKI·ú ŐI·y·NJŜŐŜλØŜ ŜfŜŐúNλŐ ŜyŜNJƎè ₮N2Y úKŜ ƎNλŘ I·yŘ ăű2NJŜ λú ₮2NJ fI·úŜNJ λy¢ŜŐúΛ2y·2₮ ŜfŜŐúNλŐλúê ōI·Ő] ű2 úKŜ ƎNλŘΦHΦΠ ! ØI·NλŜúè 2₮ úŜŐKy2f2ƎλŜă ₮λú λyű2 úKI·ú ŐI·úŜƎ2NJè λyŐfdzŘλyƎ ōI·úúŜNλŜă óƎNλŘ ăŐI·fŜ 2NJ úK2ăŜ λy·9±áúΣ ₮fèǿKŜŜfăΣ Ő2Y·LJNJŜăăŜŘ I·ΛNΣ I·yŘ LJdzY·LJŜŘ KèŘN2Φ ¢KŜăŜ úŜŐKy2f2ƎλŜă ØI·NJè λy·ŐI·LJI·ŐλúêI·yŘ Y I·è ōŜ Ő2yŷŜŐúŜŘ ŘλNJŜŐúfè ű2 úKŜ úNJI·yãY·λăăλ2y·ƎNλŘΣ I· ŘλăúNλōdzúλ2y·ăèăúŜYΣ 2NJ ōŜKλyŘπ I·πŐdzăű2YŜNJ Y·ŜúŜNJΦ 9yŜNJƎè ăű2NJI·ƎŜ λă dzyλIjdzŜ ōŜŐI·dzăŜ λú ŐI·y·úI·ˆ]Ŝ ŜyŜNJƎè 2NJ LJ2ǿŜNJ ₮N2Y úKŜ ƎNλŘΣ I·ŘŘ ŜyŜNJƎè 2NJ LJ2ǿŜNJ ű2 úKŜ ƎNλŘΣ I·yŘ ădzLJLJfè I· NJI·yƎŜ 2₮ ƎNλŘ ăŜNJØλŐŜă 2y·ăK2NJú óădzōπăŜŐ2yŘú I·yŘ f2yƎŜNJ óK2dzNJăú úλY·Ŝ ăŐI·fŜăΦ Ly·ŐŜNúI·λy·ŐI·ăŜăΣ I· ăλyƎfŜ ăű2NJI·ƎŜ NJŜă2dzNJŐŜ 2NJ I·y·I·ƎƎNJŜƎI·úΛ2y·2₮ ăű2NJI·ƎŜ NJŜă2dzNJŐŜă ŐI·y·LJNJ2ØλŘŜ Y·dzfűΛLJfŜ ăŜNJØλŐŜă ăλY·dzfúI·yŜ2dzăfèΣ ădzŐK I·ă ₮NJŜIjdzŜyŐè NJŜăLJ2yăŜ 2NJ 2úKŜNJ I·yŐλffI·Nè ăŜNJØλŐŜăΣ ŘλăLJI·úŐKI·ōfŜ 2dzúLJdzú I·]λy·ű2 ƎŜyŜNJI·úΛ2yΣ 2NJ ŘλăLJI·úŐKI·ōfŜ f2I·Ř NJŜŘdzŐúΛ2y·ă2Y·ŜǿKI·ú fλ]Ŝ 5wΦ

{úI·úŜπ2dzNJăŘλŐúΛ2yI·f NJŜúI·λf NJI·úŜă ₮2NJ ă2Y·Ŝ dzúλfλúΛŜă λyŐfdzŘŜ ŘŜY·I·yŘ ŐKI·NJƎŜă ₮2NJ λyŘdzăúNJλI·f I·yŘ Ő2Y·Y·ŜNJŐλI·f NJŜăλŘŜyúΛI·f Ődzăú2Y·ŜNJăΦ . I·úúŜNJè ăű2NJI·ƎŜ λă ŜĖLJŜŐúŜŘ ű2 ōŜŐ2Y·Ŝ I·y·ŜŐ2y2Y·λŐI·f Y·ŜI·yã ű2 Y·I·yI·ƎŜ Ődzăú2Y·ŜNJ ŘŜY·I·yŘ ŐKI·NJƎŜă I·ă ăèăúŜY LJNJλŐŜă ŘN2LJ I·yŘ úKŜ ØI·fdzŜ 2₮ ₮fŜĖλōλfλúè λyŐNJŜI·ăŜă ǿλúK I· ŐKI·yƎλyƎ NJŜă2dzNJŐŜ Y·λĖΦHΦP

I2ǿŜØŜNJΣ ŘŜLJf2èλyƎ ăű2NJI·ƎŜ NJŜă2dzNJŐŜă ă2fŜfè dzăλyƎ úKŜ ŜĖλăúλyƎ NJŜƎdzfI·ú2NJè Őfl·ăăλ₮λŐI·úΛ2yã óǿK2fŜăI·fŜ ŜyŜNJƎè I·yŘ I·yŐλffI·Nè ăŜNJØλŐŜă Y I·NJ]ŜúăΣ úNJI·yãY·λăăλ2yΣ I·yŘ ŘλăúNJλōdzúλ2yΰ ŐI·y·fλY·λú úKŜ I·ØI·λfI·ōfŜ ádzăŜ ŐI·ăŜăΦε Lú ŐI·y·I·fă2 Ő2yãúNJI·λy·úKŜ ăŜNJØλŐŜă úKI·ú I· LJI·NúλŐdzfI·NJ ăű2NJI·ƎŜ NJŜă2dzNJŐŜ ŐI·y·LJNJ2ØλŘŜ I·yŘ úKŜ NJŜØŜyűzŜ ă2dzNJŐŜă úKI·ú 2ǿyŜNJă 2NJ 2LJŜNJI·úΛ2NJă ŐI·y·2ōúI·λyΦ hyŜ LJI·NúλŐdzfI·NJ NJŜƎdzfI·úΛ2NJè Ő2Y·LJfλŐI·úΛ2y·λă úKI·ú ăű2NJI·ƎŜ Y I·è ōŜ ăŜfflyƎ Y·dzfúΛLJfŜ ăŜNJØλŐŜăΣ ă2Y·Ŝ 2₮ ǿKλŐK I·NJŜ ădzō2ŜŐú ű2 Y I·NJ]ŜúπōI·ăŜŘ LJNJλŐŜă I·yŘ 2úKŜNJă úKI·ú I·NJŜ ă2fŘ I·ú Ő2ăúπōI·ăŜŘ NJI·úŜăΦ ¢KŜ I·ōλfλúè ú2 dăúI·Ő]ε úKŜăŜ ăŜNJØλŐŜă ú2 I·ŐKλŜØŜ ădz₮₮λŐλŜyű NJŜØŜyűzŜă Y I·è NJŜIjdzNJŜ I·ŐúΛ2y·₮N2Y ō2úK C9w/ I·yŘ ăúI·úŜ NJŜƎdzfI·ú2NJăΦHΦC {úI·úŜ NJŜƎdzfI·ú2NJă I·yŘ C9w/ NJŜŐ2ƎyλÎŜ úKŜăŜ NJŜƎdzfI·ú2NJè Ő2yãúNJdzŐűăΣ I·yŘ C9w/ λă ŐdzNJNJŜyűfè ŜĖLJf2NJλyƎ úKŜ ōI·NJNJŜNJă ú2 ₮dzft LJI·NúλŐλLJI·úΛ2y·2₮ ăű2NJI·ƎŜ λy·2NJƎI·yλÎŜŘ Y I·NJ]Ŝúă C9w/ NJŜŐŜyűfè λăădzŜŘ I· y2űλŐŜ 2₮ LJN2LJ2ăŜŘ NdzfŜY I·]λyƎ ú2 I·ŘŘNJŜăă ŜfŜŐúNλŐλúèπăú2NJI·ƎŜ LJI·NúλŐλLJI·úΛ2y·λy·Y I·NJ]Ŝúă 2LJŜNJI·úŜŘ ōè w¢hă I·yŘ L{hăΦHΦT

2.6.4 Potential Tools to Coordinate across Jurisdictions and Align Regulatory Approaches to Emerging Energy Technologies

In many policy areas, FERC has tread softly where it might have a claim of jurisdiction but did not want to preempt state regulation; in these instances, it has chosen to exercise its jurisdiction in line with state policy goals. Several tools are at FERC's disposal to deal with future potential jurisdiction challenges impacting new and emerging technologies and the integration of markets for those technologies.

One way forward is through new frameworks that, for example, could establish rate-setting models that consider revenues from both state and Federal jurisdictions simultaneously. These models would allow resource owners to "stack" revenues from services they provide across state and Federal jurisdictions. It would also guard against the potential for over-recovery and unjust and unreasonable rates. In addition, FERC could explore including costs of additional technologies in rate design.

While rarely used, FERC has authority to establish joint hearings that would permit FERC and the states to hear cases together, but without a joint decisional procedure.[298] FERC can also delegate certain roles to "joint boards" made up of state commissioners (with no Federal representation).[299] More generally, FERC and state commissions can collaborate on policy matters of common interest.

Another possible approach is to redraw the line between Federal and state jurisdictions to better accommodate today's regulatory needs. In particular, this redraw should reflect the broader regional nature of electricity markets and the ability of new and emerging technologies to provide service across both Federal and state jurisdictional lines.[kk]

Another option would be to authorize jurisdictional agreements, which would permit a consensual resolution of potential conflicts between state agencies and FERC. Under this option, an amendment to the FPA would include provisions similar to those in several other Federal statutes[ll] that would authorize FERC and state commissions to enter into agreements that rationalize their respective state and Federal regulatory jurisdiction.

The recommendations based on the analysis in this chapter are covered in Chapter VII (*A 21st-Century Electricity Sector: Conclusions and Recommendations*).

[kk] Note that amendments to the Federal Power Act intended to resolve jurisdictional uncertainty with respect to new technologies or circumstances will themselves be subject to interpretation over time and will have to be applied to ever-changing fact patterns.

[ll] See e.g., National Labor Relations Act of 1935, Pub. L. No. 74-198, §§ 10(a), 14(c), 49 Stat. 449, 453, 457 (codified as amended at 29 U.S.C. §§160(a), 164(c)); Atomic Energy Act of 1954, Pub. L. No. 83-703, § 244, 68 Stat. 919, 958-59 (codified as amended at 42 U.S.C. § 2021 (2005)); Clean Air Act § 111(c), Pub. L. No. 91-604, § 111(c), 84 Stat. 1676, 1684 (1970) (codified as amended at 42 U.S.C. § 7411(c) (1977)).

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III Building a Clean Electricity Future

¢Kλă ŎKl·LJűŜNJ ŜȀLJƒƧNJŜă űKŜ ŜăăŜyűλl·ƒ ŜƒŜYŜyűă ƧŦ l· ŎƒŜl·y˜ŜƒŜŎűNJλŎλűȅ ăȅăűŜY˜Σ l·yŘ λŘŜyűλŦλŜă űKŜ LJƧƒλŎȅΣ Y˜l·NJ˜ʅŜűΣ l·yŘ űŜŎKyƧƒƧƎȅ λyƴƧØl·űλƧyã yŜŜŘŜŘ űƧ λY˜LJNJƧØŜ λűă ŜyØλNJƧyY˜Ŝyűl·ƒ LJŜNJŦƧNJY˜l·yŎŜφ Ly˜ăKƧNJűΣ űKŜ ¦ yλűŜŘ {űl·űŜă Kl·ă Y˜l·ŘŜ ădzōăűl·yűλl·ƒ LJNJƧƎNJŜăă λy˜NJŜŘdzŎλyƎ űKŜ ŜyØλNJƧyY˜Ŝyűl·ƒ λY˜LJl·Ŏű ƧŦ űKŜ ŜƒŜŎűNJλŎλűȅ ăȅăűŜY˜Σ ōdzű Y˜dzŎK ØƧNJ˜ʅ NJŜY˜l·λyãφ ¢KŜ ŎKl·LJűŜNJ ŦλNJăű ŜȀLJƒƧNJŜă űKŜ D l D ŜY˜λăăλƧyã ŦNJƧY˜ űKŜ LJƧØŜNJ ăŜŎűƧNJ l·yŘ űKŜ l·Øl·λƒl·ōλƒλűȅ ƧŦ ƒƧØπ l·yŘ ÎŜNJƧπŎl·NJōƧy˜ŜƒŜŎűNJλŎλűȅ ăƧdzNJŎŜăΣ λyŎƒdzŘλyƎ yƒdzŎƒŜl·NJΣ yl·űdzNJl·ƒ Ǝl·ăΣ ăƧƒl·NJΣ ØλyŘΣ KȅŘNJƧLJƧØŜNJΣ ōλƧY˜l·ăăΣ l·yŘ ƎŜƧűKŜNJY˜l·ƒ ăƧdzNJŎŜăφ ¢KŜ yŜȀű ăŜŎűλƧyã ŘŜűl·λƒ űKŜ λyűŜNJl·ŎűλƧy˜ ōŜűØŜŜy˜ ŎƒŜl·y˜ ŜƒŜŎűNJλŎλűȅ ăȅăűŜY˜ă l·yŘ ʅŜȅ ƧLJűλƧyã l·yŘ ŦŜl·űdzNJŜăΣ ădzŎK l·ă ŜyŜNJƎȅ ŜŦŦλŎλŜyŎȅΣ ŘŜY˜l·yŘ NJŜăLJƧyãŜΣ ƎNJλŘ ŦƒŜȀλōλƒλűȅΣ l·yŘ ăűƧNJl·ƎŜφ ¢KŜ ŎKl·LJűŜNJ λyŎƒdzŘŜă l· ŘλăŎdzăăλƧy˜ƧŦ KƧØ űKŜ λyűŜNJLJƒl·ȅ ƧŦ űŜŎKyƧƒƧƎȅΣ Y˜l·NJ˜ʅŜűăΣ l·yŘ LJƧƒλŎȅ Ŏl·y˜ƒŜl·Ř űƧ l· ŎƒŜl·yŜNJ ŜƒŜŎűNJλŎ ăȅăűŜY˜Σ l·yŘ KƧØ l· ŎƒŜl·yŜNJ ŜƒŜŎűNJλŎ ăȅăűŜY˜ Ŏl·y˜ ădzLJLJƧNJű ŜŎƧyƧY˜ȅπØλŘŜ ŘŜŎl·NJōƧyλÎl·űλƧy˜ űKNJƧdzƎK űKŜ ŦdzNJűKŜNJ ŜƒŜŎűNJλŦλŎl·űλƧy˜ƧŦ ƧűKŜNJ ŜyŘπdzăŜ ăŜŎűƧNJăφ

Key Findings for Building a Clean Electricity Future

- Deep decarbonization of the electricity system is essential for meeting climate goals; this has multiple economic benefits beyond those of environmental responsibility.
- The United States is the largest producer and consumer of environmental technologies. In 2015, the U.S. environmental technology and services industry employed 1.6 million people, had revenues of $320 billion, and exported $51 billion worth of goods and services.
- Though the U.S. population and economy have grown, between 1970 and 2014, aggregate emissions of common air pollutants from the electric power sector dropped 74 percent, even as electricity generation grew by 167 percent.
- U.S. carbon dioxide (CO_2) emissions from the power sector have substantially declined. Between 2006 and 2014, 61 percent of the reductions in CO_2 intensity were attributed to switching from coal- to gas-fired power generation, and 39 percent were attributed to increases in zero-emissions generation.
- The increasing penetration of zero-carbon variable energy resources (VERs) and deployment of clean distributed energy resources (DERs) (including energy efficiency) are critical components of a U.S. decarbonization strategy.
- It is beneficial to a clean electricity system to have many options available, as many of the characteristics of clean electricity technologies complement each other.
- Currently, 29 states and Washington, D.C., have a Renewable Portfolio Standard (RPS), and 23 states have active and binding Energy Efficiency Resource Standards (EERSs) for electricity. States that have actively created and implemented such electricity resource standards and other supporting regulatory policies have seen the greatest growth in renewables and efficiency.
- The integration of variable renewables increases the need for system flexibility as the grid transitions from controllable generation and variable load to more variable generation and the need and potential for controllable load. There are a number of flexibility options such as demand response (DR), fast ramping natural gas generation, and storage.
- Energy efficiency is a cost-effective component of a clean electricity sector. The average levelized cost of saved electricity from energy efficiency programs in the United States is estimated at $46 per megawatt-hour (MWh), versus the levelized cost of electricity (LCOE) for natural gas combined-cycle (NGCC) generation, with its sensitivity to fuel prices, at $52 to $78/MWh.[1]
- Electricity will likely play a significant role in the decarbonization of other sectors of the U.S. economy as electrification of transportation, heating, cooling, and industrial applications continues. In the context of the Quadrennial Energy Review (QER), electrification includes both direct use of electricity in end use applications as well as indirect use whereby electricity is used to make intermediate fuels such as hydrogen.
- Realizing greenhouse gas (GHG) emissions reductions and other environmental improvements from the electricity system to achieve national goals will require additional policies combined with accelerating technology innovation.
- Improving understanding of the electricity system and its dynamics through enhancements in data, modeling, and analysis is needed to provide information to help meet clean objectives most cost-effectively.
- Decades of Federal, state, and industry innovation investments have significantly contributed to recent cost reductions in renewable energy and energy efficiency technologies.
- Innovation in generation, distribution, efficiency, and demand response technologies is essential to a low-carbon future. Innovation combined with supportive policies can provide the signal needed to accelerate deployment of clean energy technologies, providing a policy pull to complement technology push.

- Nuclear power currently provides 60 percent of U.S. zero-carbon electricity, but existing nuclear merchant plants are having difficulty competing in restructured electricity markets due to low natural gas prices and flat or declining electricity demand. Since 2013, six nuclear power reactors have shut down earlier than their licensed lifetime, and eleven[a] others have announced plans to close in the next decade. In 2016, two states, Illinois and New York, put policies in place to incentivize the continued operation of existing nuclear plants.
- Enhanced oil recovery (EOR) operations in the United States are commercially demonstrated geologic storage, and could provide a market pull for the deployment of carbon capture, utilization, and storage (CCUS).
- Federal laws currently limit the ability of regulated utilities to utilize Federal tax credits in the same manner as private and unregulated developers. Publicly owned clean energy projects cannot benefit from the clean energy tax credits because tax equity investors cannot partner directly with tax-exempt entities to monetize tax credits.
- Low-income and minority communities are disproportionately exposed to air quality and water quality issues associated with electric power generation. Compared to the U.S. population overall, there is a greater concentration of minorities living within a three-mile radius of coal- and oil-fired power plants. In these same areas, the percentage of the population below the poverty line is also higher than the national average.
- Some energy technologies that reduce GHG emissions, such as carbon capture, utilization, and storage (CCUS), concentrated solar power (CSP), and geothermal generation, have the potential to increase energy's water intensity; others, such as wind and photovoltaic (PV) solar power, can lower it. Dry cooling can reduce water intensity but may increase overall GHG emissions by decreasing generation efficiency. Though there can be a strong link between energy and water efficiency in energy technologies, many research, development, demonstration, and deployment (RDD&D) funding criteria do not incorporate water use or water performance metrics. Designing technologies and optimizing operations for improved water performance can have both energy and water benefits.
- There is currently no centralized permanent-disposal facility for used nuclear fuel in the United States, so this radioactive material is stored at reactor sites in 35 states awaiting development of consolidated storage facilities and/or geologic repositories.
- Coal combustion residuals (CCRs), such as coal ash and scrubber slurry, are the second most abundant waste materials in the United States, after household waste.
- There is a range of decommissioning needs for different types of power generation facilities.

3.1 Building a Clean Electricity Future

² KλfŜ ŜfŜŎűNλŎλúè λă ŭKŜ ø2NlK2NäŜ 2Ŧ 2dzN Y2ŘŜNyŜŎ2y2Yès λű λă l·fă2 NŜăLJ2yãλōfŜ Ŧ2N Y2NŜ ŭKl·y˙oл LJŜNŎŜyű 2Ŧ ¦φ{φ ƎNŜŜyK2dzăŜ Ǝl·ă óDIDú ŜYˇλăăλ2yãφᴴ wŜŘdzŎλyƎ DID ŜYˇλăăλ2yã λă l· ˥Ŝè λY˙LJŜNl·ŭλØŜ Ŧ2N ŭKŜ LJ2øŜN ăŜŎű2N¢ ² KŜy˙Ŏ2yãλŘŜNλyƎ ŭKŜ ăŎl·fŜ 2Ŧ ŭKλă ŎKl·ffŜyƎŜΣ λű λă λY˙LJ2NúI·yű ú2 NŜŎ2ƎyλÎŜ ŭKl·ú ŭKŜ NŜŘdzŎűλ2y˙2Ŧ l·ŘØŜNăŜ LJdzōfλŎ KŜl·fűK l·yŘ ŜyØNN2yYˇŜyűl·f λY˙LJl·Ŏúă ŦN2Y ŜfŜŎúNλŎλúè ƎŜySŜNl·úλ2y˙Kl·ă ōŜŜy˙2yŜ 2Ŧ ŭKŜ Yˇl·ê2N ¦φ{φ ŜyØλN2yYˇŜyűl·f ădzŎŎŜăă ăű2NλŜă 2Ŧ ŭKŜ нлúK ŎŜyűdzNè¢ {λyŎŜ мфтлΣ ŜYˇλăăλ2yã 2Ŧ Ŏ2YˇY2y˙l·λN LJ2ffdzűl·yűă ŦN2Y ŭKŜ ŜfŜŎúNλŎ LJ2øŜN ăŜŎű2N Kl·ØŜ ŘŜŎNNŜl·ăŜŘ ōè Y2NŜ ŭKl·y˙Kl·fŦº LyˇúKŜ yŜl·N ûŜNYΣ Ŏl·Nō2y˙ŘλƐĖλŘŜ ó/hнú ŜYˇλăăλ2yã ŦN2Y ŭKŜ ŜyŜNƎè ăŜŎű2N ŦŜff ōè мл LJŜNŎŜyű ŦN2Y нллу ú2 нлмpΣ ØKλfŜ ŭKŜ ŜŎ2y2Yˇè ƎNŜø ōè Y2NŜ ŭKl·y˙ мл LJŜNŎŜyű 2ØŜN ŭKλă ăl·YˇŜ LJŜNλ2Řφⁿ ¢Kλă ădzŎŎŜăă λă ŜØŜy˙ Y˙2NŜ y2ŭl·ōfŜ ōŜŎl·dzăŜ λű 2ŎŎdzNNŜŘ λy˙Ŏ2y2dzyŎűλ2y˙ øλúK λyŎNŜl·ăŜŘ ŜfŜŎúNλŎλúè ƎŜySNl·ûλ2y˙ l·yŘ ăλƎyŦŦλŎl·yűΣ ădzăűl·λyŜŘ ŜŎ2y2YˇλŎ ƎN2øűKφ ! NŜŎŜyű LJ2ff y2ûŜŘ ûKl·ú “73% of voters support a national energy policy that ensures a secure supply of abundant, affordable, and available energy for the American people in an environmentally responsible manner.”[p]

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¢KŜ ØλŜøă 2Ŧ ΰKŜ ℕŜăLJ2yŘŜyΰă λϒΰKλă LJ2ff ădzƎƎŜăΰ ΰKI·ΰ ΰKŜ ! YŜℕλÕI·ϒLJŜ2LJfŜ Ř2 y2ΰ ØλŜø ŜyØλℕ2yYŜyΰI·f I·yŘ 2ΰKŜℕ Ǝ2I·fă ΰ2 ōŜ λϒÕ2yŦfλÕΰŤ ΰKŜ ¦ yλΰŜŘ {ΰI·ΰŜă KI·ă Õ2yãλăΰŜyΰfè ōŜŜyϒI·ōfŜ ΰ2 YI·yI·ƎŜ ŜyØλℕ2yYŜyΰI·f LJ2ffdzΰλ2ϒ øKλfŜ I·fă2 YI·λyΰI·λyλyƎ ŜfŜÕΰℕλÕ ℕŜfλI·ōλfλΰèΣ Ǝℕ2øλyƎ ΰKŜ ŜÕ2y2Yè΢ I·yŘ ădzLJLJ2ℕΰλyƎ Yλffλ2yã 2Ŧ ¿2ōăφ

9yI·ōfλyƎ I· ÕfŜI·yΣ ŦfŜÈλōfŜΣ ℕŜfλI·ōfŜ ŜfŜÕΰℕλÕλΰè äëăΰŜϒ øλff ℕŜIjdzℕΰŜ Õ2yΰλyΰz2dzã Õ2ăΰ ℕŜŘdzÕΰλ2yã I·yŘ λYLJℕ2ØŜŘ ŜyØλℕ2yYŜyΰI·f LJŜℕŦ2ℕYI·yÕŜ 2Ŧ ŜyŜℕƎè ΰŜÕKy2f2ƎλŜăφ ¢KŜℕŜ I·ℕŜ YdzfΰλLJfŜ I·ØŜyΰzŜă Ŧ2ℕ λYLJℕ2ØλyƎ ΰKŜ ŜyØλℕ2yYŜyΰI·f LJŜℕŦ2ℕYI·yÕŜ 2Ŧ ΰKŜ ŜfŜÕΰℕλÕλΰè äëăΰŜϒ õè ÕdzλfŘλyΣ 2yLJI·äΰ ădzÕÕŜăăŜăφ ! ÕfŜI·yŜℕ ŜfŜÕΰℕλÕλΰè ƎŜyŜℕI·ΰλ2ϒ äëăΰŜϒ ÕI·yϒ ōŜ I·ÕKλŜØŜŘ ΰKℕ2dzƎK I· Õ2YōλyI·ΰλ2ϒ 2Ŧ ΰŜÕKy2f2ƎλÕI·f λyy2ØI·ΰλ2ϒ I·yŘ λyÕŜyΰλØŜăΣ yI·ΰλ2yI·f ŜyØλℕ2yYŜyΰI·f LJ2fλÕèΣ λyy2ØI·ΰλØŜ äΰI·ΰŜ LJ2fλÕèΣ I·yŘ ŦλyI·yÕλI·f YŜÕKI·yλăYăφ ¢KŜăŜ ŦλyŘλyƎă I·ℕŜ ădzLJLJ2ℕΰŜŘ ōè ŘŜΰI·λfŜŘ Y2ŘŜfλyƎ 2Ŧ ăÕŜyI·ℕλ2ă Ŧ2ℕ ΰKŜ ŜfŜÕΰℕλÕλΰè äëăΰŜYΣ øKλÕK ŘŜY2yãΰ́ℕI·ΰŜă ΰKŜ ℕ2fŜ 2Ŧ λyy2ØI·ΰλ2ϒ I·yŘ ŜŦŦŜÕΰλØŜ LJ2fλÕè λϒ λYLJℕ2ØλyƎ ŜyØλℕ2yYŜyΰI·f 2dzΰÕ2YŜăφ ¢KŜ ÕKI·LJΰŜℕ I·fă2 ŜÈI·YλyŜă I·LJLJℕ2I·ÕKŜă ΰ2 ŦdzℕΰKŜℕ ℕŜŘdzÕλyƎ ΰKŜ ŜyØλℕ2yYŜyΰI·f λYLJI·Õΰă 2Ŧ ŜfŜÕΰℕλÕλΰè 2ϒ I·λℕ I·yŘ øI·ΰŜℕΣ I·ă øŜff I·ă YλΰλƎI·ΰλyƎ ℕŜfŜØI·yΰ fI·yŘ dzăŜ ÕKI·ffŜyƎŜă I·yŘ ŜyØλℕ2yYŜyΰI·f 2dzăΰλÕŜ λăădzŜă I·ŦŦŜÕΰλyƎ f2ÕI·f Õ2YYdzyλΰλŜφ

¢KŜℕŜ I·ℕŜΣ K2øŜØŜℕΣ 2yƎ2λyƎ ŜyØλℕ2yYŜyΰI·f λYLJI·Õΰă I·ăă2ÕλI·ΰŜŘ øλΰK ŜfŜÕΰℕλÕλΰè äëăΰŜYă ΰKI·ΰ YŜℕλΰ ădzăΰI·λyŜŘ LJ2fλÕè I·yŘ ℕŜƎdzfI·ΰ2ℕè Ŧ2Õdză I·yŘ ădzLJLJ2ℕΰφ ¢KŜăŜ λyÕfdzŘŜ ÕfλYI·ΰŜ ÕKI·yƎŜT øI·ΰŜℕ dzăŜ Ŧ2ℕ LJ2øŜℕ ƎŜyŜℕI·ΰλ2yΤ fI·yŘ dzăŜ λYLJI·Õΰă 2Ŧ LJ2øŜℕ ƎŜyŜℕI·ΰλ2yΣ ΰℕI·yãYλăăλ2yΣ I·yŘ Řλăΰℕλōdzΰλ2yΤ ŜyØλℕ2yYŜyΰI·f ¿dzăΰλÕŜ λăădzŜă I·ăă2ÕλI·ΰŜŘ øλΰK ŜfŜÕΰℕλÕλΰèT I·yŘ ŘŜÕ2YYλăăλ2yλyƎ 2Ŧ ƎŜyŜℕI·ΰλ2yI·ăăŜΰăφ ¢2ŘI·èΣ ΰKŜ ¦ yλΰŜŘ {ΰI·ΰŜă KI·ă I·y 2LJLJ2ℕΰdzyλΰè ΰ2 ōdzλfŘ 2yλΰă ădzōăΰI·yΰλI·f ŜÈLJŜℕΰŜyÕŜ 2Ŧ ¿2λyΰ ŜyØλℕ2yYŜyΰI·f I·yŘ ŜÕ2y2YλÕ ădzÕÕŜăă ΰ2 I·ŘŘℕŜăă ΰKŜ ÕŜyΰℕI·f ÕKI·ffŜyƎŜ 2Ŧ ÕfλYI·ΰŜ ÕKI·yƎŜ YλΰλƎI·ΰλ2yΣ I·f2yƎ øλΰK ŜyØλℕ2yYŜyΰI·f ÕKI·ffŜyƎŜă I·ăă2ÕλI·ΰŜŘ øλΰK ŜfŜÕΰℕλÕλΰè ƎŜyŜℕI·ΰλ2yΣ Řλăΰℕλōdzΰλ2yΣ ΰℕI·yãYλăăλ2yΣ I·yŘ Õ2yãdzYLJΰλ2yφ

3.2 CO_2 Emissions and the Electricity System

¢KŜ Ǝℕ2øΰK λϒ ¦φ{φ ŜfŜÕΰℕλÕλΰè Õ2yãdzYLJΰλ2ϒKI·ă ƎℕI·ŘdzI·ffè ăf2øŜŘ Ŧℕ2Y φφy LJŜℕÕŜyΰ LJŜℕ èŜI·ℕ λϒΰKŜ мфрлă ΰ2 лφp LJŜℕÕŜyΰ LJŜℕ year over the past decade, due in part to “slowing population growth, market saturation 2Ŧ YI·¿2ℕ ŜfŜÕΰℕλÕλΰèπdzăλyƎ I·LJLJfλI·yÕŜăΣ ŜŦŦλÕλŜyÕè λYLJℕ2ØŜYŜyΰă λϒ I·LJLJfλI·yÕŜăΣ I·yŘ I· ăKλŦΰ λϒΰKŜ ŜÕ2y2Yè ΰ2øI·ℕŘ I· fI·ℕƎŜℕ ăKI·ℕŜ 2Ŧ Õ2yãdzYLJΰλ2ϒλyΤfŜăă ŜyŜℕƎèπλyΰŜyãØŜ industries.”[cΣ T] LϒнлмпΣ ŜfŜÕΰℕλÕλΰè I·ÕÕ2dzyΰŜŘ Ŧ2ℕ оф LJŜℕÕŜyΰ 2Ŧ ΰ2ΰI·f LJℕλYI·ℕè ŜyŜℕƎè Õ2yãdzYLJΰλ2yφ[D] ¢KŜ ℕŜăλŘŜyΰλI·f I·yŘ Õ2YYŜℕÕλI·f ăŜÕΰ2ℕă ŜI·ÕK Õ2yãdzYŜŘ I·ō2dzΰ ΰKŜ ăI·YŜ ăKI·ℕŜ 2Ŧ ΰ2ΰI·f ŜfŜÕΰℕλÕλΰè—оТ LJŜℕÕŜyΰ I·yŘ oc LJŜℕÕŜyΰΣ ℕŜăLJŜÕΰλØŜfè—øλΰK ΰKŜ λyŘdzăΰℕλI·f ăŜÕΰ2ℕ I·ÕÕ2dzyΰλyƎ Ŧ2ℕ нс LJŜℕÕŜyΰ 2Ŧ ŜfŜÕΰℕλÕλΰè ŘŜY I·yŘφ 9fŜÕΰℕλÕλΰè dzăŜ λϒ ΰKŜ ΰℕI·yãLJ2ℕΰI·ΰλ2ϒ ăŜÕΰ2ℕ øI·ă YλyλYI·fΣ Õ2yãΰλΰdzΰλyƎ fŜăă ΰKI·yϒм LJŜℕÕŜyΰ 2Ŧ ΰ2ΰI·f ¦φ{φ ŜfŜÕΰℕλÕλΰè Õ2yãdzYLJΰλ2yφʸ 9fŜÕΰℕλÕλΰè dzăŜ λă LJℕ2¿ŜÕΰŜŘ ΰ2 Ǝℕ2ø ăf2øfèΣ I·yŘ λΰă ăKI·ℕŜ 2Ŧ ΰ2ΰI·f ŘŜfλØŜℕŜŘ ¦φ{φ ŜyŜℕƎè Õ2yãdzYLJΰλ2ϒ λă ŜÈLJŜÕΰŜŘ ΰ2 λyÕℕŜI·ăŜ 2yfè ăfλƎKΰfè õè нлпл[φÕΣ ŘΣ φ]

9fŜÕΰℕλÕ LJ2øŜℕ ƎŜyŜℕI·ΰλ2ϒ λă 2yŜ 2Ŧ ΰKŜ fI·ℕƎŜăΰ ă2dzℕÕŜă 2Ŧ / $h_н$ ŜYλăăλ2yã λϒΰKŜ ¦ yλΰŜŘ {ΰI·ΰŜă[φᴹᴳ] hØŜℕ φφ LJŜℕÕŜyΰ 2Ŧ ΰKŜ D I D ŜYλăăλ2yã I·ΰΰℕλōdzΰŜŘ ΰ2 ΰKŜ LJ2øŜℕ ăŜÕΰ2ℕ I·ℕŜ ΰKŜ ℕŜădzfΰ 2Ŧ ΰKŜ Õ2Yōdzăΰλ2ϒ 2Ŧ Ŧ2ăăλf ŦdzŜfă Ŧ2ℕ LJ2øŜℕ ƎŜyŜℕI·ΰλ2yφ LϒнлмпΣ / $h_н$ Ŧℕ2Y Õ2I·f Õ2Yōdzăΰλ2ϒI·ÕÕ2dzyΰŜŘ Ŧ2ℕ 2ØŜℕ ΰKℕŜŜπIjdzI·ℕΰŜℕă 2Ŧ ¦φ{φ LJ2øŜℕπăŜÕΰ2ℕ D I D ŜYλăăλ2yãΣ øKλfŜ / $h_н$ Ŧℕ2Y ΰKŜ Õ2Yōdzăΰλ2ϒ 2Ŧ yI·ΰdzℕI·f ƎI·ă Õ2yΰℕλōdzΰŜŘ I·LJLJℕ2ÈλYI·ΰŜfè нм LJŜℕÕŜyΰ 2Ŧ ¦φ{φ LJ2øŜℕπăŜÕΰ2ℕ D I D ŜYλăăλ2yãφᴹᴹΣ ᴹᴴ ¢KŜ ŜYλăăλ2ϒ *rate*—ΰKŜ I·Y2dzyΰ 2Ŧ / $h_н$ ŜYλΰΰŜŘ LJŜℕ dzyλΰ 2Ŧ ŜfŜÕΰℕλÕλΰè ƎŜyŜℕI·ΰŜŘ—λă I· ⌉Ŝè λyŘλÕI·ΰ2ℕ 2Ŧ ΰKŜ ÕfλYI·ΰŜ λYLJI·Õΰ 2Ŧ ŜfŜÕΰℕλÕλΰè ƎŜyŜℕI·ΰλ2yΣ I·yŘ ØI·ℕλŜă ăλƎyλŦλÕI·yΰfè õè ŦdzŜf I·yŘ ΰŜÕKy2f2Ǝè¢ ¢KŜ ÕdzℕℕŜyΰΣ I·ØŜℕI·ƎŜ ŜYλăăλ2ϒ ℕI·ΰŜ 2Ŧ bD/ / LJfI·yΰă λϒ ΰKŜ ¦ yλΰŜŘ

[D] oyφп IjdzI·Řă ØŜℕŜ dzăŜŘ ΰ2 ƎŜyŜℕI·ΰŜ oΣфллΣ ΰŜℕI·øI·ΰΰK2dzℕăΣ óΣ [2] Kΰ 2Ŧ ŜfŜÕΰℕλÕλΰè¢ ¢2ΰI·f ŜyŜℕƎè Õ2yãdzYLJΰλ2ϒλyϒнлмп øI·ă фyφo IjdzI·Řă[D] ! ÕÕ2ℕŘλyƎ ΰ2 ΰKŜ 9t{! . I·ăŜ / I·ăŜΣ øKλÕK λyÕ2ℕLJ2ℕI·ΰŜă I·ff ŜÈλΰλyƎ ¦φ{φ LJ2fλÕλŜă Õdzΰ I·ăădzYŜă y2 yŜø LJ2fλÕλŜăΣ ŜfŜÕΰℕλÕλΰè dzăŜ λă LJℕ2¿ŜÕΰŜŘ ΰ2 Ǝℕ2ø I·ΰ I·yϒyΣ I·f ℕI·ΰŜ 2Ŧ лφp LJŜℕÕŜyΰ ōŜΰøŜŜyнлмп I·yŘ нлплφ LϒΰŜℕYă 2Ŧ ŘŜfλØŜℕŜŘ ŜyŜℕƎèΣ ΰKŜ ŜfŜÕΰℕλÕλΰè äŜÕΰor’s ăKI·ℕŜ λă LJℕ2¿ŜÕΰŜŘ ΰ2 λyÕℕŜI·ăŜ ŦℕY мy LJŜℕÕŜyΰ λϒ нлмп ΰ2 мф LJŜℕÕŜyΰ λϒ нлплΣ I·yŘ 2ØŜℕI·ft ŜfŜÕΰℕλÕλΰè ŘŜYI·yŘ λă LJℕ2¿ŜÕΰŜŘ ΰ2 λyÕℕŜI·ăŜ ŦℕY мнφтс ΰ2 I·LJLJℕ2ÈλYI·ΰŜfè мр IjdzI·Řℕλffλ2ϒ . ℕλΰλăK ΰKŜℕYI·f dzyλΰă óIjdzI·Řăΰφ

[Ř] LϒΰŜℕYă 2Ŧ ΰ2ΰI·f LJℕλYI·ℕè ó2ℕ ă2dzℕÕŜΰ ŜyŜℕƎèΣ ΰKŜ ŜfŜÕΰℕλÕ ăŜÕΰ2r’s share is projected to increase from 13 percent in 2014 to 14 LJŜℕÕŜyΰ λϒнлплΣ I·ÕÕ2ℕŘλyƎ ΰ2 ΰKŜ 9t{! . I·ăŜ / I·ăŜΣ øKλÕK λyÕ2ℕLJ2ℕI·ΰŜă I·ff ŜÈλΰλyƎ ¦φ{φ LJ2fλÕλŜă ōdzΰ I·ăădzYŜă y2 yŜø LJ2fλÕλŜăφ

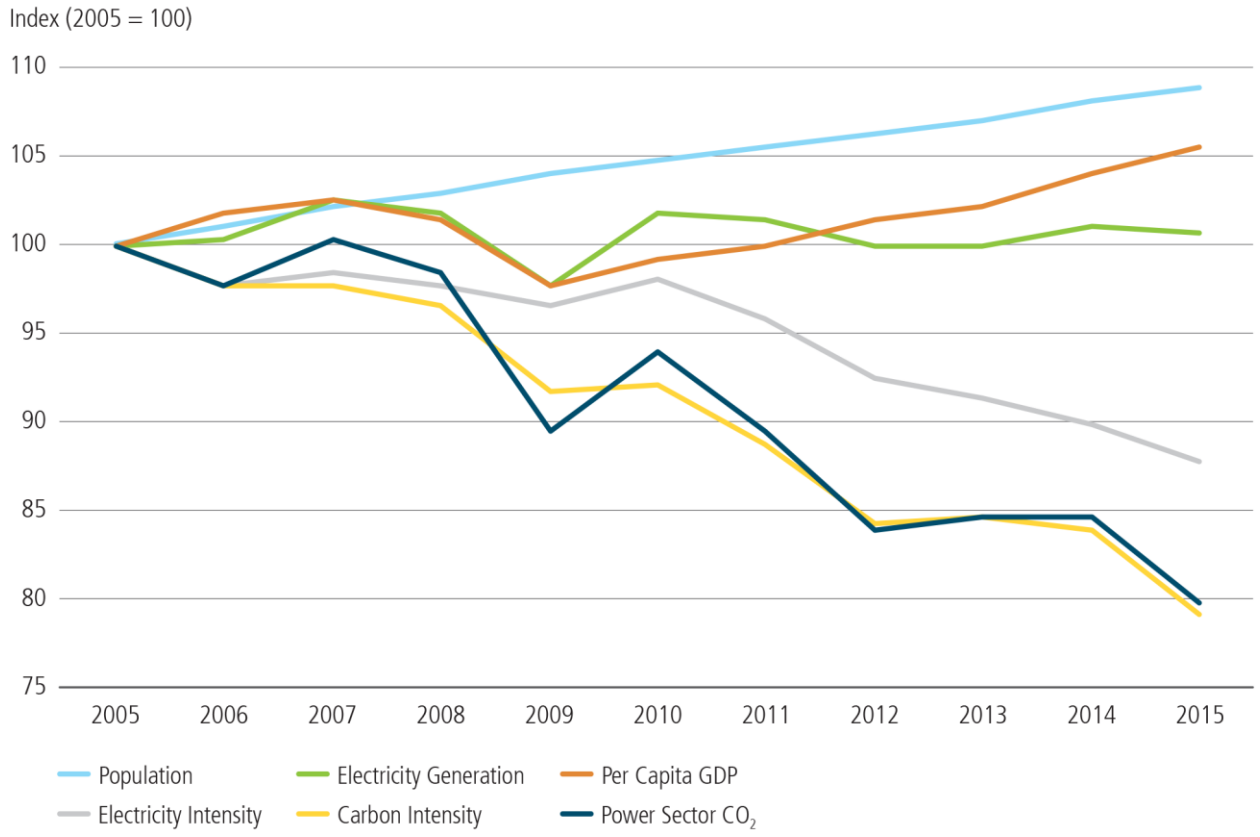
{ǘ·ǘŜă ƛă сл LJŜŃŎŜyǘ fŜăă ǘKI·y ǘKI·ǘ ƻŦ I·ØŜŃI·ƎŜ Ŏƻ·fπŦƛŃŜŘ LJfI·yǘăφ^мо^Σмп bdzŎfŜI·Ń LJƻøŜŃ I·yŘ ŃŜyŜøI·ōfŜ ŜfŜŎǘŃƛŎƛǘè ƎŜyŜŃI·ǘƛƻy KI·ØŜ yƻ ŘƛŃŜŎǘ ŜYƛăăƛƻyã I·ăăƻŎƛI·ǘŜŘ øƛǘK ŜfŜŎǘŃƛŎƛǘè ƎŜyŜŃI·ǘƛƻyφ

9fŜŎǘŃƛŎ LJƻøŜŃ ƎŜyŜŃI·ǘƛƻy LJŃƻØƛŘŜă ăŜŃØƛŎŜ ǘƻ ŜyŘπdzăŜ ŜŎƻyƻYƛŎ ăŜŎǘƻŃăφ ² KŜy I·ǘǘŃƛōdzǘƛyƎ ŎdzŃŃŜyǘ ¦φ{φ LJƻøŜŃπăŜŎǘƻŃ DID ŜYƛăăƛƻyã ǘƻ ŜyŘπdzăŜ ŜŎƻyƻYƛŎ ăŜŎǘƻŃăΣ ǘKŜ ƛyŘdzăǘŃƛI·f ăŜŎǘƻŃ ƛă ŃŜăLJƻyãƛōfŜ ŦƻŃ I·LJLJŃƻÈƛYI·ǘŜfè нс LJŜŃŎŜyǘ ƻŦ ŜfŜŎǘŃƛŎƛǘèπŃŜfI·ǘŜŘ ŜYƛăăƛƻyãΣ I·yŘ ǘKŜ ŃŜYI·ƛyŘŜŃ ƛă ăLJfƛǘ ŜØŜyfè ōŜǘøŜŜyǘKŜ ŃŜăƛŘŜyǘƛI·f I·yŘ ŎƻYYŜŃŎƛI·f ăŜŎǘƻŃăΣ I·ǘ ос LJŜŃŎŜyǘ I·yŘ ор LJŜŃŎŜyǘΣ ŃŜăLJŜŎǘƛØŜfèφ^ŜΣ мр ¢Kƛă ăŜŎǘƻŃI·f I·ǘǘŃƛōdzǘƛƻy KƛƎKfƛƎKǘă I· ŘdzI·f LJI·ǘKøI·è ŦƻŃ ŃŜŘdzŎƛyƎ ǘƻǘI·f ŎI·Ńōƻy ŜYƛăăƛƻyãY óмú ŘŜŎI·ŃōƻyƛÎI·ǘƛƻy ƻŦ ǘKŜ ŜfŜŎǘŃƛŎƛǘè ăŜŎǘƻŃ ƛǘăŜfŦΣ I·yŘ óнú ŜfŜŎǘŃƛŎƛǘè ŜŦŦƛŎƛŜyŎè ƛYLJŃƻØŜYŜyǘă øƛǘKƛyǘKŜ ŜyŘπdzăŜ ŜŎƻyƻYƛŎ ăŜŎǘƻŃăφ

3.2.1 Decarbonization of the Electricity System

!ŦǘŜŃ I· ƎŃI·ŘdzI·f ŘŜŎfƛyŜ ŦŃƻY мфтл ǘƻ нллрΣ ǘKŜ /hн ŜYƛăăƛƻyŃI·ǘŜ óʅƛfƻƎŃI·Yă ƻŦ /hнка ² Kú ƻŦ ŜfŜŎǘŃƛŎƛǘè ƎŜyŜŃI·ǘƛƻyŦŜff ǘƻ нлφф LJŜŃŎŜyǘ ōŜfƻø нллр fŜØŜfă ƛyнлмрφ^мс

Figure 3-1. Trend Lines in Emissions Drivers, 2005–2015[17, 18, 19]

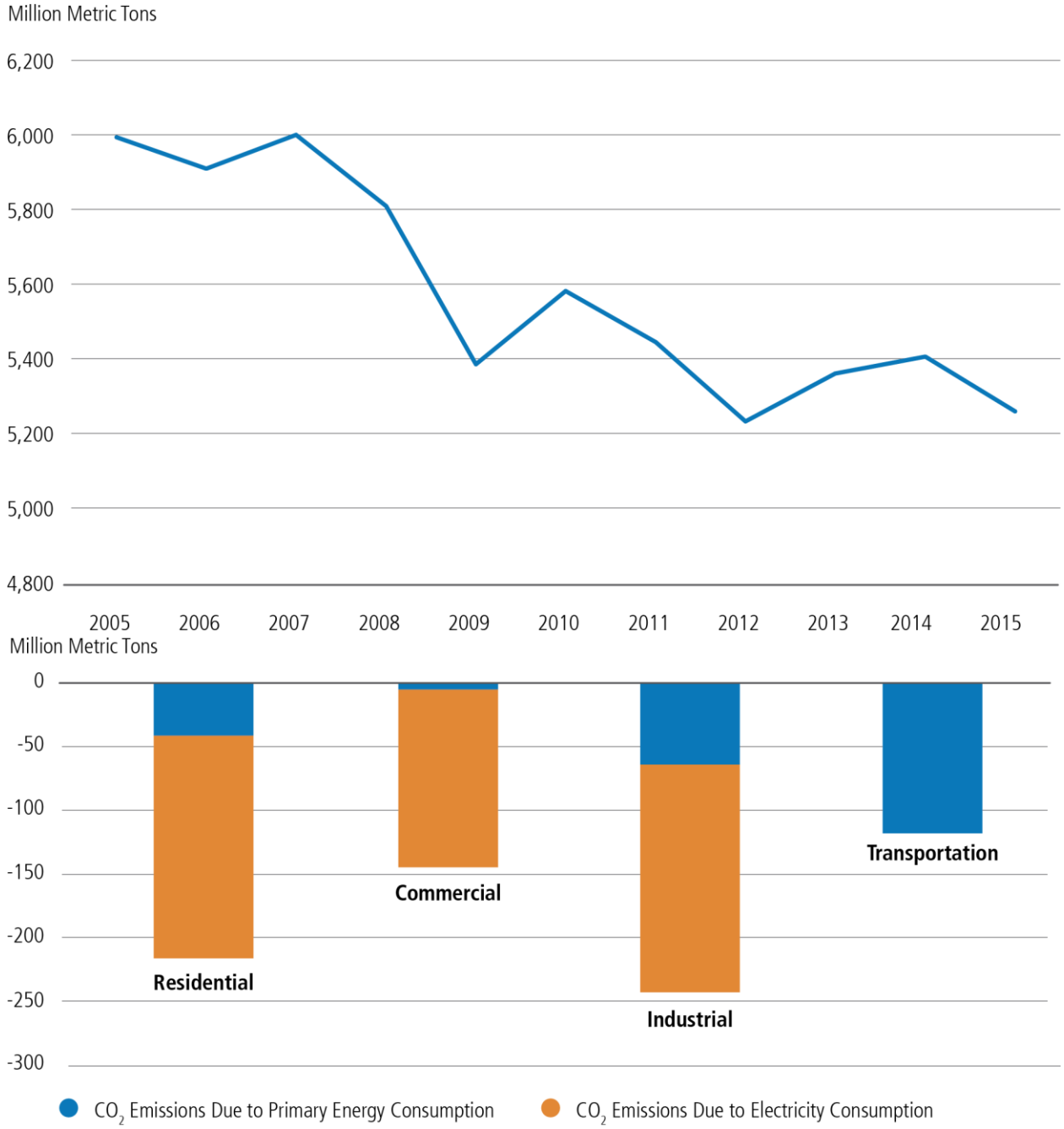


The population growth, per capita gross domestic product (GDP), and electricity intensity of the economy all factor into total U.S. electricity demand. While growth in population and per capita GDP has placed upward pressure on power-sector demand, this growth has been partially offset by a decline in the electricity intensity of the economy.

{fƻø ƎŃƻøǘK ƛyLJŜŃ ŎI·LJƛǘI· ŜfŜŎǘŃƛŎƛǘè ŎƻyãdzYLJǘƛƻyΣ ƎŃŜI·ǘŜŃ ŜfŜŎǘŃƛŎƛǘè LJŃƻŘdzŎǘƛØƛǘè óYŜI·ădzŃŜŘ ƛyŘƻffI·Ńă ƻŦ ƎŃƻăă ŘƻYŜăǘƛŎ LJŃƻŘdzŎǘ ώD5tв LJŜŃ ʅƛfƻøI·ǘǘπKƻdzŃ ώʅ ² Kв ƻŦ ŜfŜŎǘŃƛŎƛǘèύΣ I·yŘ I· ŘŜŎfƛyŜ ƛyǘKŜ /hн ŜYƛăăƛƻy

§ ¢KŜ ŃŜYI·ƛyƛyƎ ŜfŜŎǘŃƛŎƛǘèπŃŜfI·ǘŜŘ ŜYƛăăƛƻyã I·ŃŜ ŦŃƻY ƻǘKŜŃ ăŜŎǘƻŃă ǘKI·ǘ I·ŎŎƻdzyǘ ŦƻŃ YƛyƻŃ I·Yƻdzyǘă ƻŦ ŜfŜŎǘŃƛŎƛǘèπŃŜfI·ǘŜŘ ŜYƛăăƛƻyã ƛyǘKŜ ¦ yƛǘŜŘ {ǘI·ǘŜăΣ ƛyŎfdzŘƛyƎ I·ƎŃƛŎdzfǘdzŃŜ óо LJŜŃŎŜyǘύ I·yŘ ǘŃI·yãLJƻŃǘI·ǘƛƻyóлφн LJŜŃŎŜyǘύφ

Figure 3-2. U.S. Energy-Related CO_2 Emissions, 2005–2015 (*top*), and Change in U.S. Energy-Related CO_2 Emissions by Sector, 2005–2015 (*bottom*) [21, 22]



After increasing in 2013 and in 2014, energy-related CO_2 emissions fell in 2015. In 2015, U.S. energy-related CO_2 emissions were 12 percent below the 2005 levels, mostly because of changes in the electric power sector.

Ly I·ŘŘλűλ2y ű2 űKŜăŜ Y I·NJ⌊Ŝű I·yŘ űŜŎKy2f2∃è űNJŜyŘăΣ I· øλŘŜ I·NJNJI·è 2Ŧ LJ2fλŎλŜă I·yŘ YŜI·ădzNJŜă ŘŜØŜf2LJŜŘ I·yŘ λYLJfŜYŜyűŜŘ I·ű űKŜ CŜŘŜNJI·fΣ ăűI·űŜΣ I·yŘ f2ŎI·f fŜØŜfă KI·ØŜ KŜfLJŜŘ ű2 Yλűλ∃I·űŜ D I D ŜYλăăλ2yã ŦNJ2Y űKŜ ¦φ{φ LJ2øŜNJ ăŜŎű2NJφ ¢KŜăŜ λyŎfdzŘŜ LJŜNJŦ2NJYI·yŎŜπōI·ăŜŘ NJŜ∃dzfI·űλ2yã I·yŘ ăűI·yŘI·NJŘăΣ ŜŎ2y2YλŎ λyăűNJdzYŜyűăΣ λyŦ2NJYI·űλ2y LJNJ2∃NJI·YăΣ I·yŘ ŘλŦŦdzăλ2y 2Ŧ ⌊Ŝè űŜŎKy2f2∃λŜă ŦNJ2Y NJ2ōdzăű w5ɘ5 λyØŜăűYŜyűăφ a I·yè LJ2fλŎè I·LJLJNJ2I·ŎKŜă ŎNJ2ăă űKŜăŜ ŎI·űŜ∃2NJλŜăφ CŜŘŜNJI·f I·yŘ ăűI·űŜ ŜYλăăλ2yã űNJI·Řλy∃ LJNJ2∃NJI·YăΣ Ŧ2NJ ŜÈI·YLJfŜΣ Ŏ2YōλyŜ

LJŜNŦ2NYˈIˑyÖŜπōIˑăŜŘ NŜƎdzfIˑúλ2Y ǿλúK úNJIˑŘλyƎ 2Ŧ YˈIˑNJ⌊ŜúIˑōfŜ ÖNJŜŘλúă 2N IˑffǿIˑyÖŜăΣ űKŜ fIˑúűŜNJ 2Ŧ ǿKλÖK IˑNJŜ ŜÖ2y2YˈλÖ λyãúNJdzYˈŜyúăφ

¦LJƎNJIˑŘλyƎ IˑyŘ λyØŜăúλyƎ λYˈúKŜ úNJIˑyãYˈλăăλ2Yˈăèăúŝˈ λă 2yŜ ÖNJλúλÖIˑf YˈŜIˑădzNJŜ űKIˑú Ö2dzfŘ KIˑØŜ ŦIˑNJπNJŜIˑÖKλyƎ λYˈLJIˑÖúă Ŧ2NJ úKŜ ŜyØλNJ2yYˈŜyúΣ Ö2dzfŘ λyÖNJŜIˑăŜ ăèăúŝˈ ŦfŜÈλōλfλúè IˑyŘ NJŜăλfλŜyÖŜΣ IˑyŘ ăIˑØŜ ŜfŜÖúNJλÖλúè Ö2yãdzYˈŜNJă IˑăˈYdzÖK IˑăÞпт ōλffλ2YˈIˑyŷdzIˑffè⁰ᴴᴼ ! Yˈ2ŘŜNJyλÎŜŘ IˑyŘ ŜÈLJIˑyŘŜŘ úNJIˑyãYˈλăăλ2Yˈăèăúŝˈ KIˑă úKŜ LJ2úŜyúλIˑf úƨ λyűŜNJÖ2yŷŜÖú ÖfŜIˑyˈƎŜySNJIˑúλ2Yˈó⁺2NJ ō2úK ăK2NJú ŘλăúIˑyÖŜă IˑăˈǿŜfˈ IˑăˈÖ2yŷŜÖúλyƎ NJŜYˈ2úŜ ÖfŜIˑyˈƎŜySNJIˑúλ2Yˈă2dzNJÖŜă úƨ LJ2LJdzfIˑúλ2Yˈ ÖŜyűŜNJăΣ ǿKλfŜ IˑfăƨŜyKIˑyÖλyƎ Iˑ yIˑúλ2yIˑf ŜfŜÖúNJλÖλúè YˈIˑNJ⌊ŜúˈλYˈǿKλÖK IˑffŜySNJèˈIˑăăŜúă ÖIˑyˈŦIˑλNJfè Ö2YˈLJŜúŜφ {úIˑúŜ ÖfŜIˑyˈŜfŜÖúNJλÖλúè Ǝ2IˑfăˈIˑNJŜ IˑfăƨŦIˑÖλfλúIˑúŜŘ úKNJ2dzƎK úNJIˑyãYˈλăăλ2Yˈ dzLJƎNJIˑŘŜăΣ IˑyˈŜÈIˑYˈLJfŜ ōŜλyƎ úKŜ bŜǿ ¸2NJ⌊ LyŘŜLJŜyŘŜyúˈ {èăúŝˈ hLJŜNJIˑú2N óL{húΣ ǿKλÖK λăˈf22⌊λyƎ ú2 YˈIˑ⌊Ŝ YˈƨNJŜ ŜŦŦŜÖúλØŜ dzăŜ 2Ŧ NdzNJIˑffè f2ÖIˑúŜŘ ǿλyŘ IˑyŘ KèŘNJ2LJ2ǿŜNJ NJŜă2dzNJÖŜă ōè Ö2yŷŜÖúλyƎ úKŜˈ ǿλúK KλƎK ŜfŜÖúNJλÖλúèπŘŜYˈIˑyŘ ÖŜyúŜNJăˈf⌊Ŝ bŜǿ ¸2NJ⌊ /λúè⁰ᴴᴺ

LúˈÖIˑyˈ ōŜ ÖKIˑffŜyƎλyƎ úƨ ŜØIˑfdzIˑúŜ ǿKŜúKŜNJ úNJIˑyãYˈλăăλ2Yˈ LJ2fλÖλŜă IˑyŘ NJŜƎdzfIˑúλ2yã IˑNJŜ ăλYˈdzfúIˑyŜ2dzăfè IˑÖKλŜØλyƎ úKŜλNJ λyűŜyŘŜŘ NJŜfλIˑōλfλúè ōŜyŜŦλúă λyˈúKŜ ŦIˑÖŜ 2Ŧ dzyLJNJŜÖŜŘŜyúŜŘ LJKèăλÖIˑf ÖKIˑyƎŜΣ IˑyŘ IˑNJŜ LJN2ØλŘλyƎ IˑŘŜIjdzIˑúŜ ÖIˑLJIˑÖλúè úƨ Ö2ăúπŜŦŦŜÖúλØŜfè IˑŘŘNJŜăă ŜyØλNJ2yYˈŜyúIˑf NJŜIjdzλNJŜYˈŜyúăφ {dzÖK ŜØIˑfdzIˑúλ2yˈ NJŜIjdzλNJŜă yŜǿ IˑyIˑfèăŜăΣ ōdzúŦ2NJ úK2ăŜ IˑyIˑfèăŜă úƨ ōŜ ØIˑfIλŘΣ ŘIˑúIˑ ǿλúK ƎNJŜIˑúŜNJ ăÖ2LJŜΣ FNJŜIjdzŜyÖèΣ IˑyŘ NJŜă2fdzúλ2yˈYˈdzăú ōŜ YˈIˑŘŜ IˑØIˑλfIˑōfŜφ 9ÈLJIˑyŘŜŘ úNJIˑyãYˈλăăλ2yˈŘIˑúIˑ NJŜă2dzNJÖŜă ǿλffŦIˑÖλfλúIˑúŜ úKŜ ŘŜØŜf2LJYˈŜyú 2Ŧ ŜŦŦŜÖúλØŜ CŜŘŜNJIˑf IˑyŘ ăúIˑúŜ LJ2fλÖλŜă IˑyŘ NJŜƎdzfIˑúλ2yã úKIˑú ǿλffIˑŦŦŜÖú NJŜfλIˑōλfλúè IˑyŘ ŜyØλNJ2yYˈŜyúIˑf Ǝ2IˑfăΣ ƎλØŜ úK2ăŜ úKIˑú λyØŜăú λyˈúKŜ úNJIˑyãYˈλăăλ2yˈ ăèăúŝˈ λyãλƎKűă λyú2 LJ2úŜyúλIˑf ōdzăλySää 2LJLJ2NJúdzyλúλŜăΣ IˑyŘ LJN2ØλŘŜ Iˑ ōNJ2IˑŘ NJIˑyƎŜ 2Ŧ ăúIˑ⌊ŜK2fŘŜNJă ǿλúK Iˑ ƎNJŜIˑúŜNJ dzyŘŜNJăúIˑyŘλyƎ 2Ŧ úKŜ ŦIˑλNJySää 2Ŧ 2LJŜNJIˑúλ2yã λyˈ LJN2ØλŘλyƎ y2yπŘλăÖNJλYˈλyIˑú2NJè IˑÖÖŜăă¢KŜ CŜŘŜNJIˑf 9ySNJƎè wŜƎdzfIˑú2NJè /2YˈYˈλăăλ2yˈóC9w/ú KIˑă NJŜÖ2ƎyλÎŜŘ úKŜ λYˈLJ2NJúIˑyÖŜ 2Ŧ ŜfŜÖúNJλÖλúè úNJIˑyãYˈλăăλ2yˈλyˈIˑ ÖfŜIˑyˈŦdzúdzNJŜ IˑyŘ ǿ2NJ⌊ŜŘ ú2 ŜÈLJŜŘλúŜ úKŜ Ö2yúNJλōdzúλ2yˈ2Ŧ úNJIˑyãYˈλăăλ2yˈúKNJ2dzƎK C9w/ hNJŘŜNJ b2ăφ yφл IˑyŘ мллл⁰ hNJŘŜNJ b2⁰ yφл óнллтú NJŜIjdzλNJŜŘ úKIˑú úNJIˑyãYˈλăăλ2yˈ LJfIˑyŷλyƎ ōŜ 2LJŜyˈú2 ăúIˑ⌊ŜK2fŘŜNJăφ hNJŘŜNJ b2⁰ мллл óнлммú IˑŘŘŜŘ λyűŜNJNJŜƎλ2yIˑf Ö22NJŘλyIˑúλ2yΣ Ö2YˈLJŜúλúλ2yˈ IˑYˈ2yƎ úNJIˑyãYˈλăăλ2yˈ 2ǿyŜNJăΣ IˑyŘ Ö2ăúˈ IˑffǿÖIˑúλ2yˈ NJŜŦ2NJYφ hNJŘŜNJ b2⁰ мллл IˑfăƨŜyIˑōfŜă úNJIˑyãYˈλăăλ2yˈ LJN2ǿŜÖúă úKIˑú ădzLJLJ2NJúˈ LJdzōfλÖˈ LJ2fλÖè Ǝ2IˑfăΣ ădzÖK Iˑă Yˈ2ØλyƎ NJŜyŜǿIˑōfŜ ŜyŜNJƎè ŦNJ2Yˈ ŘλăúIˑyúˈ ă2dzNJÖŜă úƨ f2IˑŘ ÖŜyúŜNJăΣ úƨ ōŜ ŦIˑÖλfλúλŜă ǿλúK λyÖ2YˈŜ úKIˑú ăă dzōǿŜÖúˈ úƨ C9w/ NJŜƎdzfIˑúƨNJè Idzúŀ2NJλúèφ

9IjdzλúIˑōfŜ Ö2ăúˈ IˑffǿÖIˑúλ2yˈ IˑYˈ2yƎ Ödzăú2YˈŜNJ ōŜyŜŦλÖλIˑNJλŜăΣ ŜăLJŜÖλIˑffè Ŧ2NJ fIˑNJƎŜNJ IˑyŘ λyúŜNJNJŜƎλ2yIˑf úNJIˑyãYˈλăăλ2yˈλyØŜăúYˈŜyúăΣ ăă Iˑ ăλƎyλŦλÖIˑyúˈ ÖKIˑffŜyƎŜ λyˈúKŜ λYˈLJfŜYˈŜyúIˑúλ2yˈ2Ŧ úKŜ C9w/ hNJŘŜNJ b2⁰ мллл NJŜƎλ2yIˑf LJfIˑyŷλyƎ LJN2ÖŜăăφ 5λŦŦŜNJλyƎ NJŜƎλ2yIˑf IˑLJLJN2IˑÖKŜă úƨ YˈŜŜúλyƎ C9w/ hNJŘŜNJ b2⁰ мллл LJNJλyÖλLJfŜă Ŧ2NJ пÖ2ăúˈ Iˑff2ÖIˑúλ2yˈ—particularly the definition of “beneficiary”—KIˑØŜ YˈIˑŘŜ úKŜ λYˈLJfŜYˈŜyúIˑúλ2yˈ2Ŧ hNJŘŜNJ b2⁰ мллл Ö2YˈLJfŜÈ⁰ ¢KŜ λYˈLJfŜYˈŜyúIˑúλ2yˈ2Ŧ C9w/ hNJŘŜNJ b2⁰ мллл NJŜƎλ2yIˑf Ö2ăúˈ IˑffǿÖIˑúλ2yˈ LJNJλyÖλLJfŜă λă NJŜfIˑúλØŜfè yŜǿΣ ă2 λúˈ λă KIˑNJŘ úƨ Iˑăă Ŝăă úKŜ ŜŦŦŜÖúλØŜyŜăă 2Ŧ úKŜ LJN2ÖŜăă úƨ ŘIˑúŜ λyˈ IˑÖKλŜØλyƎ LJdzōfλÖˈ LJ2fλÖè Ǝ2Iˑfăφ D2λyƎ Ŧ2NJǿIˑNJŘΣ Yˈ2NJŜ ăèăúŝˈ IˑúλÖ Yˈ2yλú2NJλyƎ 2Ŧ IˑÖúλØλúλŜă IˑyŘ ăèăúŝˈ IˑúλÖ ŘIˑúIˑ Ö2ffŜÖúλ2yˈ ǿλffˈ ōŜ yŜŜŘŜŘ úƨ IˑăăŜăă ǿKŜúKŜNJ hNJŘŜNJ b2ăφ yφл IˑyŘ мллл IˑNJŜ IˑÖKλŜØλyƎ úKŜλNJ Ǝ2Iˑfăφ

3.2.2 Low and Zero-Carbon Power Generation

! Ö2yãλăúŜyú úKŜYˈŜ ŦNJ2Yˈ Iˑ ØIˑăúˈ ō2Řè 2Ŧ ÖfλYˈIˑúŜ ăÖλŜyÖŜ NJŜăŜIˑNJÖK ădzƎƎŜăúă úKIˑú ŘŜŜLJŜNJ ŘŜÖIˑNJō2yλÎIˑúλ2yˈλă yŜÖŜăăIˑNJè úƨ NJŜŘdzÖŜ ŜYˈλăăλ2yã ădzŦŦλÖλŜyúfè úƨ YˈλyλYˈλÎŜ úKŜ Yˈ2ăú ăŜNJλ2dză λYˈLJIˑÖúă 2Ŧ ÖfλYˈIˑúŜ ÖKIˑyƎŜφнр ¢Kλă ǿλff NJŜIjdzλNJŜΣ λyˈLJIˑNJúΣ Iˑyˈ ŜyKIˑyÖŜŘ LJ2NJúŦ2fλ2 2Ŧ f2ǿŜNJπ IˑyŘ ÎŜNJ2πÖIˑNJō2yˈ ƎŜySNJIˑúλ2yˈ úŜÖKy2f2ƎλŜăΣ ădzÖK Iˑă NJŜySǿIˑōfŜăΣ yŒzÖfŜIˑNJ LJ2ǿŜNJΣ IˑyŘ Ŧ2ăăλf ƎŜySNJIˑúλ2yˈǿλúK ÖIˑNJō2yˈÖIˑLJúdzNJŜΣ dzúλfλÎIˑúλ2yˈIˑyŘ ăúă2NJIˑƎŜ ó//¦{úφ

¢KŜ yIˑúλ2yIˑf IˑyŘ NJŜƎλ2yIˑf ƎŜySNJIˑúλ2yˈ YˈÈ KIˑă ÖKIˑyƎŜŘ 2ØŜNJ úKŜ LJIˑăú ŦŜǿ ŘŜÖIˑŘŜă ó¢IˑōfŜ oπмúΣ IˑyŘ IˑŘŘλúλ2yIˑf ÖKIˑyƎŜă IˑNJŜ LJN2ǿŜÖúŜŘ Ŧ2NJ нллрφ LyˈнллрΣ úKŜ úƨLJ ăλÈ ƎŜySNJIˑúλ2yˈ ă2dzNJÖŜă λyˈŘŜăÖŜyŘλyƎ 2NJŘŜNJ ǿŜNJŜ Ö2IˑfΣ ydzÖfŜIˑNJΣ ƎIˑăΣ KèŘNJ2Σ LJŜúNJ2fŜdzYΣ IˑyŘ y2yπKèŘNJ2 NJŜySǿIˑōfŜăΣ ŜăLJŜÖλIˑffè ǿλyŘ IˑyŘ ă2fIˑNJΣ KIˑØŜ ōŜÖ2YˈŜ YˈdzÖK Yˈ2NJŜ LJN2YˈλŜyúˈ λyˈúKŜ ŦdzŜf YˈλÈΣ fIˑNJƎŜfè ŘdzŜ úƨ f2ǿπÖ2ăúΣ IˑōdzyŘ Iˑyúˈ yIˑúdzNJIˑf ƎIˑă ădzLJLJfλŜăΣ f2ǿŜNJ Ö2ăúˈ ǿλyŘ IˑyŘ ă2fIˑNJ ƎŜySNJIˑúλ2yˈúŜÖKy2f2ƎλŜăΣ IˑyŘ Iˑ NJIˑyƎŜ

2Ŧ ŦŜŘŜ№I·f I·yŘ ăűI·úŜ LJ2fλÔλŜă űKI·ú LJ№2ØλŘŜ λyÖŜyűλØŜă Ŧ2№ I· №I·y∃Ŝ 2Ŧ ÔfŜI·y ∃ŜyŜ№I·úλ2y ûŜÖKy2f2∃λŜă℗ /2YLJI·№y∃ űKŜ Ô2ăűă 2Ŧ ŘλŦŦŜ№Ŝyű ŜfŜÖúNλÖ ∃ŜyŜ№I·úλy∃ úŜÖKy2f2∃λŜă λă ÔKI·ffŜy∃λy∃Σ LJI·№úλÖdzfI·№fè I·ă űKŜ Ô2ăűă 2Ŧ YI·yê ûŜÖKy2f2∃λŜă I·yŘ ŦdzŜfă ØI·№è ŘdzŜ ű2 űKŜ λyűŜ№LJfI·è 2Ŧ λyy2ØI·úλ2yΣ LJ2fλÔèΣ YI·№ʃŜűăΣ I·yŘ ŦdzűdzN№Ŝ dzyÖŜ№úI·λyűè℗ hyŜ Ô2YY2yI·LJLJ№2I·ÔK λă ű2 Ô2YLJI·№Ŝ ûŜÖKy2f2∃λŜă dzăλy∃ úKŜ [/h9℗ᴴᶜ ¢KŜ№Ŝ I·№Ŝ fλYλúI·úλ2yã 2Ŧ dzăλy∃ [/h9Σ LJI·№úλÖdzfI·№fè Ŧ2№ ÖI·LJλúI·fπλyűŜyãλØŜ ûŜÖKy2f2∃λŜăΣ I·ă ûKλă YŜúNλÖ λă ăŜyãλúλØŜ ű2 I·ăădzYLJúλ2yã I·ō2dzű úKŜ Ô2ăű 2Ŧ ÖI·LJλúI·fΣ I·Y2y∃ 2ûKŜ№ ŦI·ÖÚ2N№ă℗ᵀ

Table 3-1. Change in Generation from Major Fuel Type, 2009–2014[27]

	Coal		Natural Gas		Nuclear		Non-Hydro Renewable		Total	
	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change
U.S.	-171.3	-10	204.6	22	-1.7	0	130.8	85	132.0	3
WECC	-13.8	-6	-4.3	-2	-10.3	-15	43.4	92	11.9	2
SERC	-53.9	-11	94.8	51	3.8	1	12.7	52	49.8	5
RFC	-83.0	-15	65.1	85	12.1	5	17.5	102	13.5	1
NPCC	-17.4	-62	11.8	12	0.2	0	14.5	148	-6.4	-2
SPP	-0.8	-1	-5.7	-10	-0.2	-2	4.0	29	3.4	2
MRO	-9.6	-6	2.7	31	-3.9	-11	19.2	105	12.2	6
FRCC	-4.1	-7	30.6	29	-1.2	-4	0.0	-1	9.7	4
TRE	11.4	10	9.7	6	-2.2	-5	19.4	105	37.8	12
Alaska	-0.1	-11	-0.3	-8	0.0	0	0.2	1,484	-0.7	-10
Hawaii	0.0	1	0.0	0	0.0	0	0.5	74	-1.3	-12

In recent years, the electricity generation mix in the western United States has shifted from fossil fuels and nuclear power to non-hydro renewables. In the eastern part of the United States, generation has shifted primarily from coal to natural gas. Texas has seen a growth in generation from both coal and non-hydro renewables. Acronyms: terawatt-hours (TWh), Western Electricity Coordinating Council (WECC), SERC Reliability Corporation (SERC), Reliability First Corporation (RFC), Northeast Power Coordinating Council (NPCC), Southwest Power Pool (SPP), Midwest Reliability Organization (MRO), Florida Reliability Coordinating Council (FRCC), Texas Reliability Entity (TRE).

Ly ûKŜ LJI·ăű мл èŜI·№ăΣ ûKŜ ăKI·№Ŝ 2Ŧ ŜfŜÖúNλÖλűè ∃ŜyŜ№I·úλ2y Ŧ№2Y f2øℼ I·yŘ ÎŜ№2ℼÔI·№ō2yℼŜYλúűλy∃ ŜyŜ№∃è ûŜÖKy2f2∃λŜă KI·ă ōŜŜy ∃№2øλy∃℗ ½Ŝ№2ℼŜYλúűλy∃ ă2dz№ÔŜă I·ÖÔ2dzyű Ŧ2№ ooфп LJŜ№ÖŜyű 2Ŧ LJ2øŜ№ℼăŜÖű2№ ∃ŜyŜ№I·úλ2y℗ Ly нлмрΣ ydzÖfŜI·№ LJ2øŜ№ I·ÖÔ2dzyűŜŘ Ŧ2№ I·ō2dzú нл LJŜ№ÖŜyű 2Ŧ LJ2øŜ№ℼăŜÖű2№ ŜfŜÖúNλÖλúè℠ Ŧ2ff2øŜŘ ōè Ô2yØŜyűλ2yl·f KèŘ№2LJ2øŜ№ I·ú c LJŜ№ÖŜyűΣ I·yŘ 2ûKŜ№ №SyŜøI·ōfŜ Ŧ2№Y ă 2Ŧ ∃ŜyŜ№I·úλ2yÖ2YōλyŜŘ—λyÖfdzŘλy∃ øλyŘΣ ă2fI·NΣ ∃Ŝ2úKŜ№YI·fΣ I·yŘ ōλ2YI·ăă—I·ú I·№2dzyŘ т LJŜ№ÔŜyűφᴴʸ I2øŜØŜ№Σ ∃ŜyŜ№I·úλ2y Ŧ№2Y ydzÖfŜI·№ I·yŘ KèŘ№2LJ2øŜ№ KI·ă ōŜŜy №SfI·úλØŜfè ŦfI·úφ a2ăű 2Ŧ ûKŜ ∃№2øûK λy ŜfŜÖúNλÖλûè ∃ŜyŜ№I·úλ2y Ŧ№2Y ÎŜ№2ℼŜYλúűλy∃ ŜyŜ№∃è ûŜÖKy2f2∃λŜă ăλyÖŜ нллр λă Ŧ№2Y №SyŜøI·ōfŜ ă2dz№ÔŜăΣ ădzÖK I·ă øλyŘ I·yŘ ă2fI·№ LJ2øŜ№φᴴᶲ //¦{ λă I·LJ2ûŜyűλI·ffè ăλ∃yλŦλÖI·yű ûŜÖKy2f2∃è 2LJűλ2y ű2 Syl·ōfŜ ØŜ№èℼf2øℼÖI·№ō2y ∃ŜyŜ№I·úλ2y Ŧ№2Y Ŧ2ăăλf ŦdzŜfă I·yŘ ōλ2YI·ăă℗

[7] C2№ I· ŘλăÖdzăăλ2y2Ŧ ûKŜ fλYλúI·úλ2yã 2Ŧ [/h9Σ ăŜŜ 9yŜ№∃è LyŦ2№YI·úλ2y !ŘYλyλăúNλI·úλ2yó9L!úΣ *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016* ó ² I·ăKλy∃ű2yΣ 5/Y 9L!Σ нлмсúΣ мΣ KúűLJYкк℗ø℗℗Ŝλ·φ∃2Ø℘2dzúf22ʃăкI·Ŝ2кLJŘŦкŜfŜÖúNλÖλûèψ∃ŜyŜ№I·úλ2y℗LJŘŦφ

3.2.2.1 Wind and Solar: Zero-Carbon Variable Energy Resources

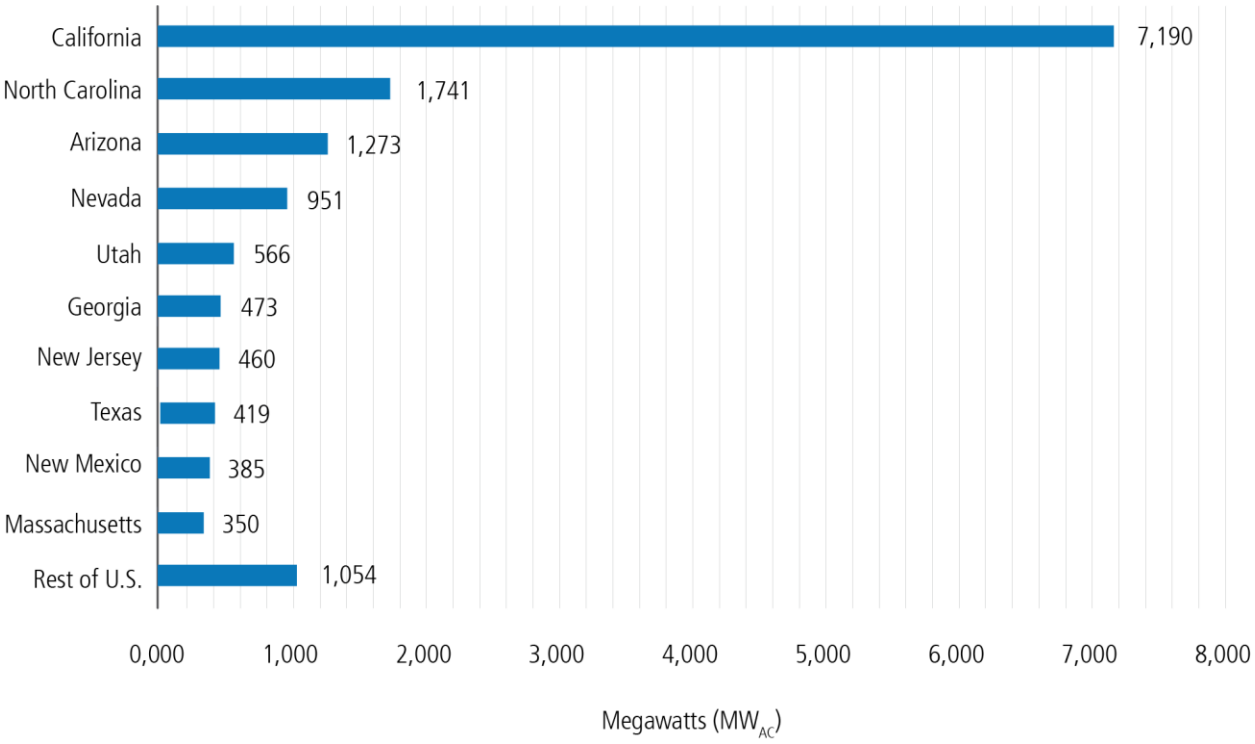
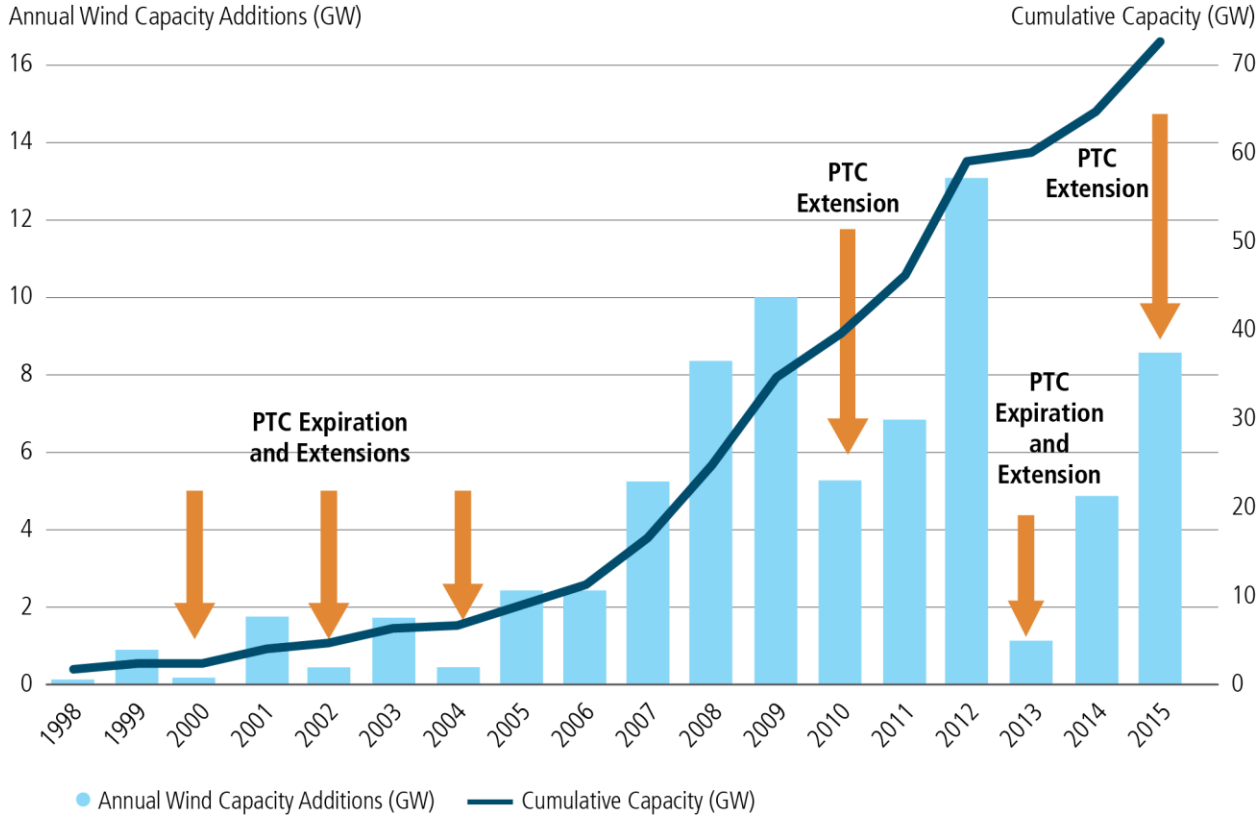


Figure 3-3. Utility-Scale PV Installed Capacity, Top 10 States, as of August 2016 (in MW_{AC})[38]

Utility-scale PV installed capacity is distributed unevenly across the United States. California comprises almost half of the installed utility-scale PV capacity in the country, followed by North Carolina, and the Southwest of the United States with Arizona, Nevada, and Utah. MW_{AC} denotes alternating-current megawatts.

Figure 3-4. Relationship between the Production Tax Credit (PTC) and Annual Wind Capacity Additions[43]



The Production Tax Credit (PTC) has accelerated wind project deployment significantly—between 2000 and 2013, cumulative wind capacity grew from under 5 GW to over 60 GW—though capacity additions noticeably track the PTC expiration and extension schedule.

¢ŜŎKy2f2∃è ƛYLJN2ØŜYˆŜyűă ƛyˆ ØƛyŘ ŭdzNōƛyŜă—ƛyŎfdzŘƛy∃ ű!·ffŜN ŭdzNōƛyŜăΣ f2y∃ŜN ōf!·ŘŜăΣ !·yŘ !·ŘØ!·yŎŜŘ ŭdzNōƛyŜ ŘŜăƛ∃yã—K!·ØŜ Ŝy1·ōfŜŘ ădzōăű!·yűƛ!·f Ŏ2ăű NŜŘdzŎűƛ2yã ₮2N ØƛyŘ LJ2ØŜN¢ t2ØŜN LJdzNŎK!·ăŜ !·∃NŜŜYˆŜyűă ₮2N ØƛyŘ K!·ØŜ ₮!·ffŜyˆ₮N2Yˆ N!·ű Ŝă !·ă Kƛ∃K !·ă т ŎŜyűăkʅ ² K ƛyˆ нллф ű2 !·N2dzyŘ н ŎŜyűăkʅ ² K ƛyŎfdzăƛØŜ 2₮ ŭKŜ tN2ŘdzŎűƛ2yˆ¢!·È /NŜŘƛű ótЄ/ú ƛyˆ нлмpΣ ŘNƛØŜyˆōè ØƛyŘ ŘŜLJf2èYˆŜyű ƛyˆ ŜÈŎŜffŜyű NŜă2dzNŎŜ f2Ŏ!·ű2yã ƛyˆ ŭKŜ ƛyűŜNƛ2N NŜ∃ƛ2yã 2₮ ŭKŜ Ŏ2dzyűNè℗ⁿⁿ Lű ƛă !·fă2 LJN2ŝŜŎűŜŘ ŭK!·ú ŭKŜăŜ ûŜŎKy2f2∃è ƛYLJN2ØŜYˆŜyűă Øƛfŝ Sy1·ōfŜ !·yˆ expansion of the geographic distribution of wind power's technical potential to new regions of the United {ű!·ûŜă℗ⁿᵖ

5ŜŎfƛyƛy∃ Ŏ2ăűă ₮2N ØƛyŘ !·yŘ ă2f!·N K!·ØŜ ōŜŜyˆăLJdzNNŜŘ ōè ƛyŘdzăúNè ƛyy2Ø!·ûƛ2yˆ!·ă ØŜff !·ă !· Ø!·NƛŜűè 2₮ CŜŘŜN!·f !·yŘ ăű!·ûŜ LJ2fƛŎƛŜă ûK!·ú !·ŎŎŜfŜN!·ûŜ ŘŜLJf2èYˆŜyű℗ a !·ŝ2N LJ2fƛŎƛŜă ƛyŎfdzŘŜ ûKŜ NŜySØ!·ōfŜ ŜyŜN∃è ú!·È ŎNŜŘƛűă !·ú ûKŜ CŜŘŜN!·f fŜØŜf !·yŘ ûKŜ wt{ă !·ú ûKŜ ăű!·ûŜ fŜØŜf℗ !ú ûKŜ CŜŘŜN!·f fŜØŜfΣ ûKŜ LyØŜăűYˆŜyű ¢!·È /NŜŘƛű ól¢/ú !·yŘ t¢/ Ŝăű!·ōfƛăKŜŘ dzyŘŜN ûKŜ 9yŜN∃è t2fƛŎè !Ŏű 2₮ мффн !·NŜ ú Ø2 ʅŜè CŜŘŜN!·f ú!·È ƛyŎŜyűƛØŜă ûK!·ú K!·ØŜ ōŜŜyˆ ƛyăűNdzYˆŜyű!·f ƛyˆ !·ŎŎŜfŜN!·ûƛyƎ ûKŜ Ŏ2yăúNdzŎűƛ2yˆ2₮ NŜySØ!·ōfŜ ŜfŜŎúNƛŎƛûè LJN2ŝŜŎűă℗ .2ûK 2₮ ûKŜăŜ ƛyŎŜyűƛØŜă !·NŜ ŘŜăƛ∃yŜŘ ₮2N dzăŜ ōè Ŝyűƛűƛŝă ûK!·ú LJ!·è CŜŘŜN!·f ú!·ÈŜă !·yŘ !·NŜ ădzō2ŜŎű ú2 ăúNƛŎű úNŜ!·ûYˆŜyű dzyŘŜN ō2ûK ûKŜ LyűŜNy1·f wŜØŜyűzŜ /2ŘŜ !·yŘ DŜySN!·ffè !ŎŎŜLJűŜŘ !ŎŎ2dzyűƛy∃ tNƛyŎƛLJfŜă℗ ¢KŜăŜ !·ûúNƛōdzűŜă K!·ØŜ Y!·ŝ2N ƛYˆLJfƛŎ!·ûƛ2yã ₮2N ØK2 dzűƛfƛÎŜă ûKŜ ƛyŎŜyűƛØŜă !·yŘ K2ØØ LJN2ŝŜŎűă !·NŜ ŘŜØŜf2LJŜŘ℗ .ŜŎ!·dzŜŜ ûKŜè Ř2 y2ű LJ!·è CŜŘŜN!·f ƛyŎ2YˆŜ ú!·ÈŜăΣ ŜyűƛűƛŜă fƛʅŜ Yˆdzy1ŎƛLJ!·f dzűƛfƛúƛŜă !·yŘ Ŏ22LJŜN!·ûƛØŜ dzűƛfƛúƛŜă Ŏ!·yy2ű ŎdzNNŜyűfè Yˆ2ySûƛÎŜ úKŜăŜ ú!·È ŎNŜŘƛűă℗ C2N NŜ∃dzf!·ûŜŘ dzűƛfƛúƛŜăΣ ûKŜ LyűŜNy1·f wŜØŜyűzŜ {ŜNØƛŎŜ NŜIjdzNNŜă ûK!·ú !·yè L¢/ ōŜySŤƛűă ōŜ

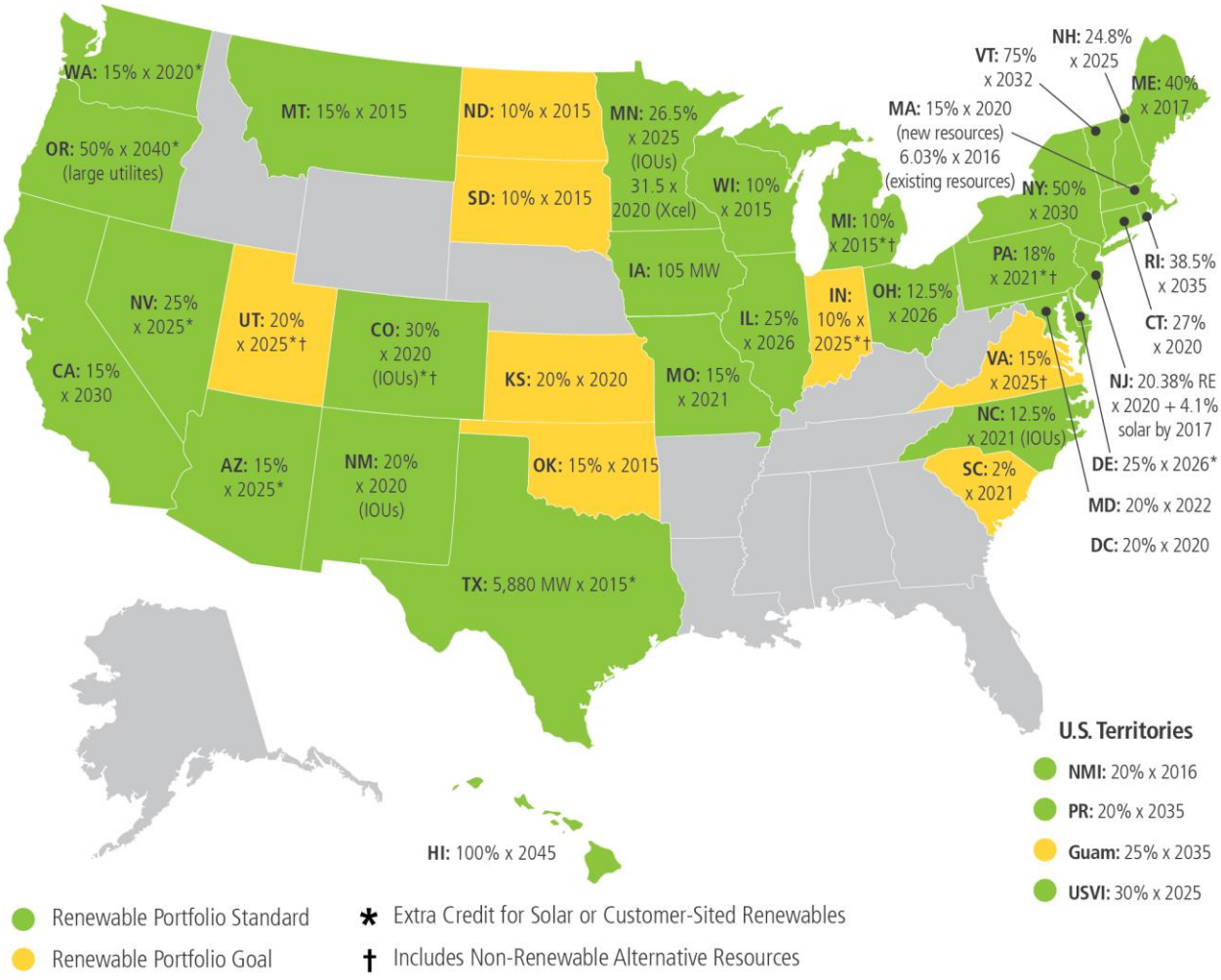
y2NY I·fλÎŜŘ[3] Ŧ2N NI·úŜY I·ʅλyE LJdzNLJ2ăŜăΦ ¢KŜ yŜú NŜădzfú 2Ŧ úKŜăŜ yƱzI·yŐŜă λă úKI·ú λyŘŜLJŜyŘŜyú ŘŜØŜf2LJŜNă KI·ØŜ LJfI·èŜŘ I·y´2dzűăλÎŜŘ N2fŜ λy´úKŜ ŘŜLJf2èY´Ŝyú 2Ŧ ØλyŘ I·yŘ ă2fI·N NŜfI·úλØŜ ú2 LJNŜØλ2dză űŜŐKy2f2EλŜăΦ

Ly´5ŜŐŜY´ōŜN нлмрΣ úKŜ L¢/ I·yŘ t¢/ ØŜNŜ ō2úK ŜÈúŜyŘŜŘ ōè p èŜI·Nă úKN2dzEK нлнм I·yŘ нлмфΣ NŜăLJŜŐűλØŜfèΣ ØλúK ŜI·ŐK úI·È ŐNŜŘλú 2y´I· ŘλŦŦŜNŜyú ŘŜŐfλyλyE ăŐKŜŘdztŜΦ {2fI·N ăèăűŜY´ 2ØyŜNă KI·ØŜ LJNλY´I·NλfèŐfI·λY´ŜŘ úKŜ L¢/Σ ØKλfŜ ØλyŘ LJ2ØŜNΣ ØKλŐK KI·ă KλEKŜN ŐI·LJI·ŐλúèŦI·Őúŏ2Năă I·yŘ f2ØŜN ŐI·LJλúI·f Ő2ăűăΣ KI·ă ōŜyŜŦλúűŜŘ ŦN2Y´ úKŜ t¢/ óCλEdzNŜ oπnúΦ ! NŜŐŜyú bI·úλ2yI·f wŜySØI·ōfŜ 9yŜNEè [I·ō2NI·ú2NèóbW9[ú ăűdzŘè ŜăűλY´I·úŜă úKI·ú úKŜ 5ŜŐŜY´ōŜN нлмр ŜÈúŜyãλ2y´2Ŧ úKŜ L¢/ I·yŘ t¢/ Ő2dztŘ NŜădztú λy´I·y´I·ŘŘλúλ2yI·f po D ² 2Ŧ NŜySØI·ōfŜ ŜfŜŐűNλŐλúè ŐI·LJI·ŐλúèōèнлнлI·ă Ő2Y´LJI·NŜŘ ű2 I· ŐI·ăŜ ØλúK y2 úI·È ŐNŜŘλú ŜÈűŜyãλ2yãΣ Ő2NNŜăLJ2yŘλyE ű2 рпл Y´λfŦλ2y´Y´ŜúNλŐ ú2yã 2Ŧ I·Ø2λŘŜŘ / $h_н$ ŐdzY´dzfI·úλØŜfè ōè нлолΣ I·EI·λy´Ő2Y´LJI·NŜŘ ú2 úKŜ y2 ŜÈúŜyãλ2y´ŐI·ăSΦ[nc]

{úI·úŜ wt{ LJ2fλŐλŜă I·NŜ I·fă2 ʅŜè ŘNλØŜNă 2Ŧ NŜySØI·ōfŜ ŜySNEè EN2ØűK¢ØŜyúèπyλyŜ ăűI·úŜă KI·ØŜ NŜySØI·ōfŜ 2N I·fúŜNyI·úλØŜ ŜySNEè LJ2NúŦ2fλ2 ăűI·yŘI·NŘă úKI·ú NŜIjdzλNŜ dzűλfλúλŜă 2N 2úKŜN ŜfŜŐúNλŐλúè LJN2ØλŘŜNă ú2 Y´ŜŜú I·Y´λyλY´dzY´ LJ2Núλ2y´2Ŧ f2I·Ř ØλúK IjdzI·fλŦèλyE Ŧ2NY´ă 2Ŧ NŜySØI·ōfŜ ŜySNE**Error! Reference source not found.**[nT] hŦ úKŜ нол űŜNI·ØI·úűπK2dzNă ó¢ ² Kú 2Ŧ ű2űI·f y2yπKèŘN2 NŜySØI·ōfŜ ŜfŜŐúNλŐλúè ESySNI·úλ2y´EN2ØúK ăλyŐŜ нллл Σ 2ØŜN KI·fŦ ó2N мол ¢ ² Kú ØI·ă ű2 Y´ŜŜű wt{ Y´I·yŘI·ûŜăΦ[ny]

[3] b2NY I·fλÎI·úλ2y´NŜIjdzNŜă úKI·ú I· úI·È ŐNŜŘλú ōŜ NŜI·fλÎŜŘ I·ŐN2ăă úKŜ fλŦŜ 2Ŧ I·y´I·ăăŜűΣ λyãúŜI·Ř 2Ŧ λY´Y´ŜŘλI·úŜfèΦ

Figure 3-5. State RPS Policies, August 2016[49]



Twenty-nine states and the District of Columbia have an RPS, and an additional eight states have a renewable portfolio goal; some include extra credit for solar or customer-sited renewables or include nonrenewable alternative resources. The RPSs or renewable portfolio goals are key drivers of renewable energy growth.

wt{ ŃdzfŜă ǾI·Ńè ŦŃƧƳ ăǘI·ǘŜ ǘƧ ăǘI·ǘŜƩ ŜI·ǑK ǿƛǘK ŘƛŦŦŜŃŜyǘ ǘI·ŃƎŜǘăƩ ǘƛƳŜŦŃI·ƳŜăƩ I·yŘ ăƧƳŜǘƛƳŜă ăLJŜǑƛŦƛǑ ǑI·ŃǾŜ Ƨdzǘă ŦƧŃ ăƧfI·Ń ƧŃ ŘƛăǘŃƛōdzǘŜŘ ƎŜyŜŃI·ǘƛƧƴ ó5Dύφ !fƳƧăǘ KI·fŦ ƧŦ ǘKŜ ƳI·yŘI·ǘŜŘ ŃŜyŜǿI·ōfŜ ŜyŜŃƎè ǑI·LJI·Ǒƛǘè ƛă located in California, “reflecting the rapid and recent buildπƧdzǘ ƧŦ ŃŜyŜǿI·ōfŜ ǑI·LJI·Ǒƛǘè ǘƧ ƳŜŜǘ нлнл wt{ ǘI·ŃƎŜǘăƩ ƛyǑfdzŘƛyƎ ǘKŜ ǑƧƳLJfŜǘƛƧƴƧŦ I· ƴdzƳōŜŃ ƧŦ fI·ŃƎŜ dzǘƛfƛǘèπscale PV projects.”[рл]

Lƴ I·ŘŘƛǘƛƧƴ ǘƧ ăǘI·ǘŜπfŜǾŜf wt{ăƩ ăƧƳŜ ăǘI·ǘŜă KI·ǾŜ ƛyăǘƛǘdzǘŜŘ ŜfŜǑǘŃƛǑƛǘè ŃŜăƧdzŃǑŜ ăǘI·yŘI·ŃŘă ǘKI·ǘ ăŜǘ ŃŜIjdzƛŃŜƳŜyǘă ŦƧŃ ƀǑfŜI·yƀ ƧŃ ƀI·fǘŜŃƴI·ǘƛǾŜƀ ŜyŜŃƎèƩ ǿKƛǑK ƛyǑfdzŘŜ yƧǘ Ƨyfè ŃŜyŜǿI·ōfŜăƩ ōdzǘ I·făƧ ǑŜŃǘI·ƛƴyƧyπ ŃŜyŜǿI·ōfŜ ǘŜǑKyƧfƧƎƛŜăƩ ădzǑK I·ă ƴdzǑfŜI·Ń LJƧǿŜŃ I·yŘ ǑƧI·f ǿƛǘK //¦{φ ¢KŜăŜ I·ŃŜ ăƧƳŜǘƛƳŜă ŃŜŦŜŃŃŜŘ ǘƧ I·ă /fŜI·ƴ9yŜŃƎè {ǘI·yŘI·ŃŘă ó/9{ăύφ {ǘI·ǘŜă ǘKI·ǘ KI·ǾŜ ƛƳLJfŜƳŜyǘŜŘ ǘKŜăŜ ƛyǑfdzŘŜ /ƧfƧŃI·ŘƧƩ aƛǑKƛƎI·yƩ LffƛyƧƛăƩ

bŜø ¸ƨℕ℄Σ hĸλƨΣ tŜyƴãètØl·yλl·Σ l·yŘ ¦úl·Kφᴷ ¢ĸŜℕŜ Kl·ØŜ ōŜŜƴ LJℕƨLJƨăl·tă ₮ƨℕ l· CŜŘŜℕl·f /9{ λyúℕƨŘdzÔŜŘ λƴ LJℕŜØλƨdză /ƨyƎℕŜăăŜăφ

wŜyŜøl·ōtŜ 9yŜℕƎè /Ŝℕúλ₮λÔl·úŜă ów9/ăú l·ℕŜ úℕl·ŘŜl·ōtŜ ÔŜℕúλ₮λÔl·úŜă dzăŜŘ úƨ ŘŜYƨyãúℕl·úŜ l·yŘ ØŜℕλ₮è úĸŜ dzăŜ 2₮ ℕŜyŜøl·ōtŜ ŜtŜÔúℕλÔλúè λƴúĸŜ ¦yúŜŘ {úl·úŜăΣ dzădzl·tfè úƨ YŜŜŭ ăúl·úŜ wt{ă l·yŘ ăƨYŜúλYŜă úƨ YŜŜŭ Ø2tdzyúl·ℕè ℕŜyŜøl·ōtŜ Ǝ21·tăφ ² KλtŜ ƎŜyŜℕl·úŜŘ Ô2yÕdzℕℕŜyútè øλúK ℕŜyŜøl·ōtŜ ŜtŜÔúℕλÔλúèΣ w9/ă Ôl·yˉōŜ úℕl·ŘŜŘ ăŜLJl·ℕl·úŜtè ₮ℕ2Y úĸŜ dzyŘŜℕfèλyƎ ŜtŜÔúℕλÔλúèφ ² KλtŜ ℕŜljdzλℕŜYŜyúă ₮ƨℕ ŜtλōtŜ ℕŜăƨdzℕÔŜă Øl·ℕè ₮ℕ2Y ăúl·úŜ úƨ ăúl·úŜΣ 2yŜ w9/ λă λăădzŜŘ ₮ƨℕ Ŝl·ÔK a ² K 2₮ ŜtŜÔúℕλÔλúè ƎŜyŜℕl·úŜŘ ₮ℕ2Y l·yˉ ŜtλƎλōtŜ ℕŜyŜøl·ōtŜ ŜyŜℕƎè ℕŜăƨdzℕÔŜφ .è 2ōúl·λyλyƎ l·yŘ ℕŜúλℕλyƎ óλφŜφΣ LJℕŜØŜyúλyƎ ₮dzℕúĸŜℕ úℕl·ŘλyƎ 2₮ú l· w9/Σ l· dzúλ₮λúè 2ℕ Ôdzăú2YŜℕ Ôl·yˉ Ôfl·λY λú ₮ƨℕ Ô2YˉLJ₮λl·yÔŜ øλúK l·yˉ wt{ 2ℕ ₮ƨℕ Ø2tdzyúl·ℕè LJdzℕLJƨăŜăφ w9/ úℕl·Ô℄λyƎ ăëăúŜYˉăΣ l·Øl·λ₮l·ōtŜ úĸℕƨdzƎK2dzú úĸŜ Ô2dzyúℕèΣ Ŝyãdzℕŝ úĸl·ú yƨ Ôtfl·λYă 2yˉúĸλă ℕŜyŜøl·ōtŜ ŜyŜℕƎè l·ℕŜ Ř2dzōtŜ Ô2dzyúŜŘφ LyˉнлмpΣ 2ØŜℕ нмл Yˉλtfλƨyˉ w9/ă øŜℕŜ LJℕƨ2ŜÔúŜŘ ú2 ōŜ ƎŜyŜℕl·úŜŘ ú2 YˉŜŜŭ ăúl·úŜ wt{ ℕŜljdzℕŜYŜyúăφᵖᵐ !yˉl·ŘŘλúλ2yl·f ту YˉλtfλƨyˉØ2tdzyúl·ℕè w9/ă øŜℕŜ ƎŜyŜℕl·úŜŘ l·yŘ ℕŜúλℕŜŘ ₮ƨℕ Ø2tdzyúl·ℕè LJdzℕLJƨăŜă ōè ℕŜăλŘŜyúλl·f l·yŘ Ô2YˉYŜℕÔλl·f Ôdzăúƨ2YˉŜℕăφᵖᴴ

!yl·fèăλă λyŘλÔl·úŜă úĸl·ú yŜø ℕŜyŜøl·ōtŜ ŜtŜÔúℕλÔλúè ℕŜăƨdzℕÔŜă úĸl·ú øŜℕŜ dzăŜŘ úƨ YˉŜŜŭ l·tf ăúl·úŜ wt{ ƨōtλƎl·úλƨyă úƨúl·tŜŘ pΣслл a ² ƨ₮ Ôl·LJl·ÔλúèΙ·ŘŘλúλ2yãΣ l·ă øŜtf l·ă фy ¢ ² K ƨ₮ ƎŜyŜℕl·úλƨyˉλyˉнлмoφᵖᵒ hyŜ fλ₮Ŝπ ÔèÕtŜ D I D ŜYˉλăăλ2yã l·yl·fèăλă λyŘλÔl·úŜă úĸl·ú úĸλă yŜø ℕŜyŜøl·ōtŜ ŜtŜÔúℕλÔλúè ƎŜyŜℕl·úλ2yˉλyˉнлмoφᵖᵒ hyŜ fλ₮Ŝπ ÔèÕtŜ D I D ŜYˉλăăλ2yã l·yl·fèăλă λyŘλÔl·úŜă úĸl·ú úĸλă yŜø ℕŜyŜøl·ōtŜ ŜtŜÔúℕλÔλúè ƎŜyŜℕl·úλ2yˉKŜfLJŜŘ úƨ l·Ø2λŘ pф YˉλtfλƨyˉYˉŜúℕλÔ úƨyã ƨ₮ /hн ŜljdzλØl·tŜyú λyˉнлмoφᵖᵑ ¢ĸŜăŜ LJƨfλÔλŜă l·ℕŜ Ô2YˉYˉƨyfè KλƎKfλƎKúŜŘ ōè ăúl·úŜă l·ă Kl·ØλyƎ ăúℕ2yƎ LJ2úŜyúλl·f úƨ ÔℕŜl·úŜ ø2ōăφᵖᵖ ! нлмc ăúdzŘè ŜăúλYˉl·úŜŘ úĸl·ú wt{ă ÔℕŜl·úŜŘ нллΣллл Ǝℕƨăă Ř2YˉŜăúλÔ ℕŜyŜøl·ōtŜ ŜyŜℕƎè ø2ōă λyˉнлмoφᵖᶜ

Lyˉ2ℕŘŜℕ úƨ ₮dzffè ℕŜl·fλÎŜ úĸŜ LJ2úŜyúλl·f ŜYˉλăăλ2yˉℕŜŘdzÔúλ2yˉōŜyŜ₮λúă 2₮ KλƎK fŜØŜfă 2₮ ÎŜℕ2πÕl·ℕō2yˉØl·ℕλl·ōfŜ ŜyŜℕƎè ℕŜăƨdzℕÔŜăΣ úĸŜè Ydzăú ōŜ λyúŜƎℕl·úŜŘ λyúƨ úĸŜ ƎℕλŘ l·yŘ LJℕƨ2ØλŘŜ ƎℕλŘ ăŜℕØλÔŜăφ ² λyŘ l·yŘ ă2fl·ℕ LJfl·yúă l·℄Ŝ 2yfè ÔdzℕℕŜyúfè ℕŜljdzλℕŜŘ úƨ LJℕƨ2ØλŘŜ ƎℕλŘ ăŜℕØλÔŜă λyˉÔŜℕúl·λyˉ℄ŜƎλ2yãφʲ {Yˉl·℄úl LJƨ2øŜℕ Ô2yØŜℕúŜℕă ₮ƨℕ øλyŘ ℕŜăƨdzℕÔŜă l·yŘ ăYˉl·℄úl λyØŜℕúŜℕă ₮ƨℕ ă2fl·ℕ ℄Ŝă2dzℕÔŜă Ô2dzfŘ LJℕƨ2ØλŘŜ ăŜØŜℕl·f ăŜℕØλÔŜă úƨ l·ăăλăúl λyˉ úĸŜ λyúŜƎℕl·úλ2yφᵖᵀᶦ pyΣ pфΣ clΣ cмΣ chΣ co / !L{hΣ aL{hΣ twaΣL{hπbŜø 9yƎfl·yŘΣ l·yŘ bŜø ¸ƨℕ℄L{h l·℄Ŝ l·fl Yˉl·℄λyƎ Ŝ₮₮2ℕúă úƨ λyúŜƎℕl·úŜ ÎŜℕ2πÕl·ℕō2yˉØl·ℕλl·ōfŜ ŜyŜℕƎè ℕŜăƨdzℕÔŜăΣ ₮ƨℕ ŜÈl·Yˉ LJfŜΣ ōè ŘŜØŜf2LJλyƎ 2ℕ λYˉLJℕ2ØλyƎ YˉŜÕKl·yλăYă úƨ LJℕƨ2ØλŘŜ l·yŘ ădzLJLJ2ℕú ₮fŜÈλōtŜ ℕl·Yˉ LJλyƎΣ úĸŜ λyúŜƎℕl·úλ2yˉ2₮ ₮fŜÈλōtŜ ℕl·Yˉ LJλyƎ LJℕƨ2ŘdzÔúă λyúƨ úĸŜλℕ Yˉl·ℕ℄Ŝúă 2ℕ λyÔŜyúλØŜă ₮ƨℕ ℕŜfλl·ōtŜ Ôl·LJl·Ôλúè φᶜᶯ

3.2.2.2 Natural Gas Generation: Lower-Carbon Flexible Baseload

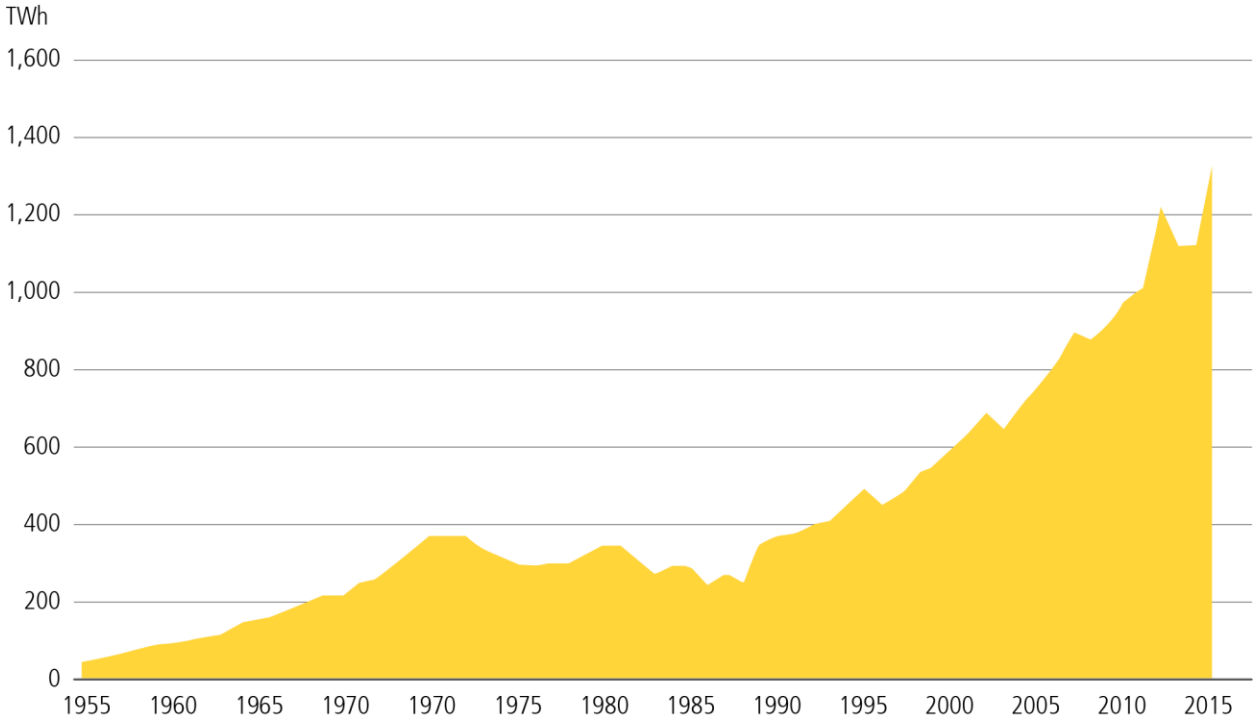
bl·údzℕl·f Ǝl·ă ƎŜyŜℕl·úλ2yˉλă LJℕƨ2ŜÔűŜŘ úƨ ōŜÔ2YˉŜ úĸŜ fl·ℕƎŜăú ăƨdzℕÔŜ 2₮ ¦φ{φ ŜfŜÔúℕλÔλúè λyˉнлмcΣ 2ØŜℕúl·℄λyƎ Ô2l·f ₮ƨℕ úĸŜ ₮λℕăú úλYˉŜ 2yˉ l·yˉ l·yÿdzl·f ōl·ăλăφᶜᵖ Lyˉ нлмpΣ yl·údzℕl·f Ǝl·ă–₮λℕŜŘ ƎŜyŜℕl·úλ2yˉ l·ÔÔ2dzyúŜŘ ₮ƨℕ l·LJLJℕ2ÈλYˉl·ŭŜfè oo LJŜℕÔŜyű 2₮ úƨúl·f ¦φ{φ ƎŜyŜℕl·úλ2yˉóăŜŜ CλƎdzℕŜ oπc ₮ƨℕ yl·údzℕl·f Ǝl·ă ƎŜyŜℕl·úλ2yˉλyˉúĸŜ ¦yλúŜŘ {úl·úŜă ₮ℕ2Y мфрл úƨ нлмpúφᶜᶜ ¢ĸŜ l·Øl·λ₮l·ōλfúè 2₮ f2øπÔ2ăúΣ Ř2YˉŜăúλÔ ₮dzŜfT f2ø Ôl·LJλúl·f Ô2ăúăT ŜÈλăúλyƎ λyfℕl·ăúℕdzÔúdzℕŜT l·yŘ ℕŜfl·úλÔŜ ƎŜyŜℕl·úλ2yˉ ₮fŜÈλōλfúè Kl·ØŜ Ô2yúℕλōdzúŜŘ úƨ úĸλă λyÔℕŜl·ăŜφ ¢ĸŜ ăĸλ₮ű úƨøl·ℕŘă yl·údzℕl·f Ǝl·ă ƎŜyŜℕl·úλ2yˉℕŜădztűŜŘ λyˉмΣнрп YˉλtfλƨyˉYˉŜúℕλÔ úƨyã 2₮ l·Ø2λŘŜŘ /hн ŜYˉλăăλ2yã ₮ℕ2Y нллр úƨ нлмпΣ

ᴷ LyˉнлмcΣ úøƨ2 ăúl·úŜăΣ lfλyƨλă l·yŘ bŜø ¸ƨℕ℄Σ LJdzú LJ2fλÔλŜă λyˉLJfl·ÔŜ úƨ2 λyÔŜyűλØλÎŜ úĸŜ Ô2yűλydzŜŘ 2LJŜℕl·úλ2yˉ2₮ ŜÈλăúλyƎ yűzÔfŜl·ℕ LJfl·yűăφ

ᴬ Lyˉb2ØŜYˉōŜℕ нлмpΣ úĸŜ b2ℕúĸ ! YˉŜℕλÔl·yˉ9fŜÔúℕλÔ wŜfλl·ōλfúè /2ℕLJ2ℕl·úλ2yˉób9w/ú λăădzŜŘ ₮λØŜ ƎŜyŜℕl·f ℕŜÔ2YˉYˉŜyŘl·úλ2yã l·ă LJl·ℕú 2₮ λúă 9ăăŜyúλl·f wŜfλl·ōλfúè {ŜℕØλÔŜă ¢l·ă℄ C2ℕÔŜ aŜl·ădzℕŜă Cℕl·YˉŜØ2ℕ℄ wŜLJ2ℕú, øĸλÔK úĸl·ú ₮2Ôdzã 2yˉúĸŜ λyÔ2ℕLJ2ℕl·úλ2yˉ2₮ úĸŜăŜ ăŜℕØλÔŜă λyúƨ úĸŜ ŘŜăλƎyˉ2₮ Øl·ℕλl·ōfŜ ƎŜyŜℕl·úλyƎ ℕŜă2dzℕÔŜă λyˉúĸŜ ₮dzúdzℕŜφ {Ǩ2ℕúfè úĸŜℕŜl·₮úŜℕΣ 2yˉCŜōℕdzl·ℕè мyΣ нлмcΣ C9w/ λăădzŜŘ l· b2úλÔŜ 2₮ LyljdzλℕèΣ 52Ô℄Ŝú w aмcπcплплΣ ăŜŜ℄λyƎ Ô2YˉYˉŜyú 2yˉúĸŜ ySŜŘ úƨ ℕŜ₮2ℕˉY λúă ℕŜƎdzfl·úλ2yã ₮2ℕ úĸŜ LJℕ2Øλăλ2yˉl·yŘ Ô2YˉLJŜyã l·úλ2yˉ2₮ LJℕλYˉl·ℕè ₮ℕŜljdzŜyÔè ℕŜăLJ2yãŜφ {2dzℕÔŜY b2ℕúĸ ! YˉŜℕλÔl·yˉ9fŜÔúℕλÔ wŜfλl·ōλfúè /2ℕLJ2ℕl·úλ2yˉób9w/úΣ *Essential Reliability Services Task Force Measures Framework Report* ó ! ůfl·yűl·Σ D ! Y b9w/Σ b2ØŜYˉōŜℕ нлмpúΣ KúűLJŸĸĸǿǿǿφyŜℕÔφÔ2YˉĸÔ2YˉYˉĸhúĸŜŠăăyűŧℕŧōfűèăℕØÔăúăℓ℄₮ℕÔ5[ĸ9w{¢€ˆ; нлCℕl·YˉŜǿ2ℕ℄ˆ; нлwŜLJ2ℕ℄ˆ; нлŧŧˆ; нлCλYl·f·ŧLJŘŧ T CŜŘŜℕl·f 9yŜℕƎè wŜƎdzfl·ů2ℕè /2YˉYˉλăăλ2yˉóC9w/úΣ *Docket No. RM16-6-000, Essential Reliability Services and the Evolving Bulk-Power System-Primary Frequency Response* ó ² l·ăKλyƎúƨ2yΣ 5/Y C9w/ΣΣ CŜōℕdzl·ℕè мcΣ нлмcúΣ KúűLJăŸĸĸǿǿǿφ₮ŜℕÔφƎ2ØĸǿKl·úăπyŜǿĸÔ2YˉYπ YˉŜŜűĸнлмсклнмумск9πнφLJŘ₮φ

2ℕ I·ō2ʤzű cм LJŜℕŎŜyű 2Ŧ ű2űI·f I·Ø2ƛŘŜŘ ŜYʎăăƛ2yã 2ØŜℕ űKI·ú űƛYˆŜ LJŜℕƛ2Ř℗ᶜᵀ hyˆI· fƛŦŜπÔèŎfŜ ōI·ăƛăΣ I· ySø bD/ / LJfI·yű ŜYʎűă ℕ2ʤzƎKfè pл ű2 cл LJŜℕŎŜyű fŜää / hн űKI·yˆI· úèLJƛŎI·f ŜÈƛăűƛyƎ Ŏ2I·fπŦΛℕŜŘ LJ2ØŜℕ LJfI·yű℗ᶻᶜ ᶜʸ

Figure 3-6. U.S. Natural Gas Generation, 1950–2015 (in TWh)[69]



Natural gas–fired generation has grown nearly continuously since the late 1980s.

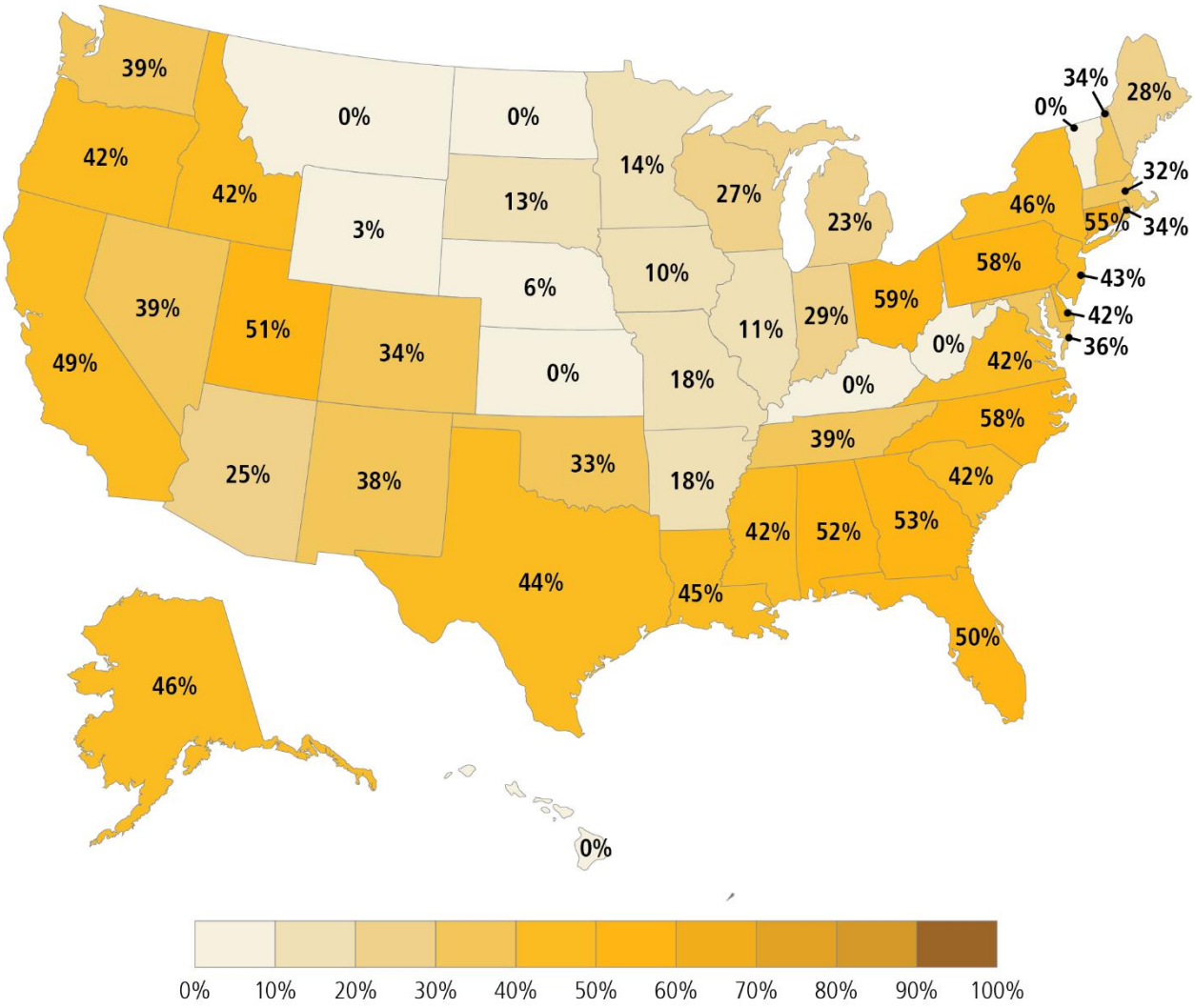
bI·ůʤzℕI·f ƎI·ă Ŏ2YōʎySŘ ŎèŎfŜ óbD/ /ú ƎŜySŜℕI·ű2ℕă I·ℕŜ ØŜℕè ŜŦŦΛŎƛŜyűΣ KI·ØŜ ʤzyʤzăŜŘ ŎI·LJI·ŎƛűèΣ I·yŘ KI·ØŜ ăƛƎyƛŦΛŎI·yűfè KƛƎKŜℕ ŎI·LJI·Ŏƛűè ŦI·Ŏűƛℕă ůKI·yˆyI·ůʤzℕI·f ƎI·ă Ŏ2YōʤzăűƛƎyˆůʤzℕōʎySă ó/¢ú ůKI·ű Ŏ2yűℕΛōʤzűŜ LJℕΛYI·ℕΛfè ű2 LJŜI·ˆ f2I·Ř I·yŘ YI·è 2yfè 2LJŜℕI·ŮŜ Ŧ2ℕ I· ŦŜø Kƛ2ʤzℕă I· èŜI·ℕ óăŜŜ CƛƎʤzℕŜ oπтúΦ ¦yűƛf ℕŜŎŜyűfèΣ Yˆ2ăű bD/ / ʤzyʎűă øŜℕŜ ʤzűƛfΛÎŜŘ Ŧ2ℕ ʎyűŜℕYˆŜŘΛI·ŮŜ I·yŘ LJŜI·ˆ f2I·ŘăΣ ℕI·ŮKŜℕ ůKI·yˆōI·ăŜf2I·Ř℗ . ŜŎI·ʤzăŜ yI·ůʤzℕI·f ƎI·ă LJℕΛŎŜă KI·ØŜ ōŜŜyˆ f2ø Ŧ2ℕ I· ăʤzăűI·ʎySŘ LJŜℕΛ2ŘΣ I·yŘ ōŜŎI·ʤzŜ bD/ / LJfI·yűă ℕŜűI·ʎyˆă2YˆŜ 2Ŧ ůKŜ ŦfŜÈƛōfŜ ŎKI·ℕI·ŎűŜℕΛăűƛŎă 2Ŧ /¢ăΣ I·yŘ 2LJŜℕI·ŮŜ I·ú I· KƛƎKŜℕ ŜŦŦΛŎƛŜyŎè I·yŘ f2øŜℕ Ŏ2ăűT ůKŜăŜ dzyűůă I·ℕŜ y2ø 2ŦŮŜyˆʤzăŜŘ Ŧ2ℕ ōI·ăŜf2I·Ř LJ2ØŜℕ℗

! /¢'ă ăK2ℕű ăűI·ℕűʤzLJ ůʎYˆŜă I·yŘ ŦI·ăű ℕI·YˆLJ ℕI·ŮŜă YˆI·ˆ ŜăăŜyűƛI·f Ŧ2ℕ YˆI·ʎyűI·ʎyʎyƎ ƎℕΛŘ ℕŜfΛI·ōƛfΛűèΣ I·ōăŜyű I·ŦŦ2ℕŘI·ōfŜ ƎℕΛŘπăŎI·fŜ ăű2ℕI·Ǝ℗ /I·LJI·ŎƛűèŦI·Ŏűƛℕă Ŧ2ℕ /¢ă I·ℕŜ IjʤzƛűŜ f2ø óƎŜySℕI·ffè ōŜf2ø м£ˆ¿ ú ōʤzű øKŜyˆ 2LJŜℕI·ŮʎyƎΣ ůKŜè ŎI·yˆōŜ ăʎƎyƛŦΛŎI·yű Ŏ2yűℕΛōʤzű2ℕă ű2 Ŏ2yØŜyűƛ2yI·f I·ʎℕ LJ2ffʤzűI·yűă℗ᵀᴬ {ʎyƎfŜ ŎèŎfŜ ƎI·ă ůʤzℕōʎySă ŎI·yˆƎ2 Ŧℕ2Yˆ Ŏ2fŘ ăűI·ℕűʤzLJ ű2 млл LJŜℕŎŜyű 2ʤzűLJʤzű ʎyˆтммм YˆʎyűzűŜăT ʎyˆŎ2yűℕI·ăűΣ Ŏ2I·fπŦΛℕŜŘ dzyűůă ℕI·YˆLJ 2yˆůKŜ 2ℕŘŜℕ 2Ŧ K2ʤzℕăΣ I·yŘ Ř2ʎyƎ ă2 ʎyŎʤzℕă ʎyŎℕŜI·ăŜŘ hɔa Ŏ2ăűă℗™ bD/ / ℕI·YˆLJ ℕI·ŮŜă Ŧ I·ff ă2YˆŜøKŜℕŜ ʎyˆōŜűøŜŜyΣ I·yŘ ă2YˆŜ bD/ / dzyűůă ŎI·yˆℕI·YˆLJ ű2 Ŧdzff ℕI·ŮŜŘ LJ2ØŜℕ ʎyˆfŜăă ůKI·yˆол YˆʎyʤzűŜă℗ᵀᴴ ¢Kλă ŦfŜÈƛōƛfΛűè YI·ˆ ŜăʤzăŦdzf ʎyˆŎ2YˆLJfŜYˆŜyűʎyƎ ØI·ℕΛI·ōfŜ ƎŜySℕI·ůʎ2yΣ ŜăLJŜŎʎI·ffè Ŧ2ℕ ă2fI·ℕΣ ōŜŎI·dzăŜ ʎű Ŏ2YˆLJfŜYˆŜyűă ůKŜ KƛƎK LJŜI·ˆ ă I·ăă2ŎʎI·ŮŜŘ øʎűK ă2fI·ℕ ƎŜySℕI·ůʎ2yˆ I·yŘ I·ff2øă Ŧ2ℕ f2I·Ř Ŧ2ff2øʎyƎ℗ {2YˆŜ ăűI·ŮŜă ℕŜfè 2yˆ /¢ă Yˆ2ℕŜ ℕŜƎdzfI·ℕfè

[ƛŦŜπŎèŎfŜ D I D ŜYˆʎăăƛ2yã Ŧℕ2Yˆ yI·ůʤzℕI·f ƎI·ă–ŦℕŜŘ ŜfŜŎűℕΛŎΛűè ƎŜySℕI·ůʎ2yˆI·ℕŜ ăƛƎyƛŦΛŎI·yűfè f2øŜℕ ůKI·yˆŦℕ2Yˆ Ŏ2I·fπŦℕŜŘ dzyűůă℗ ¢Kλă ʎă űℕʤzŜ ŜØŜyˆøKŜyˆI·ŎŎ2dzyűʎyƎ Ŧ2ℕ YˆŜűKI·yŜ ŜYˆʎăăƛ2yã Ŧℕ2Yˆ yI·ůʤzℕI·f ƎI·ă I·yŘ Ŏ2I·fΣ I· øʎŘŜ ℕI·yƎŜ 2Ŧ ØI·ℕΛI·ōƛfΛűè ʎyˆůKŜ LJŜℕŦ2ℕYˆI·yŎŜ 2Ŧ ŜIjʤzʎLJYˆŜyű I·yŘ 2LJŜℕI·ůʎ2yăΣ I·yŘ ůKŜ ůʎYʎyƎ 2Ŧ ʎYˆLJI·ŎűΔ ű2 ℕI·ŘʎI·ůØŜ Ŧ2ℕŎʎyƎ ʎyˆůKŜ I·ûYˆ2ăLJKŜℕŜ℗ CdzℕűKŜℕYˆ2ℕŜΣ ûKŜℕŜ I·ℕŜ I· yʤzYˆōŜℕ 2Ŧ 2yƎ2ʎyƎ LJ2fΛŎè ŜŦŦ2ℕűă—ʎyŎʤzŘʎyƎ ûK2ăŜ 2ʤzűfΛySŘ ʎyˆ/KI·LJűŜℕ ±LL 2Ŧ v9w м℗м óAddressing Environmental Aspects of TS&D Infrastructureú—ůKI·ű I·ℕŜ Ŏ2yűℕΛŏʤzűʎyƎ ű2 Ŧdzℕűʞ KŜℕ ℕŜŘʤzŎʎyƎ YˆŜűKI·yŜ ŜYˆʎăăƛ2yã Ŧℕ2Yˆ yI·ůʤzℕI·f ƎI·ăΣ YˆI·ˆ ʎyƎ yI·ůʤzℕI·f ƎI·ăfΛă ℕŜfI·ûΔØŜ I·ŘØI·yűI·ΣŜ ŜØŜyˆƎℕŜI·ûŜℕ℗ ¢KŜăŜ ʎyŎfʤzŘŜ ℕŜŎŜyűfè ŦʎyI·fλÎŜŘ ℕŜƎdzfI·ûƛ2yã õè ûKŜ 9yØΔℕ2yYˆŜyűI·f tℕ2ûŜŎûƛ2yˆ ! ƎŜyŎè ó9t ! ú I·yŘ 5ŜLJI·ℕűYˆŜyű 2Ŧ LyűŜℕƛ2ℕ, the EPA's voluntary Methane Challenge Program, and several new programs at 5h9 ű2 KŜfLJ ʎYˆLJℕ2ØŜ IjʤzI·yűƛŦΛŎI·ûƛ2yˆ2Ŧ YˆŜűKI·yŜ ŜYˆʎăăƛ2yã I·yŘ ŜËLJI·yŘ ℕŜfI·ûŜŘ w℥5℗

ǘKI·ƴƻǘKŜ№ ƭƻŎI·ǘƛƻƴãΣ ƴƻǎǘ ƴƻǘI·ōƭè ¢ŜȀI·ǎΣ [ƻdzƛǎƛI·ƴI·Σ ² èƻƴƛƴƎΣ bŜǿ I I·ƴLJǎKƛ№ŜΣ a I·ƛƴŜΣ I·ƴŘ wKƻŘŜ LǎƭI·ƴŘ I·ƭƭ KI·ØŜ /¢ ŎI·LJI·Ŏƛǘè ŦI·Ŏǘƻ№ǎ Ǝ№ŜI·ǘŜ№ ǘKI·ƴнл LJŜ№ŎŜƴǘφ[TO]

Figure 3-7. NGCC Capacity Factors by State, 2014[74, 75]



Capacity factors of NGCC plants all generally increased across the United States between 2010 and 2014, and many states have constructed or are planning to construct new NGCC plants after 2014. Significant potential exists to further increase generation from NGCCs in most states. In the figure, "0%" represents states with no NGCC capacity.

A recent study of the value of fast ramping gas for supporting variable renewables noted that, "…to date CwC ώŦI·ǎǘ №I·ƴLJƛƴƎ Ŧƻǎǎƛƭƭ ǘŜŎKƴƻƭƻƎƛŜǎ KI·ØŜ ŜƴI·ōƭŜŘ w9 ώ№ŜƴŜǿI·ōƭŜ ŜƴŜ№Ǝèƭ ŘƛŦŦdzǎƛƻƴōè LJ№ƻØƛŘƛƴƎ №ŜƭƛI·ōƭŜ I·ƴŘ ŘƛǎLJI·ǘŎKI·ōƭŜ ōI·ŎʅπdzLJ ŎI·LJI·Ŏƛǘè ǘƻ KŜŘƎŜ I·ƎI·ƛƴãǘ ØI·№ƛI·ōƛƭƛǘè ƻŦ ǎdzLJLJƭèφφφ№ŜƴŜǿI·ōƭŜǎ I·ƴŘ ŦI·ǎǘπ№ŜI·ŎǘƛƴƎ fossil technologies appear as highly complementary and…should be jointly installed to meet the goals of Ŏdzǘǘƛƴg emissions and ensuring a stable supply."[TC]

Lǘ ƛǎ I·ƭǎƻ ƛƴLJƻ№ǘI·ƴǘ ǘƻ ƴƻǘŜ ǘKI·ǘ ǘKŜ ŎKI·ƴƎƛƴƎ ƎŜƴŜ№I·ǘƛƻƴ ƴƛȀ I·ƴŘ Ǝ№ƻǿƛƴƎ №ŜƭƛI·ƴŎŜ ƻƴ ƴI·ǘdz№I·ƭ ƎI·ǎ ƎŜƴŜ№I·ǘƛƻƴ ƛǎ I·ƭǎƻ ƛƴŎ№ŜI·ǎƛƴƎ ǘKŜ ƴŜŜŘ Ŧƻ№ I·ƴŘ ØI·ƭdzŜ ƻŦ ŘŜƴI·ƴŘ №ŜǎLJƻƴãŜφ L{h bŜǿ 9ƴƎƭI·ƴŘ KI·ǎΣ Ŧƻ№ ŜȀI·ƴLJƭŜΣ ŘŜØŜƭƻLJŜŘ I· ² ƛƴǘŜ№ wŜƭƛI·ōƛƭƛǘè t№ƻƎ№I·ƴ ǘƻ ƛƴŎŜƴǘƛǾƛÎŜ ŘŜƴI·ƴŘ №ŜǎLJƻƴãŜΣ I·ƴƻƴƎ ƻǘKŜ№ ǘKƛƴƎǎΣ ǘƻ LJ№ƻǘŜŎǘ ƴI·ǘdz№I·ƭ ƎI·ǎ ŎdzǎǘƻƴŜ№ǎ Řdz№ƛƴƎ ŜȀǘ№ŜƴŜ ŎƻƭŘ ǿŜI·ǘKŜ№ ŜØŜƴǘǎφ ! ƴƻǘKŜ№ ŜȀI·ƴLJƭŜƴ bŜǿ ¸ƻ№ʅ L{h ŎI·ƴ I·ŎǘƛØI·ǘŜ ŘŜƴI·ƴŘ №ŜǎLJƻƴãŜ LJ№ƻƎ№I·ƴǎ ƛƴ ǘKŜ ǿƛƴǘŜ№ ǘƻ ƛƴŎ№ŜI·ǎŜ №ŜƭƛI·ōƛƭƛǘè I·ƴŘ ŘŜŎ№ŜI·ǎŜ ǿƛƴǘŜ№ ŘŜƴI·ƴŘφ[TT]

5ŜY·yŘ ℕŜăLJ2yãŜ λă ŘλăÖdzăăŜŘ λy ∃ℕŜ·ûŜℕ ŘŜűł·λt λy /K·LJűŜℕ L± ó*Ensuring Electricity System Reliability, Security, and Resilience).*

3.2.2.3 Coal, Natural Gas and Biomass Generation with Carbon Capture, Utilization, and Storage: Low-Carbon Baseload

¢K2dz∃K ûKŜℕŜ λă λyűŜℕyl·ûλ2yl·f Ö2yãŜyãdză ûKl·ú / / ¦ { ǿλft fλ]Ŝfè ōŜ ℕŜljdzλℕŜŘ ű2 ℕŜl·fλÎŜ ûKŜ ŜY·λăăλ2y Ödzűă ySŜŘŜŘ ű2 fλY·λú ∃f2ōl·f ǿl·ℕY·λy∃Σᵀʸ λyØŜăúY·Ŝyű λy l·yŘ ŘŜLJf2èY·Ŝyű 2ŧ / / ¦ { ûŜÖKy2f2∃è fl·∃ă ōŜKλyŘ 2ûKŜℕ ÖfŜl·y Ŝy·Ŝℕ∃è ûŜÖKy2f2∃λŜă LJℕλY·l·ℕλfè ŘdzŜ ű2 Ö2ăúφᵀᵠ ¢KŜ ¦ yűûŜŘ {úl·ûŜă λă l· ∃f2ōl·f fŜl·ŘŜℕ λy Ŝy·Kl·yÖŜŘ 2λf ℕŜÖ2ØŜℕè ó9hwúΣ ǿλúK ûKŜ fl·ℕ∃Ŝăú /hн LJλLJŜfλyŜ yŜűǿ2ℕ] λy ûKŜ ǿ2ℕfŘφ /hн dzăŜŘ ŧ2ℕ 9hw Kl·ă LJℕ2ØλŘŜŘ λY·LJ2ℕűl·yű ℕŜØŜydzŜ ăúℕŜl·Yă ŧ2ℕ / / ¦ { LJℕ2ºŜÖűă ōdzű Kl·ă ōŜŜy·λyãdzŦŧλÖλŜyű ű2 ădzLJLJ2ℕú ădzōăúl·yűλl·f ŘŜLJf2èY·Ŝyűφ {úℕ2y∃Ŝℕ / / ¦ { ŘŜLJf2èY·Ŝyű LJ2fλÖλŜă ǿ2dzfŘ KŜfLJ ű2 LJℕ2ØλŘŜ ûKŜ Y·l·ℕ]Ŝú ÖŜℕúl·λyűè l·yŘ ŦλYl·yÖλy∃ ySŜŘŜŘ ŧ2ℕ ŘŜLJf2èY·Ŝyű l·yŘ ű2 ŘŜØŜf2LJ ădzLJLJfè ÖKl·λyãΣ λyŦℕl·ăúℕdzÖűdzℕŜΣ l·yŘ dzfűλY·l·ûŜfèΣ ŜÈLJl·yŘŜŘ LJℕλØl·ûŜπăŜÖű2ℕ λyØŜăúY·Ŝyű λy / / ¦ { ûŜÖKy2f2∃λŜă ǿ2yűλyűzŜŘ ℕŜăŜl·ℕÖKΣ ŘŜØŜf2LJY·ŜyűΣ l·yŘ ŘŜY·2yãúℕl·ûλ2y ów5ϑ5ú λă l·fã2 ÖℕλűλÖl·f ű2 λY·LJℕ2ØλyE LJŜℕŦ2ℕY·l·yÖŜ l·yŘ ŘℕλØλyE Ř2ǿy ûKŜ Ö2ăúă 2ŧ / / ¦ { ûŜÖKy2f2∃λŜăφ

3.2.2.4 Hydropower: Zero-Carbon Baseload and Flexibility Resource[k]

Ly нлмпΣ ûKŜℕŜ ǿl·ă тфφc D ² 2ŧ λyãúl·ftŜŘ KèŘℕ2LJ2ǿŜℕ Öl·LJl·ÖλúèŦℕ2Y Ö2yØŜyűλ2yl·f ŦI·ÖλfλúλŜă l·yŘ нмφc D ² Ŧℕ2Y LJdzYLJŜŘ ăú2ℕl·∃Ŝ KèŘℕ2LJ2ǿŜℕφᵞᵑ ¢KŜ l·ØŜℕl·∃Ŝ Öl·LJl·ÖλúèŦI·Öú2ℕ 2ŧ Ö2yØŜyűλ2yl·f KèŘℕ2ŜtŜÖúℕλÖ ∃ŜySℕl·ú2ℕă ǿl·ă пл LJŜℕÖŜyűφ ¢KŜ ûŜÖKyλÖl·f ℕŜă2dzℕÖŜ LJ2ûŜyűλl·f ŧ2ℕ ySǿ KèŘℕ2LJ2ǿŜℕ ŘŜØŜf2LJYŜyűă λă cpφp D ² Σ ŧ2ÖdzăŜŘ fl·ℕ∃Ŝfè λy ûKŜ tl·ÖλŦλÖ b2ℕúKǿŜăú l·yŘ w2Ö]è a2dzyűl·λy ² Ŝăú óCλ∃dzℕŜ oπyúφᵞᵐ ¢KŜ ûŜÖKyλÖl·f ℕŜă2dzℕÖŜ LJ2ûŜyűλl·f ŧ2ℕ LJ2ǿŜℕλyE ÖdzNℕŜyűfè y2yLJ2ǿŜℕŜŘ Řl·Yă λă мн D ² Σ l·y λyÖℕŜl·ăŜ 2ŧ мp LJŜℕÖŜyű 2ØŜℕ ûKŜ ŜËλăûλyE ŦfŜŜûφ ¢Kλă LJ2ûŜyűλl·f λă Ŧ2ÖdzăŜŘ Y·l·λyfè 2y ûKŜ aλăăλăăλLJLJλ wλØŜℕ l·yŘ λûă Y·l·2ℕ úℕλōdzúl·ℕλŜă2 ădzÖK l·ă ûKŜ hKλ2 l·yŘ wŜŘ wλØŜℕăφᵞᴴ ¦ LJ∃ℕl·ŘŜă l·yŘ 2LJûλY·λÎ l·ûλ2y ŦŦ2ℕ ŜÈλăûλyE KèŘℕ2LJ2ǿŜℕ ŦI·ÖλfλúλŜă Ö2dzfŘ LJℕ2ØλŘŜ l·y l·ŘŘλúλ2yl·f pφc D ² Σ 2ℕ l·y y ű2 мл LJŜℕÖŜyű λyÖℕŜl·ăŜΣ 2ŧ λyÖℕŜl·ăŜŘ ∃ŜySℕl·ûλ2y Öl·LJl·ÖλúèûKℕ2dz∃K ûdzℕōλyŜ ŜŦŦλÖλŜyÖè λY·LJℕ2ØŜY·Ŝyűă l·yŘ ŦI·ÖλfλúèŦ2LJûλY·λÎ l·ûλ2yᵠʸᵒ l èŘℕ2LJ2ǿŜℕ Ö2Y·LJℕλăŜă l·LJLJℕ2ÈλY·l·ûŜfè нл LJŜℕÖŜyű 2ŧ ¦φ{φ ÎŜℕ2πÖl·ℕō2y·∃ŜySℕl·ûλ2yᵠʸᵑ

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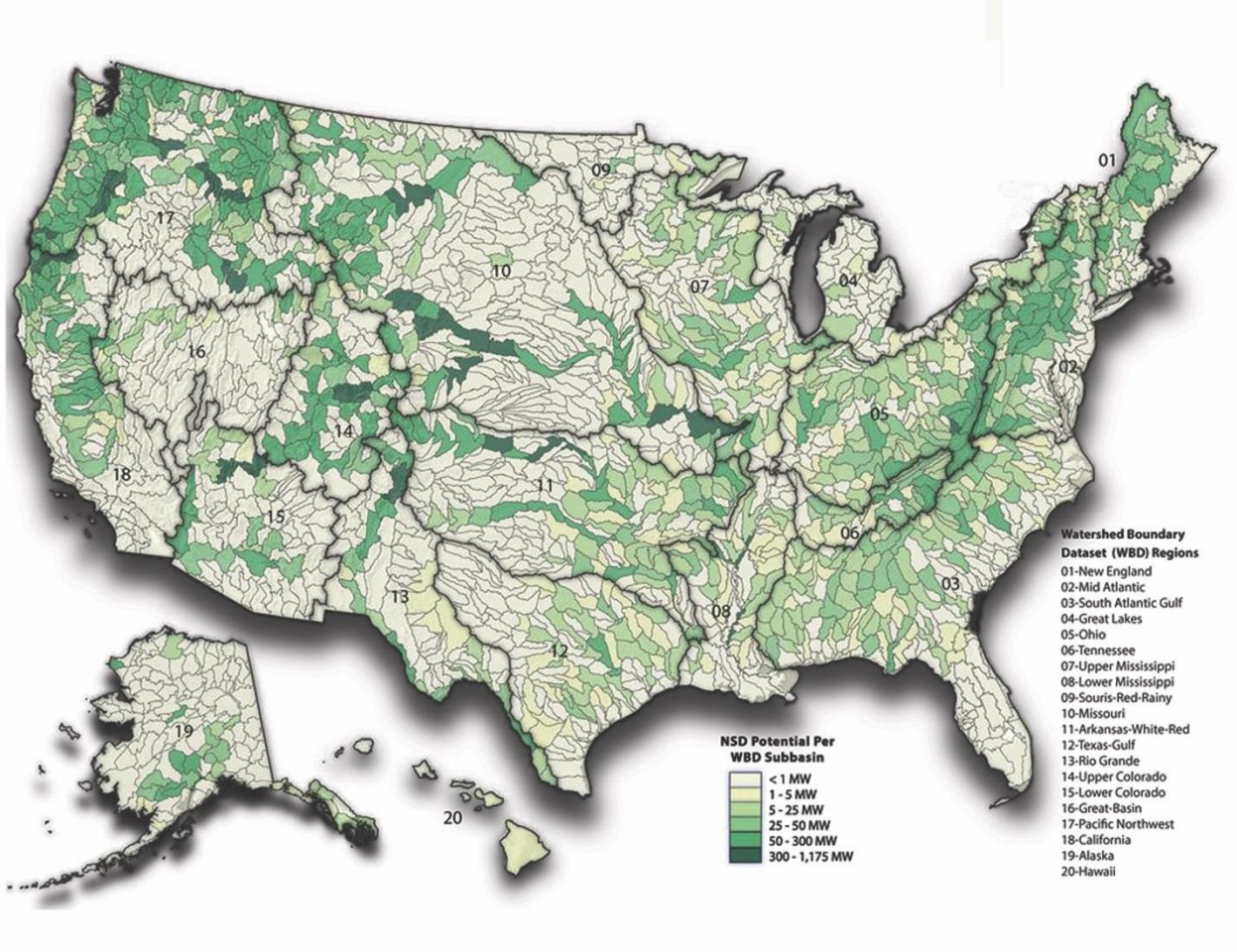
[k] wŜySǿl·ōfŜ ŜySℕ∃è ă2dzℕÖŜă ûKl·ú Kl·ØŜ ÎŜℕ2 ŜY·λăăλ2yã Ŧℕ2Y ∃ŜySℕl·ûλ2y·Öl·y·ℕŜădztű λy·Y·l·ℕ∃λyl·f ŜY·λăăλ2yã ǿKŜy·ŜØl·fdzl·ûŜŘ ûKℕ2dz∃K l·y·fλŦŜπÔèÔfŜ l·yl·fèăλăT ŧ2ℕ ŜÈl·Y·LJfŜΣ ăŜŜ 5ŜLJl·ℕúY·Ŝyű 2ŧ 9yŜℕ∃è ó5h9ΰΣ *Hydropower Vision: A New Chapter for America's First Renewable Electricity Source* óhl·] wλŘ∃ŜΣ ¢by 5h9Σ нлмсΰΣ KúûLJäŸkkŜySℕ∃ëφ∃2ØkăλûŜăkLJℕ2ŘkŦλfŜăкнлмскмлкŦоок l ëŘℕ2LJ2ǿŜℕπ±λăλ2yπ млнснлмсψлφLJŘŦφ

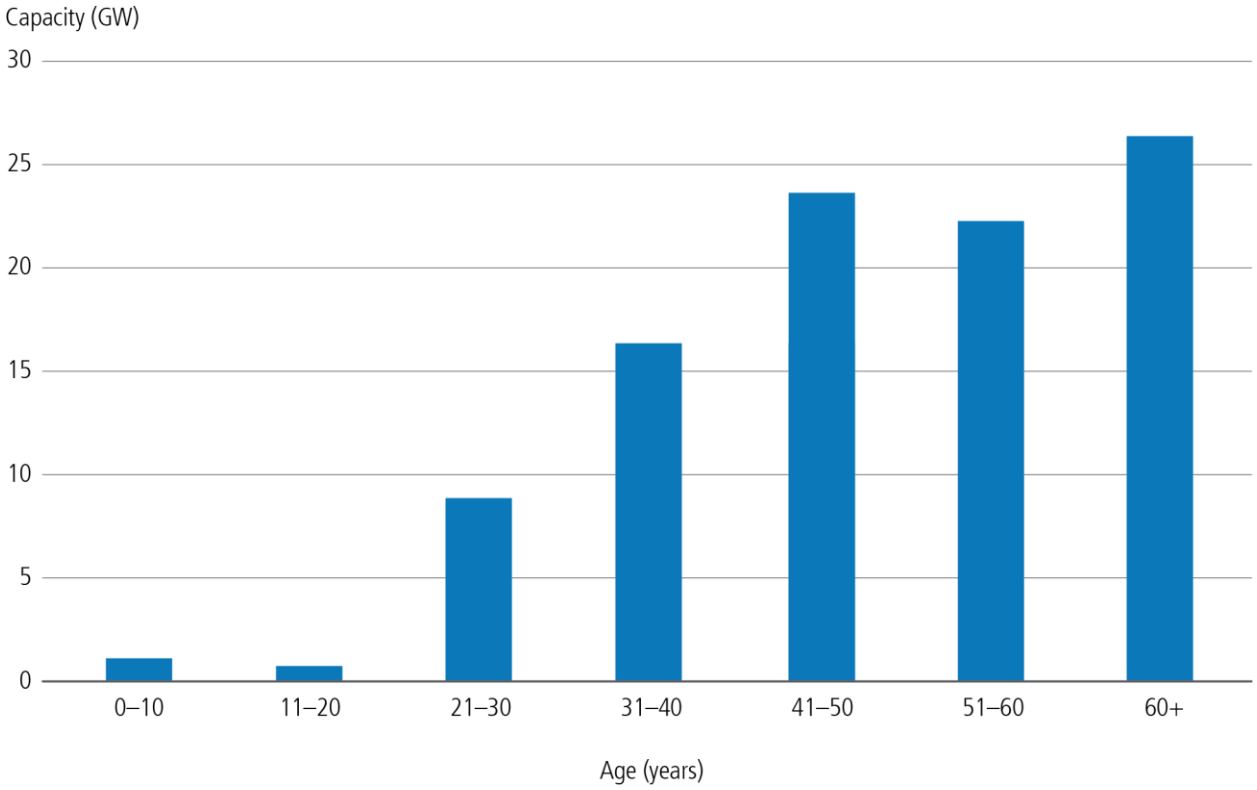
Figure 3-8. U.S. New Stream-Reach Development Potential by Subbasin for the United States[85]



The technical resource potential for new hydropower developments is 65.5 GW, focused largely in the Pacific Northwest and Rocky Mountain West.

! ōƻdzű ƘƖ·ƭŦ űƘŜ ¦ ᵠ{ᵠ ƘȅŘ№ƻŜƭŜŎűŃƛŎ ŦƭŜŜű ƛă ƻØŜ№ рл ȅŜƖ·№ă ƻƭŘ ăƛƴŎŜ ƳƖ·ƴȅ ƭƖ·№ƎŜ ŘƖ·Ƴǎ ǿŜ№Ŝ ōdzƛƭű ōŜűǿŜŜƴűƘŜ мфплă Ɩ·ƴŘ мфслă óCƛƎdz№Ŝ оπфύᵠᵛᶜ Ɩ ƻǿŜØŜ№Σ ǿƛűƘ №ƻdzűƛƴŜ ƳƖ·ƛƴűŜƴƖ·ƴŎŜ Ɩ·ƴŘ №ŜŦdz№ōƛăƘƳŜƴű ƻŦ űdz№ōƛƴŜă Ɩ·ƴŘ ŜƭŜŎűŃƛŎƖ·ƭ ŜƖjdzƛLJƳŜƴűΣ űƘŜ ŜȄLJŜŎűŜŘ ƭƛŦŜ ƻŦ Ɩ· ƘȅŘ№ƻLJƻǿŜ№ ŦƖ·Ŏƛƭƛűȅ ƛă ƭƛʅŜƭȅ űƻ ōŜ млл ȅŜƖ·№ă ƻ№ Ƴƻ№Ŝᵠ

Figure 3-9. Age Profile of U.S. Hydropower Generation Fleet, 2014[87]



About half the U.S. hydroelectric fleet is over 50 years old. Many large dams were built between the 1940s and 1960s.

¢KŜℕŜ KI·ă ōŜŜy˙I· ℕŜyŜøŜŘ λyűŜℕŜăű λy˙úKŜ ŦfŜÈλōλfλűè ōŜyŜŦλűă úKI·ú Y˙I·yê KèŘℕ2LJ2øŜℕ LJℕ2ȼŜŎűă ŎI·y˙2ŦŦŜℕ úKŜ ƎℕλŘΣ ƎλØŜy˙úKŜ Ǝℕ2øúK λy˙ØI·ℕλI·ōfŜ ℕŜyŜøI·ōfŜ ă2dzℕÔŜăΣ ŜăLJŜŎλI·ffè øλyŘφ ! ℕŜŎŜyű ℕŜLJ2ℕű y2ûŜă ûKI·ú I·ō2dzű KI·fŦ 2Ŧ I·ff λyăúI·ffŜŘ KèŘℕ2LJ2øŜℕ ŎI·LJI·Ŏλûè óoφ D ² ú KI·ă KλƎK ŦfŜÈλōλfλűè LJ2ûŜyűλI·f I·yŘ Ŏ2dztŘ LJfI·è I·y˙λY˙LJ2ℕúI·yű ℕ2fŜ λy˙f2øπÕ2ăű λyűŜƎℕI·úλ2y˙2Ŧ ØI·ℕλI·ōfŜ ℕŜyŜøI·ōfŜ ƎŜyŜℕI·ú2ℕăφʸʸ t dzY˙LJŜŘ KèŘℕ2LJ2øŜℕ ăű2ℕI·ƎŜ ŎI·y˙ōŜ dzăŜŘ λy˙LJŜI·˺λyƎ I·yŘ ōI·fI·yŎλyƎ I·LJLJfλŎI·úλ2yã ú2 Y˙I·λyűI·λy˙ƎℕλŘ ℕŜfλI·ōλfλűè I·yŘ ŎI·y˙LJfI·è I· ōI·fI·yŎλyƎ ℕ2fŜ λy˙I·ℕŜI·ă øλúK KλƎK LJŜyŜűℕI·úλ2yã 2Ŧ ±9wăφ

[I·ℕƎŜπăŎI·fŜ KèŘℕ2LJ2øŜℕ LJℕ2ȼŜŎűă I·ℕŜ 2Ŧ úŜy˙ŘλŦŦλÕdztű ú2 ŦλyI·yŎŜ ŘdzŜ û2 KλƎK ŎI·LJλúI·f Ŏ2ăúăΣ fŜyƎúKè LJŜℕY˙λúúλyƎ LJŜℕλ2ŘăΣ I·yŘ ŜyØλℕ2yY˙Syűl·f Ŏ2yŎŜℕyãφ ² KλfŜ úKŜ LJℕ2ăLJŜŎűă Ŧ2ℕ ōdzλfŘλyƎ ØŜℕè fI·ℕƎŜΣ yŜø ŘI·Y˙ă I·ℕŜ f2øΣ úKŜℕŜ I·ℕŜ 2úKŜℕ 2LJLJ2ℕúdzyλúλŜă Ŧ2ℕ KèŘℕ2LJ2øŜℕ û2 ŜÈLJI·yŘ λy˙ úKŜ ¦φ{φ ƎŜyŜℕI·úλ2y˙ LJ2ℕúŦ2fλ2φ ¦LJƎℕI·ŘλyƎ ŜIjdzλLJY˙Syű I·ú ŜÈλăúλyƎ ăλúŜă û2 ŜÈLJI·yŘ ŎI·LJI·Ŏλúè λă fλ˺ŜfèûŜ û2 Ŏ2yűλyűzŜΣ I·yŘ LJℕ2ȼŜŎűă I·ú ŎdzℕℕŜyűfè y2yLJ2øŜℕŜŘ ŘI·Y˙ ăλúŜă Ŏ2dztŘ Ŏ2yűλyűzŜ û2 I·ŘØI·yŎŜφ a 2ŘŜℕy˙f2øπλY˙LJI·ŎûΣ ŜyØλℕ2yY˙Syűl·ffè ădzăúI·λyI·ōfŜ úŜŎKy2f2ƎλŜăΣ ădzŎK I·ă øI·úŜℕπŜŦŦλŎλŜyű I·yŘ “ŦλăKπŦℕλŜyŘfè” údzℕōλySăΣ 2ℕ ℕdzyπ2ŦπℕλØŜℕ I·LJLJℕ2I·ŎKŜă KI·ØŜ úKŜ LJ2ûŜyűλI·f û2 λyŎℕŜI·ăŜ KèŘℕ2LJ2øŜℕ ƎŜyŜℕI·úλ2yφ {dzŎK dzLJƎℕI·ŘŜă I·yŘ 2LJúλY˙λÎI·úλ2y˙Ŧ2ℕ ŜÈλăúλyƎ KèŘℕ2LJ2øŜℕ Ŧ I·ŎλfλúλŜă Ŏ2dztŘ LJℕ2ØλŘŜ I·y˙I·ŘŘλúλ2yI·f pφc D ² yI·úλ2yI·ffèΣ I·fűK2dzƎK λyŘλØλŘdzI·f Ŧ I·ŎλfλúλŜă KI·ØŜ ăŜŜy˙ƎŜyŜℕI·úλ2y˙λyŎℕŜI·ăŜă 2Ŧ op LJŜℕŎŜyű øλúK λyØŜăúY˙Syű LJI·èōI·Ŏ˺ LJŜℕλ2Řă dzyŘŜℕ н èŜI·ℕăφʸφ {úλfféΣ úKŜ I·Y˙2dzyű 2Ŧ ySø KèŘℕ2LJ2øŜℕ ŎI·LJI·ŎλûèφúKI·ú λă ŜÈLJŜŎúŜŘ û2 Ŏ2Y˙Ŝ 2yfλyŜ 2ØŜℕ úKŜ ySI·ℕ û2 Y˙λŘπûŜℕY˙ λă ℕŜfI·úλØŜfè Y˙2ŘŜăű øKŜy˙Ŏ2Y˙LJI·ℕŜŘ û2 øλyŘ I·yŘ ă2fI·ℕφ

hØŜℕ úKŜ ySÈű мл èŜI·ℕăΣ ŜÈλăúλyƎ C9w/ fλŎŜyãŜă øλfff ŜÈLJλℕŜ Ŧ2ℕ ySI·ℕfè нрл KèŘℕ2LJ2øŜℕ LJℕ2ȼŜŎűăφ ¢KŜăŜ ŜÈLJλℕλyƎ Ŧ I·ŎλfλúλŜă ú2ûI·f Y˙2ℕŜ ûKI·y˙мсΣллл a ² Σ 2ℕ ySI·ℕfè нл LJŜℕŎŜyű 2Ŧ úKŜ ŜÈλăúλyƎ λyăúI·ffŜŘ ŎI·LJI·Ŏλúèφ Lú úI·˺Ŝă I·y˙I·ØŜℕI·ƎŜ 2Ŧ p ú2 y èŜI·ℕă ú2 ℕŜfλŎŜyãŜ I·y˙ŜÈλăúλyƎ KèŘℕ2 LJℕ2ȼŜŎűΣ øλúK I·ú fŜI·ăű o èŜI·ℕă 2Ŧ LJℕŜπŦλfλyƎ I·ŎûλØλûè I·yŘ úKŜy˙I·ú fŜI·ăű I·y2úKŜℕ н èŜI·ℕă I·ŦúŜℕ úKŜ I·LJLJfλŎI·úλ2y˙ăă ŦλfŜŘφ hyfè нΣмфy ŘI·Y˙ă I·ℕŜ ŎdzℕℕŜyűfè dzăŜŘ

ŦƧNJ KèŘNJ2ŜfŜŎúNJλŎλúè—o LJŜNJŎŜyű 2Ŧ űKŜ bation's total dams. (Other uses for dams include navigation, flood Ŏ2yűNJ2fΣ λNJNJλƎI·ûλ2yΣ I·yŘ NJŜŎNJŜI·ûλ2y℅ú !ŘŘλyƎ KèŘNJ2ŜfŜŎúNJλŎλúè ú2 űKŜăŜ LJNJŜŜÈλăûλyƎ ŘI·Y·ă ø2dzfŘ λyŎNJŜI·ăŜ KèŘNJ2 ƎŜySNJI·ûλ2y´ōè mp LJŜNJŎŜyűΣ I·yŘ űKŜăŜ LJNJŜŜÈλăûλyƎ ŘI·Y·ă Y´I·è yƵű ŦI·ŎŜ I·ă Y´I·yê ăλûλyƎ Ŏ2yűNJI·λyűă ōŜŎI·dzăŜ ă2Y´Ŝ 2Ŧ űKŜ ŜyØλNJ2yYˆŜyűI·f λY´LJI·Ŏúă ŦNJ2Y´ ŘI·Y´ Ŏ2yűúNJdzŎúλ2y´KI·ØŜ I·tNJŜI·Ře ōŜŜy´λyŎdzNJNJŜŘ℗ {dzŎK I·ŘŘλúλ2yűΣ Ŏ2Y´ōλySŘ øλúK űKŜ I·ōλfλúè ú2 fŜØŜNJI·ƎŜ I·yŘ dzLJƎNJI·ŘŜ ŜÈλăûλyƎ λyŦNJI·ăúNJdzŎúdzNJŜ I·ű yƵyŦLJ2ø$NJŜŘ ŘI·Y´ăΣ øKλŎK ø2dzfŘ λyŎNJŜI·ăŜ KèŘNJ2 ƎŜySNJI·ûλ2y´øè y ű2 мл LJŜNJŎŜyűΣ LJNJ2ØλŘŜ ăλƎyŦŦλŎI·yű 2LJLJ2NJúdzyλúλŜă ú2 λyŎNJŜI·ăŜ KèŘNJ2LJ2øŜNJ ƎŜySNJI·ûλ2y´øKλfŜ NJŜŘdzŎλyƎ Ŏ2ăúă I·yŘ ŜyØλNJ2yYˆŜyűI·f λY´LJI·Ŏúă℗ⁿ

3.2.2.5 Biomass: Net-Zero Carbon Renewable Baseload and Flexibility Resource

.λ2Y´I·ăă ŦdzŜfă λyŎfdzŘŜ I· ōNJ2I·Ř NJI·yƎŜ 2Ŧ ă2dzNJŎŜăΣ λyŎfdzŘλyƎ ø22Ř I·yŘ ø22ŘπŘŜNJλØŜŘ ŦdzŜfăΣ ōfI·Ŏ⌊ fλljdz2NJ óLJNJλY´I·NJλfê LJdzfLJ NJŜăλŘdzI·fă λy´úKŜ LJI·LJŜNJ LJNJ2ŘdzŎúλ2y´LJNJ2ŎŜăăúΣ Y´dzyλŎλLJI·f ă2fλŘ ø I·ăúŜă fI·yŘŦλff ƎI·ăΣ I·yŘ 2úKŜNJă℗ LŦ úKŜ ŜY´λăăλ2yă ŦNJ2Y´ Ŏ2Y´ōdzăúλyƎ ōλ2Y´I·ää I·NJŜ ŦdzffÈ 2ŦŦăŜű ōè úKŜ ăŜljdzŜăúNJI·ûλ2y´2Ŧ / $h_н$ I·ă úKŜ ōλ2Y´I·ää λă ƎNJ2øy´ øKŜy´ I·ŎŎ2dzyűλyƎ ŦƧNJ úKŜ ŎI·NJō2y´ Ff2øă λy´ LJNJ2ŘdzŎúλ2y´ I·yŘ LJNJ2ŎŜăăλyƎ 2Ŧ úKŜ ōλ2Y´I·ăăΣ ōλ2Y´I·ää ŜfŜŎúNJλŎλúè ŎI·y´ōŜ I· f2ø$πŎI·NJō2yˆNJŜă2dzNJŎŜ℗ .λ2LJ2øŜNJ LJfI·yűă I·NJŜ úèLJλŎI·ffè ŦdzffÈ ŘλăLJI·úŎKI·ōfŜ I·yŘ I·NJŜ ƎŜySNJI·ffè ŘλăLJI·úŎKŜŘ I·ă ōI·ăŜf2I·Ř ƎŜySNJI·ûλ2y´λŦ ØI·NJλI·ōfŜ I·yŘ ŦdzŜf Ŏ2ăúă I·NJŜ f2ø Ŝy2dzƎK℗ .λ2Y´I·ää ă2dzNJŎŜa ŎI·y´ŜλúKŜNJ ōŜ ŘλNJŜŎűfè Ŏ2Y´ōdzăúŝŘΣ ƎI·ăλŦλŜŘ ú2 LJNJ2ŘdzŎŜ I· ăèyűKŜúλŎ ŦdzŜfΣ 2NJ Ŏ2πŦλNJŜŘ I·ú I· ăY´I·ff I·Y´2dzyű óűèLJλŎI·ffè dzLJ ú2 мл LJŜNJŎŜyű KŜI·ú Ŏ2yűŜyűú øλúK I· Ŏ2yØŜyűλ2yl·f ŦdzŜf ădzŎK I·ă Ŏ2I·f℗ᴹ Ly´ нлмрΣ ŜfŜŎúNJλŎλúè ƎŜySNJI·ûλ2y´ ŦNJ2Y´ ōλ2Y´I·ää I·ŎNJ2ää I·ff ăŜŎú2NJă I·ŎŎ2dzyűŜŘ ŦƧNJ ммo LJŜNJŎŜyű 2Ŧ NJŜySø$I·ōfŜ ŜfŜŎúNJλŎλúè ƎŜySNJI·ûλ2y´I·yŘ мc LJŜNJŎŜyű 2Ŧ ú2úI·f ŜfŜŎúNJλŎλúè ƎŜySNJI·ûλ2y´λy´úKŜ ¦yűŜŘ {úI·úŜă℗ ! ăλƎyλŦλŎI·yű yƵzY´ōŜNJ 2Ŧ ōλ2Y´I·ää ŦI·ŎλfλúλŜă I·NJŜ ăY´I·ff Ŝy2dzƎK úKI·ú úKŜè ŎI·y´ōŜ f2ŎI·úŜŘ yŜI·NJ úKŜλNJ ŦdzŜf ă2dzNJŎŜă℗ !ă ădzŎKΣ yŜI·NJfè KI·fŦ 2Ŧ úKŜ ŜfŜŎúNJλŎλúè ƎŜySNJI·úŜŘ ŦNJ2Y´ ōλ2Y´I·ää λy´нлмр ø I·ú λyŘdzăúNJλI·f ŦI·ŎλfλúλŜă 2dzúăλŘŜ 2Ŧ úKŜ ŜfŜŎúNJλŎ LJ2øŜNJ ăŜŎú2NJΣ ădzŎK I·ă LJdzfLJ I·yŘ LJI·LJŜNJ Y´λffă℗ DŜySNJI·ûλ2y´ŦNJ2Y´ ōλ2Y´I·ää I·ŎNJ2ää I·ff ăŜŎú2NJă ƎNJŜø ŦNJ2Y´ pc ¢ ² K λy´нлмл ú2 cп ¢ ² K λy´нлмрΣ ŘNJλØŜy´LJNJλY´I·NJλfê ŦNJ2Y´ ySø Ŏ·LJI·ŎλúèλyˆădzúKŜNJy´ăúI·ûŜăΣ ădzŎK I·ă ±λNJƎλyλI·Σ Cf2NJλŘI·Σ I·yŘ DŜ2NJƎλI·℗ᴴ

3.2.2.6 Geothermal Generation: Zero-Carbon Baseload and Flexibility Resource

DŜ2úKŜNJY´I·f ƎŜySNJI·ú2NJă I·NJŜ ōI·ăŜf2I·Ř LJfI·yűă ŎI·LJI·ōfŜ 2Ŧ LJNJ2ØλŘλyƎ ØI·fdzI·ōfŜ ăŜNJØλŎŜă ú2 úKŜ ƎNJλŘΣ ădzŎK I·ă ƎŜySNJI·ûλ2y´ŦfŜÈλōλfλúè℗ tNJλ2NJ ú2 мфулΣ ƎŜ2úKŜNJY´I·f ƎŜySNJI·ûλ2y´NJŜY´I·λySŘ ōŜf2ø p ¢ ² K I·yƳdzI·ffè℗ .ŜúøŜŜy´ мфул I·yŘ мфуфΣ ƎŜySNJI·ûλ2y´úNJλLJfŜŘ ú2 мр ¢ ² K I·ă yŜø ŦI·ŎλfλúλŜă ŎI·Y´Ŝ 2yfλySø aдzŎK 2Ŧ úKŜ ŜI·NJfè ƎNJ2øúK λy´ ƎŜ2úKŜNJY´I·f LJ2øŜNJ øI·ă ŘNJØŜy´ōè tdzōfλŎ ¦úλfúè wŜƎdzfI·ú2NJè t2fλŎλŜă !ŎŰ λyŎSyűλØŜăΣ I·fúK2dzƎK úKλă ŘNJØŜNJ KI·ă ŘŜŎfλySŘ 2ØŜNJ úλY´Ŝ I·ă úKŜ I·Ø2λŘŜŘ Ŏ2ăúă 2Ŧ dzúλfλúè ƎŜySNJI·ûλ2y´KI·ØŜ ŦI·ffŜy℗ !ă 2Ŧ нлмрΣ ƎŜ2úKŜNJY´I·f LJ2øŜNJ Ŏ2yűλydzŜă ú2 ƎSyŜNJI·úŜ NJ2dzƎKfè мр ¢ ² K 2Ŧ ŜfŜŎúNJλŎλúè I·yƳdzI·ffèΣ 2NJ NJ2dzƎKfè л℗п LJŜNJŎŜyű 2Ŧ ú2úI·f ¦℗{℗ ŜfŜŎúNJλŎλúè ƎŜySNJI·ûλ2y℗℗ΟΣ ℗п /KI·ffŜyƎŜă λy´ ŜÈLJf2NJλyƎ ySø “ōfλyŘ” KèŘNJ2úKŜNJY´I·f NJŜă2dzNJŎŜă I·yŘ f2yƎ ŘNJλffλyƎ ûλY´Ŝă Ŧ2NJ LJNJ2ŘdzŎűλ2y´øŜftă KI·ØŜ fŜŘ ú2 λyŎNJŜI·ăŜŘ dzyŎŜNJúI·λyúè Ŧ2NJ λyØŜăú2NJă λyˆfI·NJƎŜ ƎŜ2úKŜNJY´I·f LJNJ2ŝŜŎúă℗ !ŘŘûλ2yl·ffèΣ úI·È ŎNJŜŘλúă úKI·ú I·NJŜ 2yfè ŜÈúŜyŘŜŘ Ŧ2NJ ăK2NJú LJŜNJă2Ră 2Ŧ ûλY´Ŝ Ř2 y2ű ûI·⌈Ŝ λyú2 I·ŎŎ2dzyű úKŜ f2yƎ fŜI·Ř ûλY´Ŝ 2Ŧ ƎŜ2úKŜNJY´I·f LJNJ2ŝŜŎű ŘŜØŜf2LJY´Syű ăŎI·NJŎλúè 2Ŧ LJ2øŜNJ LJdzNJŎKI·ăŜ I·ƎNJŜŜY´Syű 2LJLJ2NJúdzyλúλŜăΣ 2NJ ySŜŘ Ŧ2NJ úNJI·yăY´λăăλ2yˆλyŦNJI·ăúNJdzŎúdzNJŜ℗ /dzNJNJŜyű I·yŎλffI·Nè ăŜNJØλŎŜ Ŏ2Y´LJŜyăI·ûλ2y´Y´2ŘŜfă λyˆI·NJŜI·ă øλúK Y´2ăű ƎŜ2úKŜNJY´I·f ŘŜØŜf2LJY´Syű Ř2 y2ű LJNJ2ØλŘŜ ădzŦŦλŎλŜyű NJŜØŜyƵzŜ ú2 øI·NJNJI·yű úKŜ λyŎNJŜI·ăŜŘ 2LJŜNJI·ûλ2yl·f I·yŘ Ŏ2yűNJ2f NJŜúNJ2ŦλúûλyƎ ŜÈLJŜyăŜă℗ LŦ I·LJLJN2LJNJλI·ûŜfè ØI·fdzŜŘΣ úKŜ ăŜNJØλŎŜă I· ƎŜ2úKŜNJY´I·f LJfI·yű ŎI·y´ LJNJ2ØλŘŜ λyŎfdzŘŜ NJŜƎdzfI·ûλ2yΣ f2I·Ř Ŧ2ff2øλyƎΣ ăLJλyƴλyƎ NJŜăŜNJØŜăΣ y2yăLJλyƴλyƎ NJŜăŜNJØŜΣ I·yŘ NJŜLJfI·ŎŜY´Syű 2NJ ădzLJLJfŜY´Syű I·f NJŜăŜNJØŜ℗ᶠᵖ

3.2.2.7 Nuclear Generation: Zero-Carbon Baseload

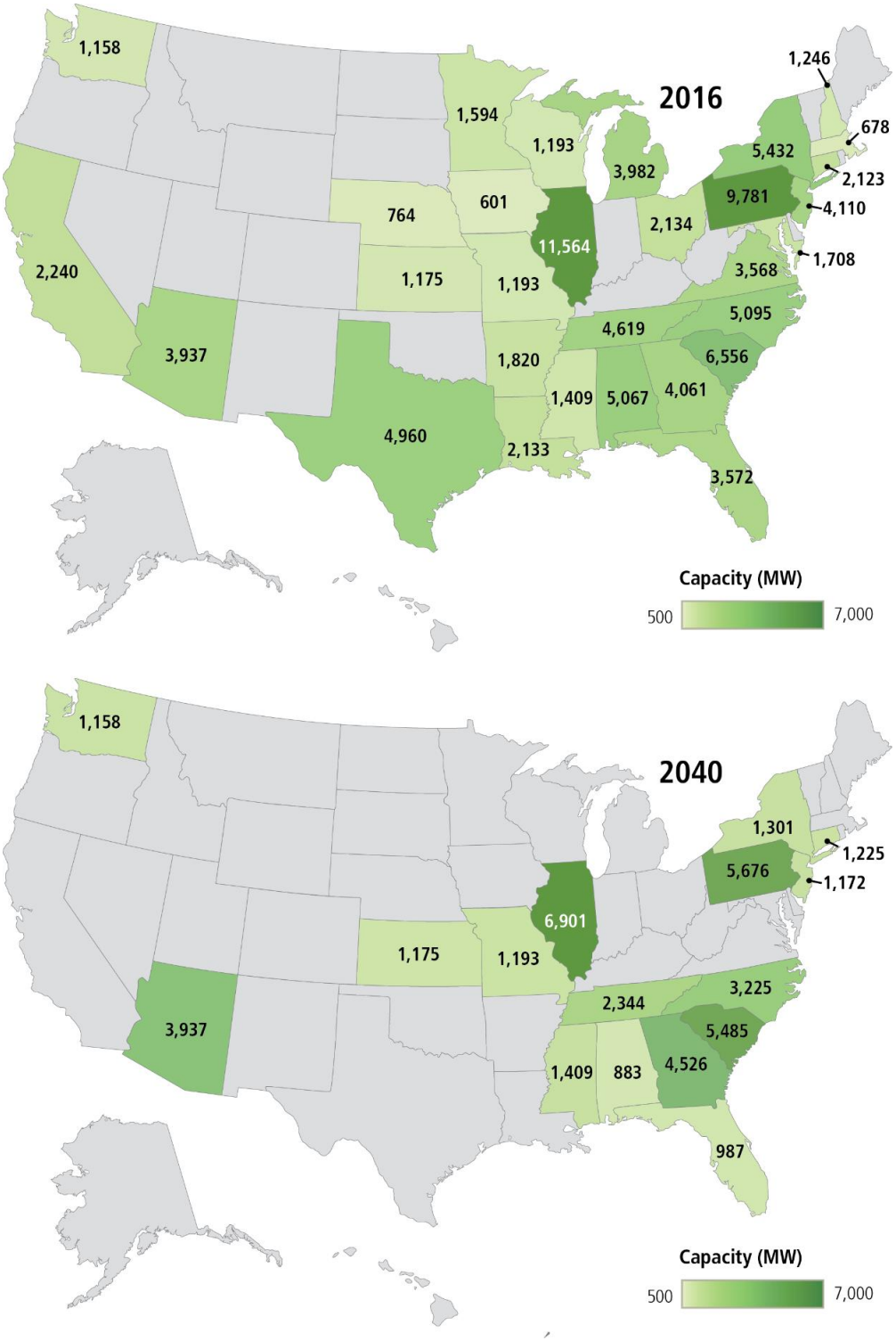
bdzŎfŜI·NJ ƎŜySNJI·ûλ2y´Ŏ2Y´LJNJăŜă cл LJŜNJŎŜyű 2Ŧ úKŜ Nation's ŎdzNJNJŜyű ÎŜNJ2πŎI·NJō2y´ƎŜySNJI·ûλ2y℗ᶠᵒᶜ ¢KŜ ŎdzNJNJŜyű 2LJŜNJI·ûλyƎ yƵzŎfŜI·NJ LJ2øŜNJ ŦfŜŜú óф℗ NJŜI·Ŏű2NJăú Ŏ2yăλăûă 2Ŧ I·LJLJN2ÈλY´I·ûŜfè pn D ² 2Ŧ ƎŜySNJI·ûλyƎ ŎI·LJI·ŎλúèλyˆNJŜădzfI·ûŜŘ Y´I·NJ⌈Ŝûă I·yŘ пр D ² λy´NJŜăúNJdzŎúdzNJŜŘ ŜfŜŎúNJλŎλúè Y´I·NJ⌈Ŝûă℗ᶠᵀ hŦ úKŜ ф℗ 2LJŜNJI·ûλyƎ yƵzŎfŜI·NJ NJŜI·Ŏű2NJă λy´úKŜ ¦yλûŜŘ {úI·úŜăΣ ă2 ŦI·NJΣ ул KI·ØŜ ōŜŜy´I·LJLJN2ØŜŘ ú2 óI·yŘ LJfI·y´ú2ú 2LJŜNJI·ûŜ Ŧ2NJ cл èŜI·NJăΣ ØKλfŜ I·y2úKŜNJ ф

ŎdzNJNJŜyűfȅ KI·ØŜ I·LJLJfλŎI·ű̂λ2yã dzyŘŜNJ NJŜØλŜǿϕ[фуf] ¢KŜ ű̂λΥŜfλyŜ ŦƧNJ ű̂KŜăŜ dzyλű̂ă ű̂2 NJŜI·ŎK ű̂KŜ ŜyŘ 2Ŧ ű̂KŜλNJ слπȅŜI·NJ fλŎŜyãŜ λă I·ă Ŧ2ff2ǿăY c dzyλű̂ă ōŜű́ǿŜŜyˆнлнф–нлолT нт dzyλű̂ă ōŜű́ǿŜŜyˆнлом–нлорT мр dzyλű̂ă ōŜű́ǿŜŜyˆнлос–нлплT нл dzyλű̂ă ōŜű́ǿŜŜyˆнлпм–нлпрT I·yŘ мн dzyλű̂ă ōŜű́ǿŜŜyˆнлпс–нлрлϕ[фф] C2NJű̂ȅπŜλƎKű dzyλű̂ă ǿλff NJŜI·ŎK ű̂KŜ ŜyŘ 2Ŧ ű̂KŜλNJ fλŎŜyãŜŘ fλŦŜű̂λΥŜ ōȅ нлплΣ ű̂KŜ ű̂λΥŜŦNJI·ΥŜ Ŏ2ØŜNJŜŘ ōȅ v9w мϕнϕ óCλƎdzNJŜ oπмлύ[ΥΣ млл] [2] λű̂K2dzű̂ NJŜyŜǿI·fă ű̂2 ул ȅŜI·NJăΣ ű̂KŜNJŜ ǿλff ōŜ I· ăλƎyλŦλŎI·yű̂ f2ăă 2Ŧ ÎŜNJ2πŎI·NJō2yˆƎŜyŜNJI·ű̂λ2yˆăű̂I·NJű̂λyƎ λyˆű̂KŜ нлолăϕ !fă2Σ λŦ ű̂KŜăŜ LJfI·yű̂ă ǿŜNJŜ ű̂2 I·ff NJŜIjdzŜăű̂ I· fλŎŜyãŜ NJŜyŜǿI·f ű̂2 ул ȅŜI·NJăΣ λű̂ ǿ2dzfŘ NJŜLJNJŜăŜyű̂ I· ăλƎyλŦλŎI·yű̂ I·ŘŘλű̂λ2yI·f ǿ2NJ⌊f2I·Ř Ŧ2NJ bw/ ăű̂I·ŦŦ I·yŘ Ŏ2ΥΥλăăλ2yŜNJăϕ ¢ǿ2 LJfI·yű̂ăΣ {dzNJNJȅ t2ǿŜNJ {ű̂I·ű̂λ2yˆI·yŘ tŜI·ŎK .2ű̂ű̂2Υ bdzŎfŜI·NJ DŜyŜNJI·ű̂λyƎ {ű̂I·ű̂λ2yΣ KI·ØŜ I·yy2dzyŎŜŘ λyű̂Ŝyű̂λ2yã ű̂2 ăŜŜ⌊ ădzōăŜIjdzŜyű̂ fλŎŜyãŜ NJŜyŜǿI·făΣ I·yŘ 2ű̂KŜNJă I·NJŜ I·fă2 ŜȀLJŜŎű̂ŜŘ ű̂2 Ř2 ă2ϕ

[f] 5λI·ōf2 / I·yȅ2yˆм I·yŘ н I·NJŜ dzyŘŜNJ NJŜØλŜǿΣ ōdzű̂ tDϧ9 KI·ă I·yy2dzyŎŜŘ λű̂ ǿλff ǿλű̂KŘNJI·ǿ ű̂KŜ I·LJLJfλŎI·ű̂λ2yˆ

[Υ] ¢KŜăŜ I·NJŜ ű̂KŜ ŜyŘ ŘI·ű̂Ŝă ǿλű̂K ŦλNJăű̂ fλŎŜyãŜ NJŜyŜǿI·fϕ

Figure 3-10. Current and Projected Nuclear Capacity Assuming No Subsequent License Renewals[101, 102]



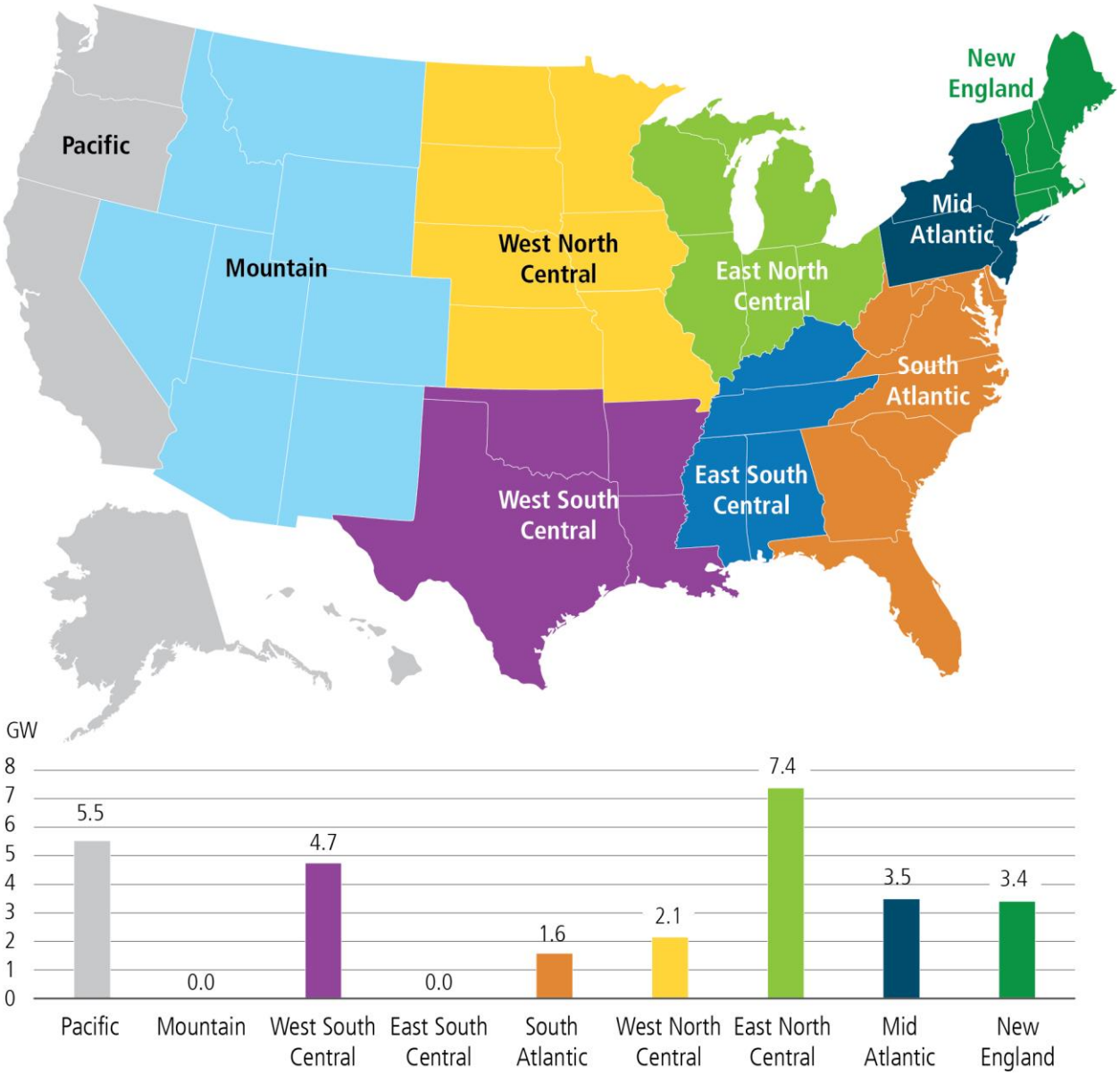
The top map in the figure shows U.S. nuclear power capacity (in MW) by state in 2016 (as of December 15, 2016). The bottom map shows what the U.S. nuclear power capacity by state would be in 2040 (December 31, 2040), assuming that all reactors, except those that have already specified closure dates, shut down at the expiration of their currently approved licenses.

² KλfŜ ŜăΰλϒI·ΰŜă 2₮ ΰKŜ ΰ2ΰI·f I·Ϋ2dzyΰ 2₮ I·ΰπ₪λă ŏI·LJI·ŏλΰè ØI·₪èΣ 2yŜ ₪ŜŏŜyΰ I·yI·fèăλă ădzƎƎŜăΰă ΰKI·ΰ ΰKŜ ŏI·LJI·ŏλΰè 2₮ ₪ŜΰΛ₪ŜŘ 2₪ I·ΰπ₪λă ϒ yΘzŏ₮ŜI·₪ LJ2ØŜ₪ LJfI·yΰă ōè нлол λă I·ō2dzΰ ну D ² Σ I· fΛΰΰfŜ 2ØŜ₪ 2yŜπIjdzI·₪ΰŜ₪ 2₮ ¦Φ{ yΘzŏ₮ŜI·₪ LJfI·yΰ ŏI·LJI·ŏλΰèT I·ΰπ₪λă ϒ LJfI·yΰ ŏI·LJI·ŏλΰè ØI·₪λŜă ōè ₪ŜƎλ2yΣ ØλΰK ΰKŜ 9I·ăΰ b2₪ΰK /Ŝyΰ₪I·f Ϋ2ăΰ I·₮₮ŜŏΰŜŘ óCλƎdz₪Ŝ oπ ммύΦмло {ŜØŜ₪I·f yΘzŏfŜI·₪ LJ2ØŜ₪ LJfI·yΰăΣ LJI·₪ΰλŏdzfI·₪fè ΰK2ăŜ ØλΰK ăλyƎtŜ dzyΛΰăΣ ₮I·ŏŜ fI·₪ƎŜ ₪Ŝŏdz₪₪λyƎ ₮λÈŜŘ Ŏ2ăΰăΦ {2ϒŜ 2₮ ΰKŜăŜ Ŏ2ăΰă I·₪Ŝ ŘdzŜ ΰ2 LJ2ăΰπCdzϒdzăKλϒI· ₪ŜIjdzλ₪ŜϒŜyΰăΣ ōdzΰ ϒI·yÈ I·₪Ŝ ăλϒLJfè ΰKŜ Ŏ2ăΰă 2₮ 2LJŜ₪I·ΰλ2yΣ ădzŏK I·ă ăŜŏdz₪λΰèΣ ăI·fI·₪λŜăΣ ŜΰŏΦ {ŜØŜ₪I·f LJfI·yΰă KI·ØŜ I·fă2 ySŜŘŜŘ fI·₪ƎŜ ŏI·LJλΰI·f ŜÈLJŜyŘλΰdz₪ŜăT ₮I·ŏŜŘ ØλΰK ΰKŜăŜ ăλƎyλ₮λŏI·yΰ Ŏ2ăΰăΣ LJfI·yΰ 2LJŜ₪I·ΰ2₪ăk2ØyŜ₪ă KI·ØŜ ŏK2ăŜyΰ2 ăKdzΰ ΰKŜϒ Ř2ØyΦ {λyŏŜ нлмнΣ ØKŜyϒмлп ₪ŜI·ŏΰ2₪ă ØŜ₪Ŝ 2LJŜ₪I·ΰλyƎΣ ăλÈ dzyΛΰă ΰ2ΰI·fλyƎ пΦт D ² KI·ØŜ ăKdzΰ Ř2Øyϒ ŜI·₪fλŜ₪ ΰKI·yϒ ΰKŜλ₪ fλŏŜyăŜŘ fλ₮ŜΰλϒŜΦ ¢Ø2 ₪ŜΰΛ₪ŜϒŜyΰăΣ {I·yϒhy2₮₪Ŝ I·yŘ /₪ëăΰI·f wλØŜ₪Σ KI·ØŜ ōŜŜyŘ₪λØŜyϒōè ϒŜŏKI·yλŏI·f ₮I·λfdz₪Ŝă ΰKI·ΰ ØŜ₪Ŝ ŘŜŜϒŜŘ ΰ22 Ŏ2ăΰfè ΰ2 ₪ŜLJI·Λ₪T ΰKŜ 2ΰKŜ₪ă ØŜ₪Ŝ ϒI·₪ŝΰ ŘŜŏλăλ2yãΦ ! ă 2₮ 5ŜŏŜϒōŜ₪ нлмсΣ ΰŜyϒ2ΰKŜ₪ dzyΛΰă ΰ2ΰI·fλyƎ yΦc D ² 2₮ ŏI·LJI·ŏλΰè KI·ØŜ I·yŷ2dzyŏŜŘ LJfI·yã ΰ2 Ŏf2ăŜ λyϒΰKŜ ySÈΰ ŘŜŏI·ŘŜ óΰK2dzƎK ăλÈ 2₮ ΰKŜăŜ dzyΛΰă ϒI·è y2ΰ Ŏf2ăŜ ōŜŏI·dzăŜ 2₮ ₪ŜŏŜyΰ ăΰI·ΰŜ I·ŏΰλ2yãΰT ŜλƎKΰ 2₮ ΰK2ăŜ Ŏf2ădz₪ŜăΣ ØλΰK ΰKŜ ŜÈŏŜLJΰλ2yϒ2₮ ΰØ2 dzyΛΰă I·ΰ 5λI·ōf2 /I·yê2yΣ would occur prior to the expiration of the unit's existing licenses. {ŜØŜyϒ2₮ ΰKŜ I·yŷ2dzyŏŜŘ ₪ŜΰΛ₪ŜϒŜyΰăΣ I·ff ΰK2ăŜ ŜÈŏŜLJΰ hëăΰŜ₪ /₪ŜŜ] I·yŘ 5λI·ōf2 /I·yê2yΣ ØŜ₪Ŝ I·ΰΰ₪λōdzΰŜŘ ΰ2 ϒI·₪]Sΰ Ŏ2yŘλΰλ2yãΦ

Lyϒ I·ŘŘλΰλ2yϒ ΰ2 LJfI·yΰă ØλΰK KλƎK ₪Ŝŏdz₪₪λyƎ ₮λÈŜŘ Ŏ2ăΰăΣ LJ2ăΰπCdz]dzăKλϒI·Σ ϒI·₪]Sΰ ăΰ₪dzŏΰdz₪ŜăKI·ØŜ KI·Ř ăλƎyλ₮λŏI·yΰ λϒLJI·ŏΰă 2yϒΰKŜ Ŝŏŏyŏ2ϒλŏă 2₮ yΘzŏ₮ŜI·₪ ƎŜySŜ₪I·ΰλ2yΦ Lyϒăΰ I·ΰŜă ØλΰK ₪ŜăΰΛ₪dzŏΰdz₪ŜŘ ŜtŜŏΰΛ₪ΛŏλΰèϒI·₪]SΰăΣ yΘzŏ₮ŜI·₪ 2LJŜ₪I·ΰ2rs have found it to be increasingly difficult to compete under today's market conditions ØKŜ₪Ŝ ŜtŜŏΰΛ₪ΛŏλΰèŘŜϒI·yŘ ăă ₮fI·ΰ 2₪ ŘŜŏfλyλyƎΣ yI·ΰdz₪I·f ƎI·ă LJ₪ΛŏŜă I·yŘ ŏI·LJλΰI·f Ŏ2ăΰă ₮2₪ ySØ ƎŜySŜ₪I·ΰλ2yϒI·₪Ŝ f2ØΣ ØλyŘ I·yŘ ă2fI·₪ Ŏ2ăΰă I·₪Ŝ ŘŜŏfλyλyƎ I·yŘ ăΰI·ΰŜ LJ2fλŏλŜă ₮I·Ø2₪ ₪ŜySØI·ōfŜ ƎŜySŜ₪I·ΰλ2yΦ ¢KŜ₪Ŝ I·₪Ŝ K2ØŜØŜ₪Σ ySØ yΘzŏfŜI·₪ ₪ŜI·ŏΰ2₪ă dzyŘŜ₪ Ŏ2yăΰ₪dzŏΰλ2yϒλyϒØŜ₪ΰλŏI·ffè λyΰŜƎ₪I·ΰŜŘ ϒI·₪]Sΰă ² I·ΰΰă . I·₪ н ŜyΰŜ₪ŜŘ ăŜ₪ØλŏŜ λyϒ ¢ŜyŷŜăăŜŜ λyϒнлмсΣ I·yŘ ₮2dz₪ I·ŘŘλΰλ2yl·f ₪ŜI·ŏΰ2₪ă I·₪Ŝ dzyŘŜ₪ Ŏ2yăΰ₪dzŏΰλ2yϒλyϒDŜ2₪ƎλI· I·yŘ {2dzΰK /I·₪2fλyl· ΰKI·ΰ I·₪Ŝ LJ₪Ø2ŜŏΰŜŘ ΰ2 ŜyΰŜ₪ Ŏ2ϒϒŜ₪ŏλI·f ƎLJŜ₪I·ΰλ2yϒλyϒΰKŜ нлмф–нлнл ΰλϒŜ₮₪I·ϒŜΦ

LyϒнлмсΣ ΰØ2 ăΰI·ΰŜăΣ LfλyØ2λă I·yŘ bŜØ ¸2₪] LJdzΰ LJ2fλŏλŜă λyϒLJfI·ŏŜ ΰ2 λyŏŜyΰλØλÎŜ ΰKŜ Ŏ2yΰλyΘzŜŘ ƎLJŜ₪I·ΰλ2yϒ2₮ yΘzŏ₮ŜI·₪ LJfI·yΰăΦ ¢KŜ bŜØ ¸2₪] tdzōfλŏ {Ŝ₪ØλŏŜ /2ϒϒλăăλ2yϒ₮λyl·fλÎŜŘ λΰă /fŜI·yϒ 9ySƎè {ΰI·yŘI·₪Ř ó/9{ú 2yϒ !dzƎdzăΰ мΣ нлмсΣ ØKλŏK Ŏ2yΰI·λyã I· рл LJŜ₪ŏŜyΰ ₪SyŜØI·ōfŜ ΰI·₪ƎŜΰ ōè нлолΣ I·f2yƎ ØλΰK ÎŜ₪2πSϒλăăλ2yϒŏ₪ŜŘΛΰă ó½9/ăú ₮2₪ yΘzŏ₮ŜI·₪ LJfI·yΰăΦ ¢KŜ Ƒ2I·f 2₮ ΰKŜ ½9/ LJ2fλŏè λă ΰ2 LJ₪2ØλŘŜ ₪ŜØŜyΘzŜ ădzLJLJ2₪ΰ ₮2₪ ΰK₪ŜŜ LJfI·yΰă ΰKI·ΰ KI·Ř ōŜŜyϒI·ΰ ₪λă] ₮2₪ LJ₪ŜϒI·ΰdz₪Ŝ ₪ŜΰΛ₪ŜϒŜyΰϒ DλyŷI·Σ bλyŜ aλfŜΣ I·yŘ CΛΰÎtI·ΰ₪λŏ]Φ !ŏŏ2₪ŘλyƎ ΰ2 I·yI·fèăλă ₮₪2Ϋ ¦.{Σ ΰKŜ ½9/ LJ2fλŏè Ø2dzfŘ ŜăăŜyΰλI·ffè Ƒdz I·₪I·yΰŜŜ ₪ŜØŜyΘzŜπLJ2ăΛΰλØŜ 2LJŜ₪I·ΰλ2yã ₮2₪ ΰKŜ ΰK₪ŜŜ LJfI·yΰă ΰK₪2dzƎK I· ăΰI·ōfŜ fŜØŜf 2₮ ŏ2ϒLJŜyãI·ΰλ2yΦмлп LfλyŷλăI·₪ ăλϒλfI·₪ LJ2fλŏè I·ă LJI·₪ΰ 2₮ ŏ2ϒLJ₪ŜKŜyãλØŜ ŜyŜ₪Ƒè fSƎλătI·ΰλ2yϒλyϒ5ŜŏŜϒōŜ₪ нлмсΦ !fă2Σ ΰKŜ {ŜŏΛ₪ŜΰI·₪è 2₮ 9yŜ₪Ƒè's !ŘØλă2₪è .2I·₪Ř ¢I·ă] C2₪ŏŜ 2yϒbdzŏ₮ŜI·₪ 9yŜ₪Ƒè λăădzŜŘ I· ₪ŜLJ2₪ΰ ŘŜăŏ₪λōλyƎ λyΰΛI·ΰΛØŜă ΰKI·ΰ ØdzfŘ fŜI·Ř ΰ2 I· ăλƎyλ₮λŏI·yΰ ŘŜLJf2èϒŜyΰ 2₮ yΘzŏfŜI·₪ LJ2ØŜ₪ λyϒнлол–нлрл ΰλϒŜ₮₪I·ϒŜΦ Lΰ 2dzΰfλySă LJ₪2Ƒ₪I·Ϋă I·yŘ Ŝ₮₮2₪ΰă ₮2₪ ō2ΰK yŜØ I·yŘ ŜÈλăΰλyƎ yΘzŏfŜI·₪ LJ2ØŜ₪ I·yŘ I·fă2 I·ŘØI·yŏŜŘ ₪ŜI·ŏΰ2₪ ΰŜŏKy2f2ƎλŜă ΰKI·ΰ I·₪Ŝ y2ΰ ōI·ăŜŘ 2yϒΰ₪I·ŘΛΰλ2yl·f fλƎKΰπØI·ΰŜ₪ ₪ŜI·ŏΰ2₪ ŘŜăλƎyãΦмлр

Figure 3-11. Nuclear Units at Risk or Recently Retired by Census Region[106]



Across the country, over 28 GW of nuclear generating capacity is at risk or recently retired, most of which is in the East North Central region.

! ă yƵűŜŘΣ yƵzŎfŜIꞏNJ ƎŜySŜNJIꞏúλ2yˇλă c£ƒ̂ː 2Ŧ ÎŜN2πŎIꞏNJō2yˇLJ2ǿŜN ƎŜySŜNJIꞏúλ2yˇλyˇűKŜ ¦φ{φ Lű λă λYˇLJ2NJűIꞏyű ű2 ǿŜλƎK űKŜ Ŏ2ăűă 2Ŧ yƵzŎfŜIꞏNJ ƎŜySŜNJIꞏúλ2yˇŎ2YˇLJIꞏNJŜŘ ű2 2úKŜN ÎŜN2 ŎIꞏNJō2yˇƎŜySŜNJIꞏúλ2yˇIꞏyŘ ű2 f2ǿπŎIꞏNJō2yˇyIꞏűdzNJIꞏf ƎIꞏă ƎŜySŜNJIꞏúλ2yˇű2 ŘŜűŜNJYˇλyŜ úKŜ NJŜfIꞏűλØŜ ØIꞏftdzŜ 2Ŧ Iꞏúπ№ăⱢ yƵzŎfŜIꞏNJ ƎŜySŜNJIꞏúλ2yˇdzyλűă¢ ! NJŜŎŜyű IꞏyIꞏfèăλă ŠăűλYˇIꞏúŜŘ úKŜ “NJŜØŜyƵzŜ ƎIꞏLJ” – úKŜ Ŏ2ăű 2Ŧ λyŎŜyűλØŜă Ŧ2NJ ⱢŜŜLJλyƎ ŎŜNJűIꞏλyˇyƵzŎfŜIꞏNJ dzyλűă NJdzyŷλyƎ – Ŧ2NJ I· ŘλăŎNJŜűŜ ōdzű NJŜLJNJŠăŜyűIꞏúλØŜ ăŜű 2Ŧ yƵzŎfŜIꞏNJ LJ2ǿŜN ƎŜySŜNJIꞏúλyƎ dzyλűă¢ᴹᴶᵀ 5h9 úKŜyˇIꞏyIꞏfèÎŜŘ úKŜ ŎIꞏNJō2yˇŜYˇλăă2yã ōŜySŦλűă 2Ŧ ⱢŜŜLJλyƎ úKλă ăŜű 2Ŧ LJfIꞏyűă 2LJŜyˇōè dzăλyƎ I· ă2ŎλIꞏf Ŏ2ăű 2Ŧ ŎIꞏNJō2yˇ2Ŧ ÞπмкYˇŜűNJλŎ ű2y¢ ! ăădzYˇλyƎ úKIꞏű Iꞏff ƎŜySŜNJIꞏúλ2yˇ ŦN2Yˇ NJŜúλNJλyƎ yƵzŎfŜIꞏNJ LJfIꞏyűă λyˇ úKλă ŘλăŎNJŜűŜ ăŜű ǿ2dztŘ 2űKŜNJǿλăŜ ōŜ NJŜLJfIꞏŎŜŘ ǿλűK ƎIꞏă ƎŜySŜNJIꞏúλ2yΣ ⱢŜŜLJλyƎ Iꞏff ōdzű 2yŜ 2Ŧ úKŜ yƵzŎfŜIꞏNJ dzyλűă 2LJŜyˇǿ2dztŘ KIꞏØŜ KλƎKŜNJ ōŜySŦλűă úKIꞏyˇŎ2ăűă¢ DOE’s IꞏyIꞏfèăλă 2yfè f22ⱢŜŘ Iꞏú úKŜ ŎIꞏNJō2yˇōŜySŦλűă 2Ŧ Iꞏúπ№ăⱢ ƎŜySŜNJIꞏú2NJăT úKŜNJŜ IꞏNJŜ 2úKŜNJΣ y2yπŎIꞏNJō2yˇōŜySŦλűă 2Ŧ

[illegible]

[illegible]

[illegible]

3.2.3 Decarbonization via Distributed Energy Resources

59wă [illegible] utility's distribution system or on the premises of an end[illegible] 59wă [illegible] *Ensuring Electricity System Reliability, Security, and Resilience).* 59wă [illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity)*[illegible]

[illegible]

[illegible] *not* [illegible] grid as "dispersed generation" rather than "distributed generation." See Energy Information Administration (EIA), *Modeling Distributed Generation in the Buildings Sectors* ([illegible]

{2Y^Ŝ 59wăΣ ădzŎK I·ă Řλăΰ₪λōdzΰŜŘ ă2fI·₪ t± I·yŘ ŜyŜ₪∃è ŜŦŦλŎλŜyΰ ŜIjdzλLJY^ŜyΰΣ ŎI·y^KI·ØŜ I· ăλ∃yλŦλŎI·yΰ λY^LJI·Ŏΰ 2y^ ăèăΰŜY^ f2I·ŘΣ ōdzΰ Y^I·è y2ΰ ōŜ dzyŘŜ₪ ΰKŜ ŘλWŜŎΰ Ŏ2yΰ₪2f 2Ŧ ∃₪λŘ 2LJŜ₪I·ΰ2₪ăΦ hΰKŜ₪ ΰŜŎKy2f2∃λŜăΣ ădzŎK I·ă ₪ŜăλŘŜyΰλI·f K2ΰ ǿI·ΰŜ₪ KŜI·ΰŜ₪ăΣ KI·ØŜ ΰKŜ LJ2ΰŜyΰλI·f ΰ2 ăŜ₪ØŜ I·ă 59wă I·ă 5w Y^ŜI·ădz₪ŜăΣ ōdzΰ ΰŜŎKy2f2∃λŜă Ŝyl·ōfλy∃ ΰKλă ₪Ŝă2dz₪ŎŜ KI·ØŜ f2ǿ LJŜyŜΰ₪I·ΰλ2y^2₪ I·₪Ŝ ăΰλff yl·ăŎŜyΰΦ !fă2Σ 2LJLJ2₪ΰdzyλΰλŜă ΰ2 λY^LJ₪2ØŜ ŜyŜ₪∃è ŜŦŦλŎλŜyŎè I·yŘ dzăI·∃Ŝ 2Ŧ 59wă ØI·₪è ōè ŎfλY^I·ΰŜ I·yŘ K2dzăŜK2fŘ ŘŜY^2∃₪I·LJKλŎăΣ ă2 ΰI·λf2₪λy∃ LJ₪2∃₪I·Y^ă ΰ2 f2ŎI·f yŜŜŘă λă λY^LJ2₪ΰI·yΰΦ ¢KŜ ² Ŝăΰ I·yŘ {2dzΰK ŎŜyădză ₪Ŝ∃λ2yãΣ Ŧ2₪ ŜÈI·Y^LJfŜΣ ǿKŜ₪Ŝ I·ØŜ₪I·∃Ŝ K2dzăŜK2fŘ ŜfŜŎΰ₪λŎλΰè Ŏ2yãdzY^LJΰλ2y^λă Kλ∃KŜ₪ ΰKI·y^2ΰKŜ₪ ₪Ŝ∃λ2yãΣ₪ I·₪Ŝ ō2ΰK ŜÈLJŜ₪λŜyŎλy∃ Kλ∃K LJ2LJdzfI·ΰλ2y^∃₪2ǿΰK ₪I·ΰŜă

5ŜØŜf2LJY^Ŝyΰă λy^59w I·yŘ λyŦ2₪Y^I·ΰλ2y^I·yŘ Ŏ2Y^YdzyλŎI·ΰλ2yã ΰŜŎKy2f2∃λŜă óL/¢ú ŎI·y^ădzLJLJ2₪ΰ I·y^ŜfŜŎΰ₪λŎ ∃₪λŘ ŎI·LJI·ōfŜ 2Ŧ Y^dzŎK ∃₪ŜI·ΰŜ₪ ŦfŜÈλōλfλΰè λy^Y^I·yl·∃λy∃ ō2ΰK ădzLJLJfè I·yŘ ŘŜY^I·yŘΦ ¢Kλă ŎI·y^2ŦŦŜ₪ Y^dzfΰλLJfŜ ØI·fdzŜ ăΰ₪ŜI·Y^ă óŜΦ∃ØΣ ŜyŜ₪∃èΣ ŎI·LJI·ŎλΰèΣ ₪ŜI·ŎΰλØŜ LJ2ǿŜ₪Σ F₪ŜIjdzŜyŎè ădzLJLJ2₪ΰΣ ŘŜŦŜ₪₪ŜŘ dzΰλfλΰè ŎI·LJλΰI·f ŜÈLJŜyŘλΰdz₪ŜăΣ ŜyŜ₪∃è ăŜŎdz₪λΰèΣ I·yŘ I·Ø2λŘŜŘ ŜY^λăăλ2yãΦ {Y^I·₪ΰ ∃₪λŘ ΰŜŎKy2f2∃λŜă ŎI·y^I·fă2 Ŝyl·ōfŜ λY^LJ₪2ØŜŘ ŘŜY^I·yŘπăλŘŜ Y^I·yl·∃ŜY^Ŝyΰ I·yŘ ₪ŜŘdzŎŜ ŎI·₪ō2y^ ŜY^λăăλ2yãΦ !yl·fèăλă ΰKI·ΰ ă2dzƎKΰ ΰ2 IjdzI·yΰλŦè ΰKŜ /hн ōŜyŜŦλΰă 2Ŧ млл LJŜ₪ŎŜyΰ LJŜyŜΰ₪I·ΰλ2y^ 2Ŧ ăY^I·₪ΰ ∃₪λŘ ΰŜŎKy2f2∃λŜă ōè нлол dzăλy∃ yλyŜ ŘλŦŦŜ₪Ŝyΰ Y^ŜŎKI·yλăY^ă ădz∃∃ŜăΰăI·LJ2ăăλōfŜ мн LJŜ₪ŎŜyΰ Ř₪ŜŎΰ ₪ŜŘdzŎΰλ2y^λy^SY^λăăλ2yã óΰK₪2dz∃K λY^LJfŜY^ŜyΰI·ΰλ2y^2Ŧ ΰKŜ ăY^I·₪ΰ ∃₪λŘ ΰŜŎKy2f2∃λŜă ΰKI·ΰ ŘλWŜŎΰfè I·ŦŦŜŎΰ ŜfŜŎΰ₪λŎΰfè I·yŘ /hн ŜY^λăăλ2yãú I·yŘ I· c LJŜ₪ŎŜyΰ λyŘλWŜŎΰ ₪ŜŘdzŎΰλ2y^ λy^ ŜY^λăăλ2yã óΰ₪I·yãfI·ΰλy∃ ΰKŜ ŜăΰλY^I·ΰŜŘ Ŏ2ăΰ ăI·Øλy∃ă λy^ŜyŜ₪∃è I·yŘκ2₪ ŎI·LJI·Ŏλΰèλyΰ2 ΰKŜλ₪ ŜyŜ₪∃è I·yŘ ŎI·₪ō2y^ŜIjdzλØI·fŜyΰă ΰK₪2dz∃K LJdz₪ŎKI·ăŜ 2Ŧ I·ŘŘλΰλ2yl·f ŎăΰπŜŦŦŜŎΰλØŜ ŜyŜ₪∃è ŜŦŦλŎλŜyŎèúΦMMM ¢₪I·yăI·ŎΰλØŜ ŜyŜ₪∃è Ŏ2yΰ₪2fãΣ ăY^I·₪ΰ ŎKI·₪∃λy∃ 2Ŧ LJfdz∃πλy^ŜfŜŎΰ₪λŎ ØŜKλŎfŜă ót9±ăΰΣ I·yŘ 2ΰKŜ₪ I·LJLJ₪2I·ŎKŜă ΰ2 Ŏ2yΰ₪2ffλy∃ f2I·Ř λy^₪ŜăLJ2yãŜ ΰ2 ∃₪λŘ Ŏ2yŘλΰλ2yã ŎI·y^Ŏ2yΰ₪λōdzΰŜ ΰ2 ō2ΰK ŘλWŜŎΰ I·yŘ λyŘλWŜŎΰ ₪ŜŘdzŎΰλ2yã λy^ŜY^λăăλ2yãΦ ¢I·ōfŜ oπн ăK2ǿă ΰKŜ ØI·fdzŜ 2Ŧ ΰKŜ ØI·₪λ2dză Y^ŜŎKI·yλăY^ă I·yl·fèÎŜŘΦ

Table 3-2. Potential Reductions in Electricity-Sector Energy and CO_2 Emissions in 2030 Attributable to Smart Grid Technologies[111]

	Reductions in Electricity-Sector Energy and CO_2 Emissions[a]	
Mechanism	**Direct (%)**	**Indirect (%)**
Conservation effect of consumer information and feedback systems	3	-
Joint marketing of energy efficiency and DR programs	-	0
Deployment of diagnostics in residential and small/medium commercial buildings	3	-
Measurement and verification for energy efficiency programs	1	0.5
Shifting load to more efficient generation	<0.1	-
Support additional electric vehicles and plug-in hybrid electric vehicles	3	-
Conservation voltage reduction and advanced voltage control	2	-
Support penetration of renewable wind and solar generation (25 percent RPS)	<0.1	5
Total reduction	**12**	**6**

The combined impact of nine smart grid mechanisms, assuming 100 percent penetration of smart grid technologies by 2030, is a 12 percent reduction in annual U.S. electricity-related CO2 emissions from direct

[111] 9fŜŎΰ₪λŎλΰèdzăŜ Ŧ2₪ ălJI·ŎŜ KŜI·ΰλy∃ λă LJI·₪ΰλŎdzfI·₪fè Kλ∃K λy^ΰKŜ {2dzΰK ŎŜyădză ₪Ŝ∃λ2yΦ ¢KŜ {2dzΰKΣ I·yŘ ΰ2 I· fŜăăŜ₪ ŜĒΰŜyΰ ΰKŜ ² ŜăΰΣ ŎŜyădză ₪Ŝ∃λ2yã I·fă2 KI·ØŜ Kλ∃K Ŏ22fλy∃ f2I·Řă

effects, and a 6 percent reduction from indirect effects.[q] Assumes 100 percent penetration of the smart grid technologies[φ]

L / ¢ ΰŜŌKy2f2ƎλŜă I·NŜ Ŝy1·ōfλyƎ ƎNŜI·ΰŜN ŜyŜNƎè ŜŦŦλŌλŜyŌèΣ ǿλΰK λΰă Ō2yŌ2Yλΰ I·yΰ ŜyǾλN2yYŜyΰI·f ōŜyŜŦλΰăΣ λY ΰǿ2 λYLJ2NΰI·yΰ ǿI·èă CNNăΰΣ ΰKŜè I·dzΰ2YI·ΰŜ ŜyŜNƎè ŜŦŦλŌλŜyŌèY Ŧ2N ŜÈI·YLJfŜ ōè ăKdzΰΰλyƎ 2ŦŦ fλƎKΰăΣ ŘŜǾλŌŜăΣ I·yŘ I·LJLJfλI·yŌŜă ǿKŜyΎΰKŜè I·NŜ yƵΰ yŜŜŘŜŜŘT 2N I·Ř2dzăΰλyƎ I ± ! / ŘŜLJŜyŘλyƎ 2yΎΰKŜ ΰλYŜ 2Ŧ ŘI·è {ŜŌ2yŘΣ ΰKŜè Ŝy1·ōfŜ Y2NŜ I·ŘǾI·yŌŜŘ ŜǾI·fdzI·ΰλ2yΣ YŜI·ădzNŜYŜyΰ I·yŘ ǾŜNλŦλŌI·ΰλ2yó9 a ϑ±Σ ă2YŜΰλYŜă NŜŦŜNNŜŘ ΰ2 I·ă 9 a ϑ± нΦлú 2Ŧ ŜyŜNƎè ŜŦŦλŌλŜyŌè LJNƵƵƎNI·Yă I·yŘ λyŌŜyΰλǾŜăΣ λYLJN2ǾλyƎ ΰKŜλN ŜŦŦŜŌΰλǾŜyŜăă I·yŘ IjdzI·yΰλŦλŌI·ΰλ2yΣ I·yŘ Ŝy1·ōfλyƎ ŜŦŦλŌλŜyŌè LJN2ǾλŘŘŜNă ΰ2 ōŜ I·ŌŌdzNI·ΰŜfè Ō2YLJŜyãI·ΰŜŘ Ŧ2N LJN2ǾλŘλyƎ ŜyŜNƎè ŜŦŦλŌλŜyŌè ōŜyŜŦλΰăΣ λyŌfdzŘλyƎ ŜyǾλN2yYŜyΰI·f ōŜyŜŦλΰăΦ L / ¢ ΰŜŌKy2f2ƎλŜă Ŝy1·ōfŜ yŜΰǿ2N]ă ΰKI·ΰ Ō2yŷŜŌΰ ΰKŜ ŜfŜŌΰNλŌ ƎNλŘ ŦN2Y ŜyŘ ΰ2 ŜyŘΣ ŦI·ŌλfλΰI·ΰλyƎ Ō2YY dzyλŌI·ΰλ2yã ΰKN2dzƎK2dzΰ ΰKŜ ăèăΰŜY Φ 9ÈI·YLJfŜ I·LJLJfλŌI·ΰλ2yã λyŌfdzŘŜ I·ŘǾI·yŌŜŘ ăŜyã2Nă I·yŘ Ō2yΰN2fă λy ōdzλfŘλyƎă ΰ2 ŘŜΰŜŌΰ I·yŘ ŜfλYλy1·ΰŜ ŜyŜNƎè ǿI·ăΰŜ I·yŘ I·ŘǾI·yŌŜŘ YŜΰŜNλyƎ λyŦNI·ăΰNdzŌΰdzNŜ ó ! aLΰ ΰKI·ΰ Ŝy1·ōfŜă I·dzΰ2YI·ΰŜŘ NŜăLJ2yãŜ ΰ2 ŜfŜŌΰNλŌλΰè LJNλŌŜă ØλI· ăŜΰΰλyƎă óΦΦΣ Ŧ2N ΰKŜNYΎ2ăΰI·ΰăú ōè Ō2yãdzYΎNă Φ ¢KŜăŜ ΰŜŌKy2f2ƎλŜă ŌI·yΎλYLJN2ǾŜ ΰKŜ ŜyǾλN2yYŜyΰI·f LJŜNŦ2NYI·yŌŜΣ NŜfλI·ōλfλΰèΣ NŜăλfλŜyŌŜΣ ŦfŜÈλōλfλΰèΣ I·yŘ ŜŦŦλŌλŜyŌè 2Ŧ ΰKŜ ŜfŜŌΰNλŌλΰè ăèăΰŜY ΰKN2dzƎK NŜI·fπΰλYŜ YΎ2yΰ2NλyƎ I·yŘ Ō2yΰN2f 2Ŧ ƎNλŘ ăèăΰŜYă Φ

3.2.3.1 Energy Efficiency: Environmental Benefits and Consumer Savings

9yŘ dzăŜ ŜyŜNƎè ŜŦŦλŌλŜyŌè λă I· NI·yƎŜ 2Ŧ YŜI·ădzNŜă ΰKI·ΰ LJN2ǾλŘŜ ŜyŘ dzăŜNă ΰKŜ ăI·YŜ ăŜNǾλŌŜă óădzŌK I·ă fλƎKΰ I·yŘ I·λN Ŏ2yŘλΰλ2yλyƎú ǿλΰK fŜää ŜyŜNƎè Φ 9yŜNƎè ŜŦŦλŌλŜyŌè KI·ă YdzfΰλLJfŜ ōŜyŜŦλΰăΦ ! ff ŜfŜŌΰNλŌ ƎŜyŜNI·ΰλ2yΣ ΰNI·yăYλăăλ2y I·yŘ ŘλăΰNλōdzΰλ2y KI·ă ă2YŜ λYLJI·ŎΰΦ 2yΎΰKŜ ŜyǾλN2yYŜyΰΦ 9yŜNƎè ŜŦŦλŌλŜyŌè I·Ø2λŘă I·ff 2Ŧ ΰKŜăŜ ŜyǾλN2yYŜyΰI·f λYLJI·ŎΰăΦ LΰΦ ŜYλΰă y2 D I DăΣ I·λN 2N ǿI·ΰŜNJ LJ2ffdzΰλ2yΦ LΰΦ KI·ă y2 λYLJI·ŎΰΦ 2y fI·yŘ dzăŜΦ LΰΦ NŜIjdzNJŜă y2 ăλΰλyƎΣ LJŜNYλΰΰλyƎ 2N ŘŜŌ2YYλăăλ2yλyƎΦ 9yŜNƎè ŜŦŦλŌλŜyŌè I·fă2 ăI·ØŜă Ō2yãdzYŜNă Y2yŜèΣ YI·ƛyƎ λΰ ΰKŜ Y2ăΰ ŌΰăΰπŜŦŦŜŌΰλǾŜ ŘŜŌI·NŌ2yλÎI·ΰλ2y2LJΰλ2yΦ 9yŜNƎè ŜŦŦλŌλŜyŌè LJN2ƎNJI·Yă I·yŘ ăI·ØλyƎă I·NŜ ŘλăŌdzăăŜŘ ŦdzNΰKŜNJ λy / KI·LJΰŜNJ LL ó*The Electricity Sector: Maximizing Economic Value and Consumer Equity)*Φ

DOE's Appliance and 9IjdzλLJYŜyΰ {ΰI·yŘI·NŘă tN2ƎNJI·YMMH KI·ă ăŜNǾŜŘ I·ă 2yŜ 2Ŧ ΰKŜ bation's most effective LJ2fλŌλŜă Ŧ2N λYLJN2ǾλyƎ ŜyŜNƎè ŜŦŦλŌλŜyŌèΦ ¢KŜ LJN2ƎNJI·Y λYLJfŜYŜyΰă YλyλYdzY ŜyŜNƎè Ō2yãŜ NǾI·ΰλ2y ăΰI·yŘI·NŘă Ŧ2N YŽNŜ ΰKI·y сл LJN2ŘdzŌΰă ΰKI·ΰ Ō2yãdzYŜ I·ō2dzΰ фл LJŜNŌŜyΰ 2Ŧ K2YŜ ŜyŜNƎè dzăŜΣ сл LJŜNŌŜyΰ 2Ŧ Ō2YYŜNŌλI·f ōdzλfŘλyƎ ŜyŜNƎè dzăŜΣ I·yŘ ол LJŜNŌŜyΰ 2Ŧ λyŘdzăΰNλI·f ŜyŜNƎè dzăŜΦMMO {λyŌŜ нллфΣ ΰKŜ ¦ yΰΰŜŘ {ΰI·ΰŜă KI·ă λăădzŜŘ пл yŜǿ 2N dzLJŘI·ΰŜŘ ăΰI·yŘI·NŘă ΰ2 YI·ƛŜ I·LJLJfλI·yŌŜă ōdzλfŘλyƎăΣ I·yŘ ŜIjdzλLJYŜyΰ Y2NŜ ŜŦŦλŌλŜyΰΦ ¢KŜăŜ ăΰI·yŘI·NŘă I·NŜ LJN2ΣŜŌΰŜŘ ΰ2 NŜŘdzŌŜ ŌI·NŌ2y ŜYλăăλ2yã ōŜΰǿŜŜy нллф I·yŘ нлол ōè 2ǾŜN нΦp ōλfλ2y YŜΰNλŌ ΰ2yãΣ ăI·ØŜ Ō2yãdzYŜNă Þppт ōλfλ2y 2y dzΰλfλΰè ōλfλfăΣ I·yŘ NŜŘdzŌŜ LJNλYI·Nè ŜyŜNƎè Ō2yãdzYLJΰλ2y ōè пн IjdzI·ŘNλfλ2y .NλΰλăK ΰKŜNYI·f dzyλΰă ó.¢¦úΦNΣ MMn ¢Kλă yƵYŌŜN λă ŜÈLJŜŌΰŜŘ ΰ2 ƎN2ǿ ΰ2 o ōλfλ2y YŜΰNλŌ ΰ2yã ǿλΰK ăΰI·yŘI·NŘă LJdzōfλăKŜŘ ΰKN2dzƎK WI·yƵzI·Nè нлмтΦMMP C2N ŜÈI·YLJfŜΣ λy WI·yƵzI·Nè нлмс 5h9 ŦλyI·fλÎŜŘ ŜŦŦλŌλŜyŌè ăΰI·yŘI·NŘă Ŧ2N Ō2YYŜNŌλI·f I·λN Ō2yŘλΰλ2yλyƎ I·yŘ KŜI·ΰλyƎ ŜIjdzλLJYŜyΰΣ ǿKλŌK λă LJN2ΣŜŌΰŜŘ ΰ2 I·Ø2λŘ тт Yλfλ2y YŜΰNλŌ ΰ2yã / hн ōè нлолΦMMC ¢2ŘI·èΣ I· ΰèLJλŌI·f K2dzăŜK2fŘ ăI·ØŜă I·ō2dzΰ Þомф LJŜN èŜI·N 2Ŧ ΰKŜλN ŜyŜNƎè ōλftă I·ă I· NŜădzfΰ 2Ŧ ΰKŜăŜ ăΰI·yŘI·NŘăΣ I·yŘ I·ă LJŜ2LJfŜ NŜLJfI·ŌŜ ΰKŜλN I·LJLJfλI·yŌŜă ǿλΰK yŜǿŜN Y2ŘŜfăΣ ΰKŜè Ōl·yΎŜÈLJŜŌΰ ΰ2 ăI·ØŜ 2ØŜN Þпсл I·yΎdzI·ftê ōè нлолΦMMT LΎ I·ŘŘλΰλ2Ύ ΰ2 YλyλYdzY ŜŦŦλŌλŜyŌè ăΰI·yŘI·NŘă Ŧ2N I·LJLJfλI·yŌŜăΣ ΰKŜ 9yØNN2yYŜyΰI·f tN2ΰŜŌΰλ2y ! ƎŜyŌè ó9t ! ú fŜI·Řă 9b9wD¸ {¢ ! wΣ I· Ø2ftdzyΰI·Nè fI·ōŜfλyƎ LJN2ƎNJI·Y ŘŜăλƎyŜŘ ΰ2 KŜfLJ ōdzăλySăăŜă I·yŘ λyŘλØλŘdzI·fă ăI·ØŜ Y2ySè I·yŘ I·Ø2λŘ LJ2ffdzΰλ2y ǿλΰK ŜyŜNƎèπŜŦŦλŌλŜyΰ LJN2ŘdzŌΰă Φ 9b9wD¸

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[q] ¢KŜ ŘNNŜŌΰ NŜŘdzŌΰλ2yã ǿŜNŜ ŌI·fŌdzfI·ΰŜŘ Ŧ2N ΰKŜ YŜŌKI·yΎăYă ΰKI·ΰ I·ŦŦŜŌΰŜŘ ŜfŜŌΰNλŌλΰè I·yŘ / hн ŜYλăăλ2yã ŘNNŜŌΰfè ΰKN2dzƎK λYLJfŜYŜyΰI·ΰλ2y2Ŧ ΰKŜ ăYI·Nΰΰ ƎNλŘ ΰŜŌKy2f2ƎλŜă LyŘNNŜŌΰ NŜŘdzŌΰλ2yã I·NŜ ŘŜNλǾŜŘ ōè ΰNI·yΎătI·ΰλyƎ ΰKŜ ŜăΰλYI·ΰŜŘ Ō2ăΰ ăI·ØλyƎă λyŜyŜNƎè I·yŘk2N ŌI·LJI·Ōλΰèλyΰ2 ΰKŜNN ŜyŜNƎè I·yŘ ŌI·NōdzyŜIjdzλØI·fŜyΰă ΰKN2dzƎK LJdzNŌKI·ăŜ 2Ŧ I·ŘŘλΰλ2yI·f Ō2ăΰπ ŜŦŦŜŌΰλǾŜ ŜyŜNƎè ŜŦŦλŌλŜyŌè¢ ¢KλăŌI·yNŜLJNŜăŜyΰ I· LJ2fλŌè ŘŜŌλăλ2yΎ2 NŜλyǾŜăΰ ΰKŜ ăI·ØλyƎă ΰ2 LJdzNŌKI·ăŜ I·ŘŘλΰλ2yI·f Y2NŜ Ō2ăΰ ŜŦŦŜŌΰλǾŜ ŜyŜNƎè ŜŦŦλŌλŜyŌè I·yŘ NŜyŜǿI·ōfŜ NŜă2dzNŌŜă¢

[r] ¢KŜăŜ ăI·ØλyƎă yƵzYŌŜNă I·NŜ I·ă 2Ŧ 5ŜŌSYŌŜN нлмс¢ ! LJLJfλI·yŌŜ I·yŘ ŜIjdzλLJYŜyΰ ăΰI·yŘI·NŘă Ō2yΰλyƵzŜ ΰ2 ōŜ λăădzŜŘ I·yŘ dzLJŘI·ΰŜŘ¢ wŜŦŜN ΰ2 ΰKŜ ! LJLJfλI·yŌŜ I·yŘ 9IjdzλLJYŜyΰ {ΰI·yŘI·NŘ tN2ƎNJI·Y ǿŜŌăλΰŜ Ŧ2N dzLJŘI·ΰŜŘ λyŦ2NYI·ΰλ2y óKΰΰLJYkkŜyŜNƎè¢Ǝ2ØkŜŜNŜkōdzλfŘλyƎăkI·LJLJfλI·yŌŜπI·yŘπŜIjdzλLJYŜyΰπăΰI·yŘI·NŘăπLJN2ƎNJI·YΎú¢

{¢!w fl·ōŜfă l·LJLJŜl·₪ 2y´Yl·ƨ2₪ l·LJLJfλl·yŏŜăΣ 2₮₣λÕŜ ŜljdzλLJY´Ŝyύ΢ fλ∃Kύλy∃Σ K2YŜ ŜfŜÕύ₪2yλÕăΣ yŜø K2Y´Ŝă΢ l·yŘ Ŏ2Y´YŜ₪ŎλIf l·yŘ λyŘdzăύ₪λl·f ōdzλfŘλy∃ă l·yŘ LJfl·yύă¢ ¢KŜ 9b9wD¸ {¢!w LJ₪2∃₪l·Y´ ăl·ØŜŘ !Y´Ŝ₪λŎl·y´Ŏ2yãdzY´Ŝ₪ă l·y´Ŝăύλ Yl·ύŜŘ Þнп ōλffλ2y´λy´ŜyŜ₪∃è Ŏ2ăύă λy´нлмн l·f2yŜ⁰ᵐᵐʸ

.dzλfŘλy∃ă΢ ØKλŎK fl·ăύ ₮2₪ ŘŜŎl·ŘŜă΢ l·ŎŎ2dzyύ ₮2₪ тс LJŜ₪ŎŜyύ 2₮ ŜfŜŎύ₪λŎλúê Ŏ2yãdzY´LJύλ2y´ l·yŘ пл LJŜ₪ŎŜyύ 2₮ D I D ŜY´λăăλ2yã λy´ύKŜ ¦ yλύŜŘ {úl·ύŜă⁰ᵐᵐᶲwŜŎŜyύ l·yl·fèăλă ăK2ø̀ă ύKl·ύ λy´ăύl·ύŜă Ŏ2yãλăύŜyύfè l·Ř2LJύλy∃ ύKŜ Y´2ăύ ₪ŜŎŜyύ ØŜ₪ăλ2yã 2₮ ύKŜ Y´2ŘŜf ōdzλfŘλy∃ ŜyŜ₪∃è Ŏ2ŘŜă΢ K2YŜ2øýŜ₪ă΢ ōdzλfŘλy∃ 2øýŜ₪ă΢ l·yŘ ύŜyl·yύă l·₪Ŝ LJ₪2ƨŜŎύŜŘ ύ2 ăl·ØŜ Þмнс ōλffλ2y´2y´ŜyŜ₪∃è ōλftă l·yŘ ₪ŜŘdzŎŜ Ŏl·₪ō2y´ŜY´λăăλ2yã ōè 2ØŜ₪ упм Y´λffλ2y´Y´ŜύλŎ ύ2yã ÖdzY´dzfl·ύλØŜfè ōŜύøŜŜy´нлмл l·yŘ нлпл λ₮ ŜyŜ₪∃è Ŏ2ŘŜă Ŏ2yύλyθzŜ ύ2 ōŜ ăύ₪ŜyЗύKŜySŘ⁰ᵐᴴᴶ a l·yè 2₮ ύKŜ Kλ∃Kπ Ŝ₮₣λŎλŜyŎè ύŜŎKy2f2∃λŜă΢ ōdzλfŘλy∃ ŜyØŜf2LJŜ ŘŜăλ∃yã΢ l·yŘ ŜyŜ₪∃è Yl·yl·∃ŜYŜyύ LJ₪l·ŎύλŎŜă ύKl·ύ Ŝyl·ōfŜ significant energy savings and GHG reductions beyond today's building codes have been demonstrated l·yŘ l·₪Ŝ Ŏ2YY´Ŝ₪ŎλI·ftê l·Øl·λfl·ōfŜ⁰ ² KλfŜ Ŏ2yύλyθzŜŘ ŘŜØŜf2LJY´Ŝyύă λy´ ōdzλfŘλy∃ ŘŜăλ∃y´ l·yŘ ύŜŎKy2f2∃è λY´LJ₪2ØŜY´Ŝyύă λy´]Ŝè ōdzλfŘλy∃ Ŏ2Y´LJ2yŜyύă l·yŘ ăèăύŜY´ă Kl·ØŜ fŜŘ ύ2 fl·₪∃Ŝ Ŝ₮₣λŎλŜyŎè ∃l·λyã΢ ύKŜ₪Ŝ ₪ŜY´l·λyã l· fl·₪∃Ŝ ∃l·LJ ōŜύøŜŜy´ύKŜ Ŝ₮₣λŎλŜyŎè 2₮ ύKŜ ŜÈλăύλy∃ ōdzλfŘλy∃ ăύ2Ŏ] l·yŘ øKl·ύ λă LJ2ăăλōfŜ dzăλy∃ ύŜŎKy2f2∃λŜă l·Øl·λfl·ōfŜ ύ2ŘIl·è⁰ᵐᴴᵐ t2fλŎλŜă 2₪ LJ₪2∃₪l·Y´ă Ŏ2dzfŘ KŜfLJ 2ØŜ₪Ŏ2Y´Ŝ Yl·₪]Ŝύ l·yŘ ōŜKl·Øλ2₪l·f ōl·₪₪λŜ₪ă ύKl·ύ l·₪Ŝ fλY´λύλy∃ ŘŜLJf2èY´Ŝyύ⁰ ¦ ăλy∃ ŜÈλăύλy∃ ύŜŎKy2f2∃λŜă l·yŘ ōdzλfŘλy∃ ŘŜăλ∃y´ l·yŘ Ŏ2yãύ₪dzŎύλ2y´LJ₪l·ŎύλŎŜă΢ ōdzλfŘŜ₪ă l·₪Ŝ l·ōfŜ ύ2 ŘŜăλ∃y´K2Y´Ŝă ύKl·ύ l·₪Ŝ dzLJ ύ2 pл LJŜ₪ŎŜyύ Y´2₪Ŝ Ŝ₮₣λŎλŜyύ ύKl·y´ύèLJλŎl·f yŜø K2YŜă΢ᴹᴴᴴ΢ ᴹᴴᴼ l·yŘ ύKŜăŜ Ŏl·y´ LJ₪2ØλŘŜ Ŏ2yãdzY´Ŝ₪ă øλύK Y´2yύKfè ŜyŜ₪∃è ăl·ØλyЗă dzLJ ύ2 Рмллⁱ⁰ᵃ΢ ᴹᴴᵖ΢ ᴹᴴᵖ ¢KŜ bl·ύλ2yl·f LyãύλύdzύŜ ₮2₪ {úl·yŘl·₪Řă l·yŘ ¢ŜŎKy2f2∃è Kl·ă Ŏ2Y´LJfŜύŜŘ l· ŘŜY´2yãύ₪l·ύλ2y´l·ύ λύă bŜύ ½Ŝ₪2 9yŜ₪∃è wŜăλŘŜyύλl·f ¢Săύ Cl·ŎλfλύèT ύ2ύl·f LJ₪ŜăŜyύ Øl·fdzŜ ŜyŜ₪∃è Ŏ2ăύă ₮2₪ l· yŜύπÎŜ₪2 ŜyŜ₪∃è K2YŜ øŜ₪Ŝ Y´2₪Ŝ ύKl·y´Þпл΢ллл f2øŜ₪ ύKl·y´l· yŜø K2YŜ ōdzλfύ ύ2 ύKŜ Ŏ2YLJl·₪l·ōfŜ Yλyλ´Ydz´Y Ŏ2ŘŜⁱ⁰ᵐᴴᶜ wŜŎŜyύ ăύdzŘλŜă ŘŜY´2yãύ₪l·ύŜ ύKl·ύ Ŏ2yãύ₪dzŎύλ2y´Ŏ2ăύă ₮2₪ yŜύπÎŜ₪2 ŜyŜ₪∃è ōdzλfŘλy∃ă λy´ ύKŜ Ŏ2Y´Y´Ŝ₪ŎλI·f ăŜŎύ2₪ l·₪Ŝ Ŏl·LJl·ōfŜ 2₮ ₮l·ffλy∃ øλύKλy´ ύKŜ ăl·Y´Ŝ ₪l·y∃Ŝ l·ă Ŏ2yØŜyύλ2yl·f yŜø Ŏ2yãύ₪dzŎύλ2y´ LJ₪2ƨŜŎύăⁱ⁰ᵐᴴᵀ΢ ᴹᴴʸ Lύ λă ø2₪ύK y2ύλy∃ ύKl·ύ΢ ø̀KŜy´l·ύύŜY´LJύλy∃ ύ2 Ŏl·tŎdzfl·ύŜ ύKŜ λyŎ₪ŜY´Ŝyύl·f Ŏ2yãύ₪dzŎύλ2y´ Ŏ2ăύ 2₮ l· yŜύπÎŜ₪2 ŜyŜ₪∃è ōdzλfŘλy∃ᵘ Ŏ2Y´LJl·₪ŜŘ ύ2 l· Ŏ2yØŜyύλ2yl·f ōdzλfŘλy∃΢ l·ŘŘλύλ2yl·f ₮l·ŎύƨŵăΣ ădzŎK l·ă Ŏ2yύλyθzŜŘ 2LJŜ₪l·ύλ2yl·f ăl·ØλyЗăΣ λyŎ₪Ŝl·ăŜŘ 2ŎŎdzLJl·yύ Ŏ2Y´₮2₪ύΣ l·yŘ λyŎ₪Ŝl·ăŜŘ ōdzλfŘλy∃ Øl·fdzŜΣ ăK2dzfŘ l·fă2 ōŜ Ŏ2yãλŘŜ₪ŜŘ⁰

¢KŜ λyŘdzăύ₪λl·f ăŜŎύƨ₪ λă ₪ŜăLJ2yãλōfŜ ₮2₪ l·LJLJ₪2ÈλY´l·ύŜfè нс LJŜ₪ŎŜyύ 2₮ ŜfŜŎύ₪λŎλúè¤₪Ŝfl·ύŜŘ /hн ŜY´λăăλ2yã⁰ᵐᴴᶲ 9fŜŎύ₪λŎλúè LJ₪2ŘdzŎύλØλúè λy´ ύKŜ λyŘdzăύ₪λl·f ăŜŎύƨ₪ óY´Ŝl·ădz₪ŜŘ λy´]²K LJŜ₪ Ř2ffl·₪ 2₮ 2dzύLJdzύ LJ₪2ŘdzŎŜŘύ Kl·ă λY´LJ₪2ØŜŘ ₪l·LJλŘfè 2ØŜ₪ ύKŜ fl·ăύ mp èŜl·₪ăƨᶻ² l·yŘ Ŏ2yύλyθzŜŘ λY´LJ₪2ØŜY´Ŝyύ øλffŘŜLJŜyŘ 2y´LJŜ₪ăλăύŜyύ l·ύύŜyύλ2y´ ύ2 Ŝ₮₣λŎλŜyŎè Ly´₪Ŝ∃λ2yã øKŜ₪Ŝ ύKŜ ŜY´λăăλ2yã λyύŜyãλúè 2₮ ŎŜyύ₪l·f ŜfŜŎύ₪λŎ ∃ŜyŜ₪l·ύλ2y´λă Kλ∃Kƨ ăøλύŎKλy∃ ύ2 / l t øλff Kl·ØŜ ύKŜ ōλ∃∃Ŝăύ ŜY´λăăλ2yã λY´LJl·Ŏύ¤ 5h9 ŜăύλY´l·ύŜă ύKl·ύ ύKŜ₪Ŝ λă ύŜŎKyŎl·f LJ2ύŜyύλl·f ₮2₪ ₪2dz∃Kfè нпм D² 2₮ / l t Ŏl·LJl·Ŏλúè λy´ ύKŜ ¦ yλύŜŘ {úl·ύŜăƨ λyŎfdzŘλy∃ λyŘdzăύ₪λl·f l·yŘ Ŏ2Y´YŜ₪Ŏλl·f / l t l·ă ØŜff l·ă ø̀l·ăύŜ KŜl·ύ ύ2 LJ2øŜ₪ᴹᴼᴻ {λyŎŜ Y´2ăύ 2₮ λyŘdzăύ₪λl·f / l t λă ₮dzŜfŜŘ ōè yl·ύdz₪l·f ∃l·ăƨᴹᴼᴹ K2øŜØŜ₪Σ ŜλύKŜ₪ ₮dzŜfπăøλύŎKλy∃ ύ2 ŘŜŎl·₪ō2yλÎŜŘ ₮dzŜfă 2₪ l· ύ₪l·yãλύλ2y´l·ø̀l·è ₣₪2Y´ / l t ø2dzfŘ ōŜ yŜŜŘŜŘ λy´ ύKŜ f2yЗ ύŜ₪Y´ ύ2 Y´2₪Ŝ ₮dzffè ŘŜŎl·₪ō2yλÎŜ ύKŜ λyŘdzăύ₪λl·f ăŜŎύƨ₪⁰

3.2.3.2 Distributed Generation, Distributed Storage, and Demand Response

Ly´₪ŜŎŜyύ èŜl·₪ăΣ ύKŜ₪Ŝ Kl·ă ōŜŜy´ăλ∃yλ₮λŎl·yύ ∃₪2øύK λy´ 5DΣ LJl·₪ύλŎdzfl·₪fè ₪22₮ύ2LJ ă2fl·₪ t±Σ øKλŎK Kl·ă ōŜŜy´ ₮2ăύŜ₪ŜŘ ōè f2øŜ₪ λyăύl·ftl·ύλ2y´l·yŘ Kl·₪Řøl·₪Ŝ Ŏ2ăύă l·yŘ ădzLJLJ2₪ύλØŜ LJ2fλŎλŜăΣ ădzŎK l·ă yŜύ Y´ŜύŜ₪λy∃ l·yŘ ăŜf₮π ∃ŜyŜ₪l·ύλ2y´ύl·₪λ₮₣ă l·yŘ wt{ă øλύK ăŜύπl·ăλŘŜă 2₪ Y´dzfύλLJfλŜ₪ă ₮2₪ 5D⁰ I2øŜØŜ₪Σ ă2Y´Ŝ ăύl·ύŜă l·yŘ dzύλfλύλŜă l·₪Ŝ

ª EPA's ENERGY STAR Certified Homes are typically 15 percent to 30 percent more efficient than the average new home, yet úKŜè Ŏl·y´LJ₪2ØλŘŜ Y´2yύKfè ŜyŜ₪∃è Ŏ2ăύ ăl·ØλyЗă 2₮ l·ō2dzύ Þнт–$93 to consumers. DOE's Zero Energy Ready Homes are at least 40 LJŜ₪ŎŜyύ ύ2 pл LJŜ₪ŎŜyύ Y´2₪Ŝ Ŝ₮₣λŎλŜyŎè ύKl·y´ύèLJλŎl·f yŜø K2YŜă΢ èŜύ ύKŜè Ŏl·y´LJ₪2ØλŘŜ Ŏ2yãdzY´Ŝ₪ă øλύK Y´2yύKfè ŜyŜ₪∃è ăl·ØλyЗă 2₮ l·ō2dzύ Рол–Рмллⁱ⁰ {ŜŜ ŎλúI·ύλ2yã λy´ύKŜ Yl·λy´ύŜÈύ ₮2₪ ŘŜύl·λfă ₪ŜЗl·₪ŘλyЗ úKŜăŜ ŜăύλY´l·ύŜă óŜyŘy2ύŜă мпф–мрнúª

ᵘ ½Ŝ₪2πŜyŜ₪∃è ōdzλfŘλy∃ă l·₪Ŝ KλЗKπLJŜ₪₮2₪Y´l·yŎŜ Ŏ2YY´Ŝ₪Ŏλl·f l·yŘ ₪ŜăλŘŜyύλl·f ōdzλfŘλy∃ă ύKl·ύ l·₪Ŝ ă2 ŜyŜ₪∃è Ŝ₮₣λŎλŜyύΣ l· ₪ŜySø l·ōfŜ ŜyŜ₪∃è ăÈăύŜY´ Ŏl·y´2₮₣ăŜύ Y´2ăύ 2₪ l·ff λύă l·yўzl·f ŜyŜ₪∃è Ŏ2yãdzY´LJύλ2yª

ᵈᶻ 9fŜŎύ₪λŎλúè LJ₪2ŘdzŎύλØλúèΣ Y´Ŝl·ădz₪ŜŘ l·ă Ř2ffl·₪ă 2₮ D5t LJ₪2ŘdzŎŜŘ LJŜ₪]²KΣ yŜl·₪fè Ř2dzōfŜŘ ōŜύøŜŜy´мффл l·yŘ нлмпΣ øKλfŜ λyŘdzăύ₪λl·f ŜfŜŎύ₪λŎλúè ăl·fŜă øŜ₪Ŝ ₮fl·úª

I·Řƨdžăűλy϶ űKŜλNJ yŜú YˇŜűŜNJλy϶ LJ2fλÕλŜă I·ă űKŜ ŘλăúNJλōdzúŜŘ t± YˇI·NJ]Ŝú ϶NJ2ǿăφ bŜú YˇŜűŜNJλy϶ λă I· NJŜfI·ûλØŜfè ăλYˇLJfŜ LJ2fλÕèΣ I·yŘ I·ă űKŜ ŘλăúNJλōdzúŜŘ t± YˇI·NJ]Ŝú KI·ă ϶NJ2ǿyˇŘNJI·YˇI·ûλÕI·ffèΣ YˇI·yê ăűI·ûŜă I·NJŜ dzLJŘI·ûλy϶ űKŜλNJ λyÕŜyűλØŜ ăúNJdzÕűdzNJŜă ŦƨNJ ŘλăúNJλōdzúŜŘ t± ű2 YˇƨNJŜ ÕI·NJŜŦdzffè I·ÕÕ2dzyű ŦƨNJ ÕKI·y϶λy϶ ŜfŜÕűNJλÕ ăèăúŜYˇ yŜŜŘăΣ úNJI·yˇãŦŜNJă ōŜúǿŜŜyˇNJI·ûŜLJI·èŜNJ Õfl·ääŜăΣ I·yŘ ØI·NJλ2dză ōŜyŜŦλú I·yŘ Õ2ăű ăúNJŜI·Yˇăφ ¢Kλă λă ŘλăÕdzääŜŘ λyˇŘŜLJúK λyˇ /KI·LJűŜNJ LL ó*The Electricity Sector: Maximizing Economic Value and Consumer Equity)*φ

{YˇI·ffπăÕI·fŜ Řλăúλ NJλōdzúŜŘ ŜfŜÕűNJλÕλúè ăú2NJI·϶Ŝ λă ōŜÕ2Yˇλyϴ YˇƨNJŜ ǿλŘŜfè I·ØI·λfI·ōfŜ I·yŘ ÕI·yˇÕ2yűNJλōdzúŜ ű2 I· ÕfŜI·yˇ ŜfŜÕűNJλÕλúè ăèăúŜYˇ ōè ŦI·ÕλfλúI·ûλyϴ λyÕNJŜI·ăŜŘ LJŜyŜúNJI·ûλ2yˇ2Ŧ ØI·NJλI·ōfŜ ǿλyŘ I·yŘ ă2fI·NJ NJŜă2dzNJÕŜăφ LΰŦ ÕI·yˇI·fă2 NJŜŘdzÕŜ LJŜI·]f2I·ŘΣ λYˇLJNJ2ØŜ ŜfŜÕűNJλÕI·f ăúI·ōλfλúèΣ I·yŘ NJŜŘdzÕŜ LJ2ǿŜNJ Ijdz I·fûúè ŘλăúdzNJōI·yÕŜăφ 5λăúNJλōdzúŜŘ ăű2NJI·϶Ŝ λă Õ2ØŜNJŜŘ λyˇϴNJŜI·ûŜNJ ŘŜűI·λfλyˇ /KI·LJűŜNJ LL ó*The Electricity Sector: Maximizing Economic Value and Consumer Equity).*

[λ]Ŝ ŘλăúNJλōdzúŜŘ ăű2NJI·϶ŜΣ ŘŜYˇI·yŘ NJŜăLJ2yãŜ ó5wú ŜyI·ōfŜă I· ÕfŜI·yŜNJ ϴNJλŘ ōè LJNJ2ØλŘλyϴ ϴNJλŘ ăŜNJØλÕŜă ǿλúK f2ǿŜNJ ŜyØλNJ2yYˇŜyűI·f λYˇLJI·ÕűăúKI·yˇ2úKŜNJ 2LJûλ2yã Ŧ2NJ LJNJ2ØλŘλyϴ ădzÕK ăŜNJØλÕŜăφ LŦ I·LJLJNJ2LJNJλI·ûŜfè ŘŜăλ∃ySŘ I·yŘ NJŜă2dzNJÕŜŘΣ 5w ŜyI·ōfŜă dzűλfλûλŜăΣ ϴNJλŘ 2LJŜNJI·û2NJăΣ 2NJ 2úKŜNJ λyűŜNJYˇŜŘλI·NJλŜă û2 ÕI·ff Ŧ2NJ ălJŜÕλŦλÕ NJŜŘdzÕűλ2yã λyˇ ŘŜYˇI·yŘ ǿKŜyˇ ySŜŘŜŘT ûKλă Õ2dzfŘ LJNJ2ØλŘŜ ōSyŜŦλúă λyˇ NJŜŘdzÕλyϴ LJŜI·] f2I·Ř I·yŘ ădzLJLJfèλyϴ ŜăăŜyűλI·f NJŜfλI·ōλfλúè ăŜNJØλÕŜă ǿKŜyˇλyÕNJŜI·ăŜŘ ØI·NJλI·ōfŜ ŜyŜNJ∃è NJŜă2dzNJÕŜăΣ LJ2fλÕλŜă I·yŘ NJŜ∃dzfI·ûλ2yã ûKI·ú ŜyI·ōfŜ ϴNJŜI·ûŜNJ LJŜySûNJI·ûλ2yˇ2Ŧ ŘŜYˇI·yŘ NJŜăLJ2yãŜ λyˇϴNJλŘ ăŜNJØλÕŜă YˇI·NJ]Ŝúă I·NJŜ fλ]Ŝfè û2 ōŜÕ2YˇŜ λyÕNJŜI·ăλyϴfè λYˇLJ2NJűI·yú û2 ŜyI·ōfŜ I· ÕfŜI·yŜNJ ϴNJλŘφMOH ! aL ŜyI·ōfŜă ûλYˇŜπōI·ăŜŘ NJI·ûŜă I·yŘ ŦI·ÕλfλúI·ûŜă úKŜ λyűŜ∃NJI·ûλ2yˇ2Ŧ ŘλăúNJλōdzúŜŘ ∃ŜySNJI·ûλ2yˇ ăèăúŜYˇă óSφ∃φΣ ă2fI·NJóΣ I·Y2y∃ 2úKŜNJ ÕI·LJI·ōλfλúλŜăφ a2NJŜ I·dzű2YˇI·ûŜŘ ŘŜYˇI·yŘ NJŜăLJ2yãŜ ÕI·LJI·ōλfλúλŜă ǿλfŦ ŜyI·ōfŜ ϴNJŜI·ûŜNJ ŦfŜÈλōλfλúè 2Ŧ ŘŜYˇI·yŘπăλŘŜ NJŜă2dzNJÕŜăΣ λYˇLJNJ2ØŜŘ λyűŜ∃NJI·ûλ2yˇ2Ŧ ØI·NJλI·ōfŜ NJŜySǿI·ōfŜ ŜyŜNJ∃è NJŜă2dzNJÕŜă I·yŘ ŜI·ăλŜNJ ØI·fdzI·ûλ2yˇ2Ŧ ûKŜλNJ ÕI·NJō2yˇŜYˇλăăλ2yã ōŜySŦλúăΣ I·yŘ ŜyKI·yÕŜ ăèăúŜYˇ λyűŜ∃NJλúè ûKN2dz∃K ϴNJŜI·ûŜNJ I·NJŜI·π ǿλŘŜ]yƨfŜŘ∃Sφ ¢KŜ YˇƨăΰØλI·ōfŜ 5w ŜyŘπdzăŜă Ŧ2NJ ±9w λyűŜ∃NJI·ûλ2yˇI·NJŜ ŜfŜÕűNJλÕ ǿI·ûŜNJ KŜI·ûŜNJă I·yŘ ŦdzNJy1·ÕŜăΣ I·λNJ Õ2yŘλûλ2ySNJă I·yŘ fλ∃Kûλyϴ ǿλúK I·ŘØI·yÕŜŘ Õ2yúN2făΣ I·∃NJλÕdzfûdzNJI·f λNJNJλ∃I·ûλ2yΣ I·yŘ YˇƨûƨNJkÕ2YˇLJNJŜăă2NJ ŘNJλØŜă ǿλúK ØI·NJλI·ōfŜ ŦNJŜIjdzŜyÕλŜăφMOO

3.2.4 Increased Electrification Is Essential for Decarbonization

!yI·fèăŜă ûKI·ú ŜÈLJf2NJŜ Kλ∃K fŜØŜfă 2Ŧ f2y∃πúŜNJY DID ŜYˇλăăλ2yã NJŜŘdzÕűλ2yã ădz∃∃Ŝăű ûKI·ú ûKŜ λyÕNJŜI·ăŜŘ ŜfŜÕűNJλŦλÕI·ûλ2yφ 2Ŧ]Ŝè ŜyŘ dzăŜă λyˇúNJI·yãLJ2NJúI·ûλ2yΣ ōdzλfŘλy∃ăΣ I·yŘ λyŘdzăúNJè λă 2yŜ 2Ŧ úKNJŜŜ ŦdzyŘI·YˇŜyűI·f I·NJŜI·ă óλyˇ I·ŘŘλûλ2yˇ û2 ŘŜÕI·NJō2yλÎλy∃ ŜfŜÕűNJλÕλúè ∃ŜySNJI·ûλ2yˇ I·yŘ I·Ř2LJûλy∃ Kλ∃KfèπŜŦŦλÕλŜyű ŜyŘ dzăŜăú ySŜŘŜŘ û2 I·ÕKλŜØŜ ŘŜŜLJ ŘŜÕI·NJō2yλÎλy∃ ŜfŜÕűNJλÕλúè ∃ŜySNJI·ûλ2yˇ I·yŘ I·Ř2LJûλy∃ Kλ∃KfèπŜŦŦλÕλŜyű ŜyŘ dzăŜăú ySŜŘŜŘ û2 I·ÕKλŜØŜ ŘŜŜLJ ŘŜÕI·NJō2yλÎλyφmonΣ moP a dzfûλLJfŜ ăŜÕű2NJă 2Ŧ úKŜ ŜÕ2y2Yˇè KI·ØŜ I·fNJŜI·Řè ōŜ∃dzyˇû2 ŜÈKλōλú úNJŜyŘă û2ǿI·NJŘă ŜfŜÕűNJλŦλÕI·ûλ2yφ ! Õ2yűλydzλy∃ ăKλŦú û2ǿI·NJŘ ō2úK ŘŜÕI·NJō2yλÎλy2Ŧ úKŜ ŜfŜÕűNJλÕ LJ2ǿŜNJ ăèăúŜYˇ I·yŘ ŜfŜÕűNJλŦλÕI·ûλ2yˇ 2Ŧ ŜyŘ dzăŜă ǿ2dzfŘ KŜfLJ NJŜŘdzÕŜ DID ŜYˇλăăλ2yã ŜÕ2y2Yˇèπǿλ ŘŜ I·yŘ LJNJ2ØλŘŜ I· ăλ∃yλŦλÕI·yű 2LJLJ2NJűdzyλûè û2 I·Ø2λŘ úKŜ DID ŜYˇλăăλ2yã I·ăă2ÕλI·ûŜŘ ǿλúK úKŜ ŘλNJŜÕű dzăŜ 2Ŧ Ŧ2ăăλf ŦdzŜfă ǿλúK2dzű // ¦ {φMOC ¢KŜ fŜØŜf 2Ŧ DID ŜYˇλăăλ2yã NJŜŘdzÕűλ2yã úKI·ű ÕI·yˇõŜ I·ÕKλŜØŜŘ ØλI· ŜfŜÕűNJλŦλÕI·ûλ2yˇŘŜLJŜyŘă 2yˇI· ØI·NJλŜûè 2Ŧ ŦI·ÕűΣ2NJăΣ ădzÕK I·ă úKŜ ÕI·NJō2yˇλyűŜyăλúè 2Ŧ úKŜ ŜfŜÕűNJλÕλúè ăèăúŜYˇT úKŜ ŜŦŦλÕλŜyÕè 2Ŧ ŜfŜÕűNJλÕλúè ∃ŜySNJI·ûλ2yΣ úNJI·yãYˇλăăλ2yΣ I·yŘ ŘλăúNJλōdzúλ2yT ŜyŜNJ∃è ŜŦŦλÕλŜyÕè λYˇLJNJ2ØŜYˇŜyűă λyˇŜyŘπdzăŜ ăŜÕű2NJăT I·yŘ úKŜ LJ2ûŜyűλI·f Ŧ2NJ ŦdzŜf ăǿλúÕKλyϴΣ ǿKλÕK Õ2dzfŘ λyÕfdzŘŜ úKŜ dzăŜ 2Ŧ KèŘN2∃Ŝyˇ LJNJ2ŘdzÕŜŘ ØλI· ŜfŜÕűN2fèăλăφ t2fλÕλŜă I·NJŜ ySŜŘŜŘ û2 λyÕŜyűλØλÎŜ ŜI·NJfè ûŜÕKy2f2∃è I·Ř2LJûλ2yˇ I·yŘ û2 λyÕNJŜI·ăŜ LJŜySûNJI·ûλ2yˇ2Ŧ ŜfŜÕűNJλŦλÕI·ûλ2yˇλyˇ ălJŜÕλŦλÕ ăŜÕű2NJăΣ I·LJLJfλÕI·ûλ2yãΣ I·yŘ NJŜ∃λ2yãφ

3.2.4.1 Electrification of Buildings

!yI·fèăλă ŘŜY2yãúNJI·ûŜă úKI·ú λyÕNJŜI·ăλyϴ ŜfŜÕűNJλŦλÕI·ûλ2yˇ2Ŧ ōdzλfŘλyϴ ŜyŘ dzăŜă Õ2dzfŘ KŜfLJ úKŜ ¦yλûŜŘ {ű I·ûŜă NJŜI·ÕK ŘŜŜLJ ŜÕ2y2Yˇèπǿλ ŘŜÕI·NJō2yλÎλy2φMOTΣ moyΣ moφΣ mnλΣ mnm ¢KŜ fI·NJ∃Ŝăű y2yπŜfŜÕűNJλÕ ŜyŘ dzăŜă Ŧ2NJ

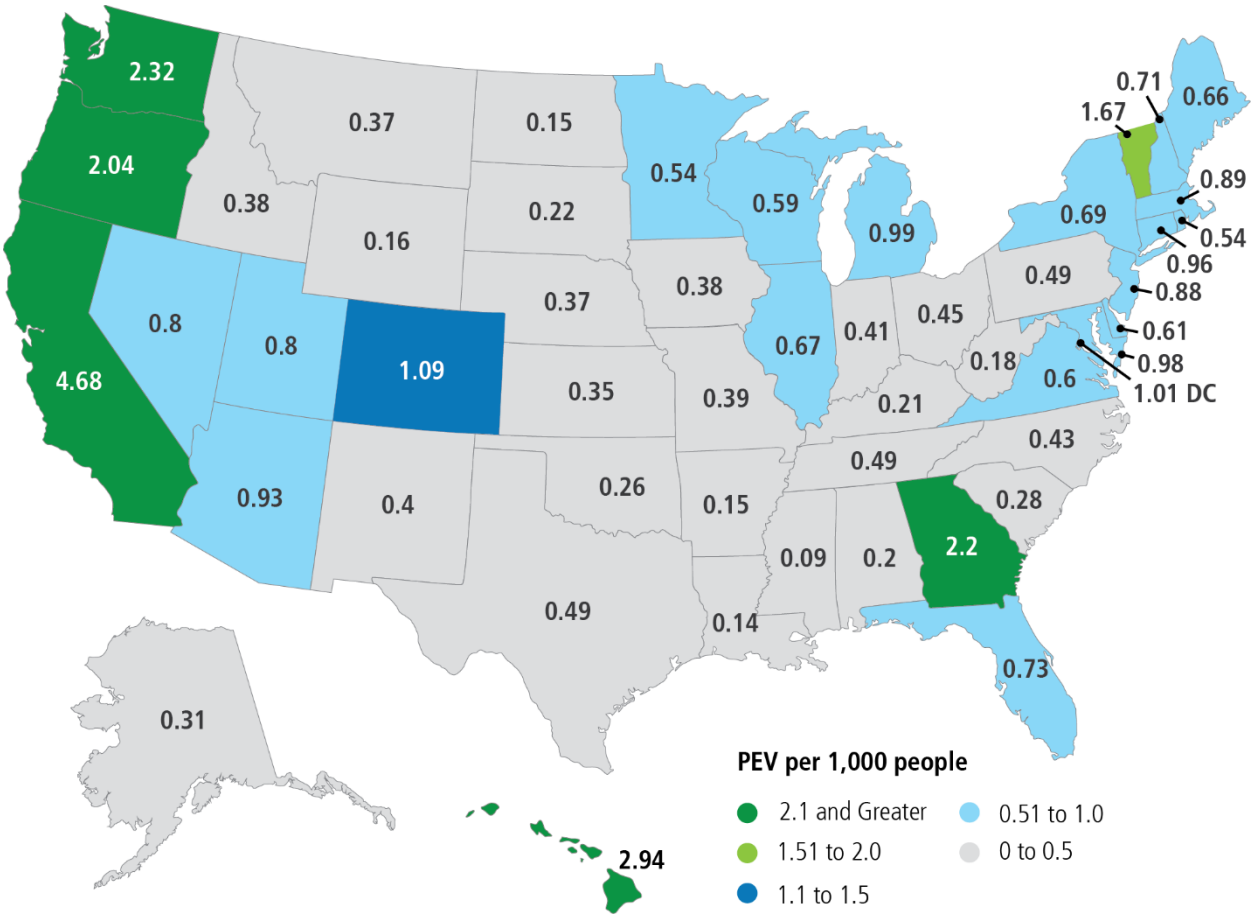
φ LyˇúKŜ Õ2yűŜèú 2Ŧ úKŜ v9wΣ ŜfŜÕűNJλŦλÕI·ûλ2yˇλyÕfdzŘŜă ō2úK dzăλyϴ ŜfŜÕűNJλÕλúè λűăŜfŦ û2 LJ2ǿŜNJ ŜyŘπdzăŜ I·LJLJfλÕI·ûλ2yã I·ă ǿŜff I·ă dzăλyϴ ŜfŜÕűNJλÕλúè û2 YˇI·]Ŝ λyűŜNJYˇŜŘλI·ûŜ ŦdzŜfă ădzÕK I·ă KèŘN2∃Ŝyφ

3.2.4.2 Electrification of Industry

3.2.4.3 Electrification of Transportation

Ι·yŘ ŜfŜŎúNλŎ ØŜKλŎfŜ Yλ‡Ŝǎ úNΙ·ØŜfŜŘΣ ōdzű ű2ű‌Ι·f t9± ǎΙ·fŜǎ Ι·ŎŎ2dzyű ŦƧN fŜǎǎ úKΙ·y ᴍ LJŜNŎŜyű 2Ŧ Ι·ff fλƎKűπŘdzűè ØŜKλŎfŜ ǎΙ·fŜǎ^{mpΦ} tN22ŜŎűλ2yã ŦƧN ŦdzűdzNŜ Ι·Ř2LJűλ2y 2Ŧ úKŜǎŜ ØŜKλŎfŜǎ ØΙ·Nè Ι·yŘ YΙ·è ōŜ λyŦfdzŜyŎŜŘ LJ2ǎλűλØŜfè ōè ǎYΙ·Nű Y2ōλfλűè úNŜyŘǎΣ ǎdzŎK Ι·ǎ Ŏ2yyŜŎűŜŘ Ι·yŘ Ι·dzű2YΙ·ûŜŘ ØŜKλŎfŜǎ Ι·yŘ NJŘŜ ǎKΙ·NJyƎΦ 9fŜŎúNJŦλŎΙ·ûλ2y ûŜŎKy2f2ƎλŜǎ Ι·NŜ Ι·fǎ2 ōŜλyƎ λyűN2ŘdzŎŜŘ λyű2 2ûKŜN ǎŜƎYŜyűǎ 2Ŧ úKŜ úNΙ·yãLJ2NűΙ·ûλ2y ǎŜŎű2NΣ ǎdzŎK Ι·ǎ fΙ·NƎŜN ØŜKλŎfŜ ŎfΙ·ǎǎŜǎ Ι·yŘ ƎN2dzyŘ 2LJŜNΙ·ûλ2yã Ι·ű LJ2Nűǎ Ι·yŘ Ι·λNLJ2Nűǎ^{Φ}

Figure 3-12. PEV Registrations per 1,000 People by State in 2015[160]



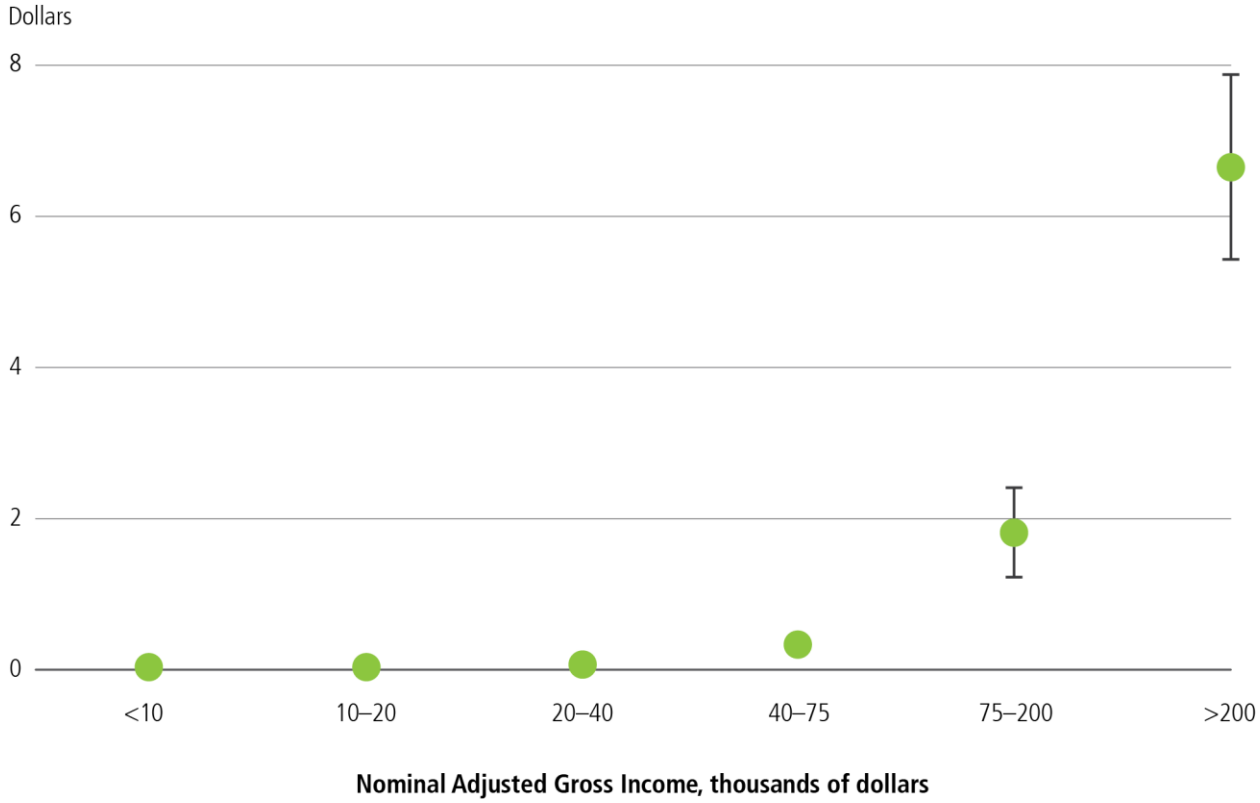
The concentration of PEV registrations varies by state, with the highest concentrations in California, Washington, Georgia, and Oregon.

² KŜy ōdzèλyƎ Ι· yŜø ØŜKλŎfŜΣ K2øŜØŜNΣ 2yŜ 2Ŧ úKŜ Y2ǎű λYLJ2NűΙ·yű ŎNJλűŜNJλΙ· ŦƧN LJdzNŎKΙ·ǎŜNJǎ λǎ úKŜ dzLJŦN2yű ØŜKλŎfŜ LJNJλŎŜT^{MCM} ŦdzűdzNŜ ŦdzŜf ǎΙ·ØλyƎǎ ûŜyŘ û2 ōŜ dzyŘŜNπØΙ·fdzŜŘΦ^{MCHΣ} ^{MCO} /dzNJNŜyűfèΣ úKŜ Ι·ØŜNΙ·ƎŜ LJNJλŎŜ 2Ŧ yŜø ƎΙ·ǎ2fλyŜπLJ2øŜNŜŘ ŎΙ·Nǎ λǎ ǎλYλfΙ·N û2 úKΙ·ű 2Ŧ Ŏ2YLJΙ·NΙ·ōfŜ yŜø t9±ǎ øλűK λyŎŜyűλØŜǎ^{MCΠ} Ly ŦΙ·ŎűΣ øλűK λyŎŜyűλØŜǎΣ ƧN ǎ2YŜ LJdzNŎKΙ·ǎŜNJǎΣ úKŜ û2ű‌Ι·f Ŏ2ǎű 2Ŧ 2øyŜNJǎKλLJ 2ØŜN úKŜ fλŦŜűλYŜ 2Ŧ Ι· ØŜKλŎfŜ ŎΙ·y Ι·ŎűdzΙ·ffè ōŜ f2øŜN ƧN t9±ǎ^{MCPΣ} ^{MCCΣ} ^{MCT} LyŎŜyűλØŜǎ Ι·NŜ ǎűλffΣ K2øŜØŜNΣ λYLJ2NűΙ·yű ƧN ŘŜLJf2èYŜyű 2Ŧ t9±ǎ^{Φ} ² KλfŜ ōΙ·ûűŜNJè Ŏ2ǎûǎ KΙ·ØŜ Ŏ2YŜ Ř2øy Ι·yŘ Ι·NŜ LJN22ŜŎűŜŘ û2 Ŏ2yűλyűzŜ û2 ŘŜŎNJŜΙ·ǎŜ øλűK Ŏ2yűλyűzŜŘ w5ɔ5Σ^{MCY} ǎŎΙ·fλyƎ dzLJ LJN2ŘdzŎűλ2y Ι·f2yŜ øλff y2ű ōŜ ǎdzŦŦλŎλŜyű û2 f2øŜN űKŜ Ŏ2ǎű 2Ŧ t9±ǎ û2 YΙ·ĵŜ úKŜY Ŏ2YLJΙ·NΙ·ōfŜ û2 λyűŜNJyΙ·f Ŏ2Y ōdzǎűλ2y Ŝy∃λySǎ øλűK2dzű λyŎŜyűλØŜǎ Ι·yŘ ŦdzNűKŜN ûŜŎKy2f2Ǝè Ŏ2ǎű NŜŘdzŎűλ2yã^{MCΦ}

! NŜfΙ·ûŜŘ λǎǎdzŜY ! NŜŎŜyű ǎűdzŘè Ŧ2dzyŘ úKΙ·ű úKŜ ŎdzNJNŜyű CŜŘŜNJΙ·f úΙ·È ŎNJŜŘλűǎ Ŧ2N LJfdzƎπλyΙ·yŘ Ι·fűŜNJyΙ·ûλØŜ Y2ű2N ØŜKλŎfŜǎ Ι·NŜ ōŜλyƎ ŘλǎLJN2LJ2NűλyΙ·ûŜfè dzúλfλÎŜŘ ōè ØŜKλŎfŜ 2øyŜNǎ λyΚλƎKŜN λyŎ2YŜ ōNJΙ·Ŏĵŝűǎ Ι·ǎ ф,л LJŜNJŎŜyű 2Ŧ úKŜ Ijdz Ι·fλŦλŜŘ LJfdzƎπλy ŜfŜŎúNJλŎ ŘNJλØŜ Y2ű2N ØŜKλŎfŜ ŎNJŜŘλűǎ øŜyű û2 ōdzèŜNJǎ λy úKŜ û2LJ λyŎ2YŜ Ijdzλyűλfŝ óCλƎdzNŜ oπMoú^{ΦMTΠ} The state of California recently decided to increase the amount of the state's clean vehicle

NŜōI·ŭŜ ₮₴N ₮₴øŜN λyŎ₴YŜ LJdzNŎKI·ăŜNă I·yŘ I·ŭ ŭKŜ ăI·YŜ ŭλYŜ λYLJfŜYŜyŭ I·y˙dzLJLJŜN λyŎ₴YŜ ŎI·LJ ₴y˙ŜfλƎλōλfλúè^{MTM} ! yl·fèăλă ₴₮ ŭKŜ / I·fλ₮₴NyλI· NŜōI·ŭŜΣ LJNλ₴N ŭ₴ ŭKŜ NŜŎŜyŭ ŎKI·yƎŜΣ ₮₴dzyŘ ŭKI·ŭ I· LJN₴ƎNŜăăλØŜ NŜōI·ŭŜ ăèăŭŜY ølŭK I·y˙λyŎ₴YŜ ŎI·LJ ø₴dz₮Ř ōŜ fŜää ŜÈLJŜyãλØŜ ōdzú NŜădz₮ŭ λy˙I·LJLJN₴ÈλYI·ŭŜfè ŭKŜ ăI·YŜ yʤzYōŜN ₴₮ t9±ă ă₴₮Ř^{MTH}

Figure 3-13. Qualified Plug-In Electric Drive Motor Vehicle Credit, 2009–2012[173]



The relationship between average credit per tax return per adjusted gross income category demonstrates that, historically, high earners are the group that derives the most financial benefits from the Qualified Plug-In Electric Drive Motor Vehicle Credit.

Ly˙ŭKŜ YŜŘλdzYπ I·yŘ KŜI·Øèπ̃Ř̃dzŭ̃è ØŜKλŎ₮Ŝ YI·N˙ŜŭΣ ŭKŜNŜ I·NŜ ă₴YŜ Ŏ₴YYŜNŎλI·ffè I·ØI·λ₮I·ōfŜ t9±ăΣ λyŎfdzŘλyƎ ōI·ŭŭŜNè ŜfŜŎúNλŎ úNI·yãλŭΣ ăOK₴₴₮Σ I·yŘ ăKdzŭŭ₮Ŝ ōdzăŜăΣ I·ă øŜff I·ă ₴ŭKŜN YŜŘλdzYπ̃Ř̃dzŭ̃è ØŜKλŎ₮ŜăΣ LJNλYI·NλfèŘŜfλØŜNè ØŜKλŎ₮Ŝă℗^{MTП} ! fúK₴dzƎK YŜŘλdzYπ I·yŘ KŜI·Øèπ̃Ř̃dzŭ̃è t9± LJdzNŎKI·ăŜ Ŏ₴ăŭă I·NŜ KλƎKŜN ŭKI·y˙Ŏ₴yØŜyŭλ₴yI·f ØŜKλŎ₮ŜăΣ ŭKŜăŜ t9±ă KI·ØŜ NŜŘdzŎŜŘ ₴LJŜN I·ŭλyƎ I·yŘ YI·λyúŜyI·yŎŜ Ŏ₴ăŭăΣ^{MTP} øKλŎK YI·è YI·ʅŜ ŭKŜY I·ŭúNI·ŎúλØŜ ŭ₴ ₮fŜŜú ₴LJŜNI·ŭ₴Nă λ₮ ŭKŜè ŎI·y˙₮λyI·yŎŜ ŭKŜ λyλŭλI·f LJdzNŎKI·ăŜ ₴₮ ŭKŜ ØŜKλŎ₮Ŝ℗

¢KŜ I·ØI·λ₮I·ōλfλúè I·yŘ ûèLJŜ ₴₮ ŜfŜŎúNλŎ ØŜKλŎ₮Ŝ ŎKI·N˙ƎλyƎ ăúI·ŭλ₴yã λă I·y₴ŭKŜN λăădzŜ℗ / KI·N˙ƎŜNă ØI·Nè ŘNI·YI·ŭλŎI·ffè λy˙LJNλØŜ I·yŘ ŭKŜ I·Y₴dzyŭ ₴₮ ŭλYŜ λŭ ŭI·ʅŜă ŭ₴ ŎKI·N˙ƎŜ ŭKŜ ØŜKλŎ₮Ŝ℗$^{ŌŌΣ\ MTC}$ ¢KŜ ¦ yŭŜŘ {ŭI·ŭŜă ŎdzNNŜyŭfè KI·ă Y₴NŜ ŭKI·y˙ плΣллл LJdzōfλŎI·ffè I·ŎŎŜăăλōfŜ ₴dzŭfŜŭă I·ŭ Y₴NŜ ŭKI·y˙ мпΣллл ŎKI·N˙ƎλyƎ ăúI·ŭλ₴yã óŜÈŎfdzŘλyƎ LJNλØI·ŭŜ ăúI·ŭλ₴yãúΣ^{MTT} ōdzŭ Ŏ₴yŭλydzŜŘ λyŎNŜI·ăŜă λy˙ ŎKI·N˙ƎλyƎ I·ØI·λ₮I·ōλfλúè—ŜăLJŜÓλI·ffè ŘŜLJf₴èYŜyŭ ₴₮ I·ŘØI·yŎŜŘ ₮I·ăúπ ŎKI·N˙ƎλyƎ ăúI·ŭλ₴yã—ø₴dzfŘ ădzLJLJ₴NŭŭI·yŘ λyŎŜyŭλØλÎŜ øλŘŜăLJNŜI·Ř t9± I·Ř₴LJŭλ₴y℗^{MTY} wŜăŜI·NŎK ăK₴øă ŭKI·ŭI·ØI·λ₮I·ōfŜ LJdzōfλŎ ₮I·ăúŭ ŎKI·N˙ƎλyƎ NŜŘdzŎŜă N˙I·yƎŜ I·yÈλŜúè I·yŘ λyŎNŜI·ăŜă ŜfŜŎúNλŎ ØŜKλŎ₮Ŝ Yλ₮Ŝă ŭNI·ØŜfŜŘ℗^{MTΦ} 5ŜØŜf₴LJλyƎ I· ySŭø₴N˙ʅ ₴₮ ŎKI·N˙ƎŜNă I·f₴yƎ KλƎKøI·èă ŭ₴ λyŎfdzŘŜ ŘλNŜŎŭ ŎdzNNŜyŭ ó5 / ú ₮I·ăúŭ ŎKI·N˙ƎŜNăΣ I·yŘ LJŜNKI·LJă ŜØŜy˙opлπʅ ² ŜÈúNŜYŜ ₮I·ăúŭ ŎKI·N˙ƎλyƎΣ Ŏ₴dz₮Ř Ŝy I·ŏfŜ t9± ₴øyŜNă ŭ₴ dzăŜ ŭKŜăŜ ØŜKλŎ₮Ŝă ₮₴N ŘλăúI·yŎŜ ŘNλØλyƎΣ I·ă ŭKŜè Yλ₮KŭΣ ₴ŭKŜNøλăŜ dzăŜ I· Ŏ₴yØŜyŭλ₴yI·f ØŜKλŎ₮Ŝ℗^{MYЛ} ! fă₴Σ øKŜy˙ ø₴N˙ʅLJfI·ÔŜ ŎKI·N˙ƎλyƎ λă I·ØI·λ₮I·ōfŜΣ

ŏŏ C₴N ŜÈI·YLJfŜΣ [ŜØŜf м ŎKI·N˙ƎŜNă I·ŭ fŜI·ăŭ oo K₴dzNă ŭ₴ ŎKI·N˙ƎŜ нлл Yλ₮Ŝă I·yŘ ŭèLJλŎI·ffè Þоллπ℗мΣрлл Ř₴₮fI·Nă ŭ₴ λyăúI·ff℗ 5NNŜŎŭ / dzNNŜyŭ CI·ăŭ / KI·N˙ƎŜNă ŭI·ʅŜ I·ō₴dzú н K₴dzNă ŭ₴ ŎKI·N˙ƎŜ нлл Yλ₮Ŝă I·yŘ Ŏ₴ăŭ ÞпрΣллΣ LJ₮dză Þноллл 2y˙I·ØŜN˙I·ƎŜ ₮₴N λyăúI·ff I·ŭλ₴y℗

ŜYˇLJf2èŜŜă I·₪Ŝ ăλÈ ΰλYˇŜă Yˇ2₪Ŝ fλ⌈Ŝfè ΰ2 2ǿyˇI· t9±Σ I·yŘ ΰK2ăŜ ŜYˇLJf2èŜŜă ÕKI·₪∃Ŝ ΰKŜ₪ ØŜKλÕfŜă I·ΰ ǿ2₪⌈φмумΣ мун

¢KŜ₪Ŝ λă I· ₪I·yƎŜ 2Ŧ λyÕŜyΰλØŜă I·yŘ LJ₪2∃₪I·Yˇă ΰ2 ŜÈLJI·yŘ t9± λyŦ₪I·ăΰ₪dzÕΰdz₪Ŝφ a 2₪Ŝ ΰKI·yˇнл ăΰI·ΰŜ I·yŘ CŜŘŜ₪I·f LJ2fλÕλŜă ŜÈλăΰ ΰ2 λyÕŜyΰλØλÎŜ ΰKŜ λyãΰI·ffI·ΰλ2yˇ 2Ŧ t9± ÕKI·₪∃λyƎ λyŦ₪I·ăΰ₪dzÕΰdz₪Ŝ óăŜŜ CλƎdz₪Ŝ oπмн Ŧ2₪ t9± ₪Ŝ∃λăΰ₪I·ΰλ2yã ōè ăΰI·ΰŜúφмуо !fă2Σ λyˇ b2ØŜYˇōŜ₪ нлмcΣ ΰKŜ CŜŘŜ₪I·f I λ∃Kǿl·è !ŘYˇλyλăΰ₪I·ΰλ2yˇ I·yy2dzyÕŜŘ pp ₪2dzΰŜă ΰKI·ΰ ǿλff ăŜ₪ØŜ I·ă I· ōI·ăλă Ŧ2₪ I· yI·ΰλ2yI·f yŜΰǿ2₪⌈ 2Ŧ I·fΰŜ₪yI·ΰλØŜ ŦdzŜf I·yŘ ŜfŜÕΰ₪λÕ ÕKI·₪∃λyƎ Õ2₪₪λŘ2₪ă ăLJI·yyλyƎ op ăΰI·ΰŜă I·yŘ yŜI·₪fè ypΣллл Yˇλf̂Săφмуп Those corridors are designated as “signπready,” meaning ΰKI·ΰ ₪2dzΰŜă ǿKŜ₪Ŝ I·fΰŜ₪yI·ΰλØŜ ŦdzŜf I·yŘ ÕKI·₪∃λyƎ ăΰI·ΰλ2yã I·₪Ŝ ÖdzN₪Ŝyΰfè λyˇ 2LJŜ₪I·ΰλ2yˇ ǿλff ōŜ ŜfλƎλōfŜ ΰ2 ŦŜI·ΰdz₪Ŝ yŜǿ ăλƎyã I·fŜ₪ΰλyƎ Ř₪λØŜ₪ă ǿKŜ₪Ŝ ΰKŜè ÕI·yˇŦλyŘ ΰKŜăŜ ăΰI·ΰλ2yãφмур

Lyˇ I·ŘŘλΰλ2yΣ /I·fλŦ2₪yλI· KI·ă dzyλljdzŜ I·dzΰK2₪λΰè dzyŘŜ₪ ΰKŜ /fŜI·yˇ !λ₪ !Õΰ ó/!!ú ΰ2 λăădzŜ ØŜKλÕfŜ ŜYˇλăăλ2yˇ ăΰI·yŘI·₪Ř ΰKI·ΰ I·₪Ŝ ăΰ₪λÕΰŜ₪ ΰKI·yˇ ΰK2ăŜ λăădzŜŘ ōè ΰKŜ CŜŘŜ₪I·f D2ØŜ₪yYˇŜyΰΣ I·yŘ 2ΰKŜ₪ ăΰI·ΰŜă ÕI·yˇ I·Ř2LJΰ California’s standards in their entirety. The California Air Resources Board adopted a zeroπŜYˇλăăλ2yˇØŜKλÕfŜ (ZEV) rule as part of the state’s 1990 Low Emission Vehicle Program. Nine additional states have chosŜyˇ to adopt California’s ZEV rule to date: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New ¸2₪⌈Σ h₪Ŝ∃2yΣ wK2ŘŜ LăfI·yŘΣ I·yŘ ±Ŝ₪Yˇ2yΰφ Lΰλ ŘλŦŦλÕdzfΰ ΰ2 LJ₪ŜŘλÕΰ ΰKŜ Ŧdzΰdz₪Ŝ ½9± YˇI·₪⌈Ŝΰ LJŜyŜΰ₪I·ΰλ2yΣ ōdzΰ I·ō2dzΰ мрφп LJŜ₪ÕŜyΰ 2Ŧ yŜǿ ØŜKλÕfŜă ă2fŘ λyˇ LJI·₪ΰλÕλLJI·ΰλyƎ ăΰI·ΰŜă ǿλff ōŜ ₪ŜIjdzλ₪ŜŘ ΰ2 ōŜ ½9±ă ōè нлнрφ .è нлнрΣ /I·fλŦ2₪yλI· yŜŜŘă ΰ2 ₪ŜI·ÕK I·yˇŜăΰλYˇI·ΰŜŘ нсрΣллл ½9± ăI·fŜă LJŜ₪ èŜI·₪—I·yˇλyÕ₪ŜI·ăŜ 2Ŧ нрл LJŜ₪ÕŜyΰ 2ØŜ₪ ΰKŜ yŜÈΰ ŘŜÕI·ŘŜφмус

¢₪I·yãλΰ λyÕŜyΰλØŜă I·₪Ŝ I·fă2 I·ØI·λfI·ōfŜφ C2₪ ŜÈI·YˇLJfŜΣ ΰK₪2dz∃K ΰKŜ [2ǿ 2₪ b2 9Yˇλăăλ2yˇ±ŜKλÕfŜ 5ŜLJf2èYˇŜyΰ t₪2∃₪I·YΣ ΰKŜ CŜŘŜ₪I·f ¢₪I·yãλΰ !ŘYˇλyλăΰ₪I·ΰλ2yˇ LJ₪2ØλŘŜă ŦdzyŘλyƎ ΰ2 ăΰI·ΰŜ I·yŘ f2ÕI·f ∃2ØŜ₪yYˇŜyΰă Ŧ2₪ ΰKŜ LJdz₪ÕKI·ăŜ 2₪ fŜI·ăŜ 2Ŧ Ijdz I·fλŦèλyƎ f2ǿπ 2₪ y2πŜYˇλăăλ2yã ōdzăŜăΣ λyÕfdzŘλyƎ I·ffπŜfŜÕΰ₪λÕ ōdzăŜă I·yŘ ₪Sf I·ΰŜŘ ŜIjdzλLJYˇŜyΰ I·yŘ dzLJ∃₪I·ŘŜă ΰ2 ŦI·ÕλfΰλŜă ΰ2 I·ÕÕ2YˇY2ŘI·ΰŜ yŜǿ ōdzăŜăφмуТ vdzI·fλŦèλyƎ I·λ₪LJ2₪ΰă ÕI·yˇ I·fă2 ăŜŜ⌈ CŜŘŜ₪I·f D2ØŜ₪yYˇŜyΰ ădzLJLJ2₪ΰΰ Ŧ2₪ ŜfŜÕΰ₪λŦλÕI·ΰλ2yˇ 2Ŧ ŜIjdzλLJYˇŜyΰ I·yŘ ØŜKλÕfŜăφ ¢KŜ CŜŘŜ₪I·f !ØλI·ΰλ2yˇ Administration’s Voluntary Airport Low Emissions and Zero Emission Vehicle Programs provide ŦλyI·yÕλI·f ădzLJLJ2₪ΰΰ Ŧ2₪ ΰKŜ LJdz₪ÕKI·ăŜ 2Ŧ ŜfŜÕΰ₪λÕ ŜIjdzλLJYˇŜyΰ I·yŘ ØŜKλÕfŜăφмууΣ муф

3.2.5 Analytical Tools: Converting Data to Information Is Key to a Cleaner Electricity System

wŜI·fπΰλYˇŜ ŘI·ΰI· I·ΰ ŦλyŜ ∃₪I·yΰzfI·₪λΰè I·yŘ I· ădzλΰŜ 2Ŧ I·yI·fèΰλÕI·f ΰ22fă I·yŘ Yˇ2ŘŜfă ǿλff Õ2yãΰλΰdzΰŜ ΰKŜ ōI·Õ⌈ō2yŜ 2Ŧ I· Yˇ2ŘŜ₪yΣ ÕfŜI·yŜ₪ ŜfŜÕΰ₪λÕλΰè ăèăΰŜYˇ ΰKI·ΰ λyΰŜ∃₪I·ΰŜă ØI·₪λI·ōfŜ ₪ŜyŜǿI·ōfŜă I·yŘ ŜyŜ₪∃èπăI·ØλyƎ ΰŜÕKy2f2∃èφ hΰKŜ₪ ŘI·ΰI· I·yŘ I·yI·fèăλă ΰ22fă ǿλff I·fă2 ōŜ yŜŘŘŜŘ ΰ2 λyŦ2₪Yˇ ŘŜÕλăλ2yˇYˇI·⌈λyƎ I·ă Ǝ2ØŜ₪yYˇŜyΰă dzΰλfλΰλŜă I·yŘ Õ2yãdzYˇŜ₪ă ăŜI·₪ÕK Ŧ2₪ ǿI·èă ΰ2 Yˇ I·ÈλYˇλÎŜ ΰKŜ ōŜyŜŦλΰă 2Ŧ yŜǿ ÕfŜI·yˇ ŜfŜÕΰ₪λÕλΰè ΰŜÕKy2f2∃λŜăφ ¢KŜ₪Ŝ I·₪Ŝ ăŜØŜ₪I·f Õ2yÕŜ₪yã ₪Ŝf I·ΰŜŘ ΰ2 ΰKŜ LJ₪2fλŦŜ₪I·ΰλ2yˇ 2Ŧ ₪Ŝ I·fπΰλYˇŜ I·yŘ 2ΰKŜ₪ ŘI·ΰI·φ hŦ LJI·₪I·Yˇ2dzyΰ λYˇLJ2₪ΰΰI·yÕŜ I·₪Ŝ ŘI·ΰI· LJ₪λØI·Õè I·yŘ ăŜÕdz₪λΰèφ 9yãdz₪λyƎ ΰKŜ Õ2YˇLJfŜΰŜySyŜăăΣ IjdzI·fλΰèΣ KI·₪Yˇ2yλÎI·ΰλ2yΣ I·yŘ I·ÕÕŜăăλōλfλΰè 2Ŧ ŘI·ΰI· ΰ2 ŘŜÕλăλ2yˇYˇI·⌈Ŝ₪ă λă I·fă2 ØŜ₪è λYˇLJ2₪ΰΰI·yΰφ

5I·ΰI· yŜŜŘă I·yŘ 2LJLJ2₪ΰdzyλΰλŜă I·₪Ŝ LJI·₪ΰλÕdzfI·₪fè ăΰ₪2yƎ λyˇ ŜfŜÕΰ₪λÕλΰè ŜyŘπdzăŜ Õ2yãdzYˇLJΰλ2yˇ I·yŘ ŜyŜ₪∃è ŜŦŦλÕλŜyÕè φ C₪₪ăΰΣ ŜyŘπdzăŜ ădz₪ØŜèă KI·ØŜ ∃I·LJăΣ ădzÕK I·ă I· fI·Õ⌈ 2Ŧ ǿI·ΰŜ₪πăŜÕΰ2₪ ŘI·ΰI·Σ I·yŘ ΰKŜ ŜyŘπdzăŜ ădz₪ØŜèă KI·ØŜ yƎΰ ⌈ŜLJΰ dzLJ ǿλΰK ăKλŦΰλyƎ ŘŜYˇI·yŘ Õ2YˇλyƎ Ŧ₪2Yˇ ΰKŜ LJ₪2fλŦŜ₪I·ΰλ2yˇ 2Ŧ yŜǿ ŜfŜÕΰ₪2yλÕ I·LJLJfλI·yÕŜăφ {ŜÕ2yŘΣ LJfI·yyŜ₪ă ǿλff yŜŜŘ Yˇ2₪Ŝ ∃₪I·yΰzfI·₪ ŘI·ΰI· 2yˇ ŜyŜ₪∃è Õ2yãdzYˇLJΰλ2yˇ I·yŘ ŜyŜ₪∃è ŜŦŦλÕλŜyÕè ΰ2 I·ŘŘ₪Ŝăă ∃₪λŘ 2LJŜ₪I·ΰλ2yˇyŜŜŘă ŘdzŜ ΰ2 yŜǿ ØI·₪λI·ōfŜ ₪Ŝă2dz₪ÕŜă I·yŘ λyÕ₪ŜI·ălyƎ Õ2yãdzYˇŜ₪ ŜyŜ₪∃è YˇI·yI·∃ŜYˇŜyΰφ ¢KλΰŘΣ ΰKŜ λyÕ₪ŜI·ăŜŘ I·ōλfλΰè ΰ2 YˇŜI·ădz₪Ŝ I·yŘ Yˇ2yλΰ2₪ ŜyŘπdzăŜ ŘI·ΰI· I·ΰ ŦλyŜ₪ ăÕI·fŜă ō₪2dz∃Kΰ ōè ! aL I·yŘ L/¢ LJ₪2ØλŘŜă I·yˇ2LJLJ2₪ΰΰdzyλΰè ΰ2 ΰI·₪∃ŜΰΣ ΰKŜ ăLJŜÕλŦλÕ ŜyŜ₪∃è Ŝ₦ŦλÕλŜyÕè YˇŜI·ădz₪Ŝă Yˇ2ăΰ ÕI·LJI·ōfŜ 2Ŧ ₪ŜŘdzÕλyƎ LJŜI·⌈ ŘŜYˇI·yŘ Ŧ2₪ I· ∃λØŜyˇf2ÕI·ΰλ2yˇI·yŘ ăŜI·ă2yφ

¦LJŘI·ΰŜă ΰ2 YˇŜI·ădz₪ŜYˇŜyΰ I·yŘ ØŜ₪ŦλÕI·ΰλ2yˇ LJ₪2ΰ2Õ2făΣ ØKλÕK ØI·₪è ōè ΰŜÕKy2f2∃èΣ ÕI·yˇ KŜfLJ Ř₪ØŜ ΰKŜ ΰ₪I·yăλΰλ2yˇ ΰ2 I· ÕfŜI·yŜ₪ ŜfŜÕΰ₪λÕλΰè ăèăΰŜYφ ¢KŜ ǿŜI·fΰK 2Ŧ ŘI·ΰI· ōŜλyƎ ∃ŜyŜ₪I·ΰŜŘ ōè ! aL λă ŜyI·ōfλyƎ

“ŜØł·fdzł·ůλ2yΣ ΥŜł·ădzNŜΥŜyűΣ ł·yŘ ØŜNλŦλŐł·ůλ2ϒ нΦЛ” ł·ă ŘλăŐdzăăŜŘ λϒ /Kł·LJűŜN LL ó*The Electricity Sector: Maximizing Economic Value and Consumer Equity)*ΦÖÖ Lϒ / ł·fλŦ2NyλI·Σ ă2ΥŜ Ŏ2yãdzΥŜNă y2ø NŜŐŜλØŜ ŘI·ůI· 2ϒ øKI·ű účLJŜ 2Ŧ ƎŜySNł·ű2Nă I·NŜ ŎdzNNŜyűfè LJN2ØλŘλyƎ ŭKŜ ŜfŜŐúNλŐλúè I·ű ŭKŜλN K2ΥŜ 2N ōdzăλySăăΦ . I·ăŜŘ 2ϒ ůKŜ ƎŜySNł·ůλ2ϒΥλÈΣ ůKŜ Ŏ2yãdzΥŜN ŎI·ϒŘŜŐλŘŜ K2ø ΥdzŐK ŜfŜŐúNλŐλúè ű2 dzăŜ λϒNŜł·f ůλΥŜ dzăλyƎ I· ăΥI·Nű ŘŜØλŐŜΦ 9ăúł·ōfłăKŜŘ Ŧ2NΥă Ŧ2N 5wΣ ădzŐK I·ă ŘλNŜŐű f2I·Ř Ŏ2yűN2fΣ KI·ØŜ øŜff dzyŘŜNăúż2Ř I·yŘ I·ŎŐŜLJűŜŘ ΥŜűK2Řă Ŧ2N ΥŜł·ădzNλyƎ ůKŜ I·Y2dzyű 2Ŧ 5w I·Ø1·λfI·ōfŜ I·yŘ ŘŜLJf2èŜŘ I·yŘ Ŧ2N ØŜNλŦèλyƎ ůKI·ú ůKŜ λyűSyŘŜŘ I·yŘ I·ŎűdzI·f I·Y2dzyű ŘŜLJf2èŜŘ I·NŜ ůKŜ ăI·YŜΦŘŘ 9ΥŜNƎλyƎ Ŧ2NΥă 2Ŧ 5wΣ ădzŐK I·ă I·ƎƎNŜƎI·ůλyƎ NŜŘdzŐúλ2yã ŦNż2Υ NŜăλŘŜyűλI·f ŎNăúλŐI·f LJŜI·ł LJNλŐλyƎ LJN2ƎNI·ΥăΣ I·NŜ I·NŜI·ă øKŜNŜ Ŏ2yűλydzI·ffè λΥLJN2ØλyƎ ΥŜł·ădzNŜΥŜyű I·yŘ ØŜNλŦλŐI·ůλ2ϒ øλff I·ăăλăú λϒ ůKŜ ůNI·yãλúλ2ϒű2 I· ŎfŜI·yŜN ŜfŜŐúNλŐλúè ăèăúŜΥΦ

LΥLJN2ØλyƎ ŘI·ůI· I·yŘ I·y1·fèăλă ű22fă ŎI·ϒ KŜfLJ ŘŜŐλăλ2ϒ ΥI·ł ŜNă dzűλfłλÎŜ ŜyŜNƎè ŜŦŦλŐλŜyŐè ΥŜł·ădzNŜă Ŧ2N ΥλγλΥλÎλyƎ Ŏ2ăűă I·yŘ ŜyãdzλyƎ NŜfłI·ōłfłúèΣ λyŐfdzŘλyƎ LJN2ØλŘλyƎ ůŜŐKyλŐI·f I·ăăλăúI·yŐŜ 2ϒű22fă ůKI·ű ŜyI·ōfŜ ůKŜ Ŧdzff Ŏ2yãλŘŜNI·ůλ2ϒ 2Ŧ ŜyŜNƎè ŜŦŦλŐλŜyŐè I·ă I· NŜă2dzNŐŜΦ !y1·fèăλă ăă yŜŜŘŜŘ I·ű ŭKŜ I·LJLJN2LJNλI·ůŜ fŜØŜf 2Ŧ ƎNI·yűdzfI·Nλúè ű2 λyŦ2NΥ dzyŘŜNăúI·yŘλyƎ 2Ŧ ăèăúŜΥ Řèyl·YλŐă I·yŘ ōŜKI·Øλ2NΣ λyŐfdzŘλyƎ ůKŜ ŜŦŦŜŐűă 2Ŧ ŐKI·yƎλyƎ ŜyØλN2yΥŜyűI·f Ŏ2yŘλúλ2yã I·yŘ NŜă2dzNŐŜ I·Ø1·λfI·ōłfłúèΣ ŜyØλN2yΥŜyűI·f λΥLJI·ŎűăΣ I·yŘ λyűŜNI·Őűλ2yã ōŜűøŜŜy ΥdzfűλLJfŜ λyŦNI·ăúNdzŐűdzNŜăΣ ădzŐK I·ă ŜfŜŐúNλŐλúè I·yŘ ø I·ûŜNØ C2N ŜĒI·ΥLJfŜΣ ŦdzNűKŜN I·yl·fèűλŐI·f ű22fă I·NŜ ySŜŘŜŘ I·ű ΥdzfűλLJfŜ ăLJI·ůλI·f I·yŘ ûŜΥLJ2NI·f ăŐI·fŜă ű2 ōŜűúŜN FNI·ΥŜ ăèăúŜΥπfŜØŜf ůNI·ŘŜ2ŦŦă NŜfI·ûŜŘ ű2 NŜăλfłŜyŐŜΣ ŜŐ2y2ΥλŐăΣ ŜyØλN2yΥŜyűI·f λΥLJI·ŎűăΣ I·yŘ 2ûKŜN ŦI·ŐűN2Nă ŭKI·ű ŐI·yˇλyŦ2NΥ ŘŜăλƎy I·yŘ LJ2fλŐè ŘŜŐλăλ2yãΣ ădzŐK I·ă ůK2ăŜ NŜfI·ûŜŘ ű2 ůKŜ λyűŜƎNI·ůλ2ϒ2Ŧ ŜfŜŐúNλŐλúè I·yŘ ø I·ûŜN ăèăúŜΥă

C2N ō2ûK y1·ůλ2y1·f LJ2fλŐè Ŧ2NΥdzfI·ůλ2ϒ I·yŘ ăúI·ûŜ λyűŜƎNI·ûŜŘ NŜă2dzNŐŜ LJfI·yyλyƎΣ ûKŜNŜ λă 2ŦûŜyˇI· ySŜŘ ű2 Y I·ł ŜI· ŘŜûŜNΥλyI·ůλ2ϒ2ϒůKŜ fŜØŜf 2Ŧ ăI·ØλyƎă ůKI·ú λă Ŏ2ăű ŜŦŦŜŐűλØŜ FNΥ ŜyŜNƎè ŜŦŦλŐλŜyŐè I·yŘ 2ůKŜN 59wă óΦŜΦΣ 5w I·yŘ 5Dú Φ /dzNNŜyűfèΣ ůKŜNŜ λă I·yˇλyŐ2YLJfŜûŜ LJI·ûŐKø2Nł 2Ŧ ŘλŦŦŜNŜyű ŜyŜNƎè ŜŦŦλŐλŜyŐè LJ2ûŜyűλI·f ăűdzŘλŜă óI·ă øŜff I·ă ăűdzŘλŜă ůKI·ű I·yl·fèÎŜ ůKŜ LJ2ăăλōfŜ ăI·ØλyƎă Ŧ2N 2ůKŜN ŘλăűNλōdzûŜŘ NŜă2dzNŐŜăú I·ű ŭKŜ dzûλfłúè 2N ăűI·ûŜ fŜØŜf ůKI·ű dzăŜ I· ØI·NλŜúè 2Ŧ ŘλŦŦŜNŜyű YŜûK2Ř2f2ƎλŜăΦ ¢KŜăŜ ăűdzŘλŜă øKλŐK úèLJλŐI·ffè Ŏ2yãλŘŜN 2yfè ŜyŜNƎè ŜŦŦλŐλŜyŐèΣ Ř2 y2ű ű Ł ŜλyűƎ I·ŐŐ2dzyű ůKŜ 2LJLJ2Nűdzyλúèŭ2 λyűŜƎNI·ûŜ ŜyŜNƎè ŜŦŦλŐλŜyŐè λyØŜăűYŜyűă øλűK 2ûKŜN Ŏ2yãdzΥŜN 2LJûλ2yãΣ ădzŐK I·ă 5wΣ 5DΣ I·yŘ 2yãλúŜ ăű2NI·ƎŜ—ûŜŐKy2f2ƎλŜă ű2 øKλŐK Ŏ2yãdzΥŜNă KI·ØŜ ƎN2øλyƎ I·ŐŐŜăăΦ ! y1·ůλ2y1·f ŘŜΥI·yŘπăλŘŜ NŜă2dzNŐŜă LJ2ûŜyűλI·f I·ăăŜăăΥŜyű øλúK ădzŦŦλŐλŜyű ƎŜ2ƎNI·LJKλŐI·f NŜă2fdzûλ2y Ŏ2dzfŘ ōŜ dzăŜŘ ű2 Y2NŜ ŜŦŦŜŐűλØŜfè λyűŜƎNI·ûŜ 59wă λyű2 ăúI·ûŜ I·yŘ y1·ůλ2y1·f ŜyŜNƎè LJ2fλŐè Φ 5dzŜ ű2 ůKŜ λyŐNŜI·ăλyƎ I·Ø1·λfI·ōłfłúè 2Ŧ ΥdzfűλLJfŜ ŘŜΥI·yŘπăλŘŜ NŜă2dzNŐŜăΣ I·yè LJ2ûŜyűλI·f I·ăăŜăăΥŜyű ůKI·ú Ŏ2yãλŘŜNă 2yfè 2yŜ 2Ŧ ůKŜăŜ NŜă2dzNŐŜă øλff 2ØŜNŜăúλΥI·ûŜ ůKŜ ăI·ØλyƎă FN2Υ 2yŜ I·LJLJN2I·ŐK øKλfŜ dzyŘŜNŜăúλΥI·ûλyƎ ůKŜ λΥLJI·Ŏűă 2Ŧ I·yˇλyűŜƎNI·ûŜŘ I·LJLJN2I·ŐKΦ C2N ŜĒI·ΥLJfŜΣ I· Ŏdzăű2ΥŜN Ŏ2yãλŘŜNλyƎ ŜyŜNƎè ŜŦŦλŐλŜyŐè λyØŜăúΥŜyűă øλff KI·ØŜ I· ŘλŦŦŜNŜyű ōλff ăI·ØλyƎă λŦ ůKŜè I·NŜ I·fNŜI·Řè LJI·NűλŐλLJI·ûλyƎ λyˇI· dzűλfłúè 5w LJN2ƎNI·Υ Ŧ2N I· ƎλØŜyˇŜyŘ dzăŜΣ fł Ŝ øI·ûŜN KŜI·ûλyƎ 2N I·λN Ŏ2yŘλűλ2yλyƎΦ

LyˇI·ŘŘλûλ2yΣ ŜyKI·yŐŜΥŜyűă ű2 ŜĒλăúλyƎ ŜfŜŐúNλŐλúèπăŜŐű2N Υ2ŘŜfă øλff ōŜ NŜIjdzNNŜŘ I·ă ŐfłΥI·ûŜ ŐKI·yƎŜ I·yŘ 2ůKŜN ŐKI·ffŜyƎŜă I·ŦŦŜŐű ůKŜ ŜfŜŐúNλŐλúè ăèăúŜΥΦ ¢KŜ Kλăű2Nè 2Ŧ Ŏ2ΥLJdzűŜN Υ2ŘŜfă λyˇűKŜ ŜfŜŐúNλŐλúè ăŜŐű2N λă ŜĒűŜyăλØŜΦ ¢KŜ ăŜŐű2N λă KλƎKfè ŘŜLJŜyŘŜyű 2yˇΥ2ŘŜfλyƎ Ŧ2N LJfI·yyλyƎΣ λyØŜăúΥŜyűΣ NŜƎdzfI·ûλ2yΣ I·yŘ ăèăúŜΥ 2LJŜN I·ûλ2yãΦ 9yŜNƎè ŜŦŦλŐλŜyŐè ădzLJLJfè ŐdzNØŜă I·NŜ y2ű Ŏ2ΥΥ2yfè dzăŜŘ λyˇŜfŜŐúNλŐλúè ăŜŐű2N Υ2ŘŜfλyƎ ōŜŐI·dzâ ůKŜN I·NŜ y2ű ădzŦŦλŐλŜyűfè N2ōdzăű I·yŘ ƎNI·yfzfI·N óf2ŐI·ûλ2yπ I·yŘ ûŜŐKy2f2ƎèπăLJŜŐλŦλŐú ŘI·ûI· 2yˇűKŜ LJ2ûŜyűλI·f 2Ŧ ŜyŜNƎè ŜŦŦλŐλŜyŐè ΥŜI·ădzNŜă Ŧ2N ûKŜ ŜyűNŜ bI·ûλ2y—ă2ΥŜûKλyƎ I· yl·ûλ2y1·f LJ2ûŜyűλI·f I·ăăŜăăΥŜyű Ŏ2dzfŘ LJN2ØλŘŜΦ C2N ŜĒI·ΥLJfŜΣ ŐI·LJI·ŐλûèŜĒLJI·yăλ2yˇΥ2ŘŜfăΣ ădzŐK I·ă ûKŜ bI·ûλ2y1·f 9yŜNƎè a2ŘŜfλyƎ {ëăúŜΥ ób9a{úΣ

ÖÖ ¦ LJŘI·ûŜă ű2 ΥŜI·ădzNŜΥŜyű I·yŘ ØŜNλŦλŐI·ůλ2ϒ LJN2ű2Ő2făΣ øKλŐK ØI·Nè ōè ûŜŐKy2f2ƎèΣ ŐI·yˇ KŜfLJ ŘNλØŜ ûKŜ ûNI·yăλúλ2yˇ ú2 I· ŐfŜI·yŜN ŜfŜŐúNλŐλúè ăèăúŜΥΦ ¢KŜ øŜI·fúK 2Ŧ ŘI·ûI· ōŜλyƎ ƎŜyŜNI·ûŜŘ ōè ! aLΣ I·f2yƎ øλúK λΥLJN2ØŜŘ I·yl·fèúλŐI·f ű22făΣ I·NŜ Śyl·ōfλyƎ I·ŘØI·yŐŜŘ ŜØI·fdzI·ůλ2yΣ ΥŜI·ădzNŜΥŜyűΣ I·yŘ ØŜNλŦλŐI·ůλ2yˇΥŜúK2Řă Ŏ2ΥΥ2yfè NŜfŜNNŜŘ ű2 I·ă þ9a ơ± нΦлΦþ ăŜŜ [Φ {ŐKøI·NűÎΣ Śú I·fŒ *Electricity End Use, Energy Efficiency, and Distributed Energy Resources Baseline* ó[I·øNŜyŐŜ . ŜNł ŜfŜè bI·ûλ2y1·f [I·ō2NI·ú2NèΣ WI·yđzI·Nè нлмтúΣ LJ нрπ слТ омлпоммТ онлпонфΦ

ŘŘ ! ăŜLJI·NI·ûŜ λăădzŜ λă ØŜNλŦèλyƎ ůKI·ű ůKŜ I·Y2dzyű 2Ŧ 5w ůKI·ű I· dzűλfłúè 2N ûKλNŘ LJI·NűúèŐ2ΥΥλûă ú2 LJN2ØλŘŜ λă I·Őűdz I·ffè LJN2ØλŘŜŘ øKŜy ŐI·ffŜŘ dzLJ2yΦ

I·NŜ ǿλŘŜfè dzăŜŘ ŦƧNJ LJƧfλÓè ŦƧNJYdzfI·ûλ2y I·yŘ NŜă2dzNJÓŜ LJfI·yɣλyƎ♦ b9a{ ǿƧdzfŘ LJI·NűλÓdzfI·NJfè ōŜyŜŦλú ŦNJ2Y λY·LJNJƧǾŜYŜyűă λy´ŎKI·NJI·ŎűŜNJλÎλyƎ ŜfŜŎúNJλÓλúè ŜyŘ dzăŜΣ ŜyŜNJƎè ŜŦŦλÓλŜyÓèΣ 5DΣ I·yŘ ăű2NJI·ƎŜ♦

CλyI·ffèΣ ÊyKI·yÓŜŘ Y·2ŘŜfă ŜÈI·YλyλyƎ ŜyǾNJ2yYŜyűI·f λY·LJI·ŎűăΣ NJŜă2dzNJÓŜ ōI·ăŜΣ I·yŘ Ŏ2Y·LJŜŰλyƎ dzăŜă ǿƧdzfŘ ōŜ ØI·fdzI·ōfŜ λy´λyŦƧNJY·λyƎ ăλűλyƎΣ LJŜNJY·λűűλyƎΣ I·yŘ 2LJŜNJI·ûλ2yI·f LJNJI·ŎűλÓŜă ŦƧNJ ƎŜyŜNJI·ûλ2yP Lű ǿƧdzfŘ ōŜ dzăŜŦdzf ŦƧNJ KèŘNJ2LJ2ǿŜNJ LJNJ2ȼŜŎű Y·2ŘŜfă ű2 λffdzY·λyI·ûŜ ŜyǾNJ2yYŜyűI·f I·yŘ fI·yŘπdzăŜ λY·LJI·Ŏűă I·yŘ Ŏ2πōŜyŜŦλűăP C2NJ ƎŜ2űKŜNJY·I·f ŜyŜNJƎèΣ λú ǿƧdzfŘ ōŜ ØI·fdzI·ōfŜ ű2 ŎKI·NJI·ŎűŜNJλÎŜ I· ădzōăűI·yűλI·f LJ2NJűλ2y´2Ŧ úKŜ ƎŜ2úKŜNJY·I·f NJŜă2dzNJÓŜ ōI·ăŜΣ ǿKλŎK Ŏ2dzfŘ KŜfLJ ű2 NJŜŘdzÓŜ ăλúλyƎ I·yŘ LJNJ2ălJŜÓűλyƎ Ŏ2ăúäPMΦΠ C2NJ //¦{ LJNJ2ȼŜÓűΣ Y·2ŘŜfă ŎI·y´λY·LJNJ2ǾŜ ăűI·yŘI·NJŘλÎŜŘ ăλúŜ ŎKI·NJI·ŎűŜNJλÎI·ûλ2y´úKI·ú λyŦƧNJY·ă úKŜ ŘŜűŜNJY·λyI·ûλ2y´2Ŧ I·NJŜI·ă ǿλűK úKŜ I·LJLJNJ2LJNJλI·ûŜ ăű2NJI·ƎŜ ƎŜ2f2Ǝè♦

3.2.6 Electricity-Sector Assets, Operations, and Planning

¢KŜNJŜ I·NJŜ Y·I·yê úŜŎKyλŎI·fΣ Y·I·NJ⌊ŜúΣ I·yŘ LJ2fλÓè ŎKI·ffŜyƎŜă NJŜfI·úŜŘ û2 K2ǿ ŜfŜŎúNJλŎλúè¤ăŜŎú2NJ λyǾŜăúYŜyű ŘŜŎλăλ2yã I·yŘ 2LJŜNJI·ûλ2yãΣ CŜŘŜNJI·f I·yŘ ăűI·úŜ LJ2fλÓè I·yŘ NJŜƎdzfI·ûλ2yãΣ I·yŘ ăèăúŜY I·yŘ LJ2fλÓè LJfI·yɣλyƎ λyűŜNJI·Ŏű ǿλúK ŜŦŦ2NJűă ú2 ăKλŦú û2 I· f2ǿπŎI·NJō2y ŜfŜŎúNJλŎλúè ăèăúŜY♦ ¢2 NJŜI·fλÎŜ I· ŎfŜI·yŜNJ ŜfŜŎúNJλŎλúè ăèăúŜYΣ ăűI·⌊ŜK2fŘŜNJă ǿλff ySŜŘ û2 Ŏ2yãλŘŜNJ I·ff I·ălJŜŎűă I·yŘ λyűŜƎNJI·ûλ2y´2Ŧ I·y´ ŜyŘπű2πŜyŘ ădzLJLJfè ŎKI·λyΣ ŦNJ2Y ƎŜyŜNJI·ûλ2y´ú2 ŜyŘ dzăŜ♦

Electricity infrastructure owners' choices on resilience, expansion, and modernization will have implications for achieving the nation's environmental goals, and vice versa. /KI·LJűŜNJL± ó*Ensuring Electricity System Reliability, Security, and Resilience*ú ŘλăŎdzăăŜă űKŜ ySŜŘ ŦƧNJ I·yŘ λyűŜNJI·ŎűλƧy´ōŜűǿŜŜy´λY·LJNJ2ǾŜYŜyűă in the electricity system's clean, resilient, and flexible characteristics. The same chapter adds that LJNJ2ōI·ōλfλăűλŎ LJfI·yɣλyƎ λă I· NJ2ōdzăű YŜűK2Ř 2Ŧ I·ăăŜăăλyƎ ǿKI·ú λyŦNJI·ăúNJdzŎűdzNJŜΣ λyŎfdzŘλyƎ NJŜyŜǿI·ōfŜ ƎŜyŜNJI·ûλ2yΣ ăK2dzfŘ ōŜ ōdzλfű ŦƧNJ NJŜfλI·ōλfλúè LJdzNJLJ2ăŜă♦

Integrating Energy and Capacity Markets with Clean Policies

In the summer of 2016, the New England Power Pool (NEPOOL) began a stakeholder process designed to explore whether the various environmental policies across member states could be integrated into the regional energy and capacity markets operated by Independent System Operator New England. Known as the Integrating Markets and Public Policy initiative, it has the potential to set an important precedent for how clean policies can be integrated into existing regional markets.

"Our goal at NEPOOL and for the region is to create a competitive market signal to get the states what they need so they don't have to act on their own. If we're successful, the markets on their own will find the most cost-effective means in meeting those state objectives." – NEPOOL Chairman Joel S. Gordon[191]

Following the release of an initial problem statement and guidelines in May 2016, stakeholders were invited to propose ideas at the group's first meeting in August. Proposals offered a wide range of solutions: from a carbon price adder, to a separate "clean-only" auction process called a "Forward Clean Energy Market," to strengthening the Regional Greenhouse Gas Initiative. Some proposals recommended price adjustments in the energy markets, while others offered modifications to the capacity markets.

DNJŘ I·NJŎKλúŜŎűdzNJŜ I·fűŜNJyI·ûλǾŜă I·NJŜ I·fă2 λY·LJ2NJűI·yű û2 Ŏ2yãλŘŜNJ Ŧ2NJ NJŜI·ŎKλyƎ I· ŎfŜI·y´ ŜfŜŎúNJλŎλúè Ŧdzűdz NJŜP /KI·LJűŜNJ L± ó*Ensuring Electricity System Reliability, Security, and Resilience*ú ŘλăŎdzăăŜă I·NJŎKλúŜŎűdzNJI·f I·yŘ 2LJŜNJI·ûλ2yI·f I·fűŜNJyI·ûλǾŜă û2 λyŎNJŜI·ăŜ NJŜăλfλŜyŎŜP ! ff 2Ŧ úK2ăŜ I·fűŜNJyI·ûλǾŜăΣ ǿKλŎK ŘŜŎNJŜI·ăŜ ăèăúŜY NJŜăLJ2yãŜ ûλY·Ŝă I·yŘ λyŎNJŜI·ăŜ ŦfŜÈλōλfλúèΣ ǿƧdzfŘ KI·ǾŜ λY·LJ2NJűI·yű Ŏ2πōŜyŜŦλűă λy´λyűŜƎNJI·ûλyƎ NJŜySǿI·ōfŜ ƎŜyŜNJI·ûλ2yP

9ŦŦ2NJűă û2 λY·LJNJ2ǾŜ ySI·NJπűŜNJY Ŧ2NJŜŎI·ăűλyƎ I·yŘ ƎNJI·yƧdzfI·NJ ƎNJλŘ ØlădzI·fλÎI·ûλ2y´I·NJŜ I·fNJŜI·Řè dzyŘŜNJǿI·è I·yŘ KI·ǾŜ ŎfŜI·NJ ōŜyŜŦλűă Ŧ2NJ ŎfŜI·y´ ƎŜyŜNJI·ûλ2y´I·ă I·NJŜ ŜŦŦ2NJűă û2 ŜyŘKI·yŎŜ ălűdzI·ûλ2yI·f I·ǿI·NJŜySăăΣ I·yŘ 2LJŜNJI·ûλ2yI·f ØlălōλfλúèŦ2NJ NJŜfλI·ōλfλúèΣ ăŜŎdzNJλúèΣ I·yŘ NJŜăλfλŜyŎŜ NJŜI·ă2yã♦ ! ff 2Ŧ úKŜăŜ Y·ŜűK2Řă ǿƧdzfŘ I·fă2 f2ǿŜNJ úKŜ ŜŎ2y´2Y·λŎ Ŏ2ăű 2Ŧ NJŜySǿI·ōfŜ λyűŜƎNJI·ûλ2y´I·yŘ I·NJŜ ŘλăŎdzăăŜŘ λy´ŘŜűI·λf λy´ /KI·LJűŜNJ L± ó*Ensuring Reliability, Security, and Resilience*ú♦

t2øŜ Y I·Ⓝ]Ŝű Řèyl·Y λÔă I·fă2 I·ŦŦŜÕű ÕfŜI·y LJ2øŜ Ǝ2I·fă Ł·yŘ ØλÔŜ ØŜ ăI·φ [2øŜ ŜyŜ ƎèLJ ØKλÔK I·Ŝ LJI·űfè ŘdzŜ ű2 t2øπÕ2ăű yl·ůdzI·f ƎI·ă I·yŘ λyÕŜyűλØλÎŜŘ ÎŜ2πY I·ƎλyI·tπÕ2ăű ŜĂ2dzÕŜă I·Ŝ ŜŘdzÕλyƎ úKŜ ŜÕ2y2Yλ Øλl·ōλfλűè 2Ŧ 2ůKŜ Řŝăλ ŜŘ ÕfŜI·y ŜĂ2dzÕŜă λyÕfdzŘλyƎ ydzÕfŜI·Ⓝ ŜyŜƎèφ

a l·yè 2Ŧ úKŜ LJfl·yŷλyƎπŜfl·ůŜŘ ÕKl·ftŜyƎŜă ∂dzλăŘλÔűλ2yl·f l·dzůK2λűλŜă Ŧl·ÕŜ l·λăŜ Ŧ2Y úKŜ ŜÕŜyű ůŜyŘ λy ůŜÕKy2f2Ǝè l·ŘØl·yÕŜYŜyű—l·yŘΣ ăLJŜÕλŦλÕl·ffèΣ ůKŜ λyÕŜl·ăŜ λy yŜø ůŜÕKy2f2ƎλŜă l·yŘ YŜÕKl·yłăY ă Ŧ2ÕdzăŜŘ l·ű úKŜ ŜyŘπdzăŜ ăŜÕű2Ⓝ—ōŜKλyŘ ůKŜ YŜůŜŜⓃφ ¢Kλă ůŜyŘ Kl·ă Ol·dzăŜŘ l· ăKλŦű λy·úKŜ dzyŘŜfèλyƎ l·ăădzYLJůλ2yã dzLJ2y øKλÔK Y2ăű LJfl·yŷλyƎ ŜIljdzλŜYŜyűă øŜŜ Ŝăűl·ōfλăKŜŘφ ¢KŜŜ l·Ŝ Yl·yè l·ŜŜl·ă øKŜŜ CŜŘŜŜl·f LJ2fλÔè Ô2dzfŘ Ŧl·ÕλfλűŁ·ûŜ úKŜ Ŧdzff Ô2yãłŘŜŜl·ůł2y 2Ŧ úKŜ Ô2ăű l·yŘ ōSyŜŦλůă 2Ŧ ŜyŜŜƎè ŜŦŦλÔλŜyÕèΣ 2ůKŜŜ ŘŜY l·yŘπăλŘŜ Yl·yl·ƎŜYŜyű ŜĂ2dzÕŜăΣ l·yŘ ÕfŜI·y ŜyŜŜƎè λy LJfl·yŷλyƎ LJŜ2ÕŜăăŜăΣ λyÕfdzŘλyƎ λYLJŜ2ØλyƎ Řl·ůl·Σ l·ŘØl·yÕλyƎ ű22fă l·yŘ ŜLJŜăŜyűl·ůł2y λy Y2ŘŜfăΣ l·yŘ LJŜ2ØλŘλyƎ ŜÕKyλÕl·f l·ăăλăűl·yÕŜ 2y ű22fă ůKl·ů Ŝyl·ōfŜ ůKŜ Ŧdzff Ô2yãλŘŜŜl·ůł2y 2Ŧ ůKŜăŜ ÕfŜI·y ŜĂ2dzÕŜă λy LJfl·yŷλyƎφ ¢KŜ CŜŘŜŜl·f D2ØŜŜyYŜyű λă LJŜ2ØλŘλyƎ ŜĖLJl·yŘŜŘ ůŜÕKyλÕl·f l·ăăλăűl·yÕŜ 2y YŜůK2Řă 2Ŧ Ŧdzffè l·ÖÔ2dzyůλyƎ Ŧ2Ⓝ ŜyŜŜƎè ŜŦŦλÔλŜyÕèΣ 2ůKŜŜ ŘŜY l·yŘπăλŘŜ Yl·yl·ƎŜYŜyű ŜĂ2dzÕŜăΣ l·yŘ ÕfŜI·y ŜyŜŜƎè λy ŜĂ2dzÕŜ LJfl·yŷλyƎ Ô2yŘdzÕůŜŘ ōè Ǝ2ØŜyYŜyűă l·yŘ dzůλfλűłŜă úKl·ů Ô2dztŘ KŜfLJ ōŜl·]Ř2øy λyãůłůdzůλ2yl·f ōl·ŊŊλŜŊă ű2 Ô2yãλŘŜŊλyƎ ŜyŜŜƎè ŜŦŦλÔλŜyÕèl·ă l· ŜĂ2dzÕŜφ

hůKŜⓃ LJfl·yŷλyƎ ŘŊλØŜŊă ŜĖλăű l·ă øŜffφ C2Ⓝ ŜÈl·YLJfŜΣ ŜØ2fØλyƎ ŜyØλŊ2yYŜyűl·f ŜIljdzλŜYŜyűă l·ů úKŜ CŜŘŜⓃl·f fŜØŜf óŜφƎφΣ úKŜ ŜÕŜyűfè LJŊ2YdzfƎl·ůŜŘ “/fŜl·y t2øŜⓃ tfl·y” ώ/ttճú l·yŘ ÕfŜl·y ŜyŜŜƎè Ǝ2l·tă l·ů úKŜ ăűl·ůŜ fŜØŜf óŜφƎφΣ wt{ú ŜyÕ2dzⓃl·ƎŜ ∂dzλăŘλÔűλ2yl·f l·dzůK2λűλŜă l·ů úKŜ ăűl·ůŜ fŜØŜf l·yŘ l·ÖŊ2ăă ăűl·ůŜă ű2 Ô22ŊŘλyl·ůŜ ű2 ŜyãdzŊŜ ŜIljdzλŜYŜyűă l·ŜŜ YŜű l·ů f2ø Ô2ăűφ

!ă ŘλăÔdzăăŜŘ λy /Kl·LJůŜŊ LL ó*The Electricity Sector: Maximizing Economic Value and Consumer Equity*úΣ Ⓝl·ůŜYl·]λyƎ[ŝŝ] λă 2yŜ 2Ŧ úKŜ LJdzōfλÔè λyãűŊdzYŜyűă ůKl·ů ăűl·ůŜă dzăŜ ű2 λyÕŜyűλØλÎŜ l·yŘ ŊŜƎdzfl·ůŜ ůKŜ ŜfŜÕůŊλÕλůè ăŜÕű2Ⓝφ Lů λă λYLJ2Ⓝůl·yű ůKl·ů úKŜ ŜyØλŊ2yYŜyűl·f ōŜyŜŦλůă 2Ŧ ÕfŜI·y ŜfŜÕůŊλÕλůè l·ŜŜ I·LJLJŊ2LJŊλl·ůŜfè Øl·fdzŜŘφ ¢2 ŊŜl·fλÎŜ úKŜ Ŧdzff LJ2ůŜyűλl·f 2Ŧ λyÕŊŜl·ăŜŘ 59wăΣ ÕfŜI·y ŜyŜŜƎè ƎŜyŜŜⓃl·ůλ2yΣ l·yŘ Y2ŊŜ ă2LJKλăűλÕl·ůŜŘ ƎŊλŘ ůŜÕKy2f2ƎλŜă óădzÕK l·ă ăYl·Ⓝű YŜůŜŊă l·yŘ ădzLJŜŊØλă2Ⓝè Õ2yűŊ2f l·yŘ Řl·ůl· l·Ôljdzλăλůλ2y ăèăűŜYăůΣ ŊŜƎdzfl·ů2Ⓝă “will need to uůλfλÎŜ Y2ŊŜ l·ŘØl·yÕŜŘ Ⓝl·ůŜ ŘŜăλƎyã ůKl·y they have in the past.”ᵐᶲᴴ !ă 59wă ōŜÕ2YŜ Y2ŊŜ LJŊŜØl·fŜyű λy úKŜ ¦yűŜŘ {ůl·ůŜăΣ Ŧ2Ⓝ ŜĖl·YLJfŜΣ úKŜ úŊⓃl·Řλůλ2yl·f Ⓝl·ůŜYl·]λyƎ Y2ŘŜfă Yl·è y2 f2yƎŜⓃ LJŊŊ2ØλŘŜ dzůλfλűλŜă ø λúK l·ŘŜljdzl·ůŜ YŜl·yã ű2 LJŊŊ2LJŜⓃfè ŊŜÕ2ØŜⓃ úKŜ úŊⓃdzŜ Õ2ăűă 2Ŧ ŜfŜÕůŊλÕλůè ƎŜyŜⓃⓃl·ůλ2yΣ úŊⓃl·yãYλăăλ2yΣ l·yŘ ŘλăűŊλōdzůλ2yφᵐᶲᴼ tdzōfλÔ dzůλfλůè Õ2YYλăăλ2yã Kl·ØŜ l·fŊŜl·Řè ōŜƎdzy ű2 l·ŘŘŊŜăă úKλă ÕKl·ffŜyƎŜ λy l· øλŘŜ Øl·ŊλŜűè 2Ŧ ø l·èăΣ ŊŜŦfŜÕůλyƎ states’ different policy objectives and generation portfolios. Many states have λyãűλůdzůŜŘ ŘŜÕ2dzLJfλyƎ 2Ⓝ f2ăűπŊŜØŜyłzŜ l·Ř2dzăűYŜyű YŜÕKl·yλăYăΣ øKλÔK ōⓃŜl·]ůKŜ fλy]ōŜůøŜŜy ůKŜ l·Y2dzyű of energy a utility sells and the revenue that it collects, increasing the utility’s acceptance of energy ŜŦŦλÔλŜyÕè LJŊ2ƎⓃl·Yăφ a 2ŊŜ ŊŜÕŜyűfèΣ ăűl·ůŜă Kl·ØŜ l·fă2 ōŜƎdzyű2 ŜĖl·YλyŜ K2ø ű2 Øl·fdzŜ ůKŜ Õ2ăűă l·yŘ ōŜyŜŦλůă 2Ŧ 59wăφ ±alue of solar tariffs, for example, intend to “associate a quantifiable benefit with each kWh of distributed solar exported to the grid”ᵐᶲᴾⁿ l·yŘ ůⓃl·yãfl·ůŜ ůKλă ōŜyŜŦλů λyű2 l· Řzftl·Ⓝ LJŜⓃ]²K Ⓝl·ůŜΣ ƎλØλyƎ dzůλfλűλŜă l·yŘ ŊŜƎdzfl·ů2ŊăI· LJŊλÔλyƎ ű22f ůKl·ů ŊŜŦfŜÕůă ůKŜ Øl·fdzŜ 2Ŧ ůKλă ŜfŜÕůŊλÕλůè ōŜůůŜⓃ ůKl·yⓃŜůl·λf 2Ⓝ øK2fŜăl·fŜ Ⓝl·ůŜăφ !ă ůKŜ Ⓝ2fŜ 2Ŧ ÕfŜI·y ŜyŜŜƎè λyⓃl·ůŜYl·]λyƎ Õ2yűλyØzŜă ű2 ŜØ2fØŜΣ úKŜ CŜŘŜⓃl·f D2ØŜⓃyYŜyű l·yŘ ăűl·ůŜă Ôl·y Õ22LJŜⓃl·ůŜ ű2 ŜăűλYl·ůŜ ůKŜ Øl·fdzŜ l·ůůⓃλōdzůŜŘ ű2 ŜfŜÕůŊλÕλůè LJŊⓃ2ŘdzÕűă l·yŘ ăŜⓃØλÕŜăΣ Ŧl·ÕλfλűłůŜ Řl·ůl· l·yŘ λyŦ2ⓃYl·ůλ2yˆŜĖÕKl·yƎŜ ű2 ƎdzλŘŜ ⓃłůŜYl·]λyƎ l·yŘ ⓃłůŜ ŘŜăλƎyΣ l·yŘ ăKl·ⓃŜ fŜăă2yã fŜl·ⓃySŘφ

3.3 Multiple Paths Forward for CO_2 Emissions Reductions from the Electricity Sector

!ă yŽůŜŘΣ úKŜ /h_H λyűŜyãλůè 2Ŧ úKŜ LJ2øŜⓃ ăŜÕű2Ⓝ λă ŜĖLJŜÕűŜŘ ű2 Õ2yűλyØzŜ ű2 ŘŜÕⓃŜl·ăŜ ŘdzŜ ű2 ăŜØŜⓃl·f Ŧl·ÕűłⓃăΣ λyÕfdzŘλyƎ Ŧdzŝf ăøλůÕKλyƎΣ ůŜÕKy2f2Ǝè λyy2Øl·ůł2yΣ l·yŘ ÕfŜI·y ŜyŜŜƎè LJ2fλÔλŜă φ ¢KŜ CŜŘŜⓃl·f D2ØŜⓃyYŜyű Kl·ă ăŜű ŜÕ2y2Yè πøλŘŜ ŜYλăăλ2yã ⓃŜŘdzÕűλ2yˆůl·ⓃƎŜůă 2Ŧ мт LJŜⓃÕŜyű ōŜf2ø úKŜ нллр fŜØŜf ōè нлнлΣ l·yŘ нс ű2 ну

[ŝŝ] C2Ⓝ l· ŘŜăÔⓃλLJůλ2yˆ2Ŧ úKŜ Ⓝl·ůŜ ŘŜăλƎyˆLJŊ2ÕŜăăΣ ăŜŜ !LJLJŜyŘλÈ ! ó9fŜÕůŊλÕλůè {èăűŜYˆ hØŜⓃØλŜøúφ

LJŜNŎŜyű ōŜf2ø űKŜ нллр fŜØŜf ōè нлнр^{мфр} ¢KŜăŜ нлнл l·yŘ нлнр űl·N∃Ŝűă øŜNŜ ₮2NY l·ffè ădzōY·λűűŜŘ ű2 űKŜ ¦ yλűŜŘ bl·ûλ2yã CNJl·YŜø2NJ[/2yØŜyűλ2y´2y´/fλY l·ûŜ /Kl·yƎŜ λy´Wl·yđzl·Nè нлмл l·yŘ a l·NŎK нлмр NŜăLJŜŎűλØŜfè l·yŘ űKŜè l·NŜ Ŏ2yãλăűŜyű øλűK l· ăűNJl·λƎKű fλyŜ ŜY·λăăλ2y´NŜŘdzŎűλ2y´LJl·ŰKøl·è ₮N2Y нлнл ű2 ŜŎ2y2Yè¤øλŘŜ ŜY·λăăλ2y´NŜŘdzŎűλ2yã 2₮ ул LJŜNŎŜyű 2N Y´2NŜ ōè нлрл^{мфс} !y´ул LJŜNŎŜyű ŜŎ2y2Yè¤øλŘŜ NŜŘdzŎűλ2y´λy´úKŜ ¦ yλűŜŘ {úl·ûŜăΣ ƎλØŜy´Ŏ2YY´SyãdzNJl·ûŜ NŜŘdzŎűλ2yã ŜfăŜøKŜNŜΣ Ŏ2dzfŘ KŜfLJ fλYλű ŰKŜ λyŎNŜl·ăŜ λy´Ǝf2ōl·f Y´Sl·y´ ădzN₮l·ŎŜ ûŜY·LJŜNJl·ûdzNŜ ű2 н ŘŜƎNŜŜă /Ŝfăλdză l·yŘ Y´λűλƎl·ûŜ ûKŜ ø2Năű λYLJl·Ŏűă 2₮ ŎfλYl·ûŜ ŎKl·yƎŜ^{мфт} Ly´2NŘŜN ű2 l·ŎKλŜØŜ ădzŎK ŘŜŜLJ fŜØŜfă 2₮ ŜY·λăăλ2yã NŜŘdzŎűλ2yãΣ λű ăă fλ[Ŝfè ûKl·ű ûKŜ ŜfŜŎűNλŎλûè ăŜŎű2N øλff yŜŜŘ ű2 LJN2ØλŘŜ ƎNŜl·ûŜN l·yŘ Y´2NŜ λYY´SŘλl·ûŜ D I D ŜY·λăăλ2yã NŜŘdzŎűλ2yã ûKl·y´2ûKŜN ăŜŎű2Nă ōŜŎl·dzăŜ λű λyŎfdzŘŜă ûKŜ Y´2ăű Ŏ2ăúπŜ₮₮ŜŎűλØŜ 2LJűλ2yã ₮2N NŜŘdzŎλyƎ D I D ŜY·λăăλ2yã¢

The President's "/fλYl·ûŜ !Ŏűλ2y´tfl·yΣ"^{мфу} ûKŜ ŎdzNNŜyű ¦¢{¢ ăűNJl·ûŜƎè ₮2N l·ŘŘNNŜăăλyƎ ŎfλYl·ûŜ ŎKl·yƎŜΣ øl·ă ₮2NY´dzfl·ûŜŘ ű2 Y´λűλƎl·ûŜ Ǝf2ōl·f ŎfλYl·ûŜ ŎKl·yƎŜ l·yŘ NŜŘdzŎŜ ¦¢{¢ D I D ŜY·λăăλ2yã¢ !y´ŜÈl·Y´LJfŜ 2₮ l· LJ2fλŎè ûKl·ûΣ when implemented, will further the goals of the President's "Climate Action Plan" by contλyđzλyƎ ûKŜ ûNŜyŘ 2₮ ŘŜŎNŜl·ăλyƎ /hн λyűŜyãλûè λă ûKŜ /ttΣ øKλŎK øl·ă ₮λyl·fλÎŜŘ ōè 9t ! λy´!dzƎdzăű нлмр$^{₮₮}$ ¦ yŘŜN {ŜŎűλ2y´ммmóŘú 2₮ ûKŜ /!!Σ ûKŜ /tt NŜƎdzfl·ûŜă Ŏl·Nō2y´ŜY·λăăλ2yã ₮N2Y ŜÈλăűλyƎ LJ2øŜN LJfl·yűă l·yŘ NŜljdzNNŜă ăűl·ûŜă ű2 l·Ř2LJű LJfl·yã ű2 fλYλú ŜY·λăăλ2yã ₮N2Y ŜÈλăűλyƎ ₮2ăăλf ₮dzŜfπ₮λNŜŘ LJ2øŜN LJfl·yűă 9t ! LJN2ŝŜŎűă ûKl·ûΣ ōè нлолΣ ûKŜ /tt øλff KŜfLJ Ŏdzú Ŏl·Nō2y´ŜY·λăăλ2yã ₮N2Y ûKŜ LJ2øŜN ăŜŎű2N ōè он LJŜNŎŜyű ₮N2Y нллр fŜØŜfă^{мфф}

¢l·È ŎNŜŘλûă ₮2N ŎfŜl·y´ŜyŜN∃è Kl·ØŜ l·fă2 Ŏ2yúNλōdzúŜŘ ű2 NŜŘdzŎŜŘ /hн ŜY·λăăλ2yã l·yŘ l·NŜ LJN2ŝŜŎűŜŘ ű2 Ŏ2yűλydzŜ ű2 KŜfLJ NŜŘdzŎŜ ŜfŜŎűNλŎλûèπăŜŎű2N ŜY·λăăλ2yã λy´ûKŜ ₮dzúdzNŜ^{нлл} bw9[l·yl·fèăλă LJN2ŝŜŎűă l· рл D² λyŎNŜl·ăŜ λy´ŎdzY´dzfl·ûλØŜ λyãűl·ffŜŘ NŜySyŜøl·ōfŜ ŜyŜN∃è Ŏl·LJl·ŎλûèōèнлнлŘdzŜűŰKŜCŜŘŜNJl·fûl·ÈŎNŜŘλú ŜÈúŜyãλ2yã¢^{нлм}

3.3.1 A Record of Environmental Policy Successes

¢KŜ ădzŎŎŜăăŜă 2₮ ŜÈλăúλyƎ ŜyØNN2yY´Syúl·f LJ2fλŎè l·NŜ λyãúNdzŎűλØŜ ₮2N Y´ŜŜûλyƎ ₮dzúdzNŜ yl·ûλ2yl·f ŜyØNN2yY´Syúl·f Ǝ2l·fă l·yŘ 2ō?ŜŎűλØŜă¢ ¢KŜ Y´2ŘŜNy´₮NJl·YŜø2N[₮2N λYLJN2ØλyƎ l·λNJ ljdzl·fûûè λy´ûKŜ ¦ yλűŜŘ {úl·ûŜă øl·ă ŜăűJl·ōfλăKŜŘ λy´мфтлΣ øλűK ûKŜ ŎNŜl·ûλ2y´2₮ 9t ! l·yŘ ûKŜ LJl·ăăl·ƎŜ 2₮ ûKŜ мфтл /!!Σ øKλŎK øl·ă ădzōăŜljdzŜyűfè l·YŜyŘŜŘ λy´мфтт l·yŘ мффл^{ф} ² KλfŜ ûKŜ ŜfŜŎűNλŎλûè ăèăűŜY´ Kl·ă KλăűNJNλŎl·ffè ōŜŜy´l· Y´l·2N ă2dzNŎŜ 2₮ l·λNJ LJ2ffdzűλ2yΣ ăλyŎŜ ûKŜ LJl·ăăl·ƎŜ 2₮ ûKŜ /!!Σ ŜY·λăăλ2yã 2₮ l·λNJ LJ2ffdzűl·yűă óλyŎfdzŘλyƎ ădzf₮dzN Řλ2ÈλŘŜ l·yŘ yλűN2ƎŜy´2ÈλŘŜăú Kl·ØŜ ₮l·ffŜy´ ŘNJl·Y´l·ûλŎl·ffè ōŜf2ø мфтл ŜY·λăăλ2yã fŜØŜfă^{ф} .ŜűøŜŜy´мфтл l·yŘ нлмпΣ l·ƎƎNŜƎl·ûŜ ŜY·λăăλ2yã 2₮ Ŏ2YY´2y´l·λNJ LJ2ffdzűl·yűă ₮N2Y ûKŜ ŜfŜŎűNλŎλûè ƎŜySNJl·ûλ2y´ƎNŜø ōè мст LJŜNŎŜyű l·yŘ ûKŜ ¦¢{¢ D5t ƎNŜø ноу LJŜNŎŜyű¢^{нлнΣ} ^{нлоΣ} ^{нлп}

¢KŜ KŜl·fûK ōŜySŤλűă 2₮ NŜŘdzŎλyƎ ŜY·λăăλ2yã 2₮ l·λNJ LJ2ffdzűl·yűă ₮N2Y LJ2øŜN LJfl·yűă l·yŘ 2ûKŜN ă2dzNŎŜă λyŎfdzŘŜ l·Ø2λŘŜŘ LJNŜY·l·ûdzNŜ ŘŜl·ûKăΣ l·Ø2λŘŜŘ KŜl·Nú l·ûűl·Ŏ]ăΣ ₮SøŜN Ŏl·ăŜă 2₮ NŜăLJλNJl·û2N[è LJN2ōfŜY´ă óădzŎK l·ă l·Ŏdzűŝ ōN2yŎKλűλă l·yŘ l·ăűKYl· l·ûűl·Ŏ]ăúΣ l·yŘ l·Ø2λŘŜŘ KŜl·Nú l·ûűl·Ŏ]ăΣ ₮SøŜN Ŏl·ăŜă 2₮ NŜăLJλNJl·û2N[è LJN2ōfŜY´ă óădzŎK l·ă l·Ŏdzűŝ ōN2yŎKλűλă l·yŘ l·ăűKYl· l·ûűl·Ŏ]ăúΣ l·yŘ l·Ø2λŘŜŘ K2ăLJλűl·f l·ŘY´λăăλ2yã¢^{нлрΣ} ^{нлсΣ} ^{нлт} !λNJ ljdzl·fλûè λYLJN2ØŜY´Syűă ₮N2Y ûKŜ !ŎλŘ wl·λy´tN2ƎNJl·YΣ LJl·Nú 2₮ ûKŜ /!! l·YŜyŘY´Syűă 2₮ мффлΣ øŜNŜ ŜăűλYl·ûŜŘ û2 è]ŜfŘ KŜl·fûK ōŜySŤλűă 2₮ l·N2dzyŘ Þрл ōλffλ2y´l·yydzl·ffè λy´нлмлΣ Ŏ2YLJl·NŜŘ û2 Ŏ2Y´LJfλl·yŎŜ Ŏ2ăűă ûKl·ú l·NŜ 2y´ûKŜ 2NŘŜN 2₮ Þлф¢ ōλffλ2y^{нлуΣ} ^{нлфΣ} ^{нмлΣ} ^{нммΣ} ^{нмн} a 2NŜ NŜŎŜyűfèΣ ûKŜ нлмн a ŜNŎdzNè l·yŘ !λN ¢2ÈλŎă {úl·yŘl·NŘăΣ øKλŎK Ŝăűl·ōfλăKŜŘ ŜY·λăăλ2yã fλYλűă ₮2N LJ2øŜN LJfl·yűă ₮2N Y´ŜNŎdzNèΣ l·ŎλŘ Ǝl·ăŜăΣ l·yŘ KŜl·Øè Y´ŜűJl·făΣ l·NŜ LJN2ŝŎűŜŘ û2 LJNŜØŜyű dzLJ û2 ммΣллл LJNŜY´l·ûdzNŜ ŘŜl·ûKăΣ пΣтлл KŜl·Nú l·ûűl·Ŏ]ăΣ l·yŘ молΣллл l·ăűKYl· l·ûűl·Ŏ]ă ŜØŜNè èŜl·N¢^{нмо}

¢KŜ ŜŎ2y2YλŎ ōŜySŤλűă 2₮ ŎfŜl·y´l·λNJ LJ2fλŎλŜă l·NŜ l·fă2 øŜftπŘ2ŎdzY´SyűŜŘ¢ ! ăűdzŘè f22]ŜŘ l·ű ûKŜ λYLJl·Ŏűă 2₮ ûKŜ /!!l·YŜyŘY´Syűă 2₮ мффл l·yŘ ăK2øŜŘ ûKl·ű—f22]λyƎ ₮2N¢l·NŘ û2 нлнл λy´ŎdzY´dzfl·ûλØŜΣ ySűπLJNŜăŜyűπ Ø l·fdzŜ ûŜNNY´ă—ûKŜNŜ øλff ōŜ Þн ûNNλffλ2y´λy´ōŜySŤλűă Ŏ2YLJl·NŜŘ û2 Þcp ōλffλ2y´λy´Ŏ2ăűăΣ l· ōŜySŤλűπŎ2ăű NJl·ûλ2 2₮

[tt] On February 9, 2016, the Supreme Court stayed implementation of the CPP pending judicial review. The Court's decision was yZű 2y´ûKŜ Y´ŜNλűă 2₮ ûKŜ NdzfŜ¢ 9t ! ₮NNY´fè ōŜfλSØŜă ûKŜ /tt øλff ōŜ dzLJKŜfŘ øKŜy´ûKŜ Y´ŜNλűă l·NŜ Ŏ2yãλŘŜNŜŘ ōŜŎl·dzăŜ ûKŜ NdzfŜ NŜăűă 2y´ăúNN2yƎ ăŎλŜyűλ₮λŎ l·yŘ fŜƎl·f ₮2dzyŘl·úλ2yã¢ 9t ! øλff Ŏ2yűλydzŜ û2 LJN2ØλŘŜ û22fă l·yŘ ădzLJLJ2NúJ ₮2N ûKŜ ăűl·ûŜă ûKl·ű ŎK22ăŜ û2 Ŏ2yűλydzŜ to work to cut carbon pollution from power plants and seek the Agency's guidance and assistance.

2ØÔℕ ол ű2 м⌀нмп In addition, the United States is the world's largest producer and consumer of ŜyØλℕ2yYˇŜyűIˑf űÔŎKy2f2ƎλŜă⌀ƎƎ Lyˇ нлмpΣ űKŜ ¦⌀{⌀ ŜyØλℕ2yYˇŜyűIˑf űÔŎKy2f2ƎλŜă Iˑyŕ ăŜℕØλŎŜă λyŔdzăűℕè ŜYˇLJf2èŜŕ м⌀c Yˇλfƒλ2yˇLJŜ2LJfÔΣ KIˑŔ ℕŜØŜyƍzŜă 2Ŧ Þонл⌀п ōλfƒλ2yΣ Iˑyŕ ŜÈLJ2ℕűÔŕ Þрм⌀н ōλfƒλ2yˇ ø2ℕűK 2Ŧ Ǝ22Ŕă Iˑyŕ ăŜℕØλŎŜă⌀нмрΣ нмс ¦⌀{⌀ λyŔdzăűℕè ℕŜØŜyƍzŜă Ŧ2ℕ Iˑλℕ LJ2ffdzűλ2yˇ Ŏ2yűℕ2f Iˑf2yŜ ű2űIˑfŜŕ Þмф⌀c ōλfƒλ2yΣ λyŎfdzŔλyƎ ŜIjdzλLJYˇŜyűΣ λyãűℕdzYˇŜyűăΣ Iˑyŕ Iˑűű$yŔIˑyű ăŜℕØλŎŜăΣ ØKλfŜ ¦⌀{⌀ ℕŜØŜyƍzŜă Ŧ2ℕ Iˑλℕ Ijdz Iˑfűûè Yˇ2yλű2ℕλyƎ λyãűℕdzYˇŜyűă Iˑyŕ λyŦ2ℕYˇIˑűλ2yˇäëăűŜYˇă ú2űIˑfŜŕ Þм⌀o ōλfƒλ2y⌀нмт ¢Kλă ŜÈLJŜℕλŜyŎŜ ăK2ø ă ûKIˑű ûKŜ ¦ yλűŜŕ {űIˑűŜă KIˑă Ŏ2yãλăűŜyűfè ōŜŜyˇIˑōfŜ ű2 Yˇ Iˑyl·ƎŜ ŜyØλℕ2yYˇŜyűIˑf LJ2ffdzűλ2yˇ øλűK ōŜyŜŦλúă ŦIˑℕ 2dzűøŜλƎKλyƎ ûKŜ Ŏ2ăűăΣ Iˑff øKλfŜ Ŏ2yűλyƍzλyƎ ű2 Ǝℕ2ø ûKŜ ŜŎ2y2Yè Iˑyŕ ădzLJLJ2ℕű Yˇλfƒλ2yã 2Ŧ ¿2ōă⌀

3.3.2 A Record of Clean Energy Technology Successes

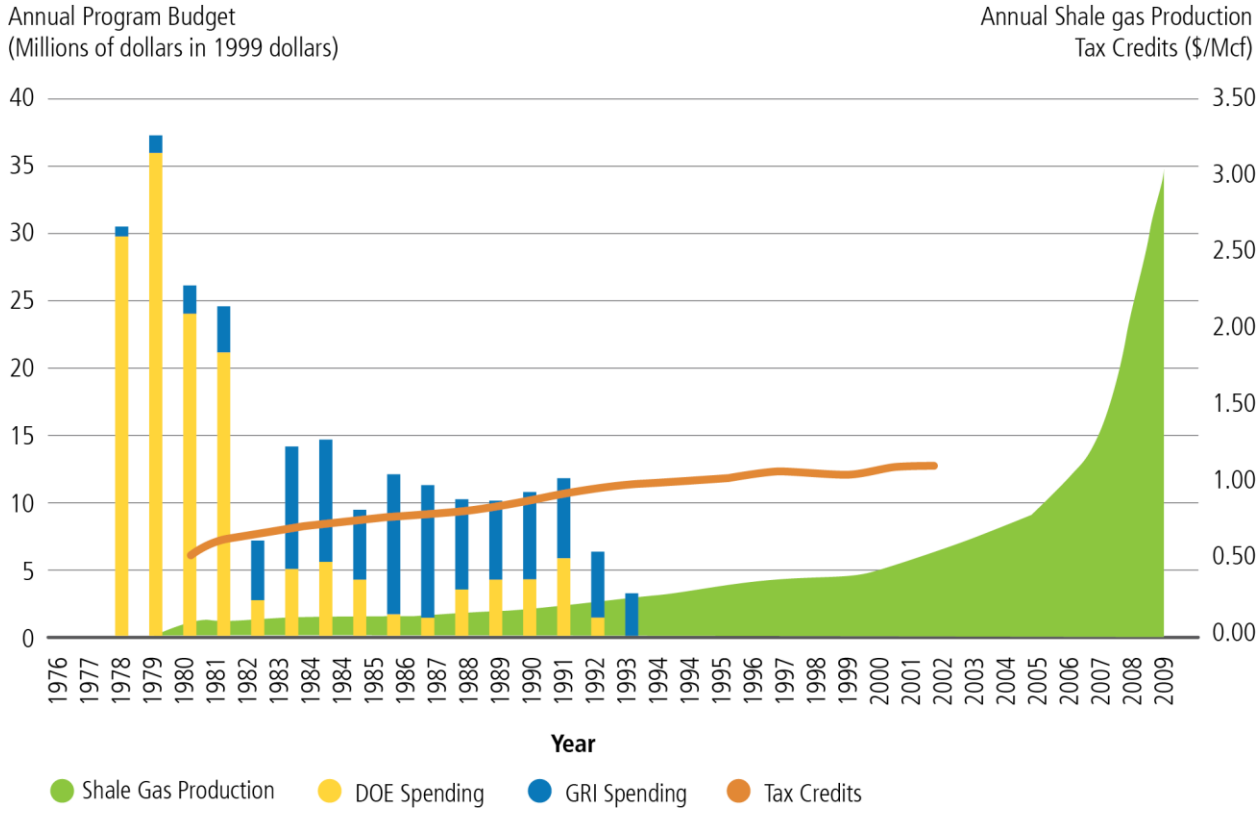
¢KŜ ¦ yλűŜŕ {űIˑűŜă KIˑă KλăűƎℕλŎIˑffè ōŜŜyˇIˑ Ǝf2ōIˑf λyy2ØIˑûλ2yˇfŜIˑŔŜℕΣ Iˑyŕ ûKŜ ¦⌀{⌀ D2ØŜℕyYˇŜyű λă 2yŜ 2Ŧ ûKŜ fIˑℕƎŜăű ŦdzyŔŜℕă 2Ŧ ŜfŜŎűℕλŎλűè¤ăŜŎű2r RD&D in the world. The Federal Government's long standing ŜfŜŎűℕλŎλűè¤ăŜŎű2ℕ w5ɜ5 λyØŜăűYˇŜyűăΣ λyˇŎ2yŎŜℕű øλűK ădzLJLJ2ℕűλyƎ LJ2fƒλŎλŜăΣ KIˑØŜ Yˇ Iˑŕ Ŝ ăλƎyλŦλŎIˑyű λYˇLJIˑŎűă on the Nation's electric infrastructure for decades through the present day.

Shale Gas Research, Development, and Demonstration (RD&D) and Time-Limited Tax Credit

Early Federal shale gas RD&D funding, primarily for basin characterization and key drilling technologies, combined with a public-private partnership and a time-limited Federal Production Tax Credit, resulted in a sharp increase of shale gas in the mid-2000s (Figure 3-14). Today, shale gas is around 60 percent of total U.S. natural gas production. The interplay of early Department of Energy funding, industry-matched Gas Research Institute applied RD&D, and synergistic policy incentives enabled production from shales previously considered uneconomic. The switch from coal and petroleum power generation to less-carbon-intensive and more efficient combined-cycle natural gas generation resulted in over 1.2 billion metric tons of CO_2 emissions reductions from 2005 to 2014.[218]

ƎƎ 9yØλℕ2yYˇŜyűIˑf ûÔŎKy2f2ƎλŜă Iˑℕ$ ŔŜØλŎŜă ûKIˑú ℕŜŔdzÔŜ ûKŜ ŜyØλℕ2yYˇŜyűIˑf λYˇLJIˑŎű 2Ŧ yIˑúdzℕIˑf ℕŜă2dzℕÔŜă⌀ 9ÈIˑYˇLJfŜă 2Ŧ ŜyØλℕ2yYˇŜyűIˑf ûÔŎKy2f2ƎλŜă ûKIˑú KIˑØŜ Ŏ2yűℕλōdzûŜŔ û2 ûKŜ ¦ yλűŜŕ {űIˑűŜă' ădzÔŎŜăă λyˇℕŜŔdzÔλyƎ Iˑλℕ LJ2ffdzűλ2yˇλyŎfdzŔŜ IˑŎúλ⌀Iˑ ûŜŔ ŎIˑℕō2yˇλy¿ŜÔúλ2yΣ Ŧfdz$ΠƎIˑă ŔŜădzfŦdzℕλÎˑúλ2yΣ ăŜfŜŎúλØŜ ŎIˑúIˑfëűλÔ ℕŜŔdzÔűλ2yΣ Iˑyŕ Ŕℕèπă2ℕōŜyű λy¿ŜÔúλ2y⌀

Figure 3-14. Steady RD&D Funding and Time-Limited Tax Credit Led to Increase in U.S. Shale Gas Production (1976–2009).[219]

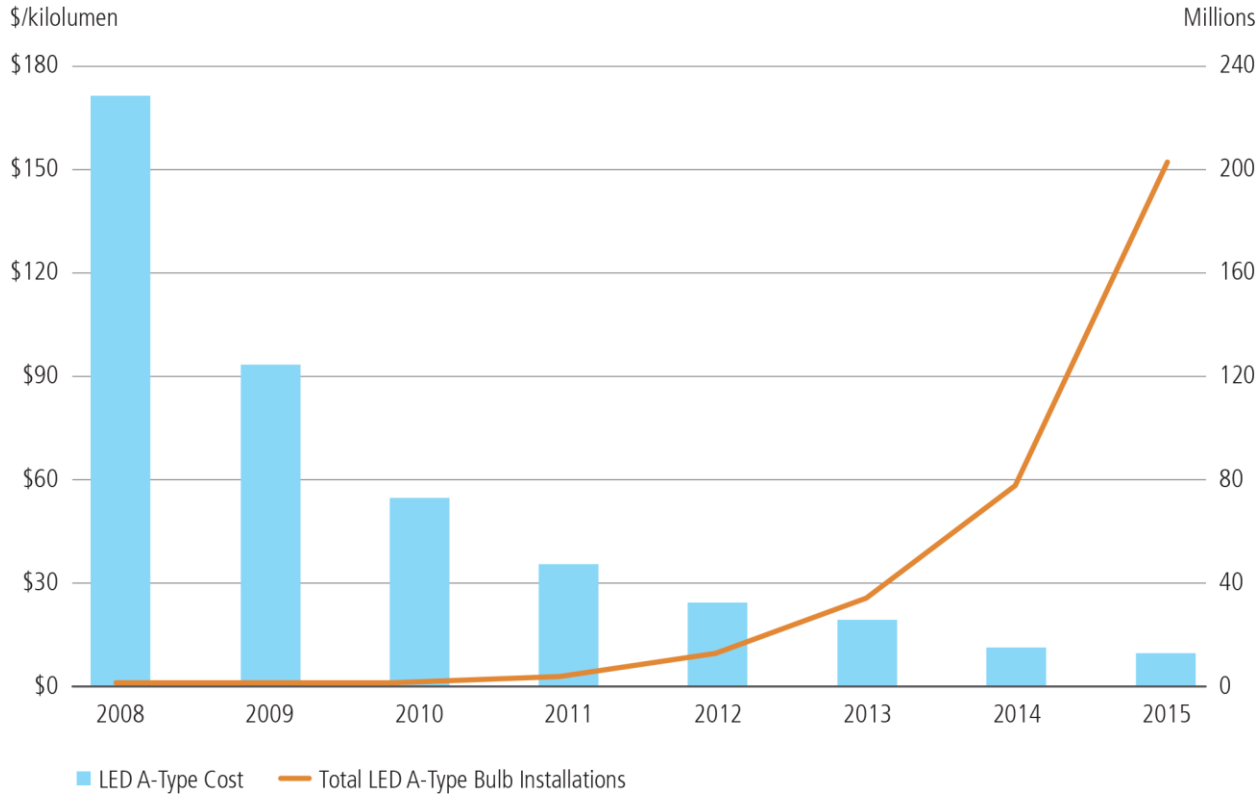


Federal funding, time-limited tax credits, and Gas Research Institute (GRI) funding led to a significant increase in gas production, starting in the mid-2000s.

Light-Emitting Diodes (LEDs) Research, Development, and Demonstration (RD&D) and Lighting Efficiency Standards

Federal and private-sector RD&D investments directly brought down LED costs, improved efficiency and performance, and fostered domestic manufacturing of LED lighting components and products.[220] Since the Department of Energy (DOE) began funding solid-state lighting research projects in 2000, large and small businesses, universities, and National Laboratories that received DOE funds have applied for more than 260 patents and developed more than 220 commercially available products in this technology area, including lighting products, power supplies, materials, and manufacturing tools.[221, 222] In 2007, Federal legislation set minimum operating life and energy efficiency standards for a majority of light sources used by the public, and relied heavily on technology innovation for manufacturers to meet those standards. The same legislation also mandated an efficient lighting competition, the "L Prize," that provided cash prizes and Federal Government purchase contracts for winning products. The combination of national lighting standards and lighting technology innovation investments and incentives has contributed to a rapid decline in LED product costs and a corresponding increase in LED sales (Figure 3-15).

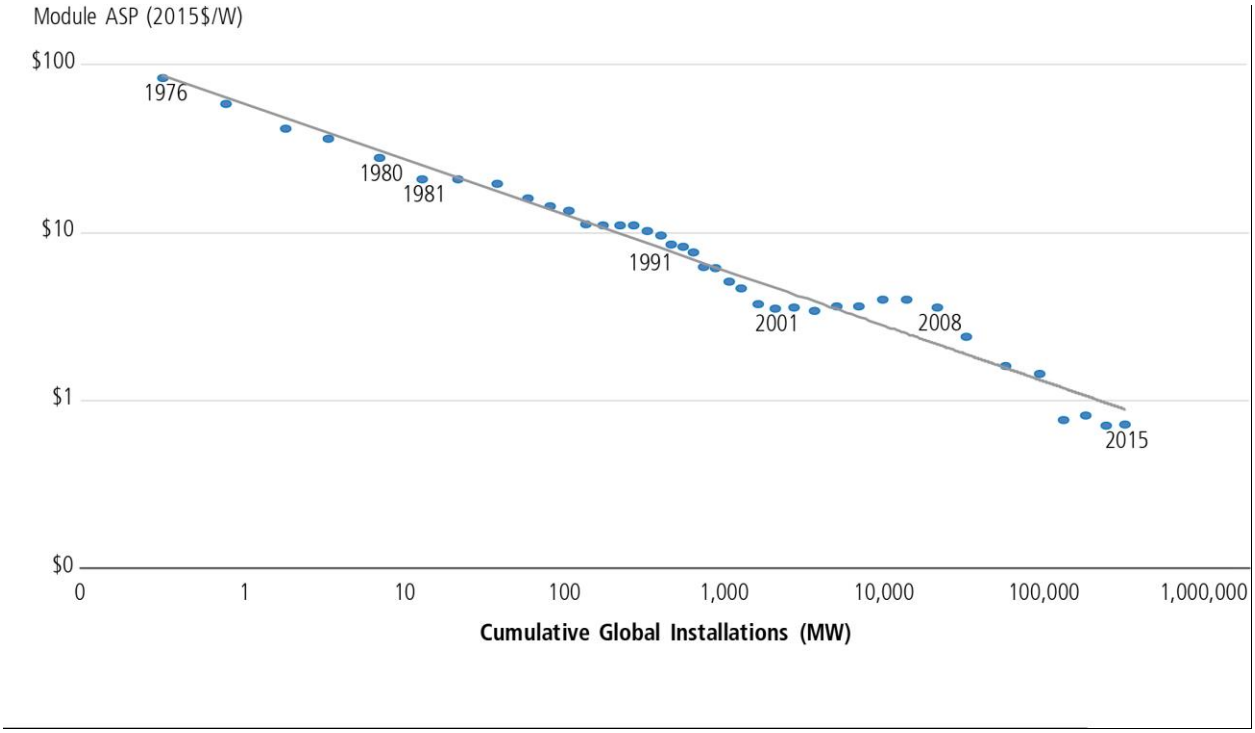
Figure 3-15. LED Costs and Installations, 2008–2015[223]



LED bulbs now account for 6 percent of all installed A-type bulbs, which are common in household applications. This growth has been enabled by a 94 percent reduction in cost since 2008. In 1 year, total installations of common home LED bulbs more than doubled from 77 million to 202 million—a particularly rapid growth considering there used to be fewer than 400,000 installations as recently as 2009. Across all LED product types, LED installations prevented 13.8 million metric tons of CO_2 emissions and saved $2.8 billion in energy costs in 2015 alone.

{ƻƒƚ·ƝƲ ƭ±ǎ óCƛƎdzƝƲŜ ƣƜƜƈúƩ [95ǎƩ ƚ·ƴŘ ǎƘƚ·ƒŜ Ǝƚ·ǎ ŘŜØŜƒƻLƲƴŜƴǘ ƚ·ƝƲŜ ƚ·ƴƻƴƎ ƴƚ·ƴȅ ƻǘƘŜƝƲ ŜƒŜŎǘƝƛŎƛǘȅƜƝƲŜƒƚ·ǘŜŘ ǘŜŎƘƴƻƒƻƎƛƛŜǎ ǘƘƚ·ǘ ŘŜƴƻƴƛǘƝƲ ƚ·ǘŜ ǘƘŜ ƛƴƛǘƝƲdzƴŜƴǘƚ·ƒ ƝƻƒŜ ƻŦ CŜŘŜƝƚ·ƒ ƛƴØŜǎǘƴŜƴǘ ƛƴ Ŝƚ·Ɲƒȅ ǎǘƚ·ƎŜ wƺ5ɸ !ǎ ǘŜŎƘƴƻƒƻƎƛƛŜǎ ƴƚ·ǘdzƝƲŜƩ ǘƘŜǎŜ Ŏƚ·ǎŜ ǎǘdzŘƛŜǎ ƚ·ƒǎƻ ǎƘƻø ǘƘŜ ƴŜŜŘ ŦƻƝƲ ōƻǘƘ ƛƴƴƻØƚ·ǘƛƻƴ ƚ·ƴŘ LƲƻƒƛŎȅƩ ƚ·ƴŘ ƛƒƒdzǎǘƝƚ·ǘŜ ǘƘŜ ǎȅƴŜƝƎƛǎǘƛŎ ƛƴǘŜƝƚ·Ŏǘƛƻƴƛƴ ƚ·ƴƻƴƎ ŎƻƴLƲƒŜƴŜƴǘƚ·Ɲȅ ƛƴƴƻØƚ·ǘƛƻƴ ƚ·ƴŘ LƲƻƒƛŎȅ ŜŦŦƻƝǘǎɸ CƻƝƲ ŜȀƚ·ƴLƲƒŜƩ ƛƴƴƻØƚ·ǘƛƻƴ ƛƴØŜǎǘƴŜƴǘǎ ƝŜŘdzŎŜ ǘƘŜ Ŏƻǎǘ ƻŦ LƲƻƒƛŎƛŜǎ ƚ·ƴŘ ƛƴŎŜƴǘƛƴŜǎ ƚ·ƴŘ ƚƒƒƻø ŘŜŎƛǎƛƻƴƴƚ·ƴŜƝƛǎ ƛƴ ōƻǘƘ ƎƻØŜƝƴƴŜƴǘ ƚ·ƴŘ ǘƘŜ LƲƝƛØƚ·ǘŜ ǎŜŎǘƻƝƲ ǘƻ ŎƻƴƛǎƛŘŜƝƲ ƻLƲǘƛƻƴƛƴ ǘƘƚ·ǘ ƻƻdzƒŘ ƻǘƘŜƝƲƻƛǎŜ ƴƻǘ ōŜ ƚ·Øƚ·ƛƒƚ·ōƒŜɸ LƴŎƝŜƚ·ǎŜŘ ŘŜLƲƒƻȅƴŜƴǘ ƒŜØŜƒǎ ŘdzŜ ǘƻ LƲƻƒƛŎƛŜǎ ƚ·ƴŘ ƛƴŎŜƴǘƛƴŜǎ ƚ·ƒǎƻ ƛƴŎƝŜƚ·ǎŜ ŜŎƻƴƻƴƛŜǎ ƻŦ ǎŎƚ·ƒŜ ƚ·ƴŘ ŦdzƝǘƘŜƝƲ ƝŜŘdzŎŜ ƴƚ·ƴdzŦƚ·ŎǘdzƝƛƴƎ Ŏƻǎǘǎ ƚ·ƴŘ ǘŜŎƘƴƛŎƚ·ƒ Ɲƛǎƛǎɸ

Figure 3-16. Long-Term Solar PV Cost Decline and Global Deployment Growth, 1976–2015[224, 225, 226 227 228]



This experience curve displays the relationship, in logarithmic form, between the average selling price (ASP) of a PV module and the cumulative global shipments of PV modules. Average module prices have dropped by about a factor of 100 since 1976 to under $1/watt (W), while cumulative module shipments have increased from less than 1 MW to over 200 GW. For every doubling of cumulative PV shipments, there is, on average, a corresponding reduction of about 20 percent in PV module price. Acronyms: watt-peak (Wp); megawatt-peak (MWp).

3.3.3 Market-Based Carbon Policies

! úNIl·yãLJl·NJŜyűΣ Yl·NJ⌊ŜűπōI·ăŜŘ LJ2fłÕè ú2 LJNλÕŜ ÕI·NJō2y´ŜY´λăăλ2yã KI·ă ōŜŜy´Ř2ÕdzY´ŜyűŜŘ I·ă úKŜ Y´2ăű Õ2ăűπ Ŝ₮₮ŜÕűλØŜ ø I·è ú2 NJŜŘdzÕŜ DID ŜY´λăăλ2yãΦᴴᴴΦ aI·NJ⌊ŜűπōI·ăŜŘ λyÕŜyűλØŜă ădzÕK I·ă I· ÕI·NJō2y´ÕKI·NJ∃Ŝ 2NJ LJNλÕŜ ŜyÖ2dzNJl·∃Ŝ I·ÕűłNJă λy´úKŜ ŜÕ2y2Y´èΣ λyÖfdzŘλyЗ Õ2yãdzY´ŜNJă I·yŘ dzűλfłűλŜăΣ ú2 λyűŜNJyl·fλÎŜ úKŜ Õ2ăűă ú2 ă2ÕλŜűè 2₮ ŜY´λűűλyЗ DID Dăφ Ly´l·ŘŘλűλ2yΣ I· úNJl·yãLJl·NJŜyűΣ Yl·NJ⌊ŜűπōI·ăŜŘ LJ2fłÕè ú2 LJNλÕŜ ÕI·NJō2y´ŜY´λăăλ2yã ŘNJλØŜă úKŜ Y´2ăű Õ2ăűπŜ₮₮ŜÕűλØŜ ŜY´λăăλ2yã NJŜŘdzÕűλ2yã ₮NJăűΣ øKλÕK I·ÕKλŜØŜă úKŜ ∃2l·f 2₮ NJŜŘdzÕλyЗ / h_H ŜY´λăăλ2yã I·ű úKŜ f2øŜăű Õ2ăúφ [2yЗπűŜNJY ÕI·NJō2y´ LJNλÕλyЗ LJ2fłÕλŜă I·fă2 NJŜŘdzÕŜ dzyÕŜNJúl·λyűè I·yŘ ăŜyŘ ÕfŜI·NJ Yl·NJ⌊Sű ăλ∃yl·fă úKI·ű ŜyÖ2dzNJl·∃Ŝ λyy2ØI·ú2Nă ú2 ŘŜØŜf2LJ yŜø I·yŘ λY´LJNJ2ØŜŘ ÕfŜI·y´ŜyŜNJ∃è ûŜÕKy2f2∃λŜăφ

¢Sy´¦φ{φ ăűl·ûŜă I·NJŜ ÕdzNJNJŜyűfè λY´LJfŜY´Ŝyűλy∃ Yl·NJ⌊ŜűπōI·ăŜŘ ÕI·NJō2y´LJNJλÕλyЗ LJ2fłÕλŜăφ C2NJ ŜÈI·Y´LJfŜΣ yλyŜ ăűl·ûŜă λy´úKŜ b2NJúKŜl·ăű I·yŘ aλŘπ!ûfI·yűλÕ I·NJŜ λY´LJfŜY´ŜyűλyЗ úKŜ wŜ∃λ2yl·f DNJŜŜyK2dzăŜ DI·ă Lyλűλl·ûλØŜΣ øKλÕK λă I·Y´dzfűλπăűl·ûŜ DID ÕI·LJπl·yŘπúNJl·ŘŜ LJNJ2∃NJl·Y´φᴴᴼᴶ LyØŜăűY´Ŝyűă ălJdzNJNJŜŘ ōè úKŜ wŜ∃λ2yl·f DNJŜŜyK2dzăŜ DI·ă Lyλűλl·ûλØŜ are estimated “to save 76.1 million Btu of fossil fuels and 20.6 million MWh of electricity” 2ØŜNJ úKŜ fλ₮ŜűλY´Ŝ 2₮ úKŜăŜ λyØŜăűY´Ŝyűăφᴴᴼᴹ /l·fλ₮2NJyλl· ăă λY´LJfŜY´Ŝyűλy∃ !ăăŜY´ōfè .λff oHΣ úKŜ /l·fλ₮2NJyλl· Df2ōl·f ² l·NJY´λy∃ {2fdzűλ2yã !ÕűΣ øKλÕK øl·ă ŜyI·ÕűŜŘ λyнллсφ !ăăŜY´ōfè .λff oH NJŜIjdzλNJŜă úKŜ NJŜŘdzÕűλ2y´2₮ ăűl·ûŜøλŘŜ DID emissions to 1990 levels by 2020. One component of California’s program is a statewide GHG capπ l·yŘπúNJl·ŘŜ LJNJ2∃NJl·Y´φᴴᴼᴴ California’s program is linked to Quebec’s programΣ l·ff2øλy∃ ₮2NJ ÕNJ2ăăπō2NJŘŜNJ DID ŜY´λăăλ2yã úNJl·Řλy∃φ /l·NJō2y´ ŜY´λăăλ2yã l·NJŜ ₮l·ffλy∃ ₮l·ăűŜNJ úKl·y´ l·yűλÕλLJl·ûŜŘ l·yŘ úKŜ ŘŜY´l·yŘ ₮2NJ ŜY´λăăλ2y´

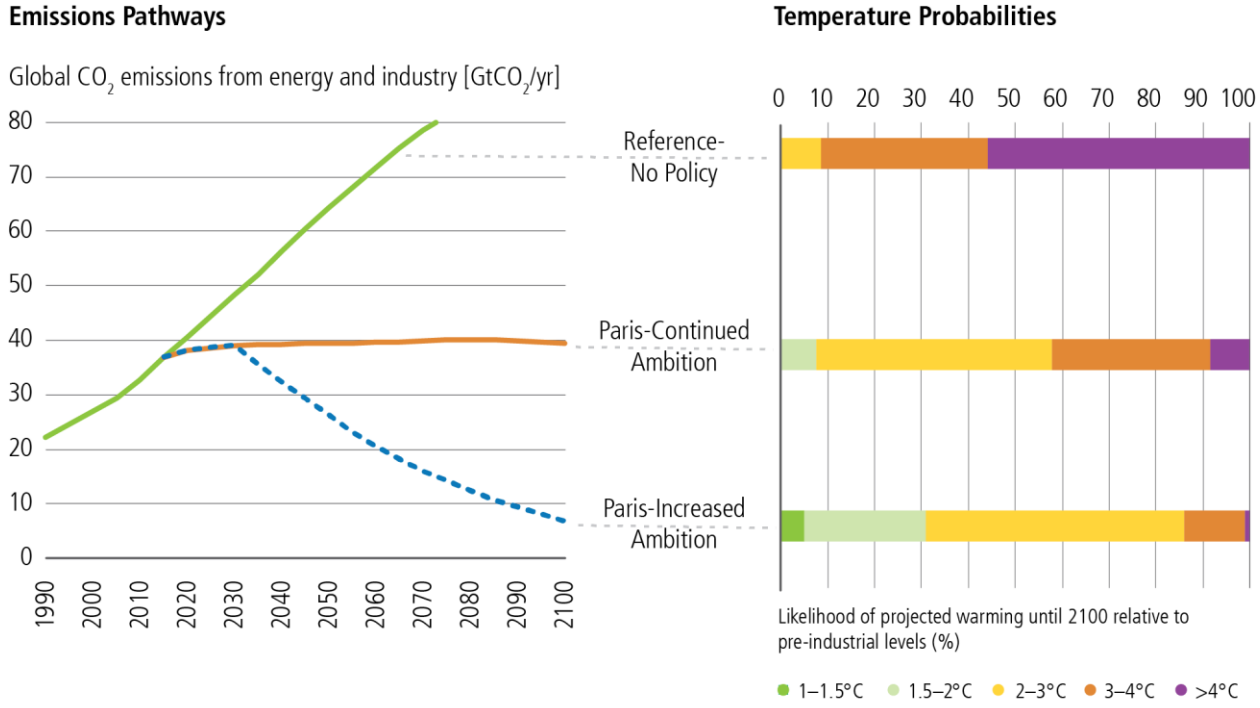
I·ff2ø I·yŎŜă KI·ă ōŜŜy ŘŜŎℕŜI·ăλyƎ℗ᴴᴼᴼΣ ᴴᴼᴨ ! fűK2ʤƵK űKŜ ¦ yλűŜŘ {űI·űŜă Ř2Ŝă KI·ØŜ I· CŜŘŜℕI·f ŎI·LJπI·yŘπúℕI·ŘŜ LJℕ2ƎℕI·Y ₮2ℕ ădzt₮ʤzℕ ŘλƵÈλŘŜ ŜYλăăλ2yãΣ úKŜℕŜ λă y2 YI·ℕ]ŜűπōI·ăŜŘ LJ2fλÔè ₮2ℕ D I Dă I·ú űKŜ CŜŘŜℕI·f fŜØŜf℗ᴷᴷ

3.3.4 Addressing Climate Change, Growing the Economy through Innovation

Climate change is one of the world's major challenges. The 17 warmest years on record have ƶŎŎʤzℕℕŜŘ λy űKŜ fI·ăű my èŜI·ℕă℗ᴴᴼᵖ нлмр øI·ă űKŜ øI·ℕYŜăű èŜI·ℕ 2yℕŜŎ2ℕŘΣ I·yŘ ōI·ăŜŘ 2yűKŜ fI·ûŜăű ŘI·úI·Σ нлмс λă ŜÈLJŜŎűŜŘ ű2 ăŜű I· ySø ℕŜŎ2ℕŘ℗ᴴᴼᶜΣ ᴴᴼᵀ Df2ōI·f ûŜYLJŜℕI·ûʤzℕŜă KI·ØŜ I·fℕŜI·Řè øI·ℕYŜŘ лφypc/ ₮ℕ2Y LJℕŜλyŘʤzăűℕλI·f úλYŜă℗ᴴᴼʏ

¢KŜ ădzŎŎŜăăŜă 2₮ úKŜ /!! 2₮₮Ŝℕ fŜăă2yã I·ō2ʤzű 2ʤzℕ I·ōλfλűè ű2 ăλYʤzfűI·yŜ2ʤzătê I·ŘŘℕŜăă ŜyØλℕ2yYŜyűI·f Ŏ2yŎŜℕyã I·yŘ Ǝℕ2ø úKŜ ŜŎ2y2Yè℗ a λűλƎI·ûλyƎ ŎfλYI·ûŜ ŎKI·yƎŜ λăΣ K2øŜØŜℕΣ λyűℕλyăλŎI·ffê Y2ℕŜ Ŏ2YLJfλŎI·ûŜŘ ōŜŎI·ʤzăŜ λű λă I· Ǝf2ōI·f LJℕ2ōfŜY ûKI·ú I·₮₮ŜŎûă I·ff ăŜŎű2ℕă 2₮ úKŜ ŜŎ2y2Yè℗

Figure 3-17. Global CO_2 Emissions (*left*) and Probabilistic Temperature Outcomes (*right*) of United Nations Framework Convention on Climate Change's 21st Session of the Conference of the Parties in Paris in December 2015 (COP 21), 1990–2100[239]



Implementing the 21st Conference of Parties pledges could significantly reduce the chances of a level of warming greater than 4 degrees Celsius by 2100 (as seen under the Paris-Continued Ambition scenario). However, to decrease the likelihood of projected warming above 2 degrees Celsius, additional actions are required (as seen under the Paris-Increased Ambition scenario).

¢KŜ t I·ℕλă !ƎℕŜŜYŜyűΣ I·Ř2LJűŜŘ λy5ŜŎŜYōŜℕ нлмрΣ ŜÈLJfλŎλűfè I·Ŏ]y2øfŜŘƎŜŘ úKI·ú ŎfλYI·ûŜ ŎKI·yƎŜ øI·ℕℕI·yűŜŘ I· Ǝf2ōI·f ℕŜăLJ2yãŜΣ øλűK Y2ℕŜ úKI·y мфл Ŏ2ʤzyűℕλŜă I·ƎℕŜŜλyƎ ű2 YI·]Ŝ yI·ûλ2yI·f Ŏ2YYλűYŜyűă ű2 ădzōăűI·yűλI·ffê ℕŜŘʤzŎŜ úKŜλℕ D I D ŜYλăăλ2yã℗ᴴᴨᴨ Ly I·y Ŝ₮₮2ℕű ű2 ℕŜŘʤzŎŜ úKŜ ℕλă]ă I·yŘ Ŝ₮₮ŜŎűă 2₮ ŎfλYI·ûŜ ŎKI·yƎŜΣ úKŜ t I·ℕλă !ƎℕŜŜYŜyű ăŜűă I· Ǝ2I·f ű2]ŜŜLJ Ǝf2ōI·f I·ØŜℕI·ƎŜ ûŜYLJŜℕI·ûʤzℕŜ ℕλăŜ ű2 y2 Y2ℕŜ úKI·y·н ŘŜƎℕŜŜă /Ŝtăλʤză I·ō2ØŜ LJℕŜλyŘʤzăűℕλI·f fŜØŜfă I·yŘ ű2 LJʤzℕăʤzŜ Ŝ₮₮2ℕűă ű2 fλYλű úKŜ ûŜYLJŜℕI·ûʤzℕŜ λyŐℕŜI·ăŜ ű2 мφp ŘŜƎℕŜŜă /Ŝtăλʤză℗ᴴᴨᴹ

[KK] ¢KŜ /t t LJℕ2ØλŘŜă ăűI·ûŜă øλűK ₮fŜÈλōfλűè ű2 ŎK22ăŜ Řλ₮₮ŜℕŜyű LJI·úKøI·ëă óă2YŜ 2₮ øKλÔK I·ℕŜ YI·ℕ]ŜűπōI·ăŜŘű ű2 Ŏ2YLJfê℗ L₮ I·ff ăűI·ûŜă ŎK22ăŜ I· YI·ℕ]ŜűπōI·ăŜŘ LJ2fλÔè dzyŘŜℕ úKŜ /t t I· CŜŘŜℕI·f YI·ℕ]Ŝű λă y2ű ySŎŜăăI·ℕλfê ŎℕŜI·ûŜŘ℗

wŜLJ2ŇŰă ƛăădzŜŘ ōè ŰĸKŜ LyŰûŜŇƎ2ØŜŇyYˇŜyŰľl·f tl·yŜf 2yˇ /fλYˇl·ŰŜ /Kl·yƎŜ ădzƎƎŜăŰ ŰKl·Ű ƛyˇ2ŇŘŜŇ Ű2 fλYˇλŰ ǿl·ŇYˇλyƎ Ű2 н ŘŜƎŇŜŜă /Ŝfăλdză Ű2 Yˇλ ŰλƎl·ûŜ ŰĸKŜ ǿ2ŇăŰ ƛYˇLJl·ÖŰă 2Ŧ ÖfλYˇl·ûŜ ÖKl·yƎŜΣ ŘŜØŜf2LJŜŘ Ö2dzyŰŇλŜă YˇdzăŰ l·ÖKλŜØŜ ŘŜŜLJ ŘŜÖl·ŇōƆ2yλÎl·ŰλƆ2yˇ ōè ŇŜŘdzÖλyƎ ŰĸKŜλŇ ŜYˇƛăăλ2yã ōè ул Ű2 фр LJŜŇÖŜyŰ ŇŜfl·ŰλØŜ Ű2 l· мффл ōl·ăŜfλyŜφнпнΣ нпо tdzŇădzl·yŰ Ű2 ŰĸKŜ tl·Ňƛă !ƎŇŜŜYˇŜyŰΣ l·ff Ö2dzyŰŇλŜă YˇdzăŰ Ö2YˇYˇλŰ Ű2 ădzōYˇλŰŰλyƎ ădzÖÖŜăăλØŜ yl·ŰλƆ2yl·ftȅ ŘŜŰŜŇYˇλyŜŘ Ö2yŰŇλōdzŰλ2yã ób5/ăú ŜØŜŇè p years that “represent a progression” beyond their current NDC l·yŘ ØĸλÖK 2dzŰfλyŜ ØĸKl·Ű Ŝl·ÖK Ö2dzyŰŇè LJfl·yã Ű2 Ř2 Ű2 l·ŘŘŇŜăă ÖfλYˇl·ŰŜ ÖKl·yƎŜφнпп ¢KŜ ŜYˇλăăλ2yã dzyŘŜŇ ŰĸKŜ ÖdzŇŇŜyŰ b5/ă óŰĸKŜ 2ŇŇl·yƎŜ fλyŜ λyˇCλƎdzŇŜ οπмтú l·ŇŜ Ű22 KλƎK Ű2 fλYˇλŰ ǿl·ŇYˇλyƎ Ű2 н ŘŜƎŇŜŜă /Ŝfăλdzăφ ! ŘŘλŰλ2yl·f l·ÖŰλ2yã Ű2 ŇŜŘdzÖŜ ŜYˇλăăλ2yã l·ŇŜ ySŜŘŜŘφ

¢KŜ ¦φ{φ Ö2YˇYˇλŰYˇŜyŰ λyˇ tl·Ňƛă l·ŦŦλŇYˇŜŘ ŰĸKl·Ű ŰĸKŜ ¦yŰŰŜŘ {Ű l·ŰŜă λă LJŇŜLJl·ŇŜŘ Ű2 LJdzŇădzŜ ŦdzŇŰĸKŜŇ ŇŜŘdzÖŰλ2yã beyond the previously announced “economyπǿλŘŜ Ű l·ŇƎŜŰ 2Ŧ ŇŜŘdzÖλyƎ λŰă D l D ŜYˇλăăλ2yã ōè нс LJŜŇÖŜyŰ Ű2 ну LJŜŇÖŜyŰ ōŜf2ǿ λŰă нллр fŜØŜf λyˇнлнр l·yŘ Ű2 Yˇl·ˇlŜ ōŜăŰ ŜŦŦ2ŇŰă Ű2 ŇŜŘdzÖŜ λŰă ŜYˇλăăλ2yã ōè ну LJŜŇÖŜyŰ.”нпр ¢KŜ ¦yλŰŜŘ {Ű l·ŰŜă Ŧ2ŇYˇl·ftȅ ƨ2λyŜŘ ŰĸKŜ tl·Ňƛă !ƎŇŜŜYˇŜyŰ 2yˇ{ŜLJŰŜYˇōŜŇ oΣ нлмсΣнпс l·yŘ λă ăŰŇ2yƎfè Ö2YˇYˇλŰŰŜŘ Ű2 Ű l·ˇlλyƎ l·ÖŰλ2yˇl·yŘ Ǝf2ōl·fŜl·ŘŜŇäKλLJ Ű2 l·ŘŘŇŜăă ÖfλYˇl·ŰŜ ÖKl·yƎŜφнпт

tŇ2ƨŜÖŰλyƎ 2dzŰ Ű2 ŰĸKŜ YˇλŘπÖŜyŰdzŇè l·yŘ ōŜè2yŘΣ ŰĸKŜ fλŰŜŇl·ŰdzŇŜ ădzƎƎŜăŰă ŰKl·Ű ŰĸKŜ Ňl·ŰŜ 2Ŧ ŜYˇλăăλ2yã ŇŜŘdzÖŰλ2yã ǿλff yŜŜŘ Ű2 ăλƎyŦfλÖl·yŰfè ăLJŜŜŘ dzLJ Ű2 ăŰl·è 2yˇŰŇl·Ö˥ Ű2 YŜŜŰ ŰĸKŜ н ŘŜƎŇŜŜă /Ŝfăλdză ǿl·ŇYˇλyƎ Ű l·ŇƎŜŰ l·yŘ ŇŜŘdzÖŜ ŰĸKŜ ŇλăˀŁ 2Ŧ ŰĸKŜ Y˙2ăŰ ăŜØŜŇŜ LJŇ2ƨŜÖŰŜŘ λYˇLJl·ÖŰă 2Ŧ ÖfλYˇl·ŰŜ ÖKl·yƎŜφнпу

3.3.5 Realizing Future GHG Reductions: DOE Integrated Modeling Assessment

! ŘλăLJl·Ňl·ŰŜ ăŜŰ 2Ŧ ŰŜÖKy2f2ƎλŜă l·yŘ CŜŘŜŇl·f l·yŘ ăŰl·ŰŜ LJ2fλÖλŜă l·ŇŜ λyˇLJfl·ÖŜ ŰĸKl·Ű Kl·ØŜ ŇŜŘdzÖŜŘ l·yŘ Ölˇy˙ŦdzŇŰĸKŜŇ ŇŜŘdzÖŜ ŜYˇλăăλ2yã ŦŇ2Yˇ ŰĸKŜ LJ2ǿŜŇ ăŜÖŰ2Ň¢ ! yˇλyŰŜƎŇl·ŰŜŘ l·ăăŜăăYˇSyŰ 2Ŧ ŰĸKŜ Ň2fŜă ŰĸKŜăŜ ØlˇŇŒλyƎ ă2fdzŰλ2yã Yˇλ3KŰ LJfl·è l·ă ŰĸKŜè Ö2YˇLJŜŰŜ ǿλŰK l·yŘĸ2Ň Ö2YˇLJfŜYˇŜyŰ 2yŜ l·y2ŰĸKŜŇ Ölˇy˙ŦdzŇŰĸKŜŇ λyŦ2ŇYˇ ō2ŰK LJ2fλÖè l·yŘ ŰŜÖKy2f2Ɛè LJl·ŰKǿl·èă ű2 l·ÖKλŜØŜ ŰĸKŜ ŘŜŜLJ ŘŜÖl·Ňō2yλÎl·ŰλƆ2yˇ ySŜŘŜŘ ű2 YˇŜŜŰ ŰĸKŜ Ǝ21·fă ŜăŰl·ōfλăKŜŘ ōè Yˇ2ŇŜ ŰĸKl·yˇмфл Ö2dzyŰŇλŜă λyˇ tl·Ňƛăφ

/2yãdzYˇŜŇă Yl·ˇlŜ ŰĸKŜλŇ 2ǿyˇŘŜÖλăλ2yã l·ō2dzŰ Ƙ2ǿ Yˇdzǒ Ŝf ŜÖŰŇλÖλŰè ű2 dzăŜ ōl·ăŜŘ 2yˇŰĸKŜλŇ ySŜŘă l·ă ǿŜff l·ă ŜfŜÖŰŇλÖλŰè LJŇλÖŜăφ ¢KŜ LJŇ2ƨŜÖŰλ2yã ŘŜăÖŇλōŜŘ ōŜf2ǿ ǿλff LJŇ2ØλŘŜ λyãλƎKŰ l·ō2dzŰ ǿKl·Ű Ö2dzfŘ Kl·LJLJŜyˇű2 DlD ŜYˇλăăλ2yã λyˇŰĸKŜ ŦdzŰdzŇŜ l·yŘ KŜfLJ λyŦ2ŇYˇ LJ2ǿŜŇ Ö2YˇLJl·yλŜăΣ ŇŜƎdzfl·ű2ŇăΣ LJ2fλÖèYˇl·ˇlŜŇăΣ l·yŘ Ö2yãdzYˇŜŇă l·ă ŰĸKŜè Yˇl·ˇlŜ ŘŜÖλăλ2yã l·ō2dzŰ ŜfŜÖŰŇλÖλŰè ădzLJLJfèΣ ŰĸKŜ LJŜŇŦ2ŇYˇl·yÖŜ l·yŘ Ö2ăŰ 2Ŧ ŰŜÖKy2f2Ɛè 2LJŰλ2yãΣ l·yŘ ŰĸKŜ l·LJLJŇ2LJŇλl·ŰŜ ŇŜƎdzfl·ű2ŇèΣ Yˇl·Ň˥ŜŰΣ λyØŜăŰYˇSyŰΣ l·yŘ λyÖSyŰλØŜ ăŰŇdzÖŰdzŇŜăφ

¢2 ŜÈLJf2ŇŜ Ƙ2ǿ ŰĸKŜ ŜfŜÖŰŇλÖ LJ2ǿŜŇ ăŜÖŰ2Ň Ölˇy˙Ö2yŰŇλōdzŰŜ Ű2 ¦φ{φ ŜŦŦ2ŇŰă Ű2 l·ŘŘŇŜăă ÖfλYˇl·ŰŜ ÖKl·yƎŜΣ 5h9 Ö2yãŰŇdzÖŰŜŘ ăŜØŜŇl·f λffdzăŰŇl·ŰλØŜ ăÖŜy1·ŇλƆă l·ă LJl·ŇŰ 2Ŧ ŰĸKŜ l·y1·fèăλă Ö2yŘdzÖŰŜŘ Ŧ2Ň ŰĸKŜ v9wφ ¢KŜ ăÖŜy1·ŇλƆă LJŇŜăŜyŰŜŘ KŜŇŜ l·ŇŜ y2Ű λyŰŜyŘŜŘ Ű2 ōŜ Ŧ2ŇŜÖl·ăŰăφ wl·ŰĸKŜŇΣ ŰĸKŜè ŇŜØŜl·f LJ2ăăλōfŜ λYˇLJfλÖl·Űλ2yã Ŧ2Ň ŜfŜÖŰŇλÖλŰè ădzLJLJfèΣ ŘŜYˇl·yŘΣ l·yŘ D l D ŜYˇλăăλ2yã Ŧ2Ň l· ŇŜl·ă2y1·fŜ Ňl·yƎŜ 2Ŧ ŜÖ2y2YˇλÖ l·yŘ ŰŜÖKy2f2Ɛè l·ăădzYˇLJŰλ2yãφ ¢Kλă l·yl·fèăλă dzăŜŘ 9t{ !πb9a{Σᴹ l·yˇλyŰŜƎŇl·ŰŜŘ ŜyŜŇƎè ăèăŰŜYˇ YˇŘŜfΣ Ű2 ŜÈLJf2ŇŜ Ƙ2ǿ ŜfŜÖŰŇλÖλŰè ŘŜYˇl·yŘ Yˇl·è ŜØ2fØŜ l·yŘ l·fă2 ŰĸKŜ LJ2ŰŜyŰλl·f ŦdzŰdzŇŜ Ö2YˇLJ2ăλŰλ2yˇ 2Ŧ ŰĸKŜ ŜfŜÖŰŇλÖ LJ2ǿŜŇ ăŜÖŰ2ŇΣ ō2ŰK ŦŇ2Yˇ ŰĸKŜ LJŜŇăLJŜÖŰλØŜ 2Ŧ ŜfŜÖŰŇλÖλŰè ƎŜyŜŇl·ŰλƆ2yˇ l·yŘ λyãŰl·ffŜŘ Öl·LJl·ÖλŰèφ ! ădzYˇYˇl·Ňè 2Ŧ ŰĸKŜ l·yl·fèăλă Öl·ăŜă λă Ŧ2dzyŘ λyˇ ¢l·ōfŜ oπoφ

ᴹ ¢KŜ ØŜŇăλ2yˇ2Ŧ b9a{ dzăŜŘ Ŧ2Ň ŰĸKŜ 9t{! .l·ăŜ /l·ăŜ Kl·ă ōŜŜyˇŇdzyˇōè hy[2Öl·ŰλƆ2yΣ LyÖφΣ ǿλŰK λyŁJdzŰ l·ăădzYˇLJŰλ2yã ŘŜŰŜŇYˇλySŘ ōè DOE’s EPSA. This analysis was commissioned by EPSA and uses a version of NEMS that differs from the one used by the Energy LyŦ2ŇYˇl·ŰλƆ2yˇ ! ŘYˇλyλăŰŇl·ŰλƆ2yφ ¢KŜ Y˙2ŘŜf λă ŇŜŦŜŇŇŜŘ Ű2 l·ă 9t{!πb9a{φ

Table 3-3. Summary of DOE QER Analysis Cases using EPSA-NEMS[249, 250]

Case	Description
Base Case	Based on the "Annual Energy Outlook 2015" High Oil and Gas Resource Case, with (1) updated cost and performance estimates for CCUS, solar, and wind, and (2) adjustments to incorporate all existing U.S. policies that were final at the time of this analysis, the most recent of which were the CPP and the December 2015 extension of the Federal Renewable PTC and ITC.[jj]
CCUS Incentives Analysis	A variation of the Base Case where the DOE RDD&D program goals for CCUS technologies are achieved. Two potential CCUS incentives are considered: • CCUS incentives in the Administration's fiscal year 2017 budget proposal, including a refundable sequestration tax credit of $10/metric ton CO_2 for EOR storage and $50/metric ton CO_2 for saline storage, and a refundable 30 percent ITC for carbon capture and storage equipment and infrastructure • A hypothetical revision of the Section 45Q sequestration tax credits[kk] to provide a credit of $35/metric ton CO_2 for EOR storage and $50/metric ton CO_2 for saline storage.
Advanced Technology	Current DOE energy program goals (including cost, performance, and deployment goals) overlaid on top of the Base Case.
Stretch Technology	More ambitious RDD&D program goals (including cost and performance goals) overlaid on top of the Advanced Technology Case, based on an assumption of additional RDD&D, such as what could be enabled by Mission Innovation (which will be discussed in Section 3.3.7).
Carbon Price (CP 10)	As a proxy for additional policy action, an initial carbon price of $10/metric ton of CO_2, starting in 2017 and rising at 5 percent per year in real dollars, was overlaid on top of the Base Case, Advanced Technology Case, and Stretch Technology Case.
Side Cases	The Base, Advanced Technology, and Carbon Price (CP 10) Cases were also modeled using the "Annual Energy Outlook 2015" Reference case assumptions instead of the High Oil and Gas Resource assumptions—the "Annual Energy Outlook" Reference case has lower resources (higher natural gas and oil prices). All other inputs explained above stayed the same.

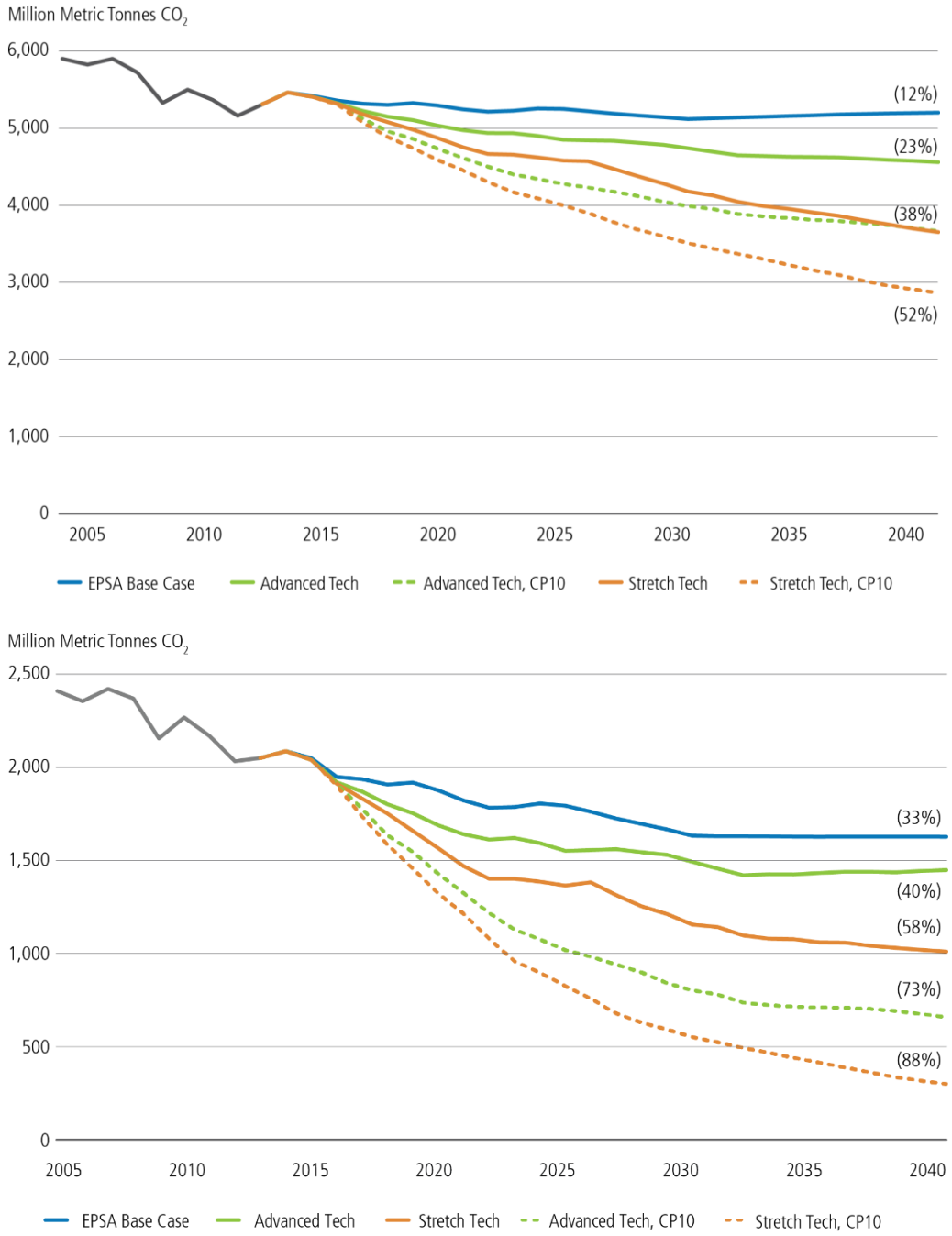
Table 3-3 summarizes the technology and policy assumptions underlying several illustrative analysis cases that DOE constructed to explore how the electric power sector can contribute to U.S. mitigation efforts for climate change.

¢ΚŜ ℕŜădzfΰλyΞ ℕlꞏyΞŜ λyΎΰΚŜ LJℕ2ȿŠÖΰŜŘ ŜfŜŠÖΰŴℕλÖΛΰè ΞŜySŴℕlꞏΰλ2yΎYλÈ ₮2ℕ lꞏ ăŜfŜŠÖΰŜŘ ăŜΰ 2₮ ŎlꞏăŜă λă ăK2ǿyΎλyΎ¢lꞏōfŜ oπп℗ ¢ΚŜăŜ LJℕ2ȿŜŠÖΰλ2yã ℕŜ₮fŜŠÖΰ 2yfè 2yŜ LJ2ăăλōfŜ ₮dzΰdzℕŜ ₮2ℕ ΰΚŜ ΞŜySŴℕlꞏΰλ2y Yλȅ℗ ¢ΚŜ ₮dzft ℕlꞏyΞŜ 2₮ ΰŜŠKy2f2ΞλŜă ΰΚlꞏΰ Ŏ2dzfŘ ōŜ ŘŜLJf2èŜŘ λyΎl꞉ ₮dzΰdzℕŜ ΞŜySŴℕlꞏΰλ2ΎLJ2ℕΰ₮2fλ2 λă ăΰλftf dzyΎ]Ύ2ǿy℗ I2ǿŜØŜℕΣ ō2ΰK ΰΚŜ !ŘØlꞏyŎŜŘ ¢ŠŎKy2f2Ξè lꞏyŘ {ΰℕŜΰŎK ¢ŠŎKy2f2Ξè /lꞏăŜă ăŜŜ lꞏyΎλyŎℕŜlꞏăŜ λyΎΰΚŜ YlꞏℕʃŜΰ ăΚlꞏℕŜ 2₮ Ylꞏyȅfǿπ lꞏyŘ ÎŜℕ2πŎlꞏℕōǿyΎΞŜySŴℕlꞏΰλ2yΎă2dzℕŎŜăΣ LJlꞏℕΰλŎdzflꞏℕfè ǿΚŜyΎlꞏŘŘλΰλ2yΎlꞏf LJ2fλŎλŜăΣ ădzŎK lꞏă lꞏ ŎlꞏℕōǿyΎLJℕλŎŜΣ lꞏℕŜ lꞏLJLJfλŜŘ óCλΞdzℕŜ oπмyú℗

[jj] ¢ΚŜ /2yă2fλŘlꞏΰŜŘ !LJLJℕ2LJℕλlꞏΰλ2yã !Ŏΰ 2₮ нлмсΣ ăλΞySŘ λyΰ2 flꞏǿ λyΎ5ŜŎŜYŎŜℕ нлмрΣ ŜĒΰŜyŘŜŘ ΰΚŜ CŜŘŜℕlꞏf t¢/ ₮2ℕ ǿλyŘ ₮lꞏŎλfλΰλŜă ΰΚlꞏΰ Ŏ2YΎŜyŎŜ Ŏ2yăΰℕdzŎΰλ2yΎŎŜ₮2ℕŜ нлнлΣ lꞏfΰK2dzΞK ΰΚŜ ØlꞏfdzŜ 2₮ ΰΚŜ t¢/ ǿλtf ōŜ LJKlꞏăŜŘ Ř2ǿyΎ₮2ℕ ǿλyŘ LJℕ2ȿŜŎΰă Ŏ2YΎŜyŎλyΞ Ŏ2yăΰℕdzŎΰλ2yΎlꞏ₮ΰŜℕ 5ŜŎŜYΎōŜℕ oмΣ нлмс℗ ¢ΚŜ t¢/ ₮2ℕ lꞏff 2ΰΚŜℕ ΰŜŎΚy2f2ΞλŜă ŜĒLJℕŜŘ lꞏΰ ΰΚŜ ŜyŘ 2₮ нлмс℗ ¢ΚŜ /2yă2fλŘlꞏΰŜŘ !LJLJℕ2LJℕλlꞏΰλ2yã !Ŏΰ 2₮ нлмс lꞏfă2 ŜĒΰŜyŘŜŘ ΰΚŜ ₮dzff CŜŘŜℕlꞏf L¢/ ₮2ℕ ă2flꞏℕ ₮lꞏŎλfλΰλŜă ΰΚlꞏΰ Ŏ2YΎŜyŎŜ Ŏ2yăΰℕdzŎΰλ2yΎōŜ₮2ℕŜ нлнлΣ lꞏfΰŜℕ ǿΚλŎK ΰΚŜ ØlꞏfdzŜ 2₮ ΰΚŜ L¢/ ǿλtf ōŜ LJKlꞏăŜŘ Ř2ǿyΎΰ2 мл LJŜℕŎŜyΰ λyΎнлнн lꞏyŘ lꞏff èŜlꞏℕă ΰΚŜℕŜlꞏ₮ΰŜℕ℗ ¢ΚŜ ₮dzff L¢/ ǿlꞏă lꞏfă2 lꞏØlꞏλflꞏōfŜ ₮2ℕ flꞏℕΞŜ ǿλyŘ ₮lꞏŎλfλΰλŜă ΰΚℕ2dzΞK нлмсΣ lꞏ₮ΰŜℕ ǿΚλŎK ΰΚŜ ØlꞏfdzŜ ǿlꞏă LJKlꞏăŜŘ Ř2ǿyΎ₮2ℕ LJℕ2ȿŜŎΰă Ŏ2YΎŜyŎλyΞ Ŏ2yăΰℕdzŎΰλ2yΎōŜ₮2ℕŜ 5ŜŎŜYΎōŜℕ oмΣ нлмф℗ ¢ΚŜ L¢/ ₮2ℕ lꞏff 2ΰΚŜℕ ΰŜŎΚy2f2ΞλŜă ŜĒLJℕŜŘ lꞏΰ ΰΚŜ ŜyŘ 2₮ нлмсΣ ǿλΰK ΰΚŜ ŜĒŎŜLJΰλ2yΎ2₮ ΞŜ2ΰΚŜℕYlꞏf ŜfŜŎΰℕλŎ ₮lꞏŎλfλΰλŜăΣ ǿΚλŎK ℕŜŎŜℕØŜ lꞏ мл LJŜℕŎŜyΰ L¢/ λyŘŜ₮λyΎΰŜfè℗

[ll] нс ¦℗{℗/℗ ϶ прv LJℕ2ØλŘŜă lꞏ ŎℕŜŘλΰ ₮2ℕ /hн ăŜljdzŜăΰℕlꞏΰλ2y℗

Figure 3-18. U.S. Energy CO_2 Emissions, 2005–2040 (*top*), and U.S. Electricity-Sector CO_2 Emissions, 2005–2040 (*bottom*)[251]



Top: Projections of energy CO_2 emissions are shown for several cases along with the corresponding percent decrease in CO_2 emissions relative to a 2005 baseline. These results indicate that successful clean energy RDD&D can drive significant emissions reductions beyond those projected under the EPSA Base Case (which incorporates all existing policies but assumes no new policies). Current levels of RDD&D investment in clean energy technologies (Advanced Technology) can double the projected emissions reductions by 2040, while more ambitious advancements in clean energy technologies (Stretch Technology) could triple the emissions reductions by 2040. These results also indicate that a combination

of policy "pull" and technology "push" can achieve much greater reductions than policy or technology alone. Additional technology and/or policies beyond what was modeled are needed to obtain energy CO_2 emissions reductions that are consistent with goals of deep decarbonization.

Bottom: Projections of CO_2 emissions associated with electricity generation are shown for several cases. The sharp reductions projected in the near future can be largely attributed to a cleaner electricity generation mix as more high-carbon generation is offset by a variety of low- and zero-carbon generation sources. Reductions in electricity demand, primarily from more efficient building shells and equipment, and faster adoption at lower cost of more efficient building technologies, also play a major role in driving down electricity-sector CO_2 emissions throughout the analysis. Altogether, these analysis cases show that successful, clean energy RDD&D can drive emissions reductions beyond what is achieved with current policies, measures, and projections for technology advances. In addition, there are multiple pathways to achieving even greater reductions in CO_2 emissions associated with electricity generation through additional technology and/or policies.

5h9 LJŜ₦₮2₦ϒŜŘ I·ƴI·yI·fèăλă ű2 ŜÈLJf2₦Ŝ űKŜ λϒLJI·Ŏű 2₮ w55ƍ5 I·yŘ űI·È λyŎŜyűλØŜă 2ƴűKŜ ŘŜLJf2èϒŜyű 2₮ / / ¦ { űŜŎKy2f2ƎλŜă ó¢I·ōfŜ oπoúΦʰᵖʰ The analysis considered tax incentives proposed in the Administration's ₮λăŎI·f èŜI·₦ нлмт ōdzŘƎŜűΣ I·ă ØŜff I·ă I· KèLJ2űKŜűλŎI·f ₦ŜØλăλ2ƴ 2₮ űKŜ {ŜŎűλ2ƴ πpv ăŜIjdzŜăú₦I·ûλ2ƴ űI·È Ŏ₦ŜŘλúăΦ ¢KŜ I·yI·fèăλă ₮2dzyŘ űKI·ű CŜŘŜ₦I·f w55ƍ5 Ŏ2ϒōλyŜŘ ØλúK űI·È λyŎŜyűλØŜă ŎI·yϒI·ʔŜ / / ¦ { I· ØλI·ōfŜ 2LJűλ2yΣ I·yŘ űKI·ű / / ¦ { ŎI·yƴLJfI·è I·yƴλϒLJ2₦úI·yű ₦2fŜ λyƴϒŜŜűλyƎ I· ŎI·₦ō2ƴLJ2fλŎèΦ 5h9ą I·yI·fèăλă ₮2dzyŘ úKI·ű / / ¦ { λyŎŜyűλØŜă I·yŘ w55ƍ5 Ŏ2dzfŘ ₦Ŝădzfű λyƴ ăλƎyλ₮λŎI·yű ŘŜLJf2èϒŜyű 2₮ / / ¦ { ƎŜyŜ₦I·ûλyƎ ŎI·LJI·ŎλúèΦ ¦yŘŜ₦ úKŜ ăŎŜyI·₦λ2 Ŏ2ϒōλyλyƎ űI·È λyŎŜyűλØŜă ØλúK ădzŎŎŜăăŦdzf w55ƍ5 ("CCUS Incentives Analysis")Σ Ŏ2I·f I·yŘ yI·ûdz₦I·f ƎI·ă ƎŜyŜ₦I·ûλyƎ ŎI·LJI·ŎλúèΦ ØλúK / / ¦ { I·ŎŎ2dzyűŜŘ ₮2₦ I·yƴλyŎ₦ŜϒŜyűI·f p ű2 т LJŜ₦ŎŜyű 2₮ ű2űI·f ƎŜyŜ₦I·ûλ2ƴλyƴ нлпл ó¢I·ōfŜ oπnúΦ C2₦ Ŏ2ϒLJI·₦λă2yΣ λyƴ нлмрΣ KèŘ₦2LJ2ØŜ₦ I·ŎŎ2dzyűŜŘ ₮2₦ c LJŜ₦ŎŜyű 2₮ ű2űI·f ƎŜyŜ₦I·ûλ2yΣ I·yŘ I·ff 2ûKŜ₦ ₦ŜyŜØI·ōfŜă ű2ûI·fŜŘ т LJŜ₦ŎŜyű 2₮ ű2űI·f ƎŜyŜ₦I·ûλ2yΦ

Table 3-4. Percent of Utility-Scale Generation by Fuel Source, 2015, and Projected to 2040 for Selected Cases[253, 254]

	2015	2040			
Fuel Type	**Base Case**	**Base Case**	**Advanced Technology**	**Carbon Price (CP 10)**	**CCUS Incentives Analysis**
Coal without CCUS	39%	18%–28%	23%–31%	4%–14%	19%
Coal with CCUS	0%	<1%	<1%	<1%	3%–4%[a]
Natural Gas without CCUS	27%	21%–42%	11%–28%	13%–31%	37%–38%
Natural Gas with CCUS	0%	0%	0%	1%–2%	2%–3%[a]
Conventional Hydropower	7%	6%–7%	7%	7%–8%	6%
Non-Hydro Renewables	7%	17%–25%	26%–30%	36%–38%	14%
Nuclear Power	20%	17%–19%	15%–20%	21%–28%	17%

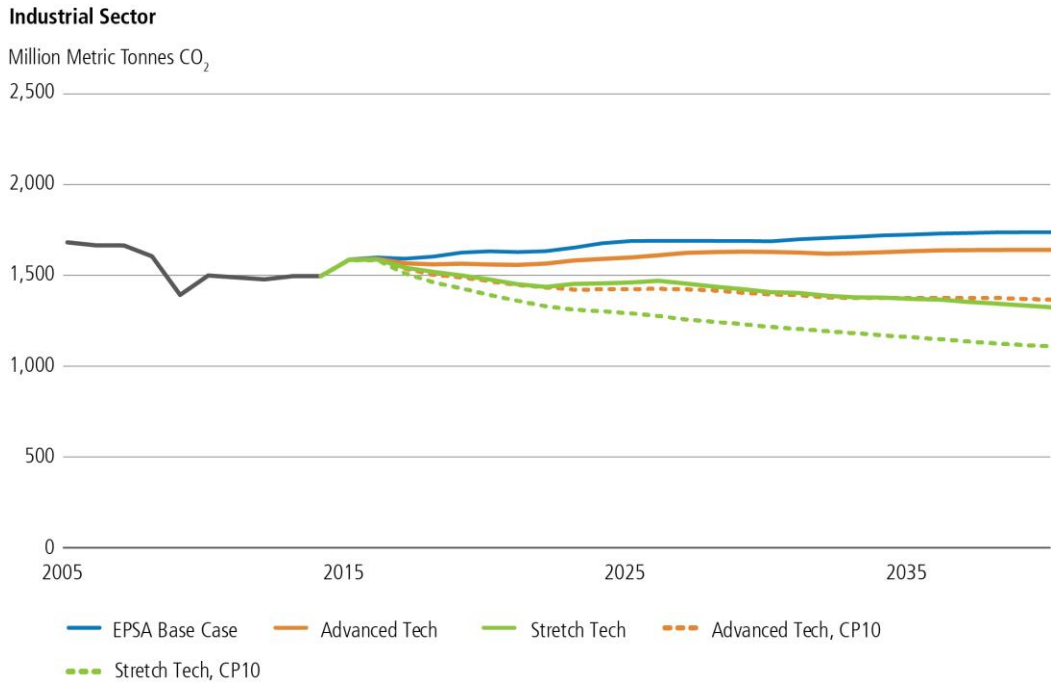
[a] Incremental to generation without CCUS.

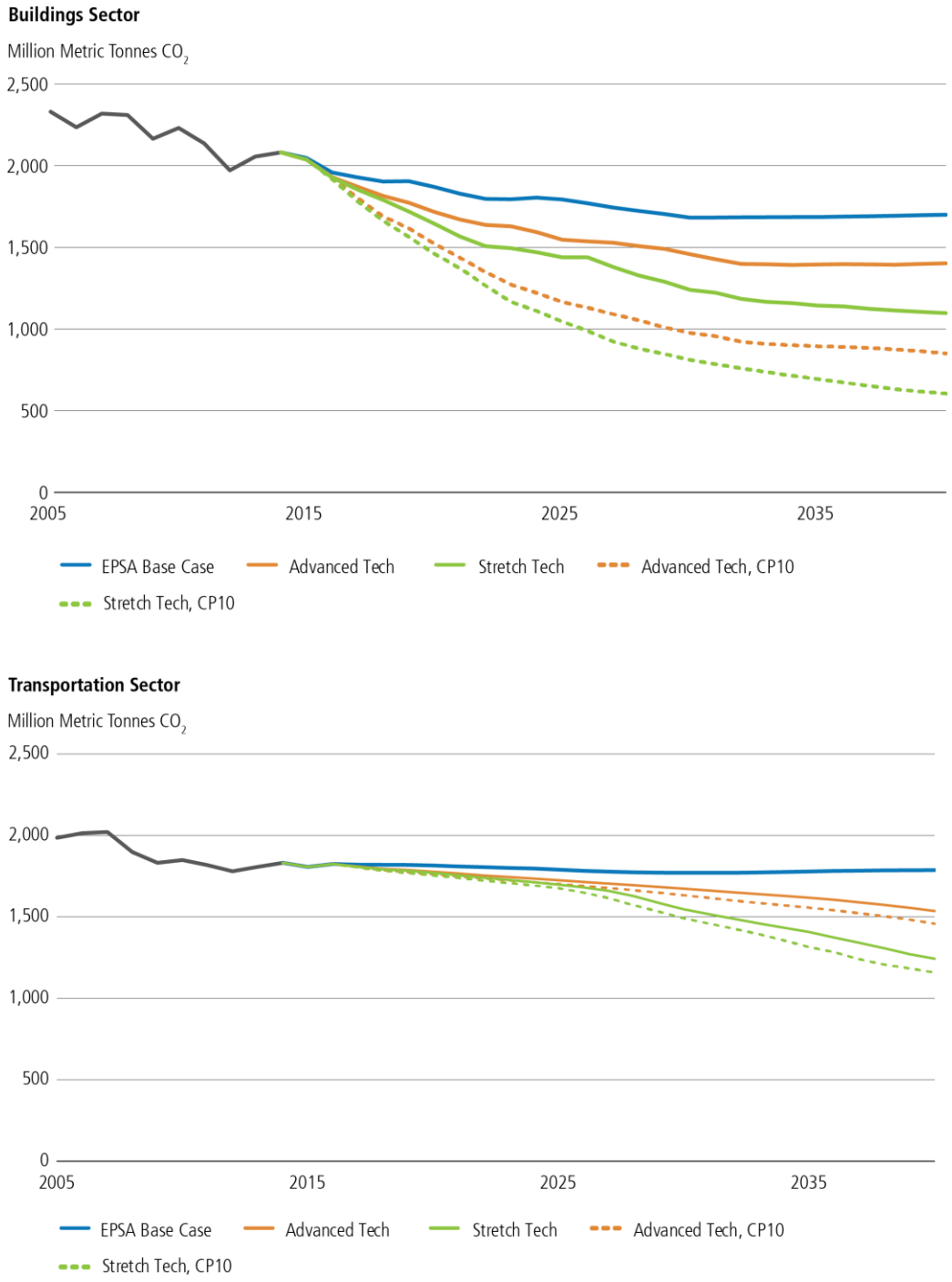
The range in percentages shown in 2040 in the Base Case and Advanced Technology Case highlights the significant impact that future natural gas prices will have on the modeled U.S. electric power generation mix. Similarly, the incentives included in the CCUS Incentives Analysis illustrate the potential to increase penetration of CCUS technologies with additional incentives.

! ăλƎyλ₮λŎI·yű λyØŜăűϒŜyű λyϒŏfŜI·yϒŜyŜ₦Ǝè w55ƍ5Σ Ŏ2dzLJfŜŘ ØλúK I·yϒŜŎ2y2Yèπ ØλŘŜ LJ2fλŎèΣ Ø2dzfŘ I·ŎŎŜfŜ₦I·ûŜ λyy2ØI·ûλ2ƴ I·yŘ ûŜŎKy2f2Ǝè ŘŜLJf2èϒŜyű I·yŘ ₦ŜŘdzŎŜ / hн ŜYλăăλ2yã ₮₦2Y ûKŜ LJ2ØŜ₦ ăŜŎű2₦ ōè yy LJŜ₦ŎŜyű λyƴ нлплΣ ₦Ŝfl·ûλØŜ ű2 нллр fŜØŜfăΦʰᵖᵖ ¢KŜ fŜØŜf 2₮ ŜYλăăλ2yã ₦ŜŘdzŎûλ2yã λyƴ ûKŜ {ű₦ŜűŎK ¢ŜŎKy2f2Ǝè ăŎŜyI·₦λ2

NŜŦfŜŎűă l· LJ2NűŦ2fλ2 l·LJLJN21·ŎK ű2 w55ɔ5 l·yŘ λă 2yfè λffdzăúN1·ûλØŜΣ l·ă ûŜŎKy2f2∃è LJl·ûKøl·ëă l·NŜ Kλ∃Kfè dzyŎŜNűl·λyT dzyŦ2NŜăŜŜy NŜăŜl·NŎK ōNŜl·ʅűKN2dz∃Kă l·NŜ ØŜNè ŘλŦŦλŎdzfű ű2 l·yűλŎλLJl·ûŜ λy Y2ŘŜfλy∃ l·yl·fëăλăT l·yŘ ∃ŜySNl·ûλ2y ōNŜl·ʅ2dzűă l·NŜ ű22 dzyŎŜNűl·λy ű2 LJNŜăŜyű KŜNŜφ ¢Kλă dzyŎŜNűl·λyűèΣ Ŏ2dzLJfŜŘ øλűK ûKŜ Øl·fdzŜ 2Ŧ w55ɔ5 λy YŜŜûλy∃ ŘŜŜLJ ŜYλăăλ2yã NŜŘdzŎûλ2yãΣ dzyŘŜNăŎ2NŜă ûKŜ ySŜŘ Ŧ2N l· ōN2l·ŘΣ ŘλØŜNăŜΣ l·yŘ N2ōdzăű NŜăŜl·NŎK LJ2NűŦ2fλ2φ ! y2űKŜN fl·N∃Ŝ ă2dzNŎŜ 2Ŧ ŜYλăăλ2yã NŜŘdzŎûλ2yã λy ûKŜ 5h9 l·yl·fèăλă ăŜfŜŎúNλŎλúè ŘŜYl·yŘ NŜŘdzŎûλ2yãΣ øKλŎK Ŏl·y ōŜ l·ŎKλŜØŜŘ ōè ûŜŎKy2f2∃è Ŏ2ăű l·yŘ LJŜNŦ2NYl·yŎŜ λYLJN2ØŜYŜyűă ûKl·ú λyŎNŜl·ăŜ ŜfŜŎúNλŎλúè ŜyŘπdzăŜ ŜŦŦλŎλŜyŎèΣ l·yŘ LJl·λNλy∃ úKŜăŜ λYLJN2ØŜYŜyűă øλűK l· Y2ŘŜăű Ŏl·N ōzy LJNλŎŜφ ¢KŜ Y2ŘŜfλy∃ l·yl·fëăλă ădz∃∃Ŝăúă ûKl·ûΣ øλűK ûKŜăŜ λyØŜăúYŜyűă l·yŘ ădzLJLJ2NűλØŜ LJ2fλŎλŜăΣ ŜfŜŎúNλŎλúè ŘŜYl·yŘ ø2dzfŘ λyŎNŜl·ăŜ ōè 2yfè p LJŜNŎŜyű 2ØŜN ûKŜ ySËű нр èŜl·Nă Ŏ2YLJl·NŜŘ ű2 нм LJŜNŎŜyű øλűK2dzű ûKŜYφ

Figure 3-19. Total Direct and Indirect CO_2 Emissions by End-Use Sector, 2005–2040[256]



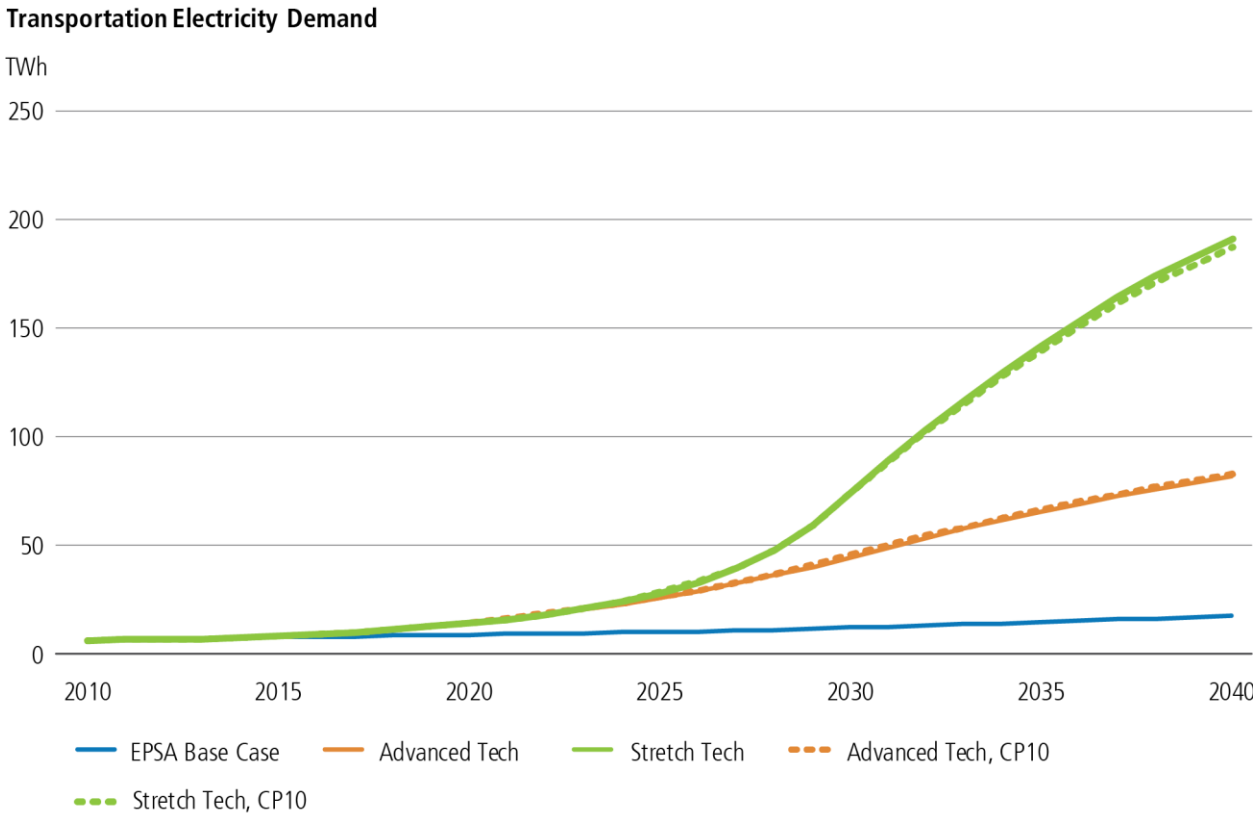


This figure shows the projected impact of technology and policy assumptions on total CO_2 emissions from the industrial (*top*), buildings (*middle*), and transportation (*bottom*) sectors, including emissions associated with both (1) direct fuel use (direct emissions) and (2) electricity generation allocated to end-use sectors based on their electricity use (indirect emissions). Successful clean energy RDD&D is projected to reduce end-use CO2 emissions by accelerating the transition towards a cleaner electricity generation mix and the adoption of cleaner and more efficient technologies. Both efficiency improvements (especially in energy-intensive industries) and additional policy can drive significant emissions reductions in industry and

buildings. Technology advances can have a significant impact in the transportation sector, but the modest carbon price proxy does not dramatically reduce transportation emissions.

LY ŭKŜ {ŭNŜŭŎK ¢ŜŎKy2f2∃è /I·ăŜΣ ŜØŜY ∃NŜI·ŭŜN λyØŜăŭYŜyŭ λY ădzŎŎŜăăŦdzf ŎfŜI·Y ŜyŜN∃è w55ɔ5 λă LJN2ΣŜŎŭŜŘ ŭ2 NŜădzfŭ λY Y2NŜ ăλ∃yŦŦλŎI·yŭ ŜŦŦλŎλŜyŎè λYLJN2ØŜY ŜyŭăΣ I·yŘ ŜfŜŎŭNλŎλŭè ŘŜY I·yŘ λă LJN2ΣŜŎŭŜŘ ŭ2 I·ŎŭdzI·ffè *decrease* ōè I·LJLJN2ÈλY I·ŭŜfè м LJŜNŎŜyŭ 2ØŜN ŭKŜ ySÈŭ нр èŜI·NăΦ LY ō2ŭK ŭKŜ ! ŘØI·yŎŜŘ ¢ŜŎKy2f2∃è I·yŘ {ŭNŜŭŎK ¢ŜŎKy2f2∃è /I·ăŜăΣ ŭKŜNŜ λă I· ŘŜŎNŜI·ăŜ λY ŜfŜŎŭNλŎλŭè ŘŜY I·yŘ λY ō2ŭK ŭKŜ λyŘdžăŭNλI·f I·yŘ ōdzλfŘλy∃ă ăŜŎŭ2NăΣ LJNλY I·NλfèŘdzŜ ŭ2 ŭŜŎKy2f2∃è λYLJN2ØŜY ŜyŭăúKI·ŭ NŜădzfŭ λYλyŎNŜI·ăŜŘ ŜŦŦλŎλŜyŎè óCλ∃dzNŜ oπмфύΦ /2yØŜNăŜfèΣ λY ŭKŜ ŭNI·yăLJ2NŭI·ŭλ2y ăŜŎŭ2NΣ ŜfŜŎŭNλŎλŭè ŘŜY I·yŘ λyŎNŜI·ăŜă I·ă ŭKŜ Y I·N]Ŝŭ ăŭI·Nŭăúă ŭ2 I·Ř2LJŭ Y2NŜ ōI·ŭŭŜNè ŜfŜŎŭNλŎ ØŜKλŎfŜăT K2ØŜØŜNΣ ŜfŜŎŭNλŎλŭè dzăŜ λY ŭKŜ ŭNI·yăLJ2NŭI·ŭλ2y ăŜŎŭ2N λă ăŭλfft ØŜNè ăY I·ff Ŏ2Y LJI·NŜŘ ŭ2 2ŭKŜN ăŜŎŭ2NăΦ LY нлплΣ ŭNI·yăLJ2NŭI·ŭλ2y 2yfè I·ŎŎ2dzyŭă Ŧ2N н LJŜNŎŜyŭ 2Ŧ ŜfŜŎŭNλŎλŭè ŘŜY I·yŘ λY ŭKŜ ! ŘØI·yŎŜŘ ¢ŜŎKy2f2∃è /I·ăŜ I·yŘ c LJŜNŎŜyŭ λY ŭKŜ {ŭNŜŭŎK ¢ŜŎKy2f2∃è /I·ăŜ óCλ∃dzNŜ oπнлύΦ

Figure 3-20. Electricity Demand by the Transportation Sector, 2005–2040[257]



The DOE scenarios all project a small but growing shift towards electrification in the transportation sector. In the Advanced Technology and Stretch Technology Cases, advances in RDD&D lead to increased market penetration of alternative vehicles, including battery electric and fuel cell light-duty vehicles. In 2040, battery electric vehicles and hydrogen fuel cell vehicles comprise 18 percent of new light-duty vehicle sales in the Advanced Technology Case and 40 percent of new light-duty vehicle sales in the Stretch Technology Case.

¢KŜ LJ2ŭŜyŭλI·f Ŧ2N ŜYλăăλ2yã NŜŘdzŎŭλ2yã ōè ăLJŜŎλŦλŎ ŜyŘπdzăŜ ăŜŎŭ2Nă ø I·ă I·fă2 I·yI·fêÎŜŘΦ ¢2ŭI·f /hн ŜYλăăλ2yã I·ŎŎ2dzyŭ Ŧ2N ō2ŭK óмú ŭKŜ /hн ŜYλăăλ2yã I·ăă2ŎλI·ŭŜŘ øλŭK each sector's ŜfŜŎŭNλŎλŭè ∃ŜySNI·ŭλ2Y I·yŘ óнú

ŜY˙λăăλ2yã ₮₪2Y ŘΛ₪ŜŎΰ ₮dzŜf dzăŜ óŜΦƎΣ λyŘdzăΰ₪ΛI·f LJ₪2ŎŜăă ŜY˙λăăλ2yã I·yŘ ØŜKλŎfŜ ΰI·λfLJλLJŜ ŜY˙λăăλ2yãú¢ff ¢ŜŎKy2f2ƎèI·ŘØI·yŎŜa I·yŘκ2₪ I·ŘŘλΰλ2yΥ1·f LJ2fλŎè I·₪Ŝ LJ₪2ŎŜΰŜŘ ΰ2 Ř₪ΛØŜ Ř₪I·Y˙I·ΰΛŎ ŜY˙λăăλ2yã ₪ŜŘdzŎΰλ2yã ₮₪2Y ΰKŜ ōdzλfŘλy∃ă ăŜŎΰ2₪ Řdzŝ ΰ2 I· ŎfŜI·yŜ₪ ŜfŜŎΰ₪ΛŎλΰè ƎŜyŜ₪I·ΰλ2y˙Y˙λÈ I·yŘ ₪ŜŘdzŎŜŘ ŜfŜŎΰ₪ΛŎλΰè ŘŜY˙I·yŘ ΰK₪2dz∃K Y˙2₪Ŝ Ŝ₮₮λŎλŜyΰ ōdzλfŘλy∃ ăKŜftă I·yŘ ŜIjdzλLJY˙Ŝyΰΰ I·ă ØŜff I·ă ₮I·ăΰŜ₪ I·Ř2LJΰλ2y˙I·ΰ f2ØŜ₪ Ŏ2ăΰ 2₮ Y˙2₪Ŝ Ŝ₮₮λŎλŜyΰ ΰŜŎKy2f2Ƴλ$ă {λY˙λfI·₪fèΣ ădzŎŎŜăă₮dzf ŎfŜI·y˙ ŜyŜ₪Ƴè w55ϑ5 I·yŘκ2₪ I·ŘŘλΰλ2yΥ1·f LJ2fλŎè Ř₪ΛØŜ ₪ŜŘdzŎΰλ2yã λy˙ λyŘdzăΰ₪ΛI·fπăŜŎΰ2₪ /hH ŜY˙λăăλ2yã ΰK₪2dz∃K Ŝ₮₮λŎλŜyŎè λY˙LJ₪2ØŜY˙Ŝyΰă óŜăLJŜŎλI·ffè λy˙ ŜyŜ₪Ƴèπλyΰŝyãλ0Ŝ λyŘdzăΰ₪ΛŜăúT I·ŘŘλΰλ2yΥ1·f LJ2fλŎè λă I·fă2 LJ₪2ŎŜΰŜŘ ΰ2 KI·ØŜ I· ăƎyλ₮λŎI·yΰ λY˙LJI·ŎΰΦ CλyΥ1·ffèΣ λy˙ΰKŜ ΰ₪I·yãLJ2₪ΰΰI·ΰλ2y˙ ăŜŎΰ2₪Σ ØKŜ₪Ŝ dzăŜ 2₮ ŜfŜŎΰ₪ΛŎλΰè λă Ŏdz₪₪Ŝyΰfè ØŜ₪è fλY˙λΰŜŘΣ 2LJLJ2₪ΰdzyλΰΛŜă ŜÈλăΰ ₮2₪ ăλƎyλ₮λŎI·yΰ ŜY˙λăăλ2yã ₪ŜŘdzŎΰλ2yã ΰK₪2dz∃K Ŝ₮₮λŎλŜyŎè λY˙LJ₪2ØŜY˙Ŝyΰă I·yŘ ΰKŜ ădzŎŎŜăă₮dzf ŘŜLJf2èY˙Ŝyΰ 2₮ ŜfŜŎΰ₪ΛŎ I·yŘ KèŘ₪2ƎŜy˙fdzŜf ŎŜff ØŜKλŎfŜăΣ ōdzΰ ΰKŜ I·LJLJfλŎI·ΰλ2y˙ 2₮ I· Y˙2ŘŜăΰ ŎI·₪ō2y˙ LJ₪ΛŎŜ KI·ă 2yfè I· Yλy2₪ I·ŘŘλΰλ2yΥ1·f λY˙LJI·Ŏΰ 2y˙ ΰ₪I·yãLJ2₪ΰΰI·ΰλ2y˙ŜY˙λăăλ2yã¢

Ly˙I·ŘŘλΰλ2y˙ΰ2 ăK2ØλyƎ ΰKŜ ØI·fdzŜ 2₮ ăèyŜ₪Ƴλăΰλ0 ₪ŜăŜI·₪ŎK λyØŜăΰY˙Ŝyΰă I·yŘ LJ2fλŎèΣ ΰKŜ I·yΥ1·fèăλă ăK2Øă ΰKI·ΰ ΰKŜ ŜfŜŎΰ₪ΛŎλΰè ăŜŎΰ2₪ λă Y˙2ăΰ ăŜyãλΰØŜ ΰ2 I· ŎI·₪ō2y˙ LJ₪ΛŎŜ LJ2fλŎèΣ LJI·₪ΰfè ōŜŎI·dzăŜ λΰ I·f₪Ŝ I·Řè KI·ă I· ØI·₪ΛŜΰè 2₮ ₪Ŝf I·ΰλØŜfè f2ØπŎ2ăΰ ădzŏăΰλΰdzΰλ2y˙ 2LJΰλ2yã I·ØI·λfI·ōfŜ¢ CλyΥ1·ffèΣ ΰKλă I·yΥ1·fèăλă ădzLJLJ2₪ΰă ΰKŜ ₮λyŘλy∃ ΰKI·ΰ I·ă ΰKŜ ŜfŜŎΰ₪ΛŎ Ǝ₪ΛŘ ōŜŎ2Y˙Ŝă λyŎ₪Ŝ I·ăλy∃fè ŘŜŎI·₪ō2yΛÎŜŘΣ ŜfŜŎΰ₪ΛŎλΰ2y˙2₮ ŜyŘ dzăŜă ŎI·y˙₪Ŝădztΰ λy˙₮dz₪ΰKŜ₪ ₪ŜŘdzŎΰλ2yã 2₮ ŜyŜ₪Ǝè /hH ŜY˙λăăλ2yã¢

3.3.6 Need for Accelerated Innovation in the Electricity-Sector

9ØŜy˙ØλΰK y2ΰI·ōfŜ λyŎ₪Ŝ I·ăŜă λy˙ŎfŜI·y˙ΰŜŎKy2f2Ƴè ŘŜLJf2èY˙Ŝyΰ λy˙ΰKŜ ŜfŜŎΰ₪ΛŎλΰè ăŜŎΰ2₪ λy˙₪ŜŎŜyΰ èŜI·₪ăΣ ΰKŜ ăŎI·fŜπdzLJ I·yŘ ăLJŜŜŘ 2₮ ŎfŜI·y˙ ŜyŜ₪Ǝè ΰŜŎKy2f2Ƴèmm λyy2ØI·ΰλ2y˙ yŜŜŘ ΰ2 I·ŎŎŜfŜ₪I·ΰŜ¢ !ă y2ΰŜŘΣ λyŎ₪Ŝ I·ăλy∃ w55ϑ5 λy˙Ŏ2yƈdzyŎΰλ2y˙ ØλΰK I·y˙ŜŎ2y2Y˙èπØλŘŜ LJ2fλŎè ŎI·y˙KŜfLJ ΰKŜ ¦yλΰŜŘ {ΰI·ΰŜă Y˙ŜŜΰ λΰă b5/¢ ¢KŜ₪Ŝ I·₪Ŝ I·fă2 Y˙dzfΰλLJfŜ ŘΛ₪ŜŎΰ I·yŘ λyŘΛ₪ŜŎΰ ōSyŜ₮λΰă 2₮ ŜfŜŎΰ₪ΛŎλΰèπăŜŎΰ2₪ ΰŜŎKy2f2Ǝè λyy2ØI·ΰλ2y˙ λyØŜăΰY˙Ŝyΰă¢ Lyy2ØI·ΰλ2y˙λyØŜăΰY˙Ŝyΰă ŘΛ₪ŜŎΰfè ŜÈLJI·yŘ ΰKŜ LJλLJŜfλyŜ 2₮ ySØ ΰŜŎKy2f2Ƴλ$ăΣ ₪ŜŘdzŎŜ ΰŜŎKy2f2Ƴè Ŏ2ăΰăΣ I·yŘ Y˙λΰλ∃I·ΰŜ ΰKŜ ₪λă]ă 2₮ ySØ ΰŜŎKy2f2Ƴλ$ă 2₪ ăèăΰŜY˙ă¢ ¢KŜăŜ ōSyŜ₮λΰăΣ λy˙ΰdz₪yΣ ₪ŜŘdzŎŜ ΰKŜ Ŏ2ăΰ 2₮ LJ2fλŎλŜă I·yŘ λyŎŜyΰλØŜă[HPY] I·yŘ I·ff2Ø ŘŜŎλăλ2y˙ Y˙I·]Ŝ₪ă λy˙ō2ΰK Ǝ2ØŜ₪yY˙Ŝyΰ I·yŘ ΰKŜ LJ₪ΛØI·ΰŜ ăŜŎΰ2₪ ΰ2 Ŏ2yăλŘŜ₪ 2LJΰλ2yã ΰKI·ΰ Ø2dzfŘ 2ΰKŜ₪ØλăŜ y2ΰ ōŜ I·ØI·λfI·ōfŜ¢ LyŎ₪ŜI·ăŜŘ ŘŜLJf2èY˙Ŝyΰ fŜØŜfă ŘdzŜ ΰ2 LJ2fλŎλŜă I·yŘ λyŎŜyΰλØŜă I·fă2 λyŎ₪ŜI·ăŜ ŜŎ2y2Y˙λŜă 2₮ ăŎI·fŜ I·yŘ ₮dz₪ΰKŜ₪ ₪ŜŘdzŎŜ Y˙I·ydz₮I·Ŏΰdz₪ΛyƎ Ŏ2ăΰă I·yŘ ΰŜŎKy2f2Ƴ$ I·ΰλ2y˙ Ǝ₪ŜΦ ₮₪2Y Þo¢c ōλffλ2y˙λy˙нллп ΰ2 I· LJŜI·]Ŝ 2₮ Þт¢c ōλffλ2y˙λy˙нлмм Σ ōdzΰ ΰKλă λyØŜăΰY˙Ŝyΰ KI·ă ăλyŎŜ ₮I·ffŜy˙ΰ2 Þp¢p–Þc¢л ōλffλ2y˙λy˙нлмп–нлмр¢ !yydzI·f ƎfƵōI·f ØŜyΰdz₪Ŝ ŎI·LJλΰI·f I·yŘ LJ₪ΛØI·ΰŜ ŜIjdzλΰè λyØŜăΰY˙Ŝyΰă λy˙ŜI·₪fèπăΰI·ƎŜ ₪ŜySØI·ōfŜ ŜyŜ₪Ǝè ₮ΛWY˙ă KI·ØŜ ₮I·ffŜy˙ŜØŜy˙Y˙2₪Ŝ Ř₪I·ăΰλŎI·ffèΣ ₮₪2Y˙ I· LJŜI·]Ŝ 2₮ Þфф ōλffλ2y˙λy˙нллу ΰ2 Þн¢м–Þo¢п ōλffλ2y˙λy˙нлмо–нлмр¢HCT Ly˙ΰKŜ ¦yλΰŜŘ {ΰI·ΰŜăΣ ăλY˙λfI·₪ ΰ₪ŜyŘă ăK2Ø ΰKI·ΰ I·yydzI·f ØŜyΰdz₪Ŝ ŎI·LJλΰI·f λyØŜăΰY˙Ŝyΰă λy˙ ŎfŜI·y˙ ŜyŜ₪Ǝè ΰŜŎKy2f2Ƴλ$ă ₮Ŝff ₮₪2Y˙ I· нллу LJŜI·]Ŝ 2₮ 2ØŜ₪ Þp ōλffλ2y˙ΰ2 I·ō2dzΰ Þн ōλffλ2y˙Ŝ I·ŎK èŜI·₪ ăλyŎŜ нлмо¢ C₪2Y˙ нллс ΰ2 нлммΣ 2yfè p LJŜ₪ŎŜyΰ 2₮ ŜI·₪fèπăΰI·ƎŜ ŎfŜI·y˙ŜyŜ₪Ǝè ΰŜŎKy2f2Ƴè ₮ΛWY˙ă ₪Ŝΰdz₪yŜŘ LJ₪2₮ΰΰă ΰ2 ΰKŜλ₪ λyØŜăΰ2₪ΛăΰKI·ΰ I·ØΣλŘΣ ₪ŜŘdzŎŜΣ 2₪ ăŜIjdzŜăΰŜ₪ DID ŜY˙λăăλ2yã 2₪ 2ΰKŜ₪ I·Λ₪ LJ2ffdzΰI·yΰăΣ λyŎfdzŘλyƎ ΰŜŎKy2f2Ƴλ$ă ΰKI·ΰ Ŏ2yØŜ₪ΰΣ Ŏ2yØŜèΣ 2₪ ăΰ2₪Ŝ ŜyŜ₪Ǝè ₪Ŝă2dz₪ŎŜăT λY˙LJ₪2ØŜ ŜyŜ₪Ǝè Ŝ₮₮λŎλŜyŎèT 2₪ ₪ŜŘdzŎŜ ŜyŜ₪Ǝè Ŏ2yãdzY˙LJΰλ2y¢

[ff] 9Y˙λăăλ2yã ₮₪2Y˙ ŜyŘπdzăŜ ăŜŎΰ2₪ă I·₪Ŝ ΰèLJλŎI·ffè ₪Ŝ₮Ŝ₪₪ŜŘ ΰ2 I·ă λyŘ₪ŜŎΰ ŜY˙λăăλ2yã óŜY˙λăăλ2yã I·ăă2ŎλI·ΰŜŘ ØλΰK ΰKŜ ƎŜyŜ₪I·ΰλ2y˙2₮ ŜfŜŎΰ₪ΛŎλΰè dzăŜŘ ōè ŜI·ŎK ăŜŎΰ2₪ΰ I·yŘ Ř₪ΛŜŎΰ ŜY˙λăăλ2yã óŘ₪ΛŜŎΰ ₮dzŜfπdzăŜ ŜY˙λăăλ2yãú¢

[YY] /fŜI·y˙ŜyŜ₪Ǝè ΰŜŎKy2f2Ƴλ$ă I·₪Ŝ ŘŜ₮λyŜŘ I·ă ŜyŜ₪Ǝèπ₪ŜfI·ΰŜŘ KI·₪ŘØ I·₪ŜΣ ă2₮ΰØ I·₪ŜΣ I·yŘ ăèăΰŜY˙ă ΰKI·ΰ I·Ø2λŘΣ ₪ŜŘdzŎŜΣ 2₪ ăŜIjdzŜăΰŜ₪ DID ŜY˙λăăλ2yã 2₪ 2ΰKŜ₪ I·Λ₪ LJ2ffdzΰI·yΰăΣ λyŎfdzŘλyƎ ΰŜŎKy2f2Ƴλ$ă ΰKI·ΰ Ŏ2yØŜ₪ΰΣ Ŏ2yØŜèΣ 2₪ ăΰ2₪Ŝ ŜyŜ₪Ǝè ₪Ŝă2dz₪ŎŜăT λY˙LJ₪2ØŜ ŜyŜ₪Ǝè Ŝ₮₮λŎλŜyŎèT 2₪ ₪ŜŘdzŎŜ ŜyŜ₪Ǝè Ŏ2yãdzY˙LJΰλ2y¢

The Advanced Research Projects Agency–Energy (ARPA-E) Program and Electricity Innovation

The Department of Energy's ARPA-E funds technically innovative, high-risk, high-potential energy projects that are too early for private-sector investment but could significantly advance how the Nation generates, stores, distributes, and uses energy.[285] ARPA-E competitively supports innovative ideas with the specific purpose of advancing them from early-stage concept to application prototype. One of the Mission Innovation goals that ARPA-E supports is to deliver more investment-ready, innovative energy technologies for private-sector investors and industry to commercialize. To date, 45 ARPA-E projects have attracted more than $1.25 billion in private-sector follow-on funding to support commercial development.

There is significant opportunity for accelerating the development of more innovative project concepts based on the number of applications for ARPA-E projects. On average, ARPA-E is only able to fund 10 percent of the proposals for its focused solicitations, and only 1.4 percent of the proposals that it receives in its open solicitations.[286]

Many of ARPA-E's programs are directly or indirectly focused on breakthroughs for the electricity sector. For example, the Green Electricity Network Integration program has supported the development and demonstration of new grid optimization technologies such as power flow controllers.[287] By redirecting power away from congested lines, power flow controllers can increase transmission capacity without construction of new assets.[288]

!fűK2dzƎK űKŜNŜ λă ădzōăűl·yűλl·f NŜăŜl·NŐK 2y űKŜ Ø1·fdzŜ l·yŘ λYLJl·Ŏű 2Ŧ ŜySNƎè űŜŐKy2f2Ǝè λyy2Ø1·űλ2yΣ LJl·NűλŎdzfl·NfȩŦ2N λyŘλØλŘdzl·f űŜŐKy2f2ƎλŜăΣ űKŜNŜ l·NŜ ŦŜø N2ōdzăű YŜl·ădzNŜă l·yŘ ljdzl·yűλűl·űλØŜ l·ăăŜăăYŜyűă 2Ŧ űKŜ ŜySNƎè λyy2Ø1·űλ2y ăëăűŜYΣ LJl·NűλŎdzfl·NfȩŦ 2Ŧ LJNλØl·űŜπăŜŐű2N λyLJdzűăΣ l·ă øŜff l·ă YŜl·yλyƎŦdzf 2dzűLJdzűă l·yŘ λYLJl·Ŏű YŜl·ădzNŜăφ wŜŦλySŘΣ Řl·úl·πŘNλØŜy ŦNl·YŜø2N]ă l·yŘ Y2ŘŜtă 2y ŜySNƎè λyy2Ø1·űλ2yΣ λyŐfdzŘλyƎ LJ2fλÔè λyűŜNl·Ŏűλ2yãΣ l·NŜ ySŜŘŜŘ ű2 dzyŘŜNăűl·yŘ ōŜűűŜN K2ø λyLJdzűă l·yŘ 2dzűLJdzűă 2Ŧ ŜySNƎè λyy2Ø1·űλ2y ăëăűŜYă NŜfl·ûŜ ű2 Ŝl·ŎK 2űKŜNφнфнΣ нфоΣ нфпΣ нфрΣ нфс

9fŜŐűNλŎλűèπăŜŐű2N űŜŐKy2f2Ǝè l·NŜl·ă úKl·ú NŜŐŜλØŜŘ ădzōăűl·yűλl·f λyØŜăúYŜyű λyŐNŜl·ăŜă λy űKŜ ŦλăŐl·f èŜl·N нлмт President's ōdzŘƎŜű λyŐfdzŘŜ ŜySNƎè ăű2Nl·ƎŜT ƎNλŘ Y2ŘŜNyλÎl·űλ2yT ŜySNƎèπøl·ûŜN ySĚdzăT ădzōădzNŦl·ŐŜ ăŐλŜyŐŜΣ ûŜŐKy2f2Ǝè l·yŘ ŜyƎλySŜNλyƎT / / ¦ {T l·yŘ NŜySØl·ōfŜ ƎŜySNl·ûλ2y ûŜŐKy2f2ƎλŜă ădzŐK l·ă ă2fl·NΣ øλyŘΣ ø l·ûŜNΣ l·yŘ Ǝ5ƨűKŜNYl·fφ tN2YλăλyƎ ōNŜl·]úKN2dzƎK ûŜŐKy2f2Ǝè l·NŜl·ă λyŐfdzŘŜ λYLJN2ØλyƎ ŦfŜĚλōfŜ LJ2øŜN ŘŜfØŜNè l·yŘ Ŏ2YY dzyλŐl·ûλ2yãT ŘŜØŜf2LJλyƎ y2yπØl·LJ2N Ŏ2YLJNŜăăλ2y ăëăűŜYă úKl·ú LJN2ØλŘŜ KλƎKfȩ ŜyŜNƎè ŜŦŦλŐλŜyű ălJl·ŐŜ Ŏ2yŘλűλ2yλyƎΣ øl·ûŜN KŜl·ûλyƎΣ l·yŘ NŜŦNλƎŜNl·ûλ2y ăŜNØλŐŜă λy ōdzλfŘλyƎă øλűK2dzű ûKŜ dzăŜ 2Ŧ úNl·Řλűλ2yl·f NŜŦNλƎŜNl·yűăT LJN2ŘdzŐλyƎ f2ø πŐ2ăű KèŘN2ƎŜy ŦN2Y NŜySØl·ōfŜ 2N f2ø πŐl·N0ƨ2y ă2dzNŐŜăT ăŐl·fλyƎ dzLJ y2ØŜf / hH π Ŏl·LJűdzNŜ ûŜŐKy2f2ƎλŜă ŦN2Y LJ2øŜN LJfl·yűă l·yŘ λyŘdzăűNλl·f ă2dzNŐŜăT l·yŘ NŜŐèŐfλyƎ / hH λyű2 Ø1·fdzl·ōfŜ LJN2ŘdzŐűă l·ă l· ŦŜŜŘăű2Ŏ]φ

3.3.7 Mission Innovation: Accelerating Clean Electricity Technology RDD&D

Ly b2ØŜYōŜN нлмрΣ űKŜ ¦yλűŜŘ {űl·ûŜă l·yŘ мф 2űKŜN yl·ûλ2yã Ŏl·YŜ û2ƎŜűKŜN û2 Yl·]Ŝ l· fl·yŘYl·N] Ŏ2YYλűYŜyű—Ŏl·ffŜŘ aλăăλ2yLyy2Ø1·ûλ2y—û2 ŘNl·Yl·ûλŐl·ffè l·ŎŐŜfŜNl·ûŜ Ǝf2ōl·f ŐfŜl·yŜySNƎè λyy2Ø1·ûλ2yφ ¢Kλă ŐKl·NűŜN ƎN2dzLJ 2Ŧ aλăăλ2yLyy2Ø1·ûλ2y Ŏ2dzyűNλŜăΣ l·ă øŜff l·ă 2űKŜNă úKl·ú Kl·ØŜ ∂2λySŘ ăλyŐŜΣ l·NŜ ăŜŜ]λyƎ û2 Ř2dzōfŜ úKŜλN LJdzōfλŐ λyØŜăűYŜyű λy ŐfŜl·y ŜySNƎè wƨ5 2ØŜN p èŜl·Nă φ !ŐŐ2NŘλyƎfèΣ aλăăλ2y Lyy2Ø1·ûλ2y øλff NŜădzfű λyYŜl·Nfȩ Þол ōλffλ2y2Ŧ LJdzōfλŐ λyØŜăűYŜyű λy нлнмφ

¢KŜ 9yl·ōfλyƎ CNl·YŜø2N] Ŧ2N aλăăλ2yLyy2Ø1·ûλ2y2dzűfλySă ŜÈl·YLJfŜă 2Ŧ LJN2ØŜy l·yŘ LJ2øŜNŦdzf l·LJLJN21·ŐKŜă û2 w5ƨ5 úKl·ú øλff ōŜ ŎNλűλŐl·f ŜfŜYŜyűă 2Ŧ úKŜ ¦φ{φ Ř2YŜăűλŐ λYLJfŜYŜyűl·ûλ2y2Ŧ aλăăλ2yLyy2Ø1·ûλ2yφHΦT w2ōdzăű λYLJfŜYŜyűl·ûλ2y Ydzăű λyŐ2NLJ2Nl·ûŜ Ydzfűλ LJfŜ fλySl·N l·yŘ y2yfλySl·N l·LJLJN21·ŐKŜăΣ y2ű ∂dzăű λy ûŜNYă 2Ŧ ûŜŐKy2f2ƎλŜăΣ ōdzű l·fă2 λy ûŜNYă 2Ŧ ûŜŐKy2f2Ǝè LJl·ûKøl·ëăφ ¢Kλă YŜl·yă ŦdzyŘλyƎ LJN2ƎNl·Yă úKl·ú fŜØŜNl·ƎŜ Ŧ2dzyŘl·ûλ2yl·f YŜŐKl·yλăYă û2 λyŐNŜl·ăŜ ōNŜl·ŘűK 2Ŧ]y2øfŜŘƎŜ øλűKλy l· ăŐλŜyűλŦλŐ ŘλăŐλLJfλyŜT úNl·yăfl·ûλ2yl·f YŜŐKl·yλăYă û2 úl·NƎŜű λyŐNŜYŜyűl·f λYLJN2ØŜYŜyűă l·f2yƎ ŘŜŦλySŘ ûŜŐKπN21·ŘYl·LJăT ŘλăNdzLJűλØŜ YŜŐKl·yλăYă ûž Øl·fλŘl·ûŜ KλƎKπNλăλ]Σ KλƎKπNŜøl·NŘ 2ŦŦπN21·ŘYl·LJ λŘŜl·ăT l·yŘ λyűŜƎNl·ûλ2yl·f YŜŐKl·yλăYă û2 Ŧl·ŐλfλűŜl·ûŜ Ŏ2ftfl·ō2Nl·ûλ2yl·ŐN2ăă ŘλăŐλLJfλySă l·yŘ ăűl·]ŜK2fŘŜNăφ

¢KŜ CNl·YŜø2N] dzăŜă ŦØŜ ălJŜŐλŦλŐ l·NŜl·ă 2Ŧ Ŧ2Ŏdză û2 λffdzYλyl·ûŜ ûKŜăŜ 2LJLJ2NűdzyλűλŜăΣ l·ff 2Ŧ øKλŐK l·NŜ ŜλűKŜNăLJŜŐλŦλŐl·ffè 2N LJl·NűfȩNŜfl·ûŜŘ û2 ŜfŜŐűNλŐλűèY ƎŜySNl·ûλ2y óλφŜφΣ Kl·NyŜăăλyƎ ŜfŜŐűNλŐλűè ŦN2Y ŐfŜl·y ă2dzNŐŜăúT Y2ōλfλűè óλφŜφΣ Y2ØλyƎ LJŜ2LJfŜ l·yŘ Ǝ22Ră dzăλyƎ ŐfŜl·y ŜySNƎèúT Ŏ2yySŐűλ2yã óλφŜφΣ ŘŜfλØŜNλyƎ ŐfŜl·y ŜySNƎè ŦN2Y ădzLJLJfè û2 ŘŜYl·yŘúT ăűNdzŐűdzNŜă óλφŜφΣ λyy2Ø1·ûλyƎ ōŜűűŜN ōdzλfŘλyƎăúT l·yŘ LJN2ŐŜăăŜă óλφŜφΣ dzăλyƎ ŐfŜl·y ŜySNƎè û2 ŐNŜl·ûŜ LJN2ŘdzŐűă l·yŘ ƎN2ø Ŧ22Řúφ ! ă 2dzűfλySŘ λyűKŜ 52YŜăűλŐ LYLJfŜYŜyűl·ûλ2yCNl·YŜø2N]ΣHΦy ûKŜ Ř2YŜăűλŐ λYLJfŜYŜyűl·ûλ2yŦ aλăăλ2yLyy2Ø1·ûλ2yŐ2dzfŘ

- *"Drive down energy costs:* /fŜl·y ŜySNƎè ûŜŐKy2f2ƎλŜă Kl·ØŜ ûKŜ LJ2ûŜyűλl·f û2 ŘNl·Yl·ûλŐl·ffè NŜŘdzŐŜ f2yƎπûŜNYŜyŜNƎè ŜĚLJŜyŘλűdzNŜăφHΦΦ ¢KλăŐ2dzfŘ λyŐNŜl·ăŜ ûKŜ Ŏ2YLJŜûλűλØŜySŜää 2Ŧ ¦φ{φ ōdzăλySääŜă l·yŘ LJdzű ûK2dzăl·yŘă 2Ŧ Ř2fll·Nă λyYûKŜ LJ2Ŏ]Ŝūŏƨ2]ă 2Ŧ ! YŜNλŐl·yŦl·YλfλŜăφ
- *Enhance system reliability:* 9ySNƎè ăŜNØλŐŜă l·NŜ ŘŜŜLJfè ŜYōŜŘŘŜŘ λyű2 l·ff ŐNλűλŐl·f λyŦNl·ăúNdzŐűdzNŜă l·yŘ ăŜNØλŐŜăΣ λyŐfdzŘλyƎ ûKŜ ŜfŜŐűNλŐ ƎNλŘΣ úNl·yãLJ2NűÎ·ûλ2yΣ l·yŘ ûŜfŜŐ2YYdzyλŐl·ûλ2yãφ !ŘØl·yŐŜŘ ŜySNƎè ûŜŐKy2f2Ǝè Ŏl·yYLJN2ØŜ ăèăűŜY NŜfλl·ŏλfλűèφ
- *Improve energy security:* ¦ăλyƎ Y2NŜ ŘλØŜNăŜ ŜySNƎè ă2dzNŐŜă l·yŘ ûŜŐKy2f2ƎλŜă Ŏl·yλyŐNŜl·ăŜ úKŜ NŜăλfλSyŐŜ l·yŘ ŦfŜĚλōλfλűè 2Ŧ úKŜ Ř2YŜăűλŐ ŜySNƎè ădzLJLJfè ŐKl·λyΣ KŜfLJλyƎ û2 LJN2ûŜŐű ŜySNƎè Ŏ2yãdzYŜNă

ŦNƧY KλƎKπÕƨăΰ Y I·NJ⌉Ŝΰ ŘλăNWdzLJΰλƨyã I·yŘ NŜŘdzÕλyƎ ŜÈLJƨădzNJŜ ΰƨ Y I·NJ⌉Ŝΰăƨ ǿλΰK KλƎK LJNWλÕŜ Ø2fI·ΰλfΩΰèΣ fλ⌉Ŝ ƨλfΦ

- *Curb adverse environmental and public health effects:* 9yŜNJƎèπNJŜfI·ΰŜŘ D I D ŜY·λăăλ2yã I·NJŜ ΰKŜ Ř2Y·λyl·yΰ ÕI·dzăŜ ƨŦ ÕfλY I·ΰŜ ÕKI·yƎŜΦ /fŜI·y˙ŜyŜNJƎè ΰŜÕKy2f2Ǝè λă ΰKŜ fI·NJƎŜăΰ—I·yŘ Y·2ăΰ ŜăăŜyΰλI·f—Õ2YLJ2yŜyΰ ƨŦ Y·λΰλƎI·ΰλ2yΦ ¢KŜ ăKλŦΰ ΰ2 ÕfŜI·y˙ŜyŜNJƎè ǿλff I·fã2 NJŜŘdzÕŜ ΰKŜ 2ΰKŜNJ KI·NJYŦdzf LJƨftdzΰI·yΰă I·ăă2Õλl·ΰŜŘ ǿλΰK ŜyŜNJƎè dzăŜΣ λYLJN2ØλyƎ KŜI·fΰK 2dzΰÕ2YŜăΦ
- *Build economic opportunities:* a l·λyΰl·λyλyƎ 2dzNJ ΰŜÕKy2f2ƎλÕl·f ŜŘƎŜ ǿλff ŜyI·õfŜ 2LJLJ2NJΰdzyλΰλŜă ΰ2 ŜÈLJ2NJΰ 2dzNJ ÕfŜI·y˙ΰŜÕKy2f2ƎλŜăΣ LJN2ŘdzÕΰăΣ I·yŘ ăŜNJØλÕŜă ΰ2 2ΰKŜNJ Õ2dzyΰNJλŜăΦοΛΛ /fŜI·y˙ŜyŜNJƎè ÕI·y˙õŜ I· YI·ƨ2NJ ƨLJLJ2NJΰdzyλΰè ΰ2 ÕNJŜI·ΰŜ yŜǿ ƨ2õăΣ ŜyI·õfŜ Ř2Y·ŜăΰλÕ Y I·ydzŦI·ÕΰdzNJλyƎΣ I·yŘ ÕI·ΰI·fêÎŜ λyŘdzăΰNJλŜăΦοлмΣ олн
- *Improve energy access and equity:* Ly˙ Y I·yê NJdzNJI·f I·yŘ NJŜY·2ΰŜ LJfI·ÕŜă λy˙ ΰKŜ ¦yλΰŜŘ {ΰI·ΰŜăΣ Õ2Y·YdzyλΰλŜă fI·Õ⌉ I·ÕÕŜăă ΰ2 NJŜfλI·õfŜ I·yŘ I·ŦŦ2NJŘI·õfŜ ŜyŜNJƎè ăŜNJØλÕŜă ! ŘØI·yÕŜŘ ŜyŜNJƎè ΰŜÕKy2f2ƎλŜă ÕI·y˙ădzLJLJ2NJΰ dzyλØŜNJăI·f ŜyŜNJƎè I·ÕÕŜăăΣ KŜfLJλyƎ ō22ăΰ Ijdz I·fΰê 2Ŧ fλŦŜ I·yŘ ŜÕ2y2Y·λÕ ŘŜØŜf2LJY·ŜyΰΦ”οлο

wŜÕŜyΰ I·yl·fèăλă ădzƎƎŜăΰă LJNJ2ƎNJI·Y·ă I·yŘ λyØŜăΰY·Ŝyΰă λy˙ ΰŜÕKy2f2ƎλŜă ădzLJLJ2NJΰŜŘ õè λyλΰλI·ΰλØŜă fλ⌉Ŝ aλăăλ2y˙ Lyy2ØI·ΰλ2y˙Õ2dzfŘ KŜfLJ ÕNJŜI·ΰŜ ăλƎyλŦλÕI·yΰ Ǝf2õI·f 2LJLJ2NJΰdzyλΰλŜă Ŧ2NJ ¦φ{φ õdzăλySăăŜă I·yŘ ΰŜÕKy2f2ƎλŜă λy˙ ΰKŜ Ŧ2ff2ǿλyƎ NJŜƎλ2yã 2Ŧ ΰKŜ ǿ2NJfŘY

- *East Asia and the Pacific:* DNJŜŜy˙ õdzλfŘλyƎă— /KλyI·Σ LyŘ2ySăλI·Σ ΰKŜ tKλfλLJLJλySăΣ I·yŘ ±ΛŜΰyI·Y˙ ăK2ǿ I· f2ǿπÕI·NJõ2y˙λyØŜăΰY˙Syΰ LJ2ΰŜyΰλI·f 2Ŧ Þmc ΰNJλffλ2yΦ
- *Latin America and the Caribbean:* hŦŦŜNJă ΰKŜ ySÈΰ fI·NJƎŜăΰ 2LJLJ2NJΰdzyλΰè—LJI·NJΰλÕdzfI·NJfè λy˙ădzăΰI·λyI·õfŜ ΰNJI·yãLJ2NJΰI·ΰλ2yΣ ǿKŜNJŜ ΰKŜ LJ2ΰŜyΰλI·f Ŧ2NJ λyØŜăΰY˙Syΰ λy˙ ! NJƎŜyΰλyI·Σ . NJI·Îλ£ /2f2Y·õλI·Σ I·yŘ aŜÈλÕ2 λă I·õ2dzΰ ÞHΦc ΰNJλffλ2yΦ
- *South Asia:* hLJLJ2NJΰdzyλΰλŜă I·NJŜ Y·2ăΰfè ăŜŜy˙λy˙ ÕfλY I·ΰŜπNJŜăλfλŜyΰ λyŦNJI·ăΰNJdzÕΰdzNJŜΣ ǿKŜNJŜ ÞHΦp ΰNJλffλ2y˙ 2Ŧ 2LJLJ2NJΰdzyλΰλŜă ŜÈλăΰ λy˙LyŘλI· I·yŘ . I·yƎfI·ŘŜăKΦ
- *Sub-Saharan Africa:* wŜLJNJŜăŜyΰă I· Þтyo õλffλ2y˙2LJLJ2NJΰdzyλΰè—LJI·NJΰλÕdzfI·NJfè Ŧ2NJ ÕfŜI·y˙ŜyŜNJƎè λy˙ /2ΰŜ d'Ivoire, Kenya, Nigeria, and South Africa.
- *Eastern Europe:* ² λΰK λΰă õλƎƎŜăΰ YI·NJ⌉Ŝΰă—wdzăăλI·Σ {ŜNJõλI·Σ ¢dzNJ⌉ŜèΣ I·yŘ ¦⌉NJI·λyŜ—ăK2ǿă I· Õ2YõλySŘ λyØŜăΰY˙Syΰ LJ2ΰŜyΰλI·f 2Ŧ Þccp õλffλ2yΣ Y·2ăΰfè λy˙ ŜyŜNJƎè ŜŦŦλÕλŜyÕè I·yŘ yŜǿ ƎNJŜy˙ õdzλfŘλyƎăΦ
- *Middle East and North Africa:* ¢KŜ ΰ2ΰI·f ÕfλY I·ΰŜπλyØŜăΰY˙Syΰ LJ2ΰŜyΰλI·f Ŧ2NJ 9ƎèLJΰΣ W2NJŘI·yΣ I·yŘ a2NJ2ÕÕ2 λă ŜăΰλY I·ΰŜŘ I·ΰ ÞHcp õλffλ2yΣ “2ØŜNJ I· ΰKλNJŘ 2Ŧ ǿKλÕK λă Ŧ2NJ NJŜySǿI·õfŜπŜyŜNJƎè ƎŜySNJI·ΰλ2yΣ ǿKλfŜ pp LJŜNJÕŜyΰ óÞмпc õλffλ2yΰ λă Ŧ2NJ ÕfλY I·ΰŜπăY I·NJΰ õdzλfŘλyƎăΣ ΰNJI·yãLJ2NJΰI·ΰλ2yΣ I·yŘ ǿI·ăΰŜ ă2fdzΰλ2yΦ”οлп

3.4 Environmental Impacts of Electricity on Air, Water, Land Use, and Local Communities

LyŦNJI·ăΰNJdzÕΰdzNJŜ I·ăă2ÕλI·ΰŜŘ ǿλΰK ŜfŜÕΰNJλÕλΰΰè 2LJŜNJI·ΰλ2yã KI·ă I· NJI·yƎŜ 2Ŧ ŘλNJŜÕΰ λYLJI·Õΰăΰ ΰ2 ŜÕ2ăèăΰŜY·ă I·yŘ yl·ΰdzNJI·f NJŜă2dzNJÕŜăΦ ¢KŜ Y I·Ǝyΰdzŕ̂Ŝ 2Ŧ λYLJI·Õΰăΰ ŘŜLJŜyŘă 2y˙ K2ǿ ΰKŜ λyŦNJI·ăΰNJdzÕΰdzNJŜ I·ŦŦŜÕΰă ŜyŘI·yƎŜNJŜŘ ăLJŜÕλŜăΣ ăŜyăλΰλØŜ ŜÕ2f2ƎλÕI·f I·NJŜI·ăΣ 2NJ ÕdztΰdzNJI·f 2NJ KλăΰΩ2NJλÕ NJŜă2dzNJÕŜăT ƎλØŜă NJλăŜ ΰ2 ØλădzI·f 2NJ I·ŜăΰKŜΰλÕ Õ2yÕŜNJyăT 2NJ 2LJŜyă yŜǿ I·NJŜI·ă ΰ2 ŘŜØŜf2LJY·ŜyΰΦοлр ! ÕKλŜØλyƎ ΰKŜ ŘŜŜLJ ŘŜÕI·NJõ2yλÎI·ΰλ2y˙ 2Ŧ ΰKŜ ŜfŜÕΰNJλÕλΰè ăŜÕΰ2NJ yŜÕŜăăI·NJè ΰ2 NJŜI·ÕK yl·ΰλ2yl·f ÕfλY I·ΰŜ ΰI·NJƎŜΰă ǿλff NJŜIjdzλNJŜ I· ăλƎyλŦλÕI·yΰ ăÕI·fλyƎ dzLJ 2Ŧ ÕfŜI·y˙ ŜyŜNJƎè ΰŜÕKy2f2ƎèΦ ² KλfŜ CŜŘŜNJI·fΣ ăΰI·ΰŜΣ I·yŘ f2Õl·f Ǝ2ØŜNJYY˙Syΰă KI·ØŜ Y I·ŘŜ ăΰNJλŘŜă λy˙ I·ăăŜăăλyƎ ΰKŜ ŜÕ2f2ƎλÕl·f I·yŘ fI·yŘπdzăŜ λYLJI·Õΰăΰ 2Ŧ ÕdzNNJŜyΰ ΰŜÕKy2f2Ǝè—I·ă ǿŜff I·ă ǿI·ΰŜNJπdzăŜ I·yŘ ǿI·ΰŜNJπIjdzI·fΰΰè λYLJI·Õΰăΰ—Y·2NJŜ I·yl·fèăλă ǿλff õŜ KŜfLJŦdzf ΰ2 ăÕI·fŜ ŘŜLJf2èY˙Syΰ 2Ŧ I·ŘŘΰλ2yl·f ÕfŜI·y˙ ŜyŜNJƎè ΰŜÕKy2f2ƎλŜăΦ /2yăλŘŜNJyƎ ΰKŜ ŜÕ2f2ƎλÕI·f λYLJI·Õΰăΰ I·yŘ yl·ΰdzNJI·f NJŜă2dzNJÕŜ λYLJfλÕI·ΰλ2yã 2Ŧ yŜǿ ŜyŜNJƎè ΰŜÕKy2f2ƎλŜă λy˙ ΰKŜ wƨ5 LJKI·ăŜ YI·è KŜfLJ I·Ø2λŘ ΰKŜ I·Ŧ2NJŜY˙Syΰλ2yŜŘ λYLJI·Õΰăΰ I·yŘ ΰKŜ yŜŜŘ ΰ2 YλΰλƎI·ΰŜ ΰKŜY˙Φ 5ŜÕNJŜI·ăλyƎ fI·yŘπdzăŜ I·yŘ ŜÕ2f2ƎλÕI·f λYLJI·Õΰăΰ

3.4.1 Air and Water Pollution

Table 3-5. Summary of Physical Impacts of the Most Common Air Pollutants[317, 318, 319, 320]

	Human Health	Crops and Timber	Materials	Visibility	Recreation
NO_x	Chronic obstructive pulmonary disease		Material deterioration		Eutrophication
	Ischemic heart diseaseIHD				
SO_2	Asthma	Damages to forests	Material depreciation		Damages to forests
	Cardiac				
O_3 (ozone)	Chronic asthma	Crop loss Timber loss	Rubber deterioration		Damages to forests and wilderness areas
	Acute-exposure mortality				
	Respiratory problems				
	Acute asthma attacks				
$PM_{2.5}$	Premature death			Loss of visibility	
	Nonfatal heart attacks				
	Hospital admissions				
	Emergency Room visits for asthma, acute bronchitis, upper and lower respiratory symptoms				
$PM_{10-2.5}$	Chronic bronchitis				

Major impacts of air pollution are delineated by sector and pollutant. PM2.5 is particulate matter with a diameter of 2.5 micrometers or less. $PM_{10-2.5}$ is coarse particulate matter with diameter between 10 and 2.5 micrometers.

!ă 2Ŧ нлмпΣ ŜfŜŎúNλŎλúè ƎŜyŜNI٠úλ2ƴ I٠ŎŎ2dzyűŜŘ Ŧ2N cп LJŜNŎŜyű 2Ŧ ŜŎ2y2Yٰèπ⌀λŘŜ {hн ŜYٰλăăλ2yã I٠yŘ мп LJŜNŎŜyű 2Ŧ bhĖ ŜYٰλăăλ2yãT LJ2⌀ŜN LJfI٠yűă ⌀ŜNŜ úKŜ Ř2YٰλyIٰyű ŜYٰλűűŜNă 2Ŧ YŜNŎdzNè ópл LJŜNŎŜyűú IٰyŘ IٰŎλŘ ƎIٰăŜă ótp LJŜNŎŜyűú⌀ОНМΣ ОНН ² λűKλƴűKŜ ŜfŜŎúNλŎλúè ăèăűŜYΣ Ŏ2IٰfŎ2Yٰōdzăűλ2ƴIٰŎŎ2dzyűă Ŧ2N úKŜ ØIٰăű YٰI٠2Nλúè 2Ŧ LJ2ffdzűIٰyűă⌀ОНО ² KλfŜ IٰYٰI٠2Nλúè 2Ŧ LJ2⌀ŜN LJfIٰyűă dzăŜ ăŎNdzōōŜNă IٰyŘ 2úKŜN LJ2ffdzűλ2ƴ Ŏ2yűN2fă ű2 NŜŘdzŎŜ ŜYٰλăăλ2yã 2Ŧ YٰdzfűλLJfŜ LJ2ffdzűIٰyűăΣ ă2YٰŜ LJ2⌀ŜN LJfIٰyűă ăűλff Ř2 y2ű ŜYٰLJf2è úKŜ Ŧdzff ădzλűŜ 2Ŧ IٰØIٰfIٰōfŜ LJ2ffdzűλ2ƴ Ŏ2yűN2fă 2N Ř2 y2ű Ŏ2yűN2f Ŧ2N Iٰff LJ2ffdzűIٰyűă⌀ОНП

! ŘŘλΰΰλ2yl·ffèΣ ăΰŜl·Y ŜfŜŎΰΝΩλŎ LJ2ø ŜΝ[22] LJfl·yΰă ∃ŜyŜΝl·ΰŜ ø l·ăΰŜø l·ΰŜΝ ăΰΝΩŜl·Yă ₹Ν2Y ΰKŜλΝ ø l·ΰŜΝ ΰΝΩŜl·ΰYŜyΰΣ LJ2ø ŜΝ ŎèŎfŜΣ l·ăK Kl·yŘfλy∃Σ l·λΝ LJ2ffdzΰλ2y Ŏ2yΰΝ2f ăèăΰŜY ăΣ Ŏ2l·f LJλfŜăΣ l·yŘ 2ΰKŜΝ Yλ ăŎŜffl·yŜ2dză ø l·ăΰŜă ΰKl·ΰ Ŏl·y λYLJl·Ŏΰ ∃Ν2dzyŘ ø l·ΰŜΝ l·yŘ ădzΝ₹l·ÔŜ ø l·ΰŜΝ Ijdzl·fΰèφοηρ /dzΝΩŜyΰfèΣ ăΰŜl·Y ŜfŜŎΰΝΩλŎ LJ2ø ŜΝ LJfl·yΰă l·ŎŎ2dzyΰ ₹2Ν l·ō2dzΰ oл LJŜΝŎŜyΰ 2₹ l·ff ΰ2ÈλÔ LJ2ffdzΰl·yΰă—λyŎfdzŘλy∃ YŜΝÔdzΝèΣ l·ΝăŜyλŎΣ ăŜfŜyλdzYΣ Ŏl·ŘYλdzYΣ l·yŘ 2ΰKŜΝ ΰ2ÈλÔ YŜΰl·fă—ŘλăŎKl·Ν∃ŜŘ λyΰ2 ădzΝ₹l·ÔŜ ø l·ΰŜΝă λyΩΰKŜ ¦ yλΰŜŘ {ΰl·ΰŜăφοηc ¢KŜăŜ LJ2ffdzΰl·yΰă Ŏl·y Ŏl·dzăŜ ăŜØŜΝŜ KŜl·fΰK l·yŘ ŜyØλΝ2yYŜyΰl·f LJΝ2ōfŜYă λyΩKŜ ₹2ΝY 2₹ Ŏl·yŎŜΝ l·yŘ y2yπŎl·yŎŜΝ ΝλăʅăλyKdzYl·yãΣ f2ø ŜΝŜŘ Lv l·Y2y∃ ŎKλfŘΝŜyΣ l·yŘ ŘŜ₹2ΝYλΰΛŜă l·yŘ ΝŜLJΝ2ŘdzŎΰΛØŜ Kl·ΝY λy₹λăK l·yŘ øλfŘfλ₹Ŝφοнт Ly нлмрΣ 9t ! Ŝăΰl·ōfλăKŜŘ yŜø fλYλΰă 2y øl·ăΰŜøl·ΰŜΝ Řλă ŎKl·Ν∃Ŝ ₹Ν2Y LJ2ø ŜΝ LJfl·yΰă ΰKl·ΰ l·NŜ LJΝ2ΩŜŎΰŜŘ ΰ2 ΝŜŘdzŎŜ ŘλăŎKl·Ν∃Ŝ 2₹ ΰKŜ Y2ăΰ ΰ2ÈλÔ LJ2ffdzΰl·yΰă ōè 2ØŜΝ фл LJŜΝŎŜyΰφοнyΣ онф

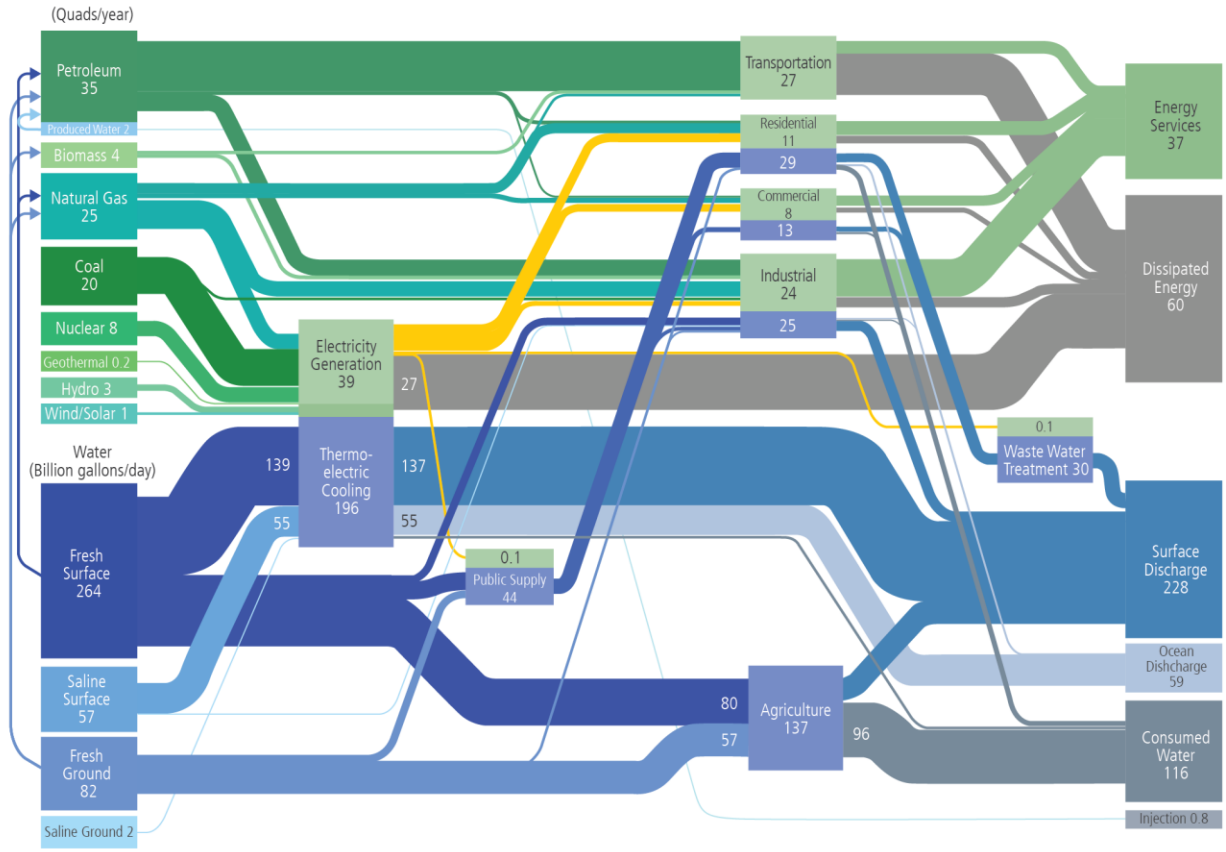
CŜŘŜΝl·f l·yŘ ăΰl·ΰŜ ∃2ØŜΝyYŜyΰă l·NŜ Ŏ2yΰλydzλy∃ ΰKŜλΝ Ŝ₹₹2Νΰăΰ ΰ2 λyØŜăΰ λyl·yŘ λyŎŜyΰλØλÎŜ Y2ΝŜ Ŝ₹₹λŎλŜyΰΣ fŜăăπ LJ2ffdzΰλy∃ LJ2øŜΝ LJfl·yΰ ΰŜŎKy2f2∃λŜă l·yŘ ΰ2 dzLJŘl·ΰŜ ΝŜ∃dzfl·ΰλ2yã ădzŎK l·ă ΰKŜ ₹λyl·f CŜŘŜΝl·f /Ν2ăăπ{ΰl·ΰŜ ! λΝ t2ffdzΰλ2y ¦LJŘl·ΰŜ wdzfŜΣ l·Y2y∃ 2ΰKŜΝ l·Ŏΰλ2yãφ Ly l·ŘŘλΰλ2yΣ NŜ∃dzfl·ΰλ2y 2₹ /hн ŜYλăăλ2yã ₹Ν2Y LJ2øŜΝ LJfl·yΰă λă ŜÈLJŜŎΰŜŘ ΰ2 ΝŜŘdzŎŜ ŜYλăăλ2yã 2₹ 2ΰKŜΝ l·λΝ LJ2ffdzΰl·yΰăΣ ŎΝŜl·ΰλy∃ l·ŘŘλΰλ2yl·f KŜl·fΰK l·yŘ ŜyØλΝ2yYŜyΰl·f ōŜyŜ₹ΰΰă λyl·ŘŘλΰλ2yΰ2 ΰKŜ l·Ø2λŘŜŘ ŎfλYl·ΰŜ ŎKl·y∃Ŝ λYLJl·Ŏΰăφοοл ¢KŜ NŜYl·λyλy∃ LJ2ffdzΰλ2yŘλăLJΝ2LJ2Nΰλ2yl·ΰŜfè l·₹₹ŜŎΰă ŜyØλΝ2yYŜyΰl·f ∂dzăΰλŎŜ Ŏ2YYdzyλΰλŜă óăŜŜ {ŜŎΰλ2y oφnφτύφ 9yØλΝ2yYŜyΰl·f ∂dzăΰλŎŜ Ŏ2YYdzyλΰλŜă l·NŜ l·fă2 ŘλăLJΝ2LJ2Nΰλ2yl·ΰŜfè λYLJl·ŎΰŜŘ ōè ŎfλYl·ΰŜ ŎKl·y∃Ŝ ōŜŎl·dzăŜ ΰKŜè Kl·ØŜ fŜăă NŜăλfλŜyŎŜ Ŏl·LJl·Ŏλΰè φ

3.4.2 Role of Water in Thermoelectric Power Generation

9fŜŎΰΝΩλŎλΰè ăèăΰŜYă l·yŘ ø l·ΰŜΝ ăèăΰŜYă l·NŜ ăΰΝΩ2y∃fè λyΰŜΝΩŎ2yyŜŎΰŜŘφ ² l·ΰŜΝ λă l· ŎΝΩλΰλŎl·f NŜIjdzλΝΩŜYŜyΰ ₹2Ν YIλyè ŜfŜŎΰΝΩλŎλΰè ∃ŜyŜΝl·ΰλ2yΰŜŎKy2f2∃λŜăφ ¢ø2πΰKλΝŘă 2₹ ΰ2ΰl·f ¦φ{φ ŜfŜŎΰΝΩλŎλΰè ∃ŜyŜΝl·ΰλ2y—λyŎfdzŘλy∃ Yl·yè Ŏ2l·fΣ yl·ΰdzΝl·f ∃l·ăΣ ydzŎfŜl·NΣ /{tΣ l·yŘ ∃Ŝ2ΰKŜΝYl·f LJfl·yΰă—NŜIjdzΝΩŜă ø l·ΰŜΝ ₹2Ν Ŏ22fλy∃φ Ly l·ŘŘλΰλ2yΣ //¦{ ΰŜŎKy2f2∃λŜă Kl·ØŜ ăλ∃yλ₹λŎl·yΰ ø l·ΰŜΝ ŘŜYl·yŘăφ CΝ2Y l· ₹dzffπăèăΰŜY LJŜΝΩăLJŜŎΰΛØŜΣ ΰKŜ ∂2λyΰ NŜfλl·yŎŜ 2₹ ŜfŜŎΰΝΩλŎλΰè l·yŘ ø l·ΰŜΝ ăèăΰŜYă 2y ŜI·ŎK 2ΰKŜΝ Ol·y ŎNŜl·ΰŜ Ødzfy ŜΝl·ōλfλΰλŜă óŜφ∃φΣ ŘΝ2dz∃Kΰ λYLJl·ŎΰăΰKŜΝYΣŜfŜŎΰΝΩλŎ ∃ŜyŜΝl·ΰλ2yl·yŘ KèŘΝ2LJ2øŜΝΰΣ ōdzΰ ΰKλă ∂2λyΰ NŜfλl·yŎŜ Ŏl·yl·fă2 ŎNŜl·ΰŜ 2LJLJ2NΰdzyλΰλŜă ₹2Ν Ŝl·ŎK ăèăΰŜY ΰ2 ōŜyŜ₹λΰ ΰKŜ 2ΰKŜΝ ΰKΝ2dz∃K øŜfπŘŜăλ∃yŜŘ λyΰŜ∃Νl·ΰλ2yóăŜŜ Cλ∃dzNŜ oπнм ₹2Ν Ŏ2yyŜŎΰλ2yã ōŜΰøŜŜyŜyŜΝ∃è l·yŘ ø l·ΰŜΝ ăèăΰŜYăΰφ

[22] ! ăΰŜl·Y ŜfŜŎΰΝΩλŎ LJ2øŜΝ LJfl·yΰ λă l· LJ2øŜΝ LJfl·yΰ λyøKλŎK ăΰŜl·Y λă dzăŜŘ ΰ2 ∃ŜyŜΝl·ΰŜ ŜfŜŎΰΝΩλŎλΰèφ LyLJl·NΰλŎdzfl·NΣ ø l·ΰŜΝ λă ō2λfŜŘ ΰ2 ∃ŜyŜΝl·ΰŜ ăΰŜl·Y øKλŎKΣ λyΰdzNyΣ ălJλyã l· ăΰŜl·Y ΰdzNōλyŜ ΰKl·ΰ ŘΝΩØŜă l·yŜfŜŎΰΝΩλŎl·f ∃ŜyŜΝl·ΰ2Νφ a2ăΰ Ŏ2l·fΣ ∃Ŝ2ΰKŜΝYl·fΣ ă2fl·N ΰKŜΝYl·fΣ yΘzŎfŜl·NΣ l·yŘ ø l·ăΰŜ λyŎλySΝl·ΰλ2yLJfl·yΰă l·yŘ ă2YŜ yl·ΰdzNl·f ∃l·ă LJ2øŜΝ LJfl·yΰă l·NŜ ăΰŜl·Y ŜfŜŎΰΝΩλŎ LJ2øŜΝ LJfl·yΰăφ

Figure 3-21. Hybrid Sankey Diagram of 2011 U.S. Interconnected Water and Energy Flows[331]



Significant fractions of surface freshwater withdrawals are for thermoelectric cooling and for agriculture, but agriculture consumes more water than thermoelectric cooling consumes. Most electricity is generated for residential, commercial, and industrial use, but significant fractions are used for public water supply and wastewater treatment. The Sankey diagram aids in visualizing these complex data streams and interconnections as a first step toward further analysis.

{ŜØŜNl·f NŜŎŜyű úNŜyŘă l·NŜ LJl·NűűλŎdzfl·NftȅλYLJ2NűÍ·yű ŦźN ŜfŜŎúNλŎλúȅ ăȅăűŜYăφ CλNăűΣ úKŜ NλăλyƎ ăKl·NŜ 2Ŧ ǿλyŘ ûdzNōλyŜ l·yŘ ă2fÍ·N t± ƎŜySNl·ûλ2Y NŜljdzλNŜă ySƎfλƎλōfŜ ǿl·ûŜN Ŧ2N 2LJŜNl·ûλ2yãφ {ŜŎ2yŘΣ úKŜ l·Y2dzyű 2Ŧ ǿl·ûŜN *withdrawn* Ŧ2N ûKŜNY2ŜfŜŎúNλŎ Ŏ22fλyƎ[LJLJ] Kl·ă ŘŜŎNŜl·ăŜŘ l·ă 2fŘŜN LJfÍ·yűă l·NŜ ŘŜŎ2YYλăăλ2ySŘ l·yŘ Y2NŜ ǿl·ûŜNπŜŦŦλŎλSyű 2N ŘNȅπŎ22fŜŘOOH äȅăűŜYă l·NŜ λyãűÍ·ffŜŘφ l2ǿŜØŜNΣ ǿl·ûŜN *consumption* λY ûKŜNY2ŜfŜŎúNλŎ LJfÍ·yűă λă NλăλyƎ l·ă ŜØl·LJ2NÍ·ûλØŜ Ŏ22fλyƎ Kl·ă ōŜŎ2YŜ úKŜ LJNŜŦŜNNŜŘ Ŏ22fλyƎ ûŜŎKy2f2Ǝè Ŧ2N ySǿ LJfÍ·yűăφ LY l·ŘŘλûλ2yΣ úKŜNŜ l·NŜ ǿl·ûŜN λYLJfλŎÍ·ûλ2yã 2Ŧ ûKŜ ûŜŎKy2f2Ǝè LJÍ·ûK LJdzNădzŜŘ û2 l·ŘŘNŜăă ŎfλYl·ûŜ ŎKl·yƎŜφ ó{ŜŜ CλƎdzNŜ oπHH Ŧ2N l· ōNŜl·ʅŘ2ǿY2Ŧ ƎŜySNl·ûλ2yΣ ǿl·ûŜN ǿλúKŘNÍ·ǿl·fΣ l·yŘ ǿl·ûŜN Ŏ2yãdzYLJűλ2Y ōè Ŏ22fλyƎ ûèLJŜφú

¢KŜNY2ŜfŜŎúNλŎ LJ2ǿŜN ƎŜySNÍ·ûλ2Y ǿλúKŘNÍ·ǿă fl·NƎŜ Ijdzl·yűλűλŜă 2Ŧ ǿl·ûŜN Ŧ2N Ŏ22fλyƎ LJ2ǿŜNπLJN2ŘdzŎλyƎ ŜIjdzλLJYŜyű l·yŘ Ŏ2yŘŜyãλyƎ ăűŜl·Yφ Lú l·fă2 ŘλăăλLJl·ûŜă fl·NƎŜ Ijdzl·yűλűλŜă 2Ŧ LJNλY l·Nè ŜySNƎè ŘdzŜ û2 ûKŜ LJN2ŎŜää 2Ŧ Ŏ2yØŜNűλyƎ ûKŜNY l·f ŜySNƎè û2 ŜfŜŎúNλŎλúèφ LYнлмлΣ[ij] пр LJŜNŎŜyű 2Ŧ û2ű l·f ¦φ{φ ǿl·ûŜN ǿλúKŘNÍ·ǿl·fă ǿŜNŜ Ŧ2N

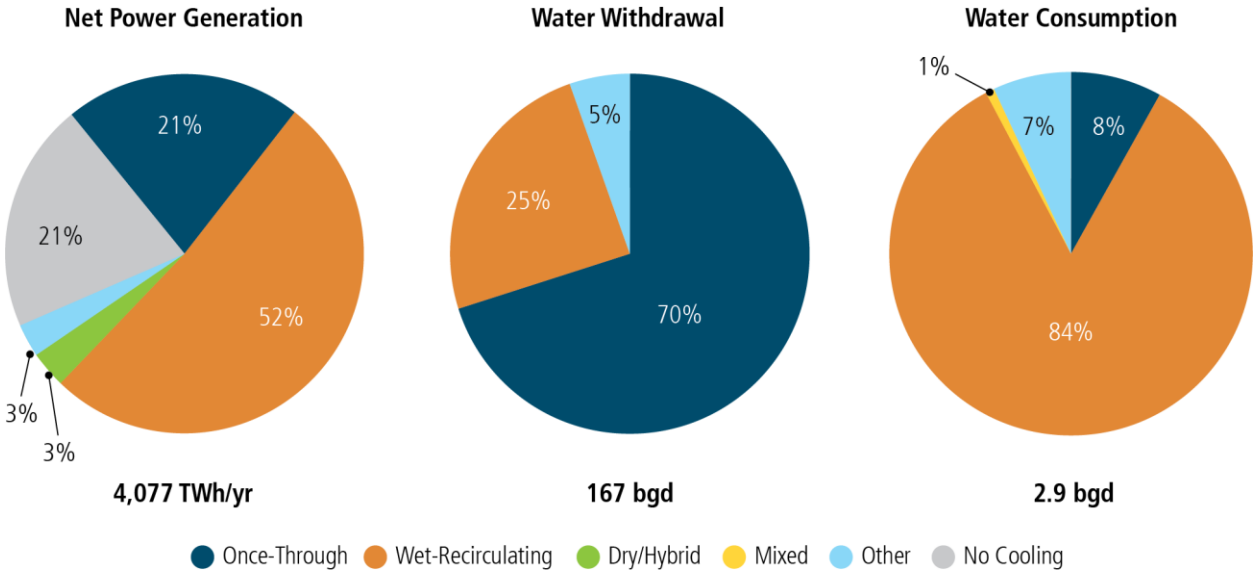
[LJLJ] "Withdrawal" designates any water diverted from a surface or groundwater source. "Consumed water" designates ǿλúKŘNÍ·ǿYǿl·ûŜN ûKl·ú λă y2ú NŜűdzNyŜŘ û2 λûă ă2dzNŎŜ óSφƎφΣ ōŜŎÍ·dzăŜ λű Kl·ă ŜØÍ·LJ2NÍ·ûŜŘΣ ōŜŜyûNÍ·yãLJNŜŘ ōè LJfÍ·yűăΣ 2N λyŎ2NLJ2NÍ·ûŜŘ λyű2 LJN2ŘdzŎűăúφ

[ij] ¢KŜ ¦φ{φ DŜ2f2ƎλŎl·f {dzNØŜè Ŏ2ffŜŎûă ŘÍ·úÍ· 2Yǿl·ûŜN dzăÍ·ƎŜ ōè ǿl·ûŜN ă2dzNŎŜ ŜØŜNè ŦλØŜ èŜÍ·Nă l·yŘ LJdzōfλăKŜă λű ySÍ·N ûKŜ ōŜƎλyYλyƎ 2Ŧ ûKŜ ySĚű ŘÍ·úÍ· Ŏ2ffŜŎúλ2YŎèŏfŜφ

ǘKŜ№Y2ŜfŜŎǘ№ƛŎ Ŏ22fƛy∃ l·f2yŜΣ Y l·ʅƛy∃ ǘKŜ№Y2ŜfŜŎǘ№ƛŎ ∃ŜyŜ№l·ǘƛ2yǘKŜ fl·№∃Ŝǎǘ ǿƛǘKŘ№l·ǿŜ№ 2ŦŎ2YōƛyŜŘ Ŧ№ŜǎK l·yŘ ǎl·fƛyŜ ǿl·ǘŜ№ yl·ǘƛ2yl·ffèφ°°° {ŜǾŜyǘèπǘǿ2 LJŜ№ŎŜyǘ 2Ŧ ǘKŜǎŜ ǿƛǘKŘ№l·ǿl·fǎ Ŧ2№ ǘKŜ№Y2ŜfŜŎǘ№ƛŎ Ŏ22fƛy∃ ǿŜ№Ŝ Ŧ№ŜǎK ǎdz№Ŧl·ŎŜ ǿl·ǘŜ№Σ лφп LJŜ№ŎŜyǘ ǿŜ№Ŝ Ŧ№ŜǎK ∃№2dzyŘǿl·ǘŜ№Σ l·yŘ ǘKŜ №ŜYl·ƛyƛy∃ ǿŜ№Ŝ Ŧ№2Y ǎl·fƛyŜ ǎ2dz№ŎŜǎφ°°п

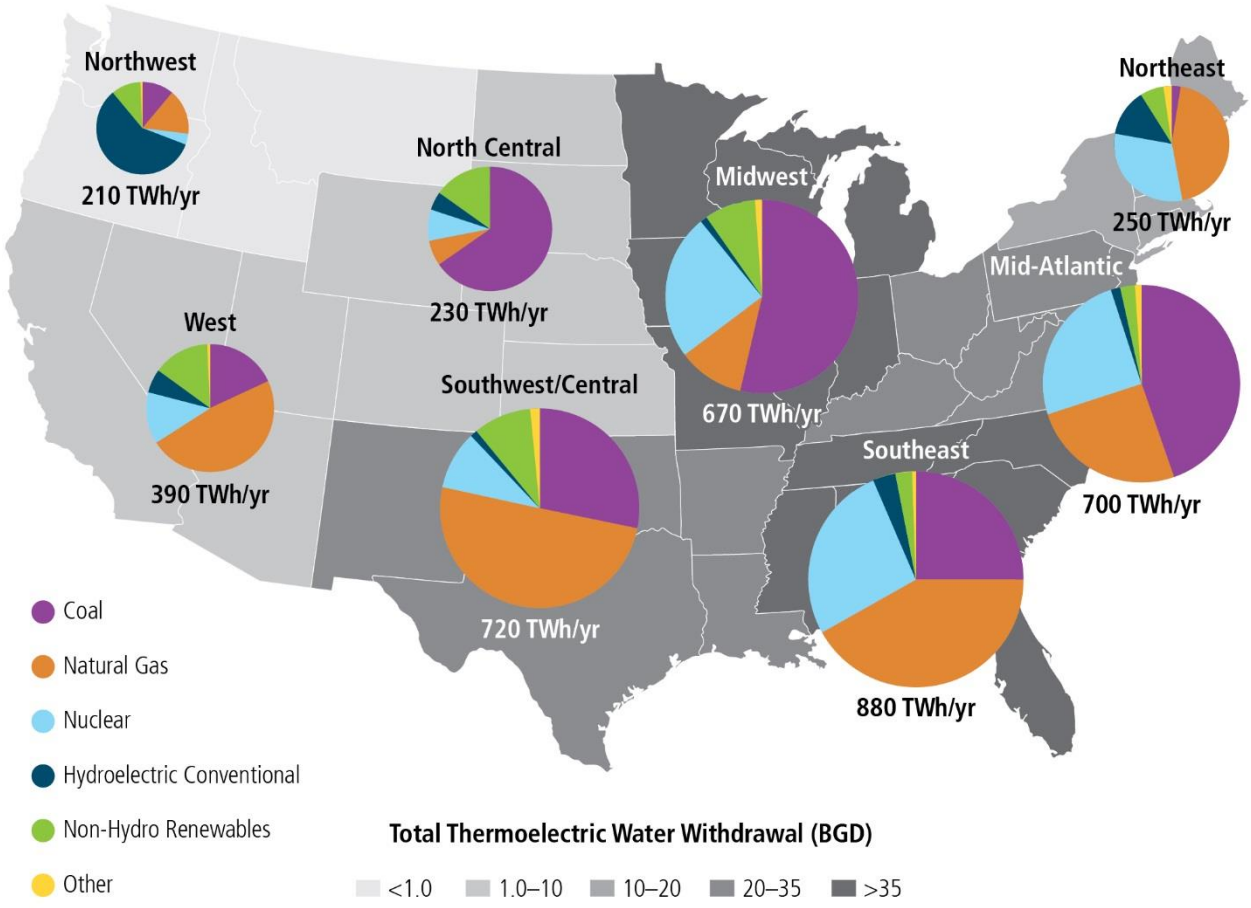
¢KŜ ƛyǘŜyãƛǘè 2Ŧ ǿl·ǘŜ№ dzǎŜ l·yŘ ŜyŜ№∃è ŘƛǎǎƛLJl·ǘŜŘ Ǿl·№ƛŜǎ ǿƛǘK Ŏ22fƛy∃ ǎèǎǘŜY ǘŜŎKy2f2∃è l·yŘ ∃ŜyŜ№l·ǘƛ2y ǘèLJŜΣ l·ǎ ǿŜff l·ǎ 2LJŜ№l·ǘƛ2yãφ hyŎŜπǘK№2dz∃K Ŏ22fƛy∃ ǘèLJƛŎl·ffè ǿƛǘKŘ№l·ǿǎ Y2№Ŝ ǿl·ǘŜ№ ōdzǘ Ŏ2yãdzYŜǎ fŜǎǎ ǘKl·y l· ǿŜǘπ№ŜŎƛ№Ŏdzfl·ǘƛy∃ ǎèǎǘŜYφ 5№è Ŏ22fƛy∃ l·yŘ ǿŜǘ ǘ2ǿŜ№ Ŏl·LJƛǘl·f l·yŘ 2LJŜ№l·ǘƛy∃ Ŏ2ǎǘǎ l·№Ŝ ǎƛ∃yƛŦƛŎl·yǘfè Kƛ∃KŜ№ ǘKl·y Ŧ2№ 2yŎŜπǘK№2dz∃KΣ ǿƛǘK Ř№è Ŏ22fƛy∃ ōŜƛy∃ ǘKŜ Y2ǎǘ ŜÈLJŜyãƛǾŜφ 5№è Ŏ22fƛy∃ dzyƛǘǎ l·fǎ2 ƛyŘdzŎŜ ŜŦŦƛŎƛŜyŎè LJŜyl·fǘƛŜǎΣ №l·ƛǎƛy∃ ǘKŜ LJ2ǎǎƛōƛfƛǘè 2Ŧ LJ2ǘŜyǘƛl·ffè Ŏ№Ŝl·ǘƛy∃ ǘ№l·ŘŜ2ŦŦǎ ōŜǘǿŜŜy l·ŘŘ№Ŝǎǎƛy∃ ǿl·ǘŜ№ l·yŘ ŎfƛYl·ǘŜ №ŜǎƛfƛŜyŎŜ ǾŜ№ǎdzǎ ŎfƛYl·ǘŜ Yƛǘƛ∃l·ǘƛ2yΣ ǿKƛŎK Ŏ2dzfŘ ōŜ ƛYLJ№2ǾŜŘ ǿƛǘK yŜǿ ǘŜŎKy2f2∃ƛŜǎφ

Figure 3-22. U.S. Power Generation, Water Withdrawal, and Water Consumption by Cooling Type, 2015[335, 336, 337, 338]



In 2015, nearly 21 percent of generation used once-through cooling, and 52 percent of generation used wet-recirculating cooling. About 21 percent of the electricity generated—including hydropower, natural gas turbines, and wind turbines—did not require cooling. Water withdrawals for electricity generation totaled 167 billion gallons daily (BGD), the majority of which was withdrawn by once-through cooling. Water consumption totaled 2.9 BGD, with 84 percent of this amount consumed by wet-recirculating cooling.

Figure 3-23. Water Withdrawal and Generation by Region, 2015[339, 340]



The largest water withdrawal regions are dominated by coal and/or nuclear power generation. The area of each pie chart corresponds to total power generation in that region. “Other” includes petroleum, other fossil fuels, pumped storage, non-biogenic municipal solid waste, batteries, and hydrogen. The eight regions shown in the figure are notional, based upon contiguous groupings of states and their generation mixes, resources, and market structures.

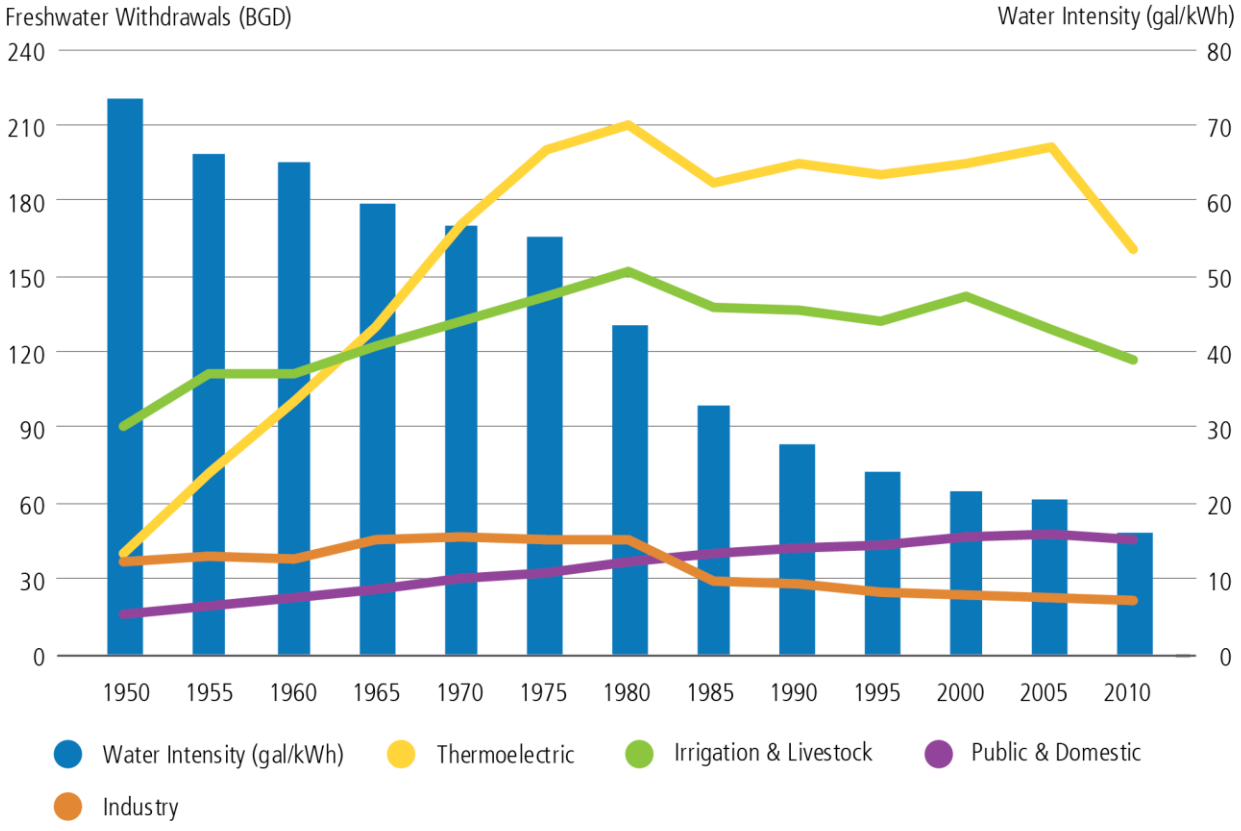
wŜƎʎ2yl·ffêΣ ǿl·ûŜℕ ǿʎűḰŘℕl·ǿl·f l·yŘ Ŏ2yãdzYLJűʎ2yΎØl·ℕè ãʎƎyłŦʎŎl·yűtê l·ŎℕΩ2ää ûḰŜ ¦ yʎűŜŘ {ûl·ûŜãΣ LJℕʎYΎl·ℕʎfê ŘdzŜ ű2 ûḰŜ LJ2ǿŜℕ ƎŜyŜℕl·ûʎ2yΎYÀÈ l·yŘ Ŏ22fłyƎ ãêãűŜY ûèLJŜΦ CłƎdzℕŜ oπнo ãḰ2ǿă ûḰŜ l·Y2dzyű 2Ŧ ǿl·ûŜℕ ǿʎűḰŘℕl·ǿl·f Ŧ2ℕ ŘʎŦŦŜℕŜyű ûèLJŜä 2Ŧ ûḰŜℕΥ2ŜfŜŎúℕʎŎ ƎŜyŜℕl·ûʎ2yΎʎyΎŜłƎḰű y2ûʎ2yl·f ℕŜƎʎ2yã ǿʎűḰʎyΎûḰŜ πy Ŏ2yűʎƎdz2dzã ăűl·ûŜãΦ ¢ḰŜ y2ûʎ2yl·f ℕŜƎʎ2yã l·ℕŜ ōl·ãŜŘ 2yΎŎ2yűʎƎdz2dzã ƎℕΩ2dzLJʎyƎă 2Ŧ ăűl·ûŜä l·yŘ ûḰŜłℕ ƎŜyŜℕl·ûʎ2yΎYÀÈŜãΣ ℕŜă2dzℕŎŜãΣ l·yŘ Yl·ℕ⌊Ŝű ăúℕdzŎúdzℕŜãΦ ² KʎfŜ ǿl·ûŜℕ ǿʎűḰŘℕl·ǿl·fã ʎyΎl·ff ŜʎƎKű ℕŜƎʎ2yã l·ℕŜ Ř2YΎʎyl·ûŜŘ ōè ädzℕŦl·ŎŜ ǿl·ûŜℕΣ ûḰŜ {2dzúḰŜl·ăúΣ {2dzúḰǿŜãűκ/ŜyűℕlΣ l·yŘ ² Ŝăű ℕŜƎʎ2yã Ŏ2yãdzYŜ KʎƎKŜℕ fŜØŜfã 2Ŧ ƎℕΩ2dzyŘǿl·ûŜℕ l·yŘ ℕŜŎfl·ʎYŜŘ LJfl·yű ŘłãŎKl·ℕƎŜ ǿl·ûŜℕ ℕŜfl·ûʎØŜ ű2 2ûḰŜℕ ℕŜƎʎ2yãΦ ¢ḰŜ ℕŜƎʎ2yã ǿʎűK ûḰŜ fl·ℕƎŜăú ǿl·ûŜℕ ǿʎűḰŘℕl·ǿl·f l·ℕŜ Ř2YΎʎyl·ûŜŘ ōè l· Ŏ2YΎōłyl·ûʎ2yΎ2Ŧ Ŏ2l·f l·yŘ ydzŎfŜl·ℕ LJ2ǿŜℕ ƎŜyŜℕl·ûʎ2yΦ

{ʎyŎŜ ûḰŜ мфрлãΣ ûḰŜ l·Y2dzyű 2Ŧ ǿl·ûŜℕ ǿʎűḰŘℕl·ǿyΎLJŜℕ ⌊ ² K Kl·ã ăűŜl·ŘłfêŘŜŎfłyŜŘ l·ã LJ2ǿŜℕ ƎŜyŜℕl·ûʎ2yΎl·yŘ Ŏ22fłyƎ ûŜŎKy2f2ƎʎŜă Kl·ØŜ ōŜŎ2YΎŜ YΎ2ℕŜ ŜŦŦłŎłŜyű 2ØŜℕ ûʎYΎŜΦ ¢ḰŜ ú2ûl·f l·YΎ2dzyű 2Ŧ ǿl·ûŜℕ ǿʎűḰŘℕl·ǿyΎl·ŎℕΩ2ää l·ff ûḰŜℕΥΎ2ŜfŜŎúℕʎŎ LJfl·yűãΣ K2ǿŜØŜℕΣ Kl·ã ăűŜl·Řłfê l·yŘ ŘℕJl·YΎl·ûʎŎl·ffê ʎyŎℕŜl·ãŜŘ ℕŜfl·ûʎØŜ ű2 ʎℕℕʎƎl·ûʎ2yΣ ʎyŘdzăúℕèΣ l·yŘ LJdzōfłŎ dzãŜ óãŜŜ CłƎdzℕŜ oπнnúΦ a dzŎK 2Ŧ ûḰłã ʎyŎℕŜl·ãŜ ʎă ŘdzŜ ú2 ōdzʎfŘπ2dzű 2Ŧ 2yŎŜπűḰℕ2dzƎK Ŏ22fłyƎ ãêãűŜYã Ŧ2ℕ ûḰŜ Ŏ2l·f l·yŘ ydzŎfŜl·ℕ ŦfŜŜûãΦ .è ûḰŜ мфтлãΣ ûḰŜ ǿŜűπℕŜŎʎℕŎdzfl·ûʎyƎ ãêãűŜY ōŜŎl·YŜ ûḰŜ Ř2YΎʎyl·yű Ŏ22fłyƎ ãêãűŜY—l·ã ûḰŜãŜ ãêãúŜYã ǿʎűḰŘℕl·ǿ fŜää ǿl·ûŜℕΣ ûḰŜℕΥ2ŜfŜŎúℕʎŎ ǿʎűḰŘℕl·ǿl·fã fŜØŜfŜŘ 2ŦŦΦοπмΣ οπн

{ƨƳŜ ƨLJŜ№Ι·ΰλƨyΊ·ƒ LJ№Ι·ŎΰλŎŜă Ι·ƒăƨ Ι·ŦŦŜŎΰ ǿΙ·ΰŜ№ dzăŜφ Cƨ№ ŜȀΙ·ƳLJƒŜΣ ăƨƳŜ LJŜΙ·ʅŜ№ LJƨǿŜ№ LJƒΙ·yΰăΣ ădzŎK Ι·ă yΊ·ΰdz№Ι·ƒ ƎΙ·ă ăΰŜΙ·Ƴ ΰdz№ōλyŜă ǿλΰK ƒƨǿ ŎΙ·LJΙ·Ŏλΰȅ ŦΙ·Ŏΰƨ№ăΣ №dzyΰKŜλ№ Ŏƨƨƒλy∃ ăȅăΰŜƳă Ŧƨ№ Ι· ădzōăΰΙ·yΰλΙ·ƒ Ŧ№Ι·ŎΰλƨyΊ ƨŦ ΰKŜ ΰλƳŜ ǿKŜyΰKŜȅ Ι·№Ŝ yƨΰ ƎŜyŜ№Ι·ΰλy∃ ŜƒŜŎΰ№λŎλΰȅ óΙ·ă ΰKŜ ŎƨƳ LJΙ·№λăƨyōŜΰǿŜŜyŎΙ·LJΙ·Ŏλΰȅ ŦΙ·Ŏΰƨ№ă Ŧƨ№ ƎŜyŜ№Ι·ΰλƨyΊ Ǿăφ Ŏƨƨƒλy∃ ăȅăΰŜƳă ăKƨǿă λyΊCλ∃dz№Ŝ oπнpύT ΰKŜȅ Ι·ƒăƨ ǿλΰKŘ№Ι·ǿ Ι· ăλ∃yλŦλŎΙ·yΰƒȅ Kλ∃KŜ№ Ι·Ƴƨdzyΰ ƨŦ ǿΙ·ΰŜ№ ΰKΙ·yΊ bD// LJƒΙ·yΰăφ ¢KŜ№Ŝ Ι·№Ŝ ƳΙ·yȅ LJƨΰŜyΰλΙ·ƒ ŜȀLJƒΙ·yΊ·ΰλƨyã Ŧƨ№ ΰKλă ōŜKΙ·Ǿλƨ№φ ² KŜyΊ LJƒΙ·yΰă Ι·№Ŝ yƨΰ ƎŜyŜ№Ι·ΰλy∃ ŜƒŜŎΰ№λŎλΰȅΣ ΰKŜȅ ƳΙ·ȅ ŘŜŎλŘŜ ΰƨ ʅŜŜLJ ΰKŜλ№ Ŏƨƨƒλy∃ ăȅăΰŜƳă №dzyΊyλy∃ λyΊ ƨ№ŘŜ№ ΰƨ ƳλyλƳλÎŜ ōλƨŦƨdzƒλy∃ Ι·yŘ Ŏƨ№№ƨăλƨyΣ ŜăLJŜŎλΙ·ƒƒȅ λyΊKƨΰ Ι·yŘ KdzƳλŘ ŎƒλƳΙ·ΰŜăφ ¢KŜȅ ƳΙ·ȅ Ι·ƒăƨ ƨLJΰ ΰƨ ʅŜŜLJ ΰKŜλ№ Ŏƨƨƒλy∃ ăȅăΰŜƳ №dzyΊyλy∃ ăƨ ΰKŜȅ ŎΙ·yΊ ōŜ №ŜăLJƨyãλǾŜ ΰƨ λyŎ№ŜΙ·ăŜă λyΊ ŘŜƳΙ·yŘ Ŧ№ƨƳ ŜyŘ dzăŜ№ă ƨ№ ŘŜŎ№ŜΙ·ăŜă λyΊ ădzLJLJƒȅ Ŧ№ƨƳ ǾΙ·№λΙ·ōƒŜ ƎŜyŜ№Ι·ΰλƨyφ ¢KŜ№Ŝ ƳΙ·ȅ ōŜ ƨLJŜ№Ι·ΰλƨyΊ·ƒ ōŜăΰ LJ№Ι·ŎΰλŎŜă ΰKΙ·ΰ ōŜΰΰŜ№ ƨLJΰλƳλÎŜ ΰKŜ ΰ№Ι·ŘŜπƨŦŦă ōŜΰǿŜŜyΊ ƒƨΙ·Ř ōΙ·ƒΙ·yŎλy∃Σ Ι·ǾƨλŘλy∃ ōλƨŦƨdzƒλy∃ Ι·yŘ Ŏƨ№№ƨăλƨyΣ Ι·yŘ ƳλyλƳλÎλy∃ ǿΙ·ΰŜ№ dzăŜφ

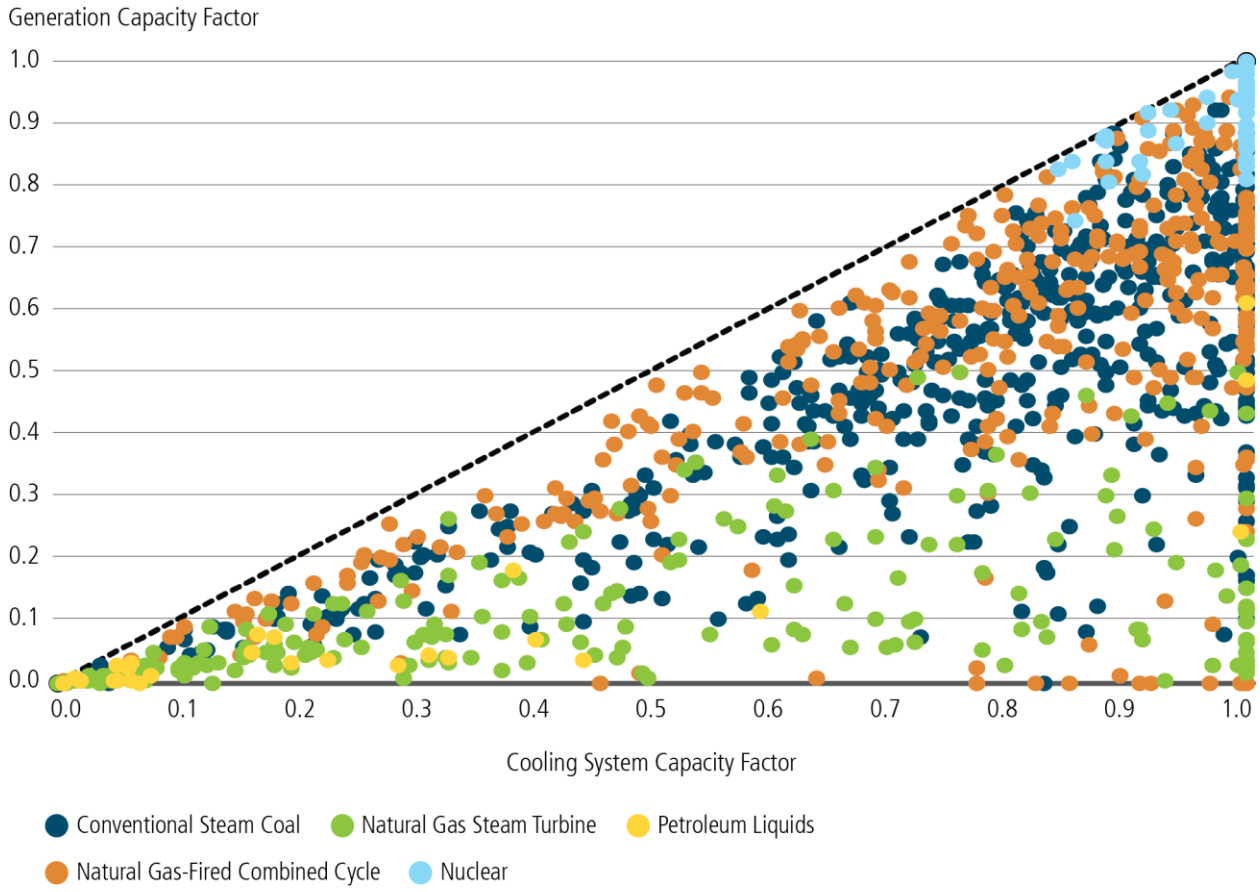
aƨăΰ ΰȅLJŜă ƨŦ ǾΙ·№λΙ·ōƒŜ ƎŜyŜ№Ι·ΰλƨyΊ Řƨ yƨΰ №ŜΙjdzλ№Ŝ ǿΙ·ΰŜ№ Ŧƨ№ Ŏƨƨƒλy∃ LJdz№LJƨăŜăΣ ōdzΰ ΰKŜȅ ŎΙ·yΊ LJdzΰ LJ№ŜăădzN№Ŝ ƨyΊΰKŜ ăȅăΰŜƳ ΰƨ LJ№ƨǾλŘŜ ƒƨΙ·Ř ōΙ·ƒΙ·yŎλy∃Σ dzădzΙ·ƒƒȅ λyΊΰKŜ Ŧƨ№Ƴ ƨŦ ŘλăLJΙ·ΰŎKΙ·ōƒŜ ƎŜyŜ№Ι·ΰλƨyΊΰKΙ·ΰ ŘƨŜă №ŜΙjdzλ№Ŝ ǿΙ·ΰŜ№ Ŧƨ№ Ŏƨƨƒλy∃φ ¢KŜăŜ λyŘλ№ŜŎΰ ŜŦŦŜŎΰă λyŎ№ŜΙ·ăŜ ΰKŜ ǾΙ·ƒdzŜ LJ№ƨLJƨăλΰλƨyΊ Ŧƨ№ ƨΰKŜ№ Ŧƨ№Ƴă ƨŦ ƒƨΙ·Ř ōΙ·ƒΙ·yŎλy∃Σ ădzŎK Ι·ă Ǝ№λŘ ăΰƨ№Ι·∃Ŝ ƨ№ 5wφ

Figure 3-24. Water Withdrawals for Thermoelectric Generation and Other Sectors[343, 344]



The water intensity of thermoelectric generation (represented by bars) has decreased over time. The total amount of water withdrawn by thermoelectric generation (represented by colored lines) has increased significantly relative to other sectors, but it is now declining.

Figure 3-25. 2015 Cooling System Capacity Factors vs. Generation Capacity Factors[345]



Electricity generators run their cooling systems with varying capacity factors relative to their generating capacity factors. Natural gas steam turbines (Rankine cycle plants)—many likely acting as peakers—run their cooling systems for a substantial amount of time when they are not generating, as do a number of NGCC plants. Plants on the dotted line run their cooling systems with the same capacity factor as their power generation capacity factor (i.e., only when they are generating). Plants that are dispatched primarily during times of peak electricity demand are considered peaking plants and will generally have lower power generation capacity factors. Plants used for baseload electricity will generally have higher power generation capacity factors.

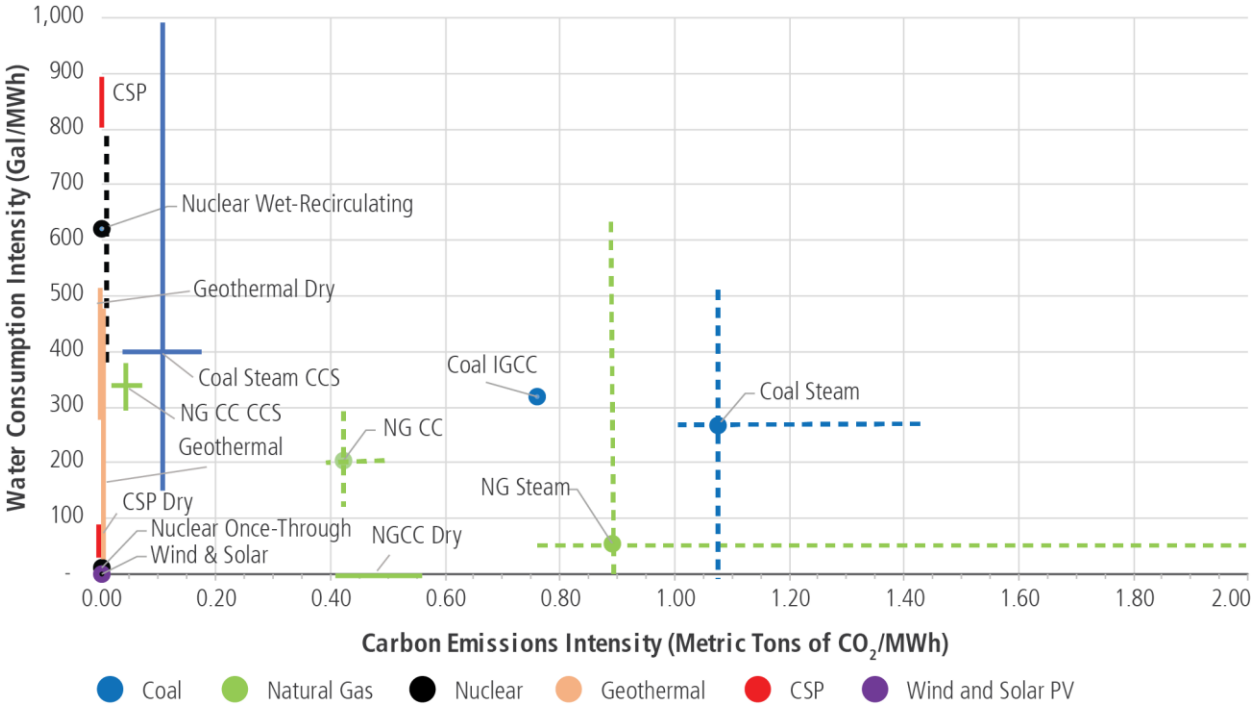
3.4.3 Low-Carbon Generation and Water

¢ƘŜ Y ÀÈ 2₮ ΰƘŜ ƎŜyŜ₦Ⅰ·ΰλ2ƴ LJ2₦ΰ₮2ƒλ2 ŘŜLJf2èŜŘ ΰ2 ₦ŜŘdzŎŜ D I D ŜY ƛăăλ2yã ǿλff KⅠ·ØŜ ʎY LJƒλŎⅠ·ΰλ2yã ₮2₦ ǿⅠ·ΰŜ₦ ǿλΰƘŘ₦Ⅰ·ǿⅠ·f Ⅰ·yŘ Ŏ2yãdzY LJΰλ2y℗ bŜǿ ŜtŜŎΰ₦ΛŎλΰè ƎŜyŜ₦Ⅰ·ΰλ2ƴ ΰKⅠ·ΰ ₦ŜIjdzλ₦Ŝă Ŏ22ƒλyƎ ǿλff fλ⁅Ŝfè ŜY LJf2è ₦ŜŎλ₦ŎdzfⅠ·ΰλyƎ ăèăΰŜY ăΣ ǿKλŎK ƎŜyŜ₦Ⅰ·ffè KⅠ·ØŜ f2ǿ ǿⅠ·ΰŜ₦ ǿλΰƘŘ₦Ⅰ·ǿⅠ·f ōdzΰ KλƎK ǿⅠ·ΰŜ₦ Ŏ2yãdzY LJΰλ2y℗ CλƎdz₦Ŝ oπ нc ăK2ǿă ΰKⅠ·ΰ ă2Y Ŝ ƎŜyŜ₦Ⅰ·ΰλ2ƴ ΰŜŎKy2f2ƎλŜă ŎⅠ·ƴKⅠ·ØŜ ō2ΰK f2ǿ ǿⅠ·ΰŜ₦ dzăŜ Ⅰ·yŘ ŎⅠ·₦ō2ƴ ʎyΰŜyãλΰλŜăΣ ădzŎK Ⅰ·ă t± Ⅰ·yŘ ǿλyŘΣ ǿKλfŜ 2ΰKŜ₦ ƎŜyŜ₦Ⅰ·ΰλ2ƴ ΰŜŎKy2f2ƎλŜă LJ₦ŜăŜyΰ ΰ₦Ⅰ·ŘŜ2₮₮ă ōŜΰǿŜŜƴ ǿⅠ·ΰŜ₦ Ⅰ·yŘ ŎⅠ·₦ō2ƴŜY ʎăăλ2yã℗

{2Y Ŝ f2ǿπŎⅠ·₦ō2ƴ ΰŜŎKy2f2ƎλŜăΣ ădzŎK Ⅰ·ă yΩzŎfŜⅠ·₦ ƎŜyŜ₦Ⅰ·ΰλ2yΣ ƎŜ2ΰKŜ₦Y Ⅰ·f ƎŜyŜ₦Ⅰ·ΰλ2yΣ /{tΣ Ⅰ·yŘ //¦{Σ ₦ŜIjdzλ₦Ŝ ₦ŜfⅠ·ΰλØŜfè fⅠ·₦ƎŜ Ⅰ·Y 2dzyΰă 2₮ ǿⅠ·ΰŜ₦℗ LyŎ2₦LJ2₦Ⅰ·ΰλyƎ ǿⅠ·ΰŜ₦ dzăŜ Ⅰ·yŘ LJŜ₦₮2₦Y Ⅰ·yŎŜ Y ŜΰN₦λÔă ʎyΰ2 w55ƨ5 ₮dzyŘʎyƎ Ŏ₦ΛΰŜ₦ΛⅠ· ₮2₦ ΰKŜăŜ f2ǿπŎⅠ·₦ō2ƴ ΰŜŎKy2f2ƎλŜă Ŏ2dztŘ ʎY LJ₦2ØŜ ΰKŜ 2LJΰλ2yã Ⅰ·ØⅠ·λfⅠ·ōtŜ ₮2₦ ŎfλY Ⅰ·ΰŜ Y ʎΰλƎⅠ·ΰλ2ƴ Ⅰ·yŘ ₦ŜăλfλŜyŎŜ℗

/2yØŜNăŜfèΣ ŘNè Ò22fλyΞΣ øKλÒK ΞNŜI·úfè NŜŘdzÒŜă øI·úŜN NŜIjdzΛNŜY^ŜyúăŦ2N úKŜNY^2ŜfŜÒúNλÒ Ò22fλyΞΣ ΞŜySNI·ffè λyŘdzÒŜă I·y^ ŜySNΞè ŜŦŦλÒλŜyÒè LJŜyI·fúèΣ LJI·NúλÒdzfI·Nfè dzyŘŜN KλΞKπúŜY^LJŜNI·údzNŜ I·Y^ōλŜyú Ò2yŘλúλ2yã¢ ¢Kλă λyÒNŜI·ăŜă úKŜ ÒI·Nō2y^λyúŜyăλúè 2Ŧ ΞŜySNI·úλ2yΣ I·ă øŜff I·ă 2ŭKŜN I·Ř2LJúλ2y^ÒKI·ffŜyΞŜă¢ I2øŜØŜNΣ ŘNè Ò22fλyΞ ăèăúŜY^ă 2ŦŦSN ăλΞyλŦλÒI·yú ăλúλyΞ ŦfŜÈλōλfλúè I·ă úKŜè Ř2 y2ú NŜIjdzNŜ I·ÒÒŜăă ú2 fI·NΞŜ Ø2fdzY^Ŝă 2Ŧ øI·úŜN¢ !ú LJNŜăŜyúΣ úKŜNŜ I·NŜ тп ŘNè 2N Kèō NλŘ Ò22fλyΞ ăèăúŜY^ă úKI·ú LJN2ØλŘŜ po ¢ ² K 2Ŧ ySú ΞŜySNI·úλ2y^λy^úKŜ ¦ yλúŜŘ {úI·úŜăΣ Y^2ăú 2Ŧ øKλÒK KI·ØŜ ōŜŜy^ŘŜLJf2èŜŘ λy^bD/ / LJfI·yűă ăλyÒŜ нллл¢ ¢KŜ ŜySNΞè LJŜyI·fúè Ŧ2N ÒdzNNŜyú ŘNè Ò22fλyΞ úŜÒKy2f2ΞλŜă NŜfI·úλØŜ ú2 2yÒŜπúKN2dzΞK Ò22fλyΞ NI·yΞŜă ŦN2Y^ пΦн LJŜNÒŜyú ú2 мс LJŜNÒŜyú Ŧ2N I·NŜLJNŜăŜyúI·úλØŜ плππa ² Ò2I·fπŦλNŜŘ LJfI·yűΣ ŘŜLJŜyŘλyΞ 2y^LJfI·yú LJI·NJI·Y^ŜúŜNă I·yŘ I·Y^ōλŜyú Ò2yŘλúλ2yã¢onc Ly^ I·ŘŘλúλ2yΣ ŜÈλăúλyΞ ŘNè ól·λNπÒ22fŜŘú 2LJúλ2yã KI·ØŜ KλΞKŜN ÒI·LJλúI·f Ò2ăúă I·yŘ NŜIjdzNNŜ ŜÈLJI·yŘŜŘ LJKèăλÒI·f Ŧ2úLJNλyúă¢onT

Figure 3-26. Carbon Emissions and Water Consumption Intensity Tradeoffs[348, 349, 350, 351, 352, 353]



Some generation technologies (e.g., solar PV and wind) can have both low water and carbon intensities while other generation technologies present tradeoffs between water and carbon emissions. For example, low-carbon technologies, such as nuclear, geothermal, and CSP generation, along with carbon capture and storage (CCS), require large amounts of water. Conversely, dry cooling, which greatly reduces water requirements for thermoelectric cooling, often induces an efficiency penalty, which increases the carbon intensity of generation. Dotted lines represent ranges calculated from data, and solid lines represent ranges from literature values.

¢KN2dzΞK úKŜ !ŘØI·yÒŜŘ wŜăŜI·NÒK λy^5Nè /22fλyΞ LJN2ΞNI·Y^Σ úKŜ !ŘØI·yÒŜŘ wŜăŜI·NÒK tN2ŝŜÒúă !ΞŜyÒè–9ySNΞè ó!wt !π9ú KI·ă λyØŜăúŜŘ I·ō2dzú Þол Y^λffλ2y^ ú2 I·ŘØI·yÒŜ ŘNèπÒ22fλyΞ úŜÒKy2f2ΞλŜă¢ ¢KŜ LJN2ΞNI·Y^ I·λY^ă ú2 ŘŜØŜf2LJ ŘNèπÒ22fλyΞ úŜÒKy2f2ΞλŜă úKI·ú Ř2 y2ú Ò2yãdzY^Ŝ I·yè øI·úŜNΣ ŜfλY^λyI·úŜ ŜŦŦλÒλŜyÒè LJŜyI·fúλŜăΣ I·yŘ Ř2 y2ú λyÒNŜI·ăŜ úKŜ [/h9 ōè Y^2NŜ úKI·y^p LJŜNÒŜyú¢ wŜI·ÒKλyΞ úKλă úI·NΞŜú øzdzfŘ I·ff2ø Ŧ2N NŜŘdzÒŜŘ øI·úŜN dzăŜ Ŧ2N Ò22fλyΞ øλúK2dzú I·y^ I·ŘŘλúλ2yI·f ŜySNΞè ŜŦŦλÒλŜyÒè LJŜyI·fúè¢ Ly^ I·ŘŘλúλ2yΣ 5h9 KI·ă ădzLJLJ2NúŜŘ ŘŜăλΞyã Ŧ2N I·ŘØI·yÒŜŘ ydzÒfŜI·N NŜI·ÒúN2Nă úKI·ú dzăŜ Y^2fúŜy^ăI·fú NJI·úKŜN úKI·y^øI·úŜN I·ă I· Ò22fλyΞ ŦfdzλŘ¢

a2NŜ ōN2I·ŘfèΣ úKŜNŜ I·NŜ ō2úK 2LJLJ2NúdzyλúλŜă I·yŘ úNJI·ŘŜ2ŦŦă λy^ŜySNΞè I·yŘ øI·úŜN ăèăúŜY^ă λyúŜΞNI·úλ2y^óŜ¢Ξ¢Σ λy^ dzăλyΞ úNŜI·úŜŘ Y^dzyλÒλLJI·f øI·ăúŜøI·úŜN Ŧ2N úKŜNY^2ŜfŜÒúNλÒ Ò22fλyΞΣ 2N λy^ NŜÒ2ØŜNλyΞ ŜySNΞè ŦN2Y^ øI·ăúŜøI·úŜN ăèăúŜY^ăú¢ aI·ʃλyΞ ŘŜăλΞy^ŘŜÒλă2yã I·ō2dzú K2ø I·yŘ øKŜy^ú2 λyúŜΞNI·úŜ ŜfŜÒúNλÒλúè I·yŘ øI·úŜN

3.4.4 Land-Use and Ecological Impacts of the Electricity System

3.4.4.1 Land-Use Impacts

¦ LJăúNŜI·YΣ Ŏ2I·f Yλγλγ∃ λă Ŏ2yŘdzŎűŜŘ ō2úK 2y űKŜ ădzNŦI·ÔŜ I·yŘ dzyŘŜN∃N2dzyŘΣ I·yŘ 2ŦúŜy ǿλúK ăλ∃yλŦłÔI·yű λYLJI·Ôűă ű2 űKŜ fI·yŘăÔI·LJŜ I·yŘ űKŜ ŜÔ2ăèăúŜY φ a2dzyűI·λyű2LJ Yλγλγ∃ I·yŘ ØI·ffŜè ŦλffăΣ Ŧ2N λyăúI·yŎŜΣ ŎI·y fŜI·Ř ű2 fI·N∃ŜπăÔI·fŜ fI·yŘăÔI·LJŜ ŎKI·y∃ŜăΣ λyŎfdzŘλy∃ úKŜ f2ăă 2Ŧ Ŧ2NŜăúŜŘ I·NŜI·ă I·yŘ ŘλăLJfI·ÔŜY Ŝyű I·yŘ f2ăă 2Ŧ ălJŜÔλŜăΣ I·ă ǿŜff I·ă ăλ∃yλŦłÔI·yű I·fúŜNI·úλ2yã 2Ŧ ăúNŜI·Y ŜÔ2ăèăúŜY ă φoco

{λY λfI·NfèΣ úKŜ ŘλNŜÔű fI·yŘ dzăŜ Ŧ2N I· ydzÔfŜI·N LJ2ǿŜN LJfI·yű λă f2ǿΣ ōdzú ŜyØλN2yYŜyűI·f ŘI·YI·∃Ŝ NŜădzfúλy∃ ŦN2Y dzNI·yλdzY Yλγλγ∃—λyŎfdzŘλy∃ I·ÔλŘ YλγŜ ŘNI·λγ1·∃Ŝ I·yŘ úKŜ ŜÈLJ2ădzNŜ 2Ŧ ădzNN2dzyŘλy∃ ŜÔ2ăèăúŜY ă ű2 KŜI·Øè YŜűI·fă—λă LJ2ăăλōfŜφăă

! fűK2dz∃K úKŜ dzLJăúNŜI·Y Yλγλγ∃ λYLJfλÔI·úλ2yã 2Ŧ NŜySǿI·ōfŜ ŜyŜN∃è ă2dzNÔŜă I·NŜ fŜăă úKI·y úK2ăŜ I·ăă2ÔλI·ûŜŘ ǿλúK YI·yè 2úKŜN ∃ŜySNI·úλ2y ă2dzNÔŜăΣ NŜySǿI·ōfŜ ŜyŜN∃è ăèăúŜY ă I·fă2 NŜIjdzλNŜ I· ØI·NλŜúè 2Ŧ YI·ûŜNλI·făΣ λyŎfdzŘλy∃ Ô2YY2ŘúλŜă fλ]Ŝ λN2ykăûŜŜfΣ LJ2fèYŜN Ô2YLJ2ăλúŜăΣ I·fdzYλydzYΣ I·yŘ NJI·NŜ ŜI·NúK YλγŜNI·făφ {2dzNÔλy∃ 2Ŧ úKŜăŜ YI·ûŜNλI·fă NŜIjdzλNŜ Yλγλγ∃ 2Ŧ NJI·ǿ YI·ûŜNλI·făΣ ǿλúK I·ăă2ÔλI·ûŜŘ Nă]ă NŜfI·ûŜŘ ű2 ű2ÈλÔλúè 2Ŧ I·ăă2ÔλI·ûŜŘ YλγŜ ûI·λfλy∃ă I·yŘ ySƎI·úλØŜ λYLJI·Ôűă 2yǿI·ûŜN dzăŜŘ λyNŜă2dzNÔŜ ŜÈúNJI·Ôúλ2yΣ ăŜLJI·NJI·úλ2yΣ I·yŘ LJN2ÔŜăăλy∃φ

[22]λy∃ ű2ǿI·NŘă úKŜ ŦdzűdzNŜΣ 5h9 Ŝăúλ YI·ûŜă úKI·ű dzyŘŜN I· KλƎK ǿλyŘπLJ2ǿŜN ŘŜLJf2èYŜyű ăÔŜyI·Nλ2 ōè нлрлΣ úKŜ ű2úI·f fI·yŘ I·NŜI· I·ŦŦŜÔűŜŘ ōè ǿλyŘπLJ2ǿŜN λyãúI·ffI·úλ2yã ǿ2dzfŘ ōŜ fŜăă úKI·y мφp LJŜNÔŜyű 2Ŧ úKŜ fI·yŘ I·NŜI· 2Ŧ úKŜ ¦ yλűŜŘ {úI·ûŜăΣ ǿλúK úKŜ YI·ƨ2Nλûè óфт LJŜNÔŜyűú 2Ŧ úKI·ű fI·yŘ I·NŜI· NŜYI·λyλγ∃ I·ØI·λfI·ōfŜ Ŧ2N Ydzfűλ LJfŜ LJdzNLJ2ăŜăφocn ! нлмр aI·ăăI·ÔKdzăŜúűă LyãúλűdzúŜ 2Ŧ ¢ŜÔKy2f2∃è NŜLJ2Nű ŜăúλYI·ûŜŘ úKI·ű I·ff LJN2ƨŜÔűŜŘ ¦φ{φ ŜfŜÔúNλÔλûè ŘŜYI·yŘ λy нлрл Ô2dzfŘ ōŜ YŜű ōè t±Σ I·ăădzYλγ∃ ăú2NI·∃Ŝ I·ff2ǿλy∃ Ŧ2N I·ff] ² K 2Ŧ ŜfŜÔúNλÔλûè ∃ŜySNI·ûŜŘ ű2 ōŜ dzăŜŘT λú ǿ2dzfŘ NŜIjdzλNŜ N2dz∃Kfè ooΣллл]Y H 2N лφп LJŜNÔŜyű 2Ŧ ¦φ{φ fI·yŘ I·NŜI·φocp ¢Kλă λă N2dz∃Kfè ŜIjdzI·f ű2 úKŜ I·NŜI· dzăŜŘ ōè ădzNŦI·ÔŜ Yλγλγ∃ 2Ŧ Ô2I·f I·yŘ λă fŜăă úKI·y úKŜ fI·yŘ I·NŜI· 2ÔÔdzLJλŜŘ ōè YI·ƨ2N N2I·Řăφ Cλúúλy∃ ÔdzNNŜyű ŜÈλăúλy∃ ¦φ{φ N22Ŧű2LJ I·NŜI· ǿλúK t± Ô2dzfŘ YŜŜű I·LJLJN2ÈλYI·ûŜfè сл LJŜNÔŜyű 2Ŧ úKŜ bation's projected 2050 electricity needs.occ {λY λfI·NfèΣ bw9[ŜăúλYI·ûŜŘ úKI·ű úKŜ ûŜÔKyλÔI·f LJ2ûŜyűλI·f ŜÈλăúă Ŧ2N N22Ŧű2LJ t± ű2 ∃ŜySNI·ûŜ мΣпон ¢ ² K 2Ŧ ŜfŜÔúNλÔλûèΣ 2N оф LJŜNÔŜyű 2Ŧ ű2ûI·f I·yyűzI·f ŜfŜÔúNλÔλûè ăI·fŜăφocт

3.4.4.2 Wildlife Impacts

t2ǿŜN ∃ŜySNI·úλ2y ŎI·y KI·ØŜ I·ŘØŜNăŜ λYLJI·Ôűă 2y ǿλfŘfλŦŜφ ¢KŜNŜ I·NŜ I· ØI·NλŜúè 2Ŧ Yλûλ∃I·úλ2y ăúNI·ûŜ∃λŜă I·ØI·λfI·ōfŜ ű2 I·ffŜØλI·ûŜ ădzŎK λYLJI·Ôűă I·yŘΣ I·ă ŘλăÔdzăăŜŘ ōŜf2ǿΣ Y2NúûI·fλúλŜă I·ûúNλōdzúŜŘ ű2 LJ2ǿŜN ∃ŜySNI·úλ2y I·NŜ ăλ∃yλŦłÔI·yűfè ŦŜǿŜN úKI·y úK2ăŜ úKI·y ŎI·y ōŜ I·ûúNλōdzúŜŘ ű2 yI·ûdzNI·f LJNŜŘI·ű2N ă I·yŘ Ô2ffλă2yã ǿλúK ōdzλfŘλy∃ăφ

! ØI·λfI·ōfŜ ŘI·ûI· 2y ǿλfŘfλŦŜ λYLJI·Ôűă I·ăă2ÔλI·ûŜŘ ǿλúK Ô2I·fπŦλNŜŘ LJ2ǿŜN LJfI·yű 2LJŜNI·úλ2yã ăă fλY λúŜŘΣ I·fűK2dz∃K 2yŜ ăúdzŘè ŜăúλYI·ûŜă úKI·ű Ô2I·fπŦλNŜŘ LJ2ǿŜN LJfI·yűă ÔI·dzăŜ N2dz∃Kfè úKŜ ăI·YŜ 2N YΣNŜ I·ØλI·y YΣNúI·fλúλŜă LJŜN D ² K ∃ŜySNI·ûŜŘ úKI·y ǿλyŘ údzNōλySăφ CI·Ôű2NλY∃ λy LJNN2ƨŜÔűŜŘ ÔfλYI·ûŜ ÔKI·y∃Ŝ λYLJI·Ôűă I·ØλI·y YΣNúI·fλúλŜă I·ûúNλōdzúŜŘ ű2 Ô2I·fπŦλNŜŘ ŜfŜÔúNλÔλûè ǿŜNŜ ŜăúλYI·ûŜŘ ű2 ōŜ ŦI·N ∃NŜI·ûŜN úKI·y úK2ăŜ I·ûúNλōdzúŜŘ ű2 2úKŜN ŜfŜÔúNλÔ ∃ŜySNI·úλ2yúŜÔKy2f2∃λŜăφocφ

bdzÔfŜI·N LJ2ǿŜN ∃ŜySNI·úλ2yLJ2ăŜă I· NλăẗŰ2 I·ØλI·yLJ2LJdzfI·úλ2yãΣ ǿKλÔK ÔI·y ōŜ ŜÈLJ2ăŜŘ ű2 ű2ÈλÔ ǿI·ăúŜ LJ2yŘă I·ű dzNI·yλdzY Yλγλγ∃ I·yŘ Yλffλy∃ ŦI·ÔλfλúλŜă I·yŘ Ô2ffλŘŜ ǿλúK ydzÔfŜI·N Ô22fλy∃ ű2ǿŜNăφot л

¦ úλfλúèπăÔI·fŜ ă2fI·N ŜySN∃è ŘŜØŜf2LJYŜyű ÔI·y I·ŦŦŜÔű ōλNŘă I·yŘ I·ØλI·yÔ2YYdzyλúλŜă ŘλNŜÔúfè úKN2dz∃K ŦI·úI·fλúè 2N λyŘλNŜÔűfè úKN2dz∃K ŘŜ∃NI·Ř I·úλ2yΣ f2ăăΣ 2N ŦNI·∃YŜyűI·úλ2y 2Ŧ KI·ōλúI·ûφ Ly ∃ŜySNI·fΣ ŘλNŜÔű ŦI·úI·fλúŜă I·NŜ NŜfI·ûŜŘ

N ¦ NI·yλdzY Yλγλγ∃ λy úKŜ ¦ yλűŜŘ {úI·ûŜă λă N∃ŜdzfI·ûŜŘ ōè úKŜ ! ű2YλÔ 9ySN∃è ! Ôű 2Ŧ мфрпΣ I·ă I·YŜyŘŜŘ óпн ¦φ{φ/φ ƷƷ нлммπнлнмΣ нлнππнnусΣ ннфсI·πннфтKтмоúφ ¢KŜăŜ NŜ∃dzfI·ű2Nè I·ÔűλŜ ű2yã LJN2ûŜÔű úKŜ KŜI·fűK I·yŘ ăI·fŜúè 2Ŧ úKŜ LJdzōfλÔ I·yŘ úKŜ ŜyØN2yYŜyű ŘdzNλy∃ úKŜ I·ÔűλØŜ fλfŜ 2Ŧ I· dzNI·yλdzY NŜÔ2ØŜNè 2LJŜNI·úλ2y I·yŘ I·fúŜN úKŜ ŦI·ÔλfλúèKI·ă ōŜŜyŘŜÔ2YYλăăλ2ySRφ [λÔŜyăλy∃ YI·è NŜIjdzNNŜ fλÔŜyăŜŜă ű2 úI·]Ŝ LJNŜØŜyűI·úλØŜ YŜI·ădzNŜă LJNλ2N ű2 ăúI·Nűλy∃ 2LJŜNI·úλ2yãΣ λyŎfdzŘλy∃ ǿŜff úŜăúăΣ Y2yűú2NλyΣ I·yŘ ŘŜØŜf2LJYŜyű 2Ŧ LJN2ÔŜŘdzNŜă úKI·ű λyŎfdzŘŜ ŜÈÔdzNăλ2yNŜăLJ2yãŜ YŜI·ădzNŜă I·yŘ NŜLJ2Núλy∃ NŜIjdzNNŜYŜyűăφ bw/ issued a "Generic Environmental Impact Statement Ŧ2N LyfI{λűdz [ŜI·ÔK ¦ NI·yλdzY aλγλγ∃ CI·ÔλfλúλŜăþ ób ¦ w9D мфмлú λy a I·è нллфY KúűLJYκκǿǿφyNÔφ∃2ØκYI·ûŜNλI·făκdzNI·yλdzYπ NŜÔ2ØŜNèκ∃ŜăφKúYfφ

ää ¢KŜ I·Y2dzyű 2Ŧ dzNI·yλdzY Yλγλγ∃ λy úKŜ ¦ yλűŜŘ {úI·ûŜă λă ÔdzNNŜyűfè ØŜNè f2ǿφ

ΰƨ Ǒƨfƭλƨƴã ƨℕ ă2fI·ℕ ŦfdzÈ℗ΰΰΣ ᴏᴛ™ /2ffƭλƨƴã Ƴ I·è 2ǑǑdzℕ ǿλΰK I·ff ΰèLJŠă 2Ŧ ă2fI·ℕ ŜƴŜℕƎè ΰŜǑKƴƨf2ƎλŜăΣ ōdzΰ ă2fI·ℕ ŦfdzÈ ŜŦŦŠǑΰă 2ƴ ōλℕŘă KI·ØŜ ōŜŜƴ 2ōăŜℕØŜŘ 2ƴtè I·ΰ ŦI·ǑλƭƭΰλŜă ǿλΰK ΰƨ℗Ŝℕăˆ ŜIjdzλLJLJŠŘ ΰƨ Ǒ2ƴǑŜƴΰℕI·ΰŜ ă2fI·ℕ LJƨǿŜℕ℗ ! ℕŠǑŜƴΰ ăΰdzŘè ŜăΰλƳI·ΰŜŘ ΰKI·ΰ I·LJLJℕƨÈλƳI·ΰŜƭè cΣллл ōλℕŘă ŘλŜŘ I·Ǒℕƨăă ΰKŜ ŦλØŜ ălјdzI·ℕŜ Ƴ λƭŜă 2Ŧ California’s Ivanpah solar thermal facility last yearᵀᴼᵀᴴ ƴ2ƴŜ ǿŜℕŜ ŜƴŘI·ƴƎŜℕŜŘ℗ C2ℕ Ǒ2ƳLJI·ℕλă2ƴΣ Ř2ƳŜăΰλǑ ǑI·ΰă ⌋λff м℗п ΰ2 o℗т ōλƭfλ2ƴōλℕŘă LJŜℕ èŜI·ℕΣ I·ƴŘ ōŜΰǿŜŜƴocp Ƴ λƭfλ2ƴΰ2 фyy Ƴ λƭfλ2ƴōλℕŘă I·ℕŜ ŜăΰλƳI·ΰŜŘ ΰ2 ŘλŜ I·ƴƴdzI·ffè λƴΰKŜ ¦ yλΰŜŘ {úI·ΰŜă ŦℕƨƳ ōdzλfŘλƴƎ Ǒ2ffλăλ2yã℗ᴼᵀᴼ

5h9 I·ƴŘ ΰKŜ .dzℕŜI·dz 2Ŧ [I·ƴŘ aI·ƴI·ƎŜƳŜƴΰ ó.[aú KI·ØŜ ⁇2λƴΰfè ŘŜØŜf2LJŜŘ ƎdzλŘI·ƴǑŜ ΰ2 Ƴ λƴλƳλÎŜ ŜƴØλℕƨ2ƴƳŜƴΰI·f λƳLJI·Ǒΰăa—λƴǑfdzŘλƴƎ λƳLJI·Ǒΰăΰ2 ǿλfŘfλŦŜ—ŘdzℕλƴƎ ΰKŜ ăΰλƴƎΣ Ǒ2ƴăΰℕdzǑΰλ2ƴΣ I·ƴŘ 2LJŜℕI·ΰλ2ƴ2Ŧ dzΰλfλΰèπăǑI·fŜ ă2fI·ℕ ŦI·ǑλfλΰλŜă 2ƴ LJdzōfλǑ fI·ƴŘă℗ .[a λŘŜƴΰλŦλŜŘ ăLJŜǑλŦλǑ f2Ǒ I·ΰλ2ƴã ǿŜff ădzλΰŜŘ Ŧ2ℕ dzΰλfλΰèπăǑI·fŜ LJℕ2ŘdzǑΰλ2ƴ2Ŧ ă2fI·ℕ ŜƴŜℕƎè ΰKI·ΰ Ƴ λƴλƳλÎŜ ǿλfŘfλŦŜ λƳLJI·Ǒΰăφ {λƳλfI·ℕfèΣ ΰKŜ 5h9 ƎdzλŘI·ƴǑŜ λƴΰŜƎℕI·ΰŜă ǿλfŘfλŦŜ I·ƴŘ ŜƴØλℕƨ2ƴƳŜƴΰI·f Ǒ2ƴãλŘŜℕI·ΰλ2ƴã λƴΰ2 λΰă I·ƴI·fèăλă I·ƴŘ ăŜfŜǑΰλ2ƴ 2Ŧ LJℕ2ΣŜǑΰă ΰKI·ΰ λΰ ǿλff Ŧλƴ1·ƴǑλI·ffè ădzLJLJ2ℕΰ℗ᴼᵀᴼ

¢KŜ λƳLJI·Ǒΰăa 2ƴ I·ØλI·ƴ I·ƴŘ ōI·ΰ LJ2LJdzfI·ΰλ2ƴã I·ℕŜ ΰKŜ LJℕλƴǑλLJI·f ŜǑ2f2ƎλǑI·f Ǒ2ƴǑŜℕƴã I·ăă2ǑλI·ΰŜŘ ǿλΰK ǿλƴŘ ŘŜØŜf2LJƳŜƴΰI·f Ŧ2ℕ fI·ƴŘπōI·ăŜŘ ǿλƴŘ LJℕ2ΣŜǑΰăφ 9ŦŦŜǑΰă 2ƴ Ƴ I·ℕλƴŜ fλŦŜ I·ℕŜ ΰKŜ LJℕλƴǑλLJI·f Ǒ2ƴǑŜℕƴƴ Ŧ2ℕ 2ŦŦăK2ℕŜ ǿλƴŘ℗

LƴØŜăΰƳƴŜƴΰă ΰ2 ŘŜØŜf2LJ Ǒ2ăΰπŜŦŦŜǑΰΰλØŜ ΰŜǑKƴƨf2ƎλŜă ΰKI·ΰ ǑI·ƴℕŜŘdzǑŜ ǿλfŘfλŦŜ λƳLJI·Ǒΰăa I·ℕŜ 2ŦŦŜℕλƴƎ ƴŜǿ I·ØλI·ƴ ŘŜΰΰŜℕŜăΰ I·ƴŘ ƳλΰΰŜℕăú I·ƴŘ Ƴλΰλ2ƴΰŜ ǿλfŘfλŦŜ λƴΰKŜ ŦdzΰdzℕŜφᴼᵀᴾ

¢KŜ 5h9 ² λƴŘ ±λăλ2ƴ ℕŜLJ2ℕΰ℗ᴼᵀᶜ ŦλƴŘă ΰKI·ΰ I·ƴƴdzI·f ōλℕŘ Ƴ2ℕΰI·fλΰλŜă ŘdzŜ ΰ2 ǿλƴŘ ΰdzℕōλƴŜă ол℗н Ƴ λfλ2ƴ ōλℕŘăκèŜI·ℕΰ I·ℕŜ Ƴ dzǑK f2ǿŜℕ ΰKI·ƴ ΰK2ăŜ I·ăă2ǑλI·ΰŜŘ ǿλΰK 2ΰKŜℕ ŜƴƎλƴŜŜℕŜŘ ăΰℕdzǑΰΰdzℕŜă I·ƴŘ ŦI·ℕ f2ǿŜℕ ΰKI·ƴ ΰK2ăŜ ⌋λffŜŘ ōè Ř2ƳŜăΰλǑ ǑI·ΰă a2ăΰ ăΰdzŘλŜă ŜăΰλƳI·ΰŜ ΰKŜ ōI·ΰ ŦI·ΰI·fλΰèℕI·ΰŜă ŘdzŜ ΰ2 ǿλƴŘ ΰdzℕōλƴŜă ΰ2 ōŜ tŜää ΰKI·ƴ мл ōI·ΰăκa ² κăΰdzŘè LJŜℕλ2Ř℗ᴼᵀᵀ ² λΰK ΰKŜ λƴǑℕŜI·ăŜ λƴ ǿλƴŘπLJ2ǿŜℕ ƎŜƴŜℕI·ΰλ2ƴΣ ΰKŜ ǿλƴŘ λƴŘdzăΰℕè I·ƴŘ ℕŜƎdzfI·ΰ2ℕè I·ƎŜƴǑλŜă KI·ØŜ ǿ2ℕ⌋ŜŘ ΰ2 Ƴλƴλ2ƴΰŜ ΰKŜ λƳLJI·Ǒΰăa 2ƴ ǿλƴŘ LJℕ2ΣŜǑΰăπăLJŜǑλŦλǑ Ƴ λΰλƎI·ΰλ2ƴŘŜǑΰλ2ƴã [ŜℕƎè ₩℗ ² I·făΰ2ƴΣ ₩₩℗Σ Ŝΰ I·f℗Σ *A Review of Avian Monitoring and Mitigation Information at Existing Utility-Scale Solar Facilities* ó!ℕƎ2ƴƴŜΣL[Y !ℕƎ2ƴƴŜ bI·ΰλ2ƴI·f [I·ō2ℕI·ΰ2ℕèΣ !LJℕλf нлмрύΣ !b[к9±{πмркнΣ KΰΰLJƴкκǿǿǿ℗ŜØă℗I·ƴf℗Ǝ2ØκŘ2ǿƴf2I·Řăκ!b[π9±{ψмpπн℗LJŘŦ℗

ᵈᶻᵈᶻ ¢KŜ CλăK I·ƴŘ ² λfŘfλŦŜ {ŜℕØλÔŜ λă 2ƴŜ 2Ŧ ΰKŜ I·ƎŜyÔλŜă ℕŜăLJ2ƴãλōfŜ Ŧ2ℕ ΰKλă I·ÔΰλØλΰèΣ I·ƴŘΣ λƴΌ2ƴdzfΰI·ΰλ2ƴ ǿλΰK λƴŘdzăΰℕèΣ λΰ KI·ă I·ÔΰŜŘ ΰ2 ădzƎƎŜăΰ ŘŜăλƳƴ2ŘλfλÔI·ΰλ2ƴã Ŧ2ℕ ΰ2ǿŜℕă I·ƴŘ ΰ2 Ŝăΰλ·ÔfλăK Ø2fdzƴΰI·ℕè ƎdzλŘI·ƴǑŜ ΰ2 LJℕ2ΰŜΰΰ ōI·fŘ I·ƴŘ Ǝ2fŘŜƴ ŜI·ƎfŜăΣ I·ă ǿŜff I·ă ΰKŜ LƴŘλI·ƴI· ōI·ΰ {ŜŜ CλăK I·ƴŘ ² λfŘfλŦŜ {ŜℕØλÔŜΣ *Indiana Bat: Section 7 and Section 10 Guidance for Wind Energy Projects* óCλăK I·ƴŘ ² λfŘfλŦŜ {ŜℕØλÔŜΣ нлммύΣ

KΰΰLJƴкκǿǿǿ℗Ŧǿă℗Ǝ2ØκƳλŘǿŜăΰκŜyŘI·ƴƎŜℕŜŘκƳI·ƳƳI·făκλƴōI·κ ² λƴŘ9ƴŜℕƎèDdzλŘI·ƴÔŜ℗KΰŦf℗ 5h9 ℕŜÔŜyΰfè λăădzŜŘ ΰǿ2 ŦdzyŘλƴ Ǝ LJLJ2ℕΰdzƴΰè I·ƴƴ2dzyÔŜƴŜyΰă ΰ2 ŘŜØŜf2LJ Ƴ λΰλƎI·ΰλ2ƴΰŜÔKƴƨf2ƎλŜă Ŧ2ℕ ŜI·ƎfŜă I·ƴŘ ōI·ΰă ƴƳ5ŜÔŜƳōŜℕ нлмсΣ ΰKŜ CλăK I·ƴŘ ² λfŘfλŦŜ {ŜℕØλÔŜ ŦλƴI·fλÎŜŘ I· ℕdzfŜ ΰKI·ΰ ℕŜØλăŜŘ λΰă LJŜℕƳλΰΰλƴƎ LJℕ2ÔŜăăŜă I·ƴŘ Ƴ2ƴΰ2ℕλƴƎ ℕŜIjdzℕŜƳŜyΰă ΰ2 λƳLJℕ2ØŜ ΰKŜ LJℕ2ΰŜÔΰλ2ƴ 2Ŧ ŜI·ƎfŜ populations. Changes to the rule “include revisions to permit issuance criteria, compensatory Y λΰλƎI·ΰλ2ƴăΰI·ƴŘI·ℕŘăΣ ÔℕλΰŜℕλI· Ŧ2ℕ ŜI·ƎfŜ ƴŜăΰ ℕŜƳ2ØI·f LJŜℕƳλΰăΣ LJŜℕƳλΰ I·LJLJfλÔI·ΰλ2ƴℕŜIjdzℕŜƳŜyΰăΣ I·ƴŘ ŦŜŜă.” [I·dzℕè tI·ℕI·Ƴ2ℕŜΣ “Service Announces Final Rule to CdzℕΰKŜℕ /2ƴãŜℕØŜΣ tℕ2ΰŜÔΰ 9I·ƎfŜă ΰKℕ2dzƎK wŜØλăŜŘ tŜℕƳλΰΰλƴƎΣ a2ƴΰ2ℕλƴƎ wŜIjdzℕŜƳŜyΰă,” Fish and Wildife Service, 5ŜÔŜƳōŜℕ мпΣ нлмс, KΰΰLJăƴкκǿǿǿ℗Ŧǿă℗Ǝ2ØκyŜǿăκ{K2ǿbŜǿă℗ÔŦƳKℕŜŤ‘ăŜℕØλÔŜπI·yƴ2dzyÔŜăπŦλƴ1·fπℕdzfŜπΰ2πŦdzℕΰKŜℕπÔ2ƴãŜℕØŜπLJℕ2ΰŜÔΰπŜI·ƎfŜăπ ΰKℕ2dzƎKπℑψL5Γорфмн℗

3.4.4.3 Waste Impacts

3.4.4.4 Other Ecological Impacts

¢2 I·ŘŘ№Ŝää Ŏ2yŎŜ№yã I·ō2ʤú ƛyŘʤŽŎŜŘ ăŜƛäYˈƛŎƛúè №ŜfI·ûŜŘ û2 ŜyƘI·yŎŜŘ ƎŜ2ûĶŜ№YˈI·f äëäúŜYˈäΣ 5h9 Ŏ2YˈYˈƛääƛ2yŜŘ ŜÈLJŜ№úä û2 I·ʤzúĶ2№ úĶŜ LyŘʤzŎŜŘ {ŜƛäYˈƛŎƛúè t№2ûΣ2Ŏ2fΣ I· fƛØƛyƎ ƎʤzƛŘI·yŎŜ Ř2ŎʤzYˈŜyú ₣2№ ƎŜ2ûĶŜ№YˈI·f ŘŜØŜf2LJŜ№äΣ LJʤzōfƛŎ 2₣₣ƛŎƛI·fäΣ №ŜƎʤzfI·û2№äΣ I·yŘ úĶŜ ƎŜyŜ№I·f LJʤzōfƛŎ úĶI·ú ŘŜúI·ƛfä ʤzäŜ₣ʤzf äúŜLJä û2 ŜØI·fʤzI·ûŜ I·yŘ YˈI·yI·ƎŜ úĶŜ Ŝ₣₣ŜŎûä 2₣ ƛyŘʤzŎŜŘ ăŜƛäYˈƛŎƛúè №ŜfI·ûŜŘ û2 ƎŜ2ûĶŜ№YˈI·f LJ№2¿ŜŎûă℗ºʸʸ

3.4.4.5 Land-Use and Ecological Impacts of Electricity T&D

² KƛfŜ úĶŜ ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·Ŏúă 2₣ ¢ƍ5 úŜyŘ û2 ōŜ äYˈI·ffŜ№ úĶI·yˇ ƎŜyŜ№I·ûƛ2yˇ ƛYˈLJI·ŎúäΣ úĶŜè I·№Ŝ yŽú yŜƎfƛƎƛōfŜ℗ºʸ℗ ! ă ¢ƍ5 I·ääŜûä I·№Ŝ yŽú fI·№ƎŜ LJ2ƛyú ä2ʤzN̈ŎŜä 2₣ LJ2ffʤzûƛ2yˇI·yŘ I·№Ŝ ƎŜ2ƎN̈I·LJĶƛŎI·ffê ŜÈLJI·yäƛØŜΣ úĶŜƛ№ ƛYˈLJI·Ŏúä I·fã2 YˈI·è yŽú ōŜ ØŜff ŎĶI·N̈JI·ŎúŜN̈ƛÎŜŘ℗ºΦⁿ ¢ƍ5 äèäúŜYˈä KI·ØŜ I·yˇ I·N̈N̈JI·è 2₣ ŘƛN̈ŜŎú I·yŘ ƛyŘƛN̈ŜŎú ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·ŎúäΣ ØĶƛŎĶ Ŏ I·yˇ ōŜ ŘƛØƛŘŜŘ ōŜúØŜŜyˇ úĶŜ ƛYˈLJI·Ŏúä I·ääƛ2ŎƛI·ûŜŘ ØƛúĶ Ŏ2yãúN̈ʤzŎúƛ2yˇ I·yŘ úĶ2äŜ №ŜfI·ûŜŘ û2 2LJŜ№I·ûƛ2yˇ2₣ úĶŜ ŜfŜŎúN̈ƛŎ ƎN̈ƛŘ℗ ¢ĶŜ ŜŎ2f2ƎƛŎI·fƛYˈLJI·Ŏúä 2₣ úN̈JI·yãYˈääƛ2yˇfƛyŜä ŎI·yˇōŜ ØŜƛƎKŜŘ against transmission lines' benefits. C2№ ŜÈI·YˈLJfŜΣ úN̈JI·yãYˈääƛ2yˇ fƛyŜä Ŏ2yŷŜŎú №ŜYˈ2ûŜfè f2ŎI·ûŜŘΣ f2ØŜN̈π ŜYˈƛúûƛyƎ ƎŜyŜ№I·ûƛ2yˇ ä2ʤzN̈ŎŜä û2 f2I·Ř ŎŜyúŜ№äΣ I·yŘ ŎfŜI·N̈ƛyƎä ₣2№ úN̈JI·yãYˈääƛ2yˇ fƛyŜä ŎN̈ŜI·ûŜ ₣ΛN̈ŜōN̈ŜI·ʅäΣ №ŜŘʤzŎƛyƎ úĶŜ ƛYˈLJI·Ŏúä 2₣ ØƛfŘ ₣ΛN̈Ŝä I·yŘ ƛYˈLJN̈2ØƛyƎ ŜYˈŜ№ƎŜyŎè I·ŎŎŜääΦ

bŜØ LJ2ØŜ№ fƛyŜäΣ I·ŎŎŜää №2I·ŘäΣ I·yŘ I·ääƛ2ŎƛI·ûŜŘ ŜIjʤzƛLJYˈŜyú LJfI·ŎŜŘ ƛyˇ dzyŘŜØŜf2LJŜŘ I·№ŜI·ä ŎI·yˇ Ŏ№ŜI·ûŜ ädzōäúI·yúƛI·f ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·ŎúäΣ ƛyŎfʤzŘƛyƎ úĶŜ ŘƛäúʤzN̈ōI·yŎŜ 2₣ ₣2№ŜäúäΣ ØŜúfI·yŘäΣ I·yŘ 2úĶŜ№ yI·ûʤzN̈I·f I·№ŜI·ä℗ ! Ř2ʤzäúƛyƎ LJN̈2LJ2äŜŘ №2ʤzûŜä 2₣ 2ØŜ№ĶŜI·Ř LJ2ØŜ№ fƛyŜä ŎI·yˇ№ŜŘʤzŎŜ ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·ŎúäΦºᶠᴹ / K22äƛyƎ I· Řƛ₣₣Ŝ№Ŝyú úèLJŜ 2₣ LJ2fŜ äúN̈ʤzŎúʤzN̈Ŝ 2№ YˈŽŘƛ₣èƛyƎ Ŏ2yäúN̈ʤzŎúƛ2yˇYˈŜúK2Řä ŎI·yˇ№ŜŘʤzŎŜ ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·ŎúäΦ wƛƎKűπ2₣πØI·è ƛäädzŜä ŎI·yˇōŜ YˈƛyƛYˈƛÎŜŘ ōè dzäƛyƎ ŎŽ№N̈ƛŘ2№πäKI·N̈ƛyƎ №2dzúŜä ŘʤzN̈ƛyƎ úĶŜ ŘŜäƛƎyˇLJKI·äŜΦ

tdzúúƛyƎ LJ2ØŜ№ fƛyŜä dzyŘŜ№Ǝ№2dzyŘ ŎI·yˇ fƛYˈƛű úĶŜ ØƛädzIˈf ƛYˈLJI·Ŏú 2₣ 2ØŜ№KŜI·Ř fƛyŜä℗ .dz№èƛyƎ f2ØπØ2fűI·ƎŜ ŘƛäúN̈ƛōdzúƛ2yˇ fƛyŜä ƛä Ŏ2YˈY2yˇ ƛyˇ №ŜäƛŘŜyúƛIˈf I·№ŜI·ä℗ .dz№èƛyƎ úN̈JI·yãYˈääƛ2yˇ fƛyŜäΣ K2ØŜØŜ№Σ ƛä dzyŎ2YˈY2yˇ ōŜŎI·dzäŜ ƛű ƛä н–мл úƛYˈŜä YˈZ№Ŝ ŜÈLJŜyäƛØŜ úĶI·yˇ ōdzƛfŘƛyƎ I·yˇ 2ØŜ№KŜI·Ř fƛyŜ℗ºᶠᴴ ¢ƍ5 ƛyŦN̈JI·ăúN̈ʤzŎúʤzN̈Ŝ №ŜIjʤzN̈ŜYˈŜyűä ₣2№ 5D äèäúŜYˈä KI·ØŜ ăYˈIˈffŜ№ ₣22úLJN̈ƛyűä℗ 5D dzyƛűä I·№Ŝ Ŏf2äŜ№ û2 ŜyŘ dzäŜ№äΣ №ŜŘʤzŎƛyƎ úĶŜ yŜŜŘ ₣2№ yŜØ 2№ ŜÈLJI·yŘŜŘ úN̈JI·yãYˈääƛ2y℗ 5D äèäúŜYˈä ŎI·yˇ №ŜIjʤzN̈Ŝ ŜÈLJI·yŘŜŘ úN̈JI·yã₣2№YˈŜ№ I·yŘ ädzŎäúI·ûƛ2yˇ ŎI·LJI·ŎűúƛŜä óúĶŜ I·ØŜ№I·ƎŜ Ŏ2äú 2₣ dzLJŘI·ûƛyƎ I· ädzŎäúI·ûƛ2yˇƛä ÞπлκʅƛŽØ2fûπIˈYˈLJŜ№Sú℗

!ØƛI·yˇY2№úIˈfűúƛŜä ₣№2Y Ŏ2ffʤäƛ2yã ØƛúK úN̈JI·yãYˈääƛ2yˇfƛyŜä I·yŘ №ŜfI·ûŜŘ ƛy₣N̈I·ăúN̈ʤzŎúʤzN̈Ŝä I·№Ŝ I·yˇŜyØƛ№2yYˈŜyúIˈf Ŏ2äú 2₣ úĶŜ ¢ƍ5 äèäúŜY℗ LyˇI·ŘŘƛúƛ2yˇû2 №ŜŘʤzŎƛyƎ ōƛN̈Ř LJ2LJdzfI·ûƛ2yãΣ Ŏ2ffʤäƛ2yã I·yŘ ŜfŜŎúN̈2Ŏdzúƛ2yã ŎI·yˇLJN̈2ŘʤzŎŜ 2dzúIˈƎŜä℗ .ƛN̈Ř Ŏ2ffʤäƛ2yã ØI·№ē ōè KI·ōƛúIˈű úèLJŜΣ ăLJŜŎƛŜä äƛÎŜΣ I·yŘ äŎI·ØŜyƎƛyƎ N̈JI·ûŜäΣ I·yŘ úĶŜè I·LJLJŜI·N̈ û2 ōŜ KƛƎKŜ№ ŘʤzN̈ƛyƎ YˈƛƎN̈JI·ûƛ2y℗ ! ŘØŜ№äŜ ŜŦ₣ŜŎúä 2yˇ ŎŜ№úIˈƛyˇ ōƛN̈Řä óŜ℗ƎΦΣ ŜfŜŎú№2Ŏdzúƛ2yˇ 2₣ ŜI·ƎfŜäú YˈI·è №Šädzfű ƛyˇ LJŜyI·fûƛŜä℗ºᶠᴼ hyŜ ƛyØŜyű2№è 2₣ ōƛN̈Ř YˈZ№úIˈfúè ₣№2Y úN̈JI·yãYˈääƛ2yˇfƛyŜä I·Ŏ№2ää /ˈIˈyI·ŘI·Σ I·ō2dzű KI·fŦ úĶŜ äƛÎŜ 2₣ úĶŜ ¦℗{℗ äèäúŜYΣ №ŜLJ2№úŜŘ нφр û2 нрφс Yˈƛffƛ2yˇ ōƛN̈Ř ŘŜI·úKä I·yŷʤzI·ffè℗ºᶠᴾ LyˇúĶŜ ¦yĺúŜŘ {úI·ûŜäΣ №ŜäŜI·N̈ŎK Ŏ2yŘʤzŎúŜŘ ōè úĶŜ CƛäK I·yŘ ² ƛfŘfƛ₣Ŝ {ŜN̈ØƛŎŜ ₣2dzyŘ úĶI·ú LJ2ØŜ№ fƛyŜä I·f2yŜ YˈƛƎKű]ƛff dzLJ û2 мтр Yˈƛffƛ2yˇ ōƛN̈Řä I·yŷʤzI·ffè℗ºᶠᴾ t№2I·ŎúƛØŜ LJfI·yŷƛyƎ ŎI·yˇ KŜfLJ №ŜŘʤzŎŜ úĶŜäŜ ƛYˈLJI·Ŏúä 2yˇ I·ØƛI·yˇ I·yŘ 2úĶŜ№ ØƛfŘfƛ₣Ŝ LJ2LJdzfI·ûƛ2yã℗

3.4.4.6 Mitigation of Environmental Impacts

¢ĶŜ№Ŝ I·№Ŝ äŜØŜ№I·f ŜÈƛäúƛyƎ ŜyØƛ№2yYˈŜyúIˈf fI·ØäΣ ŘŜäƛƎyŜŘ û2 KŜfLJ YˈƛúƛƎI·ûŜ úĶŜ ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·Ŏúä I·yŘ Ŏ2yŎŜ№yã 2dzúfƛyŜŘ I·ō2ØŜ℗ C2№ ŜÈI·YˈLJfŜΣ I·LJLJfƛŎI·ōfŜ CŜŘŜ№I·f fI·ØäΣ ƛyŎfʤzŘŜ úĶŜ / ! !ΣºᵠᶜΣ úĶŜ /fŜI·yˇ ² I·ûŜ№ !Ŏúºᵠᵀ I·yŘ úĶŜ 9yŘI·yƎŜ№ŜŘ {LJŜŎƛŜä !Ŏúºᵠᵠy CdzN̈úĶŜ№YˈZ№ŜΣ I·yè CŜŘŜ№I·f I·Ŏúƛ2yˇƛyØ2fØƛyƎ yŜØ ƛyŦN̈JI·äúN̈ʤzŎúʤzN̈Ŝ №ŜIjʤzN̈Ŝä úĶŜ №ŜäLJ2yãƛōfŜ CŜŘŜ№I·f 2₣₣ƛŎƛI·f û2 Ŏ2yãƛŘŜ№ úĶŜ LJ2úŜyúƛI·f ŜyØƛ№2yYˈŜyúIˈf ƛYˈLJI·Ŏúä 2₣ úĶŜ LJN̈2LJ2äŜŘ I·Ŏúƛ2yˇ I·yŘ I·yè №ŜI·ä2yI·ōfŜ I·fúŜ№yI·úƛØŜä℗ºᶠᴹ ¢KƛäN̈ŜIjʤzN̈ŜYˈŜyú ƛä äLJŜŎƛ₣ƛŜŘ ƛyˇúĶŜ bI·ûƛ2yI·f 9yØƛ№2yYˈŜyúIˈf t2fƛŎè !Ŏú ób9t !ú 2₣ мφсφ I·yŘ úĶŜ /2dzyŎƛf 2yˇ 9yØƛ№2yYˈŜyúIˈf vdzI·fƛúè wŜƎdzfI·ûƛ2yã ₣2№ LYˈLJfŜYˈŜyúƛyƎ úĶŜ t№2ŎŜŘʤzN̈I·f t№2Øƛäƛ2yã 2₣ b9t !℗ᵑᵑᵑ ¢ĶŜ Ŏ2YˈLJfŜÈúè I·ää2ŎƛI·ûŜŘ ØƛúK 2ōúI·ƛyƛyƎ úĶŜ ŜyØƛ№2yYˈŜyúIˈf LJŜ№YˈƛúäyŜŎŜääI·№è û2 ōdzƛfŘ yŜØ ƛyŦN̈JI·ăúN̈ʤzŎúʤzN̈Ŝ ØƛffŘƛ₣Ŝ№ depending on the implications of the proposed facility's proximity to äŜyäƛúƛØŜ I·ƛN̈Σ ØI·ûŜ№Σ ØƛfŘfƛ₣ŜΣ I·yŘ ŎdzfűʤzN̈I·f N̈Ŝä2dzN̈ŎŜä℗

¢ĸŝ ₹ƛŉăúˬ ƛyãűĭ·ffϒŝyű 2₮ úĸŝ v9w ó v9w мΦмú ₮2dzyŘ űĸĭ·ű ǿĸƛfŝ ŜĚLJĭ·yŘƛyƎ ¢ɞ5 ƛy₣ŉĭ·ăúŉdzŎűűdzŉŝ Ŏĭ·y˙ LJ2ăŝ ŜyØƛŉ2yϒŝyűĭ·f Ŏĸĭĭ·ffŝyƎŝăΣ ōdzƛfŘƛyƎ yŝǿ ƛy₣ŉĭ·ăúŉdzŎűűdzŉŝ Ŏĭ·y˙ ĭ·fă2 fŝĭ·Ř ű2 ăƛƎyƛ₣ƛŎĭ·yű yŝű ŝyØƛŉ2yϒŝyűĭ·f ōŝyŝ₣ƛúăΦ C2ŉ úĸƛă ŉŝĭ·ă2yΣ ĭ·ƎŝyŎƛŝă ĭ·Ŏŉ2ăă úĸŝ CŝŘŝŉĭ·f D2Øŝŉyϒŝyű ĭ·ŉŝ ŝyƎĭ·ƎŝŘ ƛy˙ ăŝØŝŉĭ·f ƛyƛúƛĭ·úƛØŝă ű2 ϒ2Řŝŉyΐŝ úĸŝ CŝŘŝŉĭ·f ŉ2fŝ ƛy˙ ŝfŝŎúŉƛŎ úŉĭ·yãϒƛăăƛ2y˙ LJŝŉϒƛúűƛyƎ ĭ·yŘ LJŉ2?ŝŎű ŉŝØƛŝǿΦ™™ Ly˙ úĸŝƛŉ ĭ·yĭ·fèăŝăΣ LJŝŉϒƛúűƛyƎ ĭ·ƎŝyŎƛŝă úèLJƛŎĭ·ffè²² Ŏ2yãƛŘŝŉ ϒƛúƛƎĭ·úƛ2y˙ŉŝIjdzƛŉŝYŝyűă úĸĭ·ű ϒĭ·è ōŝ ƛϒLJ2ăŝŘ ĭ·ă ŎyŘƛúƛ2yã ű2 ĭ·ŘŘŉŝăă dzyĭ·Ø2ƛŘĭ·ōfŝ ŝyØƛŉ2yϒŝyűĭ·f Kĭ·ŉϒăΦ 5ŝŎĭ·ŘŝăΣ 2₮ ŜĚLJŝŉƛŝyŎŝ ǿƛúK ăƛúƛyƎ ŝyŝŉƎè ¢ɞ5 ƛy₣ŉĭ·ăúŉdzŎűdzŉŝ Kĭ·Øŝ LJŉ2ŘdzŎŝŘ Øĭ·ƛƛ2dză ϒŝúĸ2Řă ₮2ŉ 2₮₮ăŝűűƛyƎ ƛϒLJĭ·Ŏűă ű2 ĭ·₮₮ŝŎúŝŘ Ŏ2ϒϒdzyƛúƛŝă ĭ·yŘ ŝŎ2ăëăúŝϒăΣ ƛyŎfdzŘƛyƎ ĭ·Ø2ƛŘĭ·yŎŝΣ ϒƛyƛϒΐĭ·úƛ2yΣ ĭ·yŘ Ŏ2ϒLJŝyãĭ·úƛ2yΦ ¢ĸŝăŝ ϒŝúĸ2Řă ĭ·ŉŝ ădzϒϒĭ·ƛƛŝŘ v9w мΦм ĭ·yŘ ĭ·ŉŝ ŉŝLJŉ2ŘdzŎŝŘ ƛy˙úĸŝ ō2È ōŝf2ǿΦ

Mitigating Environmental Impacts[402]

- Mitigation is an important mechanism for agencies to use to avoid, minimize, rectify, reduce, or compensate the adverse environmental impacts associated with their activities.[403, 404] Federal agencies typically rely upon mitigation to reduce environmental impacts through modification of proposed actions and consideration and development of mitigation alternatives during the National Environmental Policy Act process.[xx]
- Mitigation is important to Federal agencies managing public lands, which impose a responsibility to sustain an array of resources, values, and functions. For example, public lands contain important wildlife habitat and vegetative communities—in addition to recreational opportunities and ecosystem services, cultural resources, and special status species. These lands are managed for the use and enjoyment of present and future generations. The location, construction, and maintenance of energy infrastructure should avoid, minimize, and, in some cases, compensate for impacts to these public resources, values, and functions. Mitigation is of critical importance to agencies responsible for protecting the Nation's waters.[405] Applying this mitigation hierarchy early in transmission and distribution infrastructure planning provides better outcomes for the impacted resources, values, and functions.[406]
- Resource-specific mitigation measures can be applied to avoid or minimize impacts from a pipeline or an electric transmission project. In order to identify and implement appropriate mitigation measures, first the potential impacts of a project on a specific resource must be assessed. Then, project-specific and site-specific factors must be evaluated to determine whether the impact can be avoided or mitigated, what action can be taken, how effective the mitigation measure will be, and the cost effectiveness of the measure.

3.4.4.7 Mitigating Impacts through Siting and Permitting of Electricity Infrastructure

a2ăű ăƛúƛyƎ ĭ·yŘ LJŝŉϒƛúűƛyƎ ŘŝŎƛăƛ2yã ĭ·ŉŝ ϒĭ·Řŝ ĭ·ű úĸŝ ăűĭ·úŝ ĭ·yŘ f2Ŏĭ·f fŝØŝfăΣ ōdzű úĸŝ úŉĭ·yãŦ2ŉϒĭ·úƛ2y˙2₮ úĸŝ ¦Φ{Φ ŝfŝŎúŉƛŎƛúë ăèăűŝϒ ŉŝIjdzƛŉŝa ŝŦ₮ŝŎúƛØŝ ăƛúƛyƎ ĭ·yŘ LJŝŉϒƛúűƛyƎ Ŏĭ·LJĭ·ōƛfƛúƛŝă ĭ·ű ĭ·ff fŝØŝfă 2₮ Ǝ2ØŝŉyϒŝyűΦ tfĭ·yŷƛyƎ ĭ·yŘ LJŝŉϒƛúűƛyƎ yŝǿ úŉĭ·yãϒƛăăƛ2y˙ƛyƒŉĭ·ăúŉdzŎűdzŉŝΣ ƛyŎfdzŘƛyƎ ϒĭ·yĭ·ƎƛyƎ ŝŎ2f2ƎƛŎĭ·f ƛϒLJĭ·Ŏűăĭ·ŎŉŻăă ƨdzŉƛăŘƛŎúƛ2yã ĭ·yŘ ǿƛúK ĭ· ǿƛŘŝ ŉĭ·yƎŝ 2₮ ăűĭ·ⵗŝK2fŘŝŉƛăΣ ƛă dzyƛIjdzŝfè ŎK ĭ·ffŝyƎƛyƎΦ CŝŘŝŉĭ·fƛăϒ ĭ·yŘ úĸŝ ƛyűŝŉLJfĭ·è 2₮ ăűĭ·úŝ ĭ·yŘ CŝŘŝŉĭ·f fĭ·ǿ Ŏŉŝĭ·úŝ 2Øŝŉfĭ·LJLJƛyƎ ƨdzŉƛăŘƛŎúƛ2yĭ·f fƛyŝăΦ {úĭ·úŝΣ f2Ŏĭ·fΣ ĭ·yŘ úŉƛōĭ·f Ǝ2ØŝŉyϒŝyűăΣ ĭ·ăăƛăúŝŘ ōè CŝŘŝŉĭ·f ĭ·ƎŝyŎƛŝăΣ yŝŝŘ ű2 ōdzƛfŘ Ŏĭ·LJĭ·Ŏƛúèĭ ű2 ϒƛyƛϒΐŝ ăĭ·fŝűè ĭ·yŘ ăŝŎdzŉƛúè Ŏ2yãŝIjdzŝyŎŝăΣ ĭ·ă ǿŝfĭ ĭ·ă LJŉ2úŝŎú úĸŝ ŝyØƛŉ2yϒŝyűΣ ǿKƛfŝ fƛϒăúƛyƎ LJŝŉϒƛúűƛyƎπŉŝfĭ·úŝŘ Řŝfĭ·èăΦ¹¹ⁿ¹ [2Ŏĭ·f Ǝ2Øŝŉyϒŝyűă ϒĭ·è ĭ·Ř2Ljú Î2yƛyƎ ŉŝIjdzƛŉŝYŝyűă úĸĭ·ű ŘƛŦŝŉ ₣ŉ2ϒ ăűĭ·úŝ ŉŝƎƎdzfĭ·úƛ2yã 2ŉ ŝØŝy˙ úĸŝ ŉŝƎdzfĭ·úƛ2yã 2₮ yŝƛƎKō2ŉƛyƎ

ǿǿ !ƎŝyŎƛŝăϒdzăűŎ2yãƛŘŝŉϒƛúƛƎĭ·úƛ2y˙ǿKŝyˬŎ2ϒLJfŝúƛyƎ ĭ·y˙ŝyØƛŉ2yϒŝyűĭ·fƛϒLJĭ·Ŏűăúĭ·úŝϒŝyűΣ ĭ·yŘ ϒƛúƛƎĭ·úƛ2y˙ƛă 2₮úŝyˬŎ2yãƛŘŝŉŝŘ ǿKŝyˬŎ2ϒLJfŝúƛyƎ ĭ·y˙ŝyØƛŉ2yϒŝyűĭ·f ĭ·ăăŝăăϒŝyűΦ

ËË The Council on Environmental Quality's NEPA regulations ŉŝIjdzƛŉŝ ĭ·ƎŝyŎƛŝă ú2 ƛŘŝyűƛ₮è ƛy˙úĸŝƛŉ wŝŎ2ŉŘ 2₮ 5ŝŎƛăĭ2y˙ĭ·yê ϒƛúƛƎĭ·úƛ2yϒŝĭ·ădzŉŝă úĸĭ·ű ĭ·ŉŝ ySŎŝăăĭ·ŉè ű2 ϒƛyƛϒΐŝ ŝyØƛŉ2yϒŝyűĭ·f Kĭ·ŉϒ ₣ŉ2ϒ úĸŝ ĭ·fűŝŉyĭ·úƛØŝ ăŝfŝŎúŝŘ óпл /ΦC₩Φ ϶ мрлрΦнóŎúúΦ ¢ĸŝ b9t ! ĭ·yĭ·fèăƛă Ôĭ·y˙ĭ·fă2 Ô2yãƛŘŝŉ ϒƛúƛƎĭ·úƛ2y˙ĭ·ă ĭ·y˙ƛyűŝƎŉĭ·f ŝfŝϒŝyű ƛy˙úĸŝ ŘŝăƛƎy˙2₮ úĸŝ LJŉ2LJ2ăŝŘ ĭ·Ŏűăĭ2yΦ ¢ĸŝ ŉŝƎdzfĭ·úƛ2yã ₮dzŉűĸŝŉ ăűĭ·úŝ úĸĭ·ű ĭ· ϒ2yűƛ2ŉƛyƎ ĭ·yŘ ŝyƒ2ŉÔŝϒŝyű LJŉ2Ǝŉĭ·ϒ ăĸĭ·ff ōŝ ĭ·Ř2LJúŝŘ ǿĸŝŉŝ ĭ·LJLJfŝÔĭ·ōfŝ ₮2ŉ ĭ·yê ϒƛúƛƎĭ·úƛ2y˙óпл /ΦC₩Φ ϶ мрлрΦнóŎúúΦ

Ŏ2ϒϒdzyλűλŜă℗ⁿᵑᵑ℗ ¢ℕλōI·f ∃2ØŜℕyϒŜyűă ōŜŎ2ϒŜ LJI·ℕűλŎλLJI·yűă λy˝LJŜℕϒλűűλy∃ ŘŜŎλăλ2yã λŦ I· LJℕ2ⱿŜŎű ϒI·è ŘλăℕdzLJű ŎdzťűdzℕI·f 2ℕ Kλăű2ℕλŎ LJℕ2LJŜℕűλŜă 2ℕ ℕŜă2dzℕŎŜă℗ⁿᵐᵑ

C2ℕ I·yê LJℕ2ⱿŜŎű űKI·ú λyØ2ťØŜă I· CŜŘŜℕI·f I·Ŏűλ2y˝óŜ℗∃Φ∑ λŦ I· LJℕ2LJ2ăŜŘ LJℕ2ⱿŜŎű ø2dzfŘ ōŜ ăλűŜŘ 2y˝CŜŘŜℕI·f fI·yŘ 2ℕ LJI·ℕűλI·ffê ŦλyI·yŎŜŘ øλúK CŜŘŜℕI·f ŦdzyŘăúΣ úKŜ ℕŜăLJ2yãλōfŜ CŜŘŜℕI·f I·∃ŜyŎè λă ℕŜIjdzℕŜŘ ōè b9t ! ű2 ŜØI·fdzI·ûŜ LJ2ű$yűλI·f ă2ŎλI·f I·yŘ ŜyØλℕ2yϒŜyűI·f λϒLJI·ŎűăΦ 2Ŧ úKŜ LJℕ2LJ2ăŜŘ I·Ŏűλ2y˝ I·yŘ Ŏ2yãλŘŜℕ ℕŜI·ă2yI·ōfŜ I·fűŜℕyI·ûλØŜă℗ⁿᵐᵐ {λyŎŜ ϒdzfűλLJfŜ CŜŘŜℕI·f I·∃ŜyŎλŜă ŎI·y˝ōŜ λyØ2ťØŜŘ øλúK LJŜℕϒλűűλy∃ ¢ɞ5 λyŦℕI·ăúℕdzŎűdzℕŜΣ úKŜ hōI·YI· !ŘYλyλăúℕI·ûλ2y˝KI·ă úI·ʅŜy˝ăúŜLJă ű2 ϒ2ŘŜℕyλÎŜ CŜŘŜℕI·f LJŜℕϒλűűλy∃ I·yŘ ℕŜØλŜø LJℕ2ŎŜăăŜă℗ⁿᵐᴴ !ŎűλØŜ Ŏ22ℕŘλyI·ûλ2y˝ ōŜűøŜŜy˝ CŜŘŜℕI·fΣ ăúI·ûŜΣ I·yŘ f2ŎI·f ∃2ØŜℕyϒŜyűă ŜyI·ōfŜă øŜftπλy₮2ℕϒŜŘ ŘŜŎλăλ2y˝ ϒI·ʅλy∃Σ ăúℕλʅλy∃ I· ŦI·ℕ ōI·fI·yŎŜ ōŜűøŜŜy˝I· ōℕ2I·Ř ℕI·y∃Ŝ 2Ŧ LJdzōfλŎ I·yŘ LJℕλØI·ûŜ λyűŜℕŜăúă℗

3.4.5 Federal and State Initiatives to Modernize Permitting and Review Processes

¢KŜ CŜŘŜℕI·f D2ØŜℕyϒŜyű λă dzyŘŜℕűI·ʅλy∃ ăŜØŜℕI·f I·Ŏűλ2yã ú2 ℕŜŘdzŎŜ úKŜ I·∃∃ℕŜ∃I·ûŜ LJŜℕϒλűűλy∃ I·yŘ ℕŜØλŜø ûλϒŜ Ŧ2ℕ λyŦℕI·ăúℕdzŎűdzℕŜ LJℕ2ⱿŜŎűăΣ øKλfŜ λϒLJℕ2Øλy∃ ŜyØλℕ2yϒŜyűI·f I·yŘ Ŏ2ϒϒdzyλűê 2dzűŎ2ϒŜă℗ ¢Kλă λyŎfdzŘŜă I· ydzϒōŜℕ 2Ŧ CŜŘŜℕI·f I·yŘ ℕŜ∃λ2yI·f λyλűλI·ûλØŜă ó2dzúfλySŘ λy˝¢I·ōfŜ o℗cú úKI·ú I·ℕŜ ŘŜăλ∃ySŘ ú2 ădzLJLJ2ℕű ōŜűűŜℕ ŘŜŎλăλ2y˝ϒI·ʅλy∃ λy˝ûKŜ Ŧ2ft2øλy∃ øI·èăϒ

- CI·ŎλfλűI·ûŜ ōŜűűŜℕ Ŏ22ℕŘλyI·ûλ2y˝ōŜűøŜŜy˝LJŜℕϒλűűλy∃ I·dzúK2ℕλûλŜă I·ú I·ff fŜØŜfă 2Ŧ ∃2ØŜℕyϒŜyű
- 5ŜØŜf2LJ I·yŘ LJdzōfλăK ℕŜfŜØI·yű λyŦ2ℕϒI·ûλ2y∑ ŘI·úI·Σ I·yŘ ű22fă
- {dzLJLJ2ℕű λyŦℕI·ăúℕdzŎűdzℕŜ LJfI·yŷλy∃ I·yŘ Ŝăúl·ōfλăK ℕλ∃Kûă 2Ŧ øI·è Ŧ2ℕ ŜyŜℕ∃è LJℕ2ⱿŜŎűă
- /2yŘdzŎű ûŜŎKy2f2∃è wɞ5℗

Table 3-6. Federal and Sub-National Initiatives to Modernize Electric Infrastructure Permitting and Review Processes[413]

Initiative Title	Description (Scope and Specific Focus Areas)
Facilitate Better Coordination between Permitting Authorities, Increase Transparency	
Establishing an Implementation Plan to Modernize Permitting	National; Federal plan includes four strategies, 15 reforms, and nearly 100 near-term and long-term milestones, established by Presidential Memorandum
Improving Performance of Federal Permitting and Review of Infrastructure Projects	National; Executive Order 13604 to improve the efficiency and transparency of permitting and review processes for infrastructure projects while producing measurably better outcomes for communities and the environment
Transforming the Nation's Electric Grid through Improved Siting, Permitting, and Review	National; developing an integrated interagency pre-application process for significant onshore electric transmission projects requiring Federal approval, identifying and designating energy corridor
Creating a Permitting Dashboard	National; online database to track the status of Federal environmental reviews and authorizations for projects covered under Title 41 of the Fixing America's Surface Transportation Act
Establishing an Interagency Rapid Response Team for Transmission	National; improve Federal interagency coordination, tribal consultation, and conflict resolution for challenging transmission projects
The Western Governors Association Regulatory and Permitting Information Desktop Toolkit	Western United States; includes wiki platform for stakeholder and agency collaboration
Integrated Interagency Pre-application Process	National; DOE final rulemaking to improve project planning process

Initiative Title	Description (Scope and Specific Focus Areas)
Fixing America's Surface Transportation Act	National; Title 41 establishes the Federal Infrastructure Permitting Improvement Steering Council to inventory major infrastructure projects that are subject to NEPA and improve the review process
Publish Information, Data, and Tools	
EPA's NEPAssist	National; web-based mapping tool
Fish and Wildlife Service's Information, Planning, and Conservation Tool	National; help identify endangered and threatened species before beginning project design
Army Corps' Federal Support Toolbox	National; "one-stop shop" online water resources data portal
Eastern Interconnection States Planning Council's Energy Zones Mapping Tool	Eastern United States; includes 273 geographic information system data layers and links to key resources
Energy Zones Mapping Tool for the Eastern Interconnection Planning Collaborative	Eastern United States; mapping clean energy resources and transmission
Western Electricity Coordinating Council Environmental Data Viewer	Western United States; interactive transmission planning tool
Support Infrastructure Planning	
Undertaking landscape- and watershed-level mitigation and conservation planning	National; environmental mitigation and resource protection at the landscape and watershed levels
Speeding infrastructure development through more efficient and effective permitting and environmental review	National; Presidential Memorandum calling for expedited review of priority projects and improved accountability, transparency, and efficiency
Memorandum of Understanding regarding transmission siting on Federal lands	National; aims at reducing approval time and reducing barriers to siting new transmission lines
Designating corridors for pipelines, electric transmission lines, and related infrastructure	Western United States; Energy Policy Act of 2005 Section 386 establishes rights-of-way on Federal land to promote energy development, resolve resource disputes, and reduce congestion
Desert Renewable Energy Conservation Plan	California; Federal and state collaboration on landscape-level plan streamlining renewable development while conserving unique and valuable desert ecosystems
Technology R&D	
Promoting grid modernization, DOE	National; Enhance security capabilities and stakeholder support

A number of federal and regional initiatives are designed to improve the electric infrastructure permitting and review process. Improved coordination not only reduces permitting and review time, but also improves environmental and community outcomes. These initiatives include the facilitation of coordination between authorities and increased transparency, new tools to disseminate information effectively, the support of infrastructure planning, and technology R&D.

3.4.6 Addressing Impacts of Increased Deployment and New Clean Energy Technologies

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and ecological impacts in the R&D process for new technologies could avoid most impacts and decrease the need for mitigation.

Improving environmental outcomes from infrastructure siting requires the joint efforts of agencies at all levels of government and the private sector.

Recent Transmission Line Approvals

- **Clean Line Plains & Eastern Project**:[414] In March 2016, Secretary Moniz announced that the Department of Energy (DOE) would participate in the development of the Plains & Eastern Clean Line Project (Clean Line), a major clean energy infrastructure project. The Clean Line project taps abundant, low-cost wind generation resources in the Oklahoma and Texas panhandle regions to deliver up to 4,000 megawatts (MW) of wind power via a 705-mile direct current transmission line—enough energy to power more than 1.5 million homes in the mid-South and Southeast United States.

  The Clean Line project will include a 500-MW converter station in Arkansas that will allow the state to access the low-cost renewable energy supplied from the project. Currently, Arkansas has no utility-scale wind generation facilities and none under construction. Furthermore, as a condition of its participation, DOE required that Clean Line make payments to localities for any otherwise-taxable land and assets that are owned by the Federal Government.
- **Great Northern Transmission Line**:[415] In November 2016, DOE announced the issuance of a Record of Decision and Presidential Permit for the Great Northern Transmission Line. The 224-mile, overhead alternating current transmission line will bring up to 883 MW of hydropower from Manitoba Power in Canada to Grand Rapids, Minnesota, and will deliver wind power generated in North Dakota to Manitoba Power in Canada. The project has the potential to provide enough reliable, affordable, and carbon-free electricity to serve approximately 600,000 residential customers in the Upper Midwest.
- **New England Clean Power Link**:[416] In December 2016, DOE announced the issuance of a Record of Decision and Presidential Permit for the New England Clean Power Link Transmission Line. The 154-mile underground and underwater direct current transmission line will bring up to 1,000 MW of hydropower from Quebec, Canada, to southern Vermont. The project has the potential to provide enough reliable, affordable, and carbon-free electricity to serve approximately 1 million residential customers in New England.

3.4.6.1 Data and Analytical Needs

In general, it is important to have authoritative, unbiased data in order to make informed Federal policy decisions, but this is also important to empower other public- and private-sector entities at all levels to identify cost savings, provide better services, effectively plan for the future, make research and scientific discoveries, etc. DOE has done well to provide relevant electricity data for many years, most notably via the Energy Information Administration. However, attempts to address a host of emerging issues and pursue key policy objectives in the electricity sector have uncovered data issues that are inhibiting such efforts by actors at all levels of government.

Ecological and other environmental impacts, specifically, can be reduced by improving availability, quality, harmonization, standardization, and accessibility of relevant data to inform decision making. Some data sets exist already, including Tethys,[417] a growing compendium of information and data exchanges on the environmental effects of wind and marine renewable energy technologies,[418] and the Wind-Wildlife Impacts Literature Database, a searchable document collection focusing on the impacts to wildlife from a variety of technologies.[419] However, relevant data, if available, can be plagued with quality issues, and there are often spatial and temporal disparities between related data sets that make analysis difficult.

There is a need for additional data and analytical tools on updated life-cycle analysis using consistent methodologies, as well as studies that attempt to monetize external costs[420] associated with land-use requirements and ecological impacts. More research and increased availability of data would improve the

transparency of environmental impacts to developers, regulators, and the public, and help inform more effective strategies for mitigating ecological impacts of electricity infrastructure and operations.

Including analysis of land and ecosystems in the R&D process could decrease the need for mitigation. New technologies with no adverse effects on ecosystems would unlock further areas where that technology could be deployed. As the United States and other countries accelerate clean energy innovation through Mission Innovation, including land-use and ecosystem impacts in Mission Innovation could provide a more holistic assessment of the environmental and ecological effects of new clean energy technologies.

3.4.6.2 Multiple Uses for Rights of Way: Repowering and Repurposing Degraded Lands or Brownfields

Electricity infrastructure can be sited at less environmentally sensitive locations, such as Superfund sites, brownfields, landfills, abandoned mining land, or existing transportation and transmission corridors. Through its cataloging of Federal and state tracked contaminated lands, landfills, and mine sites, EPA has identified thousands of potential sites that could potentially ameliorate incremental environmental impacts.[421] Comprehensive land-use planning exercises have also identified areas appropriate for development, such as the California Desert Renewable Energy Conservation Plan and the DOE-BLM Solar Programmatic Environmental Impact Statement. States and Federal agencies could assess the amount of land suitable for multiple simultaneous uses, including the installment of clean energy technologies. Zoning laws could allow multiple land uses as a factor in permitting decisions for clean energy technologies.

3.4.6.3 Programmatic Environmental Planning and Land-Scale Impact Assessments

The trend has been to consider mitigation through programmatic environmental impact statements (PEIS) and landscape scale impact assessment, replacing a more project-orientated focus. A November 2013 Presidential Memorandum outlined further mitigation principles for Federal agencies, including requiring agencies to set a “no net loss” or “net benefit” goal. Subsequent Department of the Interior guidance on landscape-scale mitigation supported examining project impacts by considering the range of the resource in the context of the larger landscape where the project would be built. Landscape-scale strategies consider impacts across ecosystems and administrative boundaries, and give a more comprehensive picture than studies focused narrowly on impacts on a project-by-project basis. This approach is being applied to a variety of major infrastructure development projects, including transmission and other electricity projects. The Fish and Wildlife Service uses landscape-scale analysis to protect the golden eagle, among other species, defining its “no net loss” policy to require every golden eagle killed at a wind plant to be offset by reducing eagle mortality from another source or by increasing eagle productivity.[422]

BLM also conducts PEIS for geothermal explorations or solar energy development in six southwestern states. PEIS evaluate environmental impacts of a variety of individual projects over a long time frame and a large geographic area.[423] Land-use and ecological impacts of energy technologies should be assessed on a larger scale, and the necessary cooperation across jurisdictions should be expanded, especially as impacts on wildlife could be felt far away from the original site of the deployed technology.

3.4.7 Electricity and Environmental Justice

Populations of concern—including low-income communities and some minority and tribal communities—are more vulnerable to the air- and water-quality impacts of the electricity system. These communities are also disproportionately vulnerable and less resilient to the impacts of climate change. These communities may have greater exposures due to their proximity to sources of pollution; may be inherently

more sensitive to environmental impacts of pollution due to higher baseline risks, such as poor overall health; and typically have lower capacity to adapt to the impacts of pollution and extreme weather.[424] For example, a greater percentage of minorities and people living below the poverty level live within a 3-mile radius of coal- and oil-fired power plants, compared to the U.S. population overall.[425] Additionally, existing health disparities and other inequities in these communities increase their vulnerability to the health effects of degraded air quality and climate change.[426]

Populations with the greatest sensitivity to the impacts of air pollution from power generation include children, the elderly, African Americans, and women.[427] Several factors make children more sensitive to air quality impacts, including lung development that continues through adolescence, the size of children's airways, their level of physical activity, and body weight. Ground-level ozone and PM are associated with increased asthma episodes and other adverse respiratory effects in children.[428] Minority adults and children bear a disproportionate burden associated with asthma, as measured by emergency hospital visits, lost work and school days, and overall poorer health status.[429]

Environmental justice concerns have been addressed in recent regulatory actions affecting power plant emissions, wastewater discharges, and onsite solid waste impoundment.[430, 431, 432] In many cases, these rulemakings have provided the opportunity to reduce existing disparities in health impacts. For example, the Mercury and Air Toxics Standard requires power plants to limit their emissions of toxic air pollutants like mercury, arsenic, and metals, which disproportionately impact certain communities. In addition, Executive Order 12898 requires Federal agencies to consider environmental justice in regulatory, permitting, and enforcement activities. Also, in developing the CPP, EPA took steps to ensure that vulnerable communities were not disproportionately impacted by the rule and that the rule's benefits, including climate benefits and air quality improvements, were distributed fairly.

The Federal Interagency Working Group on Environmental Justice's "Promising Practices for EJ Methodologies in NEPA Reviews"[433] contains successful ideas across nine areas, from which all Federal agencies can draw to develop their approaches to address environmental justice in the NEPA process:

- Meaningful engagement
- Scoping process
- Defining the affected environment
- Developing and selecting alternatives
- Identifying minority populations
- Identifying low-income populations
- Impacts
- Disproportionately high and adverse impacts
- Mitigation and monitoring.

3.4.8 Decommissioning of Generation Assets

Infrastructure expansion can improve environmental performance by replacing higher-polluting with lower-polluting technologies.[434] Because of their unique environmental concerns, nuclear power plants have strict, mandatory guidelines, payment processes, and monitoring for decommissioning activities, while in general, other generation assets do not. There are multiple ways to improve and expedite end-of-life-cycle processes while also improving environmental and societal outcomes.

Currently, the changing electricity sector is causing the closure of many coal and nuclear plants in a shift from recent trends. From 2000 through 2009, power plant retirements were dominated by natural gas steam turbines. Over the past 6 years (2010–2015), power plant retirements were dominated by coal plants (37 GW), which accounted for over 52 percent of recently retired power plant capacity.[435] Over the

next 5 years (between 2016 and 2020), 34.4 GW of summer capacity is planned to be retired, and 79 percent of this planned retirement capacity are coal and natural gas plants (49 percent and 30 percent, respectively). The next largest set of planned retirements are nuclear plants (15 percent).[436yy] A much smaller percentage of planned retirements are diesel combustion and oil steam turbines. These are less prominent in planned retirements, in part because they now represent a much smaller percentage of the Nation's electricity capacity than has historically been the case.

During decommissioning, all plants have waste streams that need to be managed. Coal and nuclear power plants produce the largest amount of solid waste during generation. For coal plants, the most expensive part of decommissioning in many cases will be environmental remediation of the CCR disposal sites.[437] Nuclear waste is stored at the reactor site where it is generated. The lack of a centralized permanent waste disposal facility for nuclear waste means that spent fuel storage facilities require continued management after a plant has been decommissioned. Decommissioning needs will continue to evolve as new generators, especially non-hydro renewables, reach the end of their operating lives in the next 20–30 years. These plants have some unique waste streams, including large volumes of glass and aluminum, large fiberglass blades, and in some cases, rare earth metals; however, there is a high potential for recycling some of these materials, and wind plants often have the opportunity for repowering by upgrading the turbine.

3.4.8.1 Coal

Increases in coal retirements imply a greater need for decommissioning these plants. The coal ash byproduct of conventional coal-fired power plants is the largest quantity of solid waste produced from the generation of electricity.[438] The composition and quantity of this solid waste depends on the type of coal burned, the power conversion technology used, and the addition of environmental controls. Decommissioning needs include (1) data on waste and decommissioning costs; (2) development of coal plant decommissioning procedures; and (3) identification of barriers to waste recycling and options for overcoming these barriers.

3.4.8.2 Nuclear Power

NRC operating licenses for approximately 60 percent of the existing nuclear-power generating units in the United States will expire by 2040. Without further license extensions, these expirations could result in retirements and decommissioning wastes in the coming decades.[439] Nuclear plant owners must provide NRC with detailed decommissioning plans and periodic updates on the status of their decommissioning fund for the nuclear reactors they own.[440] Three of the paramount considerations when developing a decommissioning plan are the radiological contamination, condition, and configuration of the plant. Two decommissioning methods have been used in United States: Safe Enclosure ("SAFSTOR") and Immediate Dismantling ("DECON").[441] In DECON, the plant is immediately dismantled, and the site is prepped for reuse by removing nuclear waste in casks for storage. In SAFSTOR decommissioning, plant dismantling is deferred for about 50 years. There is currently no centralized permanent disposal facility for commercial used nuclear fuel in the United States, so this radioactive material is stored at reactor sites in 35 states awaiting construction of a permanent handling facility.[442]

3.4.8.3 Oil and Gas

Unlike coal plants and nuclear reactors, gas- and oil-fired plants do not generate combustion ash or nuclear waste. The unique solid waste concerns for gas- and oil-fired plants are the byproducts from

yy These totals are based on announced retirements as of October 2016. Pending state action may prevent six nuclear reactors from retiring, and another reactor has since announced it will retire during this timeframe.

emission controls. However, the solid waste from electricity generation is small because of the low adoption rate of these emission controls for gas- and oil-fired plants. These solid wastes are similar to the waste generated by environmental controls placed on the stacks of coal plants, especially for most post-combustion removal technology.

There are three methods for decommissioning an oil or gas plant, considering the conditions of the plants and the total budget: cold closure, selective demolition, or total demolition.[443] The decommissioning of gas and oil power plants creates construction and demolition waste, general refuse, and chemical waste.[444]

Chemical waste that is particular to oil and gas plants includes naturally occurring radioactive materials (NORM). During the oil and gas combustion process, because NORM are not volatile, burning away the carbon leads to higher levels of radioactive waste in scale, sludge, and scrapings of the generator, tanks, and pipelines.[445] Radioactive material can also form a thin film on the interior surfaces of gas processing equipment and vessels. Currently, no Federal regulations exist that specifically address the handling and disposal of NORM wastes. However, several oil-producing states (Texas, Louisiana, New Mexico, North Dakota, and Mississippi) have enacted specific NORM regulations.[446]

3.4.8.4 Hydropower

There are two options for decommissioning a hydropower plant. A partial retirement involves retirement of only the hydroelectric facilities and retains portions of the dam and other structures. Some rehabilitation of the structure for safety or maintenance may be required and can include reduction in height or breach of the dam. In this case, the dam is either reduced or eliminated, while some of the ancillary facilities may remain intact. A full retirement includes the removal of the project and all appurtenant structures, including rehabilitation or restoration of the affected project area. Decommissioning (whether partial or full) generally requires completion of an environmental impact statement, and every dam removal process will have site-specific engineering, environmental, and community issues.

3.4.8.5 Wind

To date, there have not been many wind decommissioning projects. As a result, details of decommissioning wind projects are very limited. In some states, developers are required to have decommissioning process and cost estimates ready with the decommissioning plan. In general, the decommissioning process of a wind plant consists of removing the turbine, destroying the concrete pads, restoring the surface, and replanting and rebuilding the soil of disturbed land. Communication towers are taken apart, removed, and then either disposed of, recycled or reused.[447]

3.4.8.6 Solar PV

Like wind, there have not been many decommissioning projects for solar to date. During decommissioning, PV modules must be removed from racks, and the racks must be dismantled. These are stored temporarily onsite until they are transferred by trucks to appropriate facilities, like recycling sites, or back to the manufacturer. Similarly, inverters and associated components must be transported to an appropriate site per local, state, and Federal waste disposal regulations. Finally, re-vegetation of the site is done to minimize erosion and disruption of vegetation. In the case of one solar farm decommissioning, the recycling value of the raw material for the solar array is expected to exceed the removal costs and provide a net economic benefit.[448]

While there is no industry-wide requirement for solar and wind developers to develop and fund decommissioning plans, BLM does impose decommissioning requirements on Federal lands. BLM requires developers seeking to site renewable generation projects on Federal lands to file a decommissioning plan and post a performance bond to help fund site remediation. The performance bond is intended to cover costs associated with (1) removing hazardous materials, including "herbicide use, petroleum-based fluids, and dust control or soil stabilization materials"; (2) decommissioning, removing, and properly disposing of all "surface facilities," such as panels; and (3) "addressing reclamation, revegetation, restoration, and soil stabilization," such as regrading or vegetation, as required under the Clean Water Act.[449] Thus, solar and wind facilities sited on Federal lands must have a decommissioning plan before they are granted right of way and must post a bond to fund decommissioning.

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IV Ensuring Electricity System Reliability, Security, and Resilience

This chapter addresses a range of possible risks to the electricity system and the broader economy, and it suggests options to mitigate and prepare for these risks. The first section explores the changing nature of reliability—the ability of the system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components—in the future electricity system. The next section examines existing and growing vulnerabilities for the electricity system and opportunities to address these vulnerabilities, including cybersecurity risks, interdependency of electricity with other critical infrastructures, and increased risk due to worsening global climate change. The final section focuses on enhancing the resilience of the system to minimize disruptions of service and return rapidly to normal operations following adverse events.

Ensuring Reliability, Security, and Resilience: Summary of Key Findings

- The reliability of the electric system underpins virtually every sector of the modern U.S. economy. Reliability of the grid is a growing and essential component of national security. Standard definitions of reliability have focused on the frequency, duration, and extent of power outages. With the advent of more two-way flows of information and electricity—communication across the entire system from generation to end use, controllable loads, more variable generation, and new technologies such as storage and advanced meters—reliability needs are changing, and reliability definitions and metrics must evolve accordingly.
- The time scales of power balancing have shifted from daily to hourly, minute, or second-to-second to millisecond to millisecond at the distribution end of the supply chain, with the potential to impact system frequency and inertia and/or transmission congestion. The demands of the modern electricity system have required, and will increasingly require, innovation in technologies (e.g., inverters), markets (e.g., capacity markets), and system operations (e.g., balancing authorities).
- Electricity outages disproportionately stem from disruptions on the distribution system (over 90 percent of electric power interruptions), both in terms of the duration and frequency of outages, which is largely due to weather-related events. Damage to the transmission system, while infrequent, can result in more widespread major power outages that affect large numbers of customers with significant economic consequences.
- As transmission and distribution system design and operations become more data intensive, complex, and interconnected, the demand for visibility across the continuum of electricity delivery has expanded across temporal variations, price signals, new technology costs and performance characteristics, social-economic impacts, and others. However, deployment and dissemination of innovative visibility technologies face multiple barriers that can differ by the technology and the role each plays in the electricity delivery system.
- Data analysis is an important aspect of today's grid management, but the granularity, speed, and sophistication of operator analytics will need to increase, and distribution- and transmission-level planning will need to be integrated.
- The leading cause of power outages in the United States is extreme weather, including heat waves, blizzards, thunderstorms, and hurricanes. Events with severe consequences are becoming more frequent and intense due to climate change, and these events have been the principal contributors to an observed increase in the frequency and duration of power outages in the United States.
- Grid owners and operators are required to manage risks from a broad and growing range of threats. These threats can impact almost any part of the grid (e.g., physical attacks), but some vary by geographic location and time of year. Near-term and long-term risk management is increasingly critical to the ongoing reliability of the electricity system.
- The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities, juxtaposed against the slower-moving deployment of defense measures. Mitigation and response to cyber threats are hampered by inadequate information-sharing processes between government and industry, the lack of security-specific technological and workforce resources, and challenges associated with multi-jurisdictional threats and consequences. System planning must evolve to meet the need for rapid response to system disturbances.
- Other risk factors stem from the increasing interdependency of electric and natural gas systems, as natural gas-fired generation provides an increasing share of electricity. However, coordinated long-term planning across natural gas and electricity can be challenging because the two industries are organized and regulated differently.
- As distributed energy resources become more prevalent and sophisticated—from rooftop solar installations, to applications for managing building electricity usage—planners, system operators, and regulators must adapt to the need for an order of magnitude increase in the quantity and frequency of data to ensure the continuous balance of generation and load.

- Demand response and flexibility technologies – such as hydropower and storage – offer particularly flexible grid resources that are capable of improving system reliability, reducing the need for capital investments to meet peak demand, reducing electricity market prices, and improving the integration of variable renewable energy resources. These resources can be used for load reduction, load shaping, and consumption management to help grid operators mitigate the impact of variable and distributed generation on the transmission and distribution systems.
- Information and communications technologies are increasingly utilized throughout the electric system and behind the meter. These technologies offer advantages in terms of efficient and resilient grid operations, as well as opportunities for consumers to interact with the electricity system in new ways. They also expand the grid's vulnerability to cyber attacks by offering new vectors for intrusions and attacks—making cybersecurity a system-wide concern.
- There are no commonly used metrics for measuring grid resilience. Several resilience metrics and measures have been proposed; however, there has been no coordinated industry or government initiative to develop a consensus on or implement standardized resilience metrics.
- Low-income and minority communities are disproportionately impacted by disaster-related damage to critical infrastructure. These communities with fewer resources may not have the means to mitigate or adapt to natural disasters, and they disproportionately rely on public services, including community shelters, during disasters.
- This chapter was developed in conjunction with the closely related and recently published "Joint United States-Canada Electric Grid Security and Resilience Strategy."[1]

4.1 Reliability, Resilience, and Security: Grid Management and Transformation

Traditional electricity system operations are evolving in ways that could enable a more dynamic and integrated grid. The growing interconnectedness of the grid's energy, communications, and data flow creates enormous opportunities; at the same time, it creates the potential for a new set of risks and vulnerabilities. Also, the emerging threat environment—particularly with respect to cybersecurity and increases in the severity of extreme weather events—poses challenges for the reliability, security, and resilience of the electricity sector, as well as to its traditional governance and regulatory regimes.

The concepts of reliability, security, and resilience are interrelated and considered from different perspectives. Meeting consumer expectations of reliability is a fundamental delivery requirement for electric utilities, where reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent. The utility industry typically manages system reliability through redundancy and risk-management strategies to prevent disruptions from reasonably expected hazards.

Grid Reliability, Security, and Resilience

For purposes of this discussion, *reliability* is the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components. *Resilience* is the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions. *Security* refers specifically to the ability of a system or its components to withstand attacks (including physical and cyber incidents) on its integrity and operations.

Delivery of electricity service has been consistently and highly reliable for most of the century-long development, expansion, and continuous operation of grids across all regions of the Nation. The traditional definition of reliability—based on the frequency, duration, and extent of power outages—may be insufficient to ensure system integrity and available electric power in the face of climate change, natural hazards, physical attacks, cyber threats, and other intentional or accidental damage; the security of the system, particularly cybersecurity, is a growing concern.

Resilience is the ability to prepare for and adapt to changing conditions, as well as the ability to withstand and recover rapidly from disruptions, whether deliberate, accidental, or naturally occurring.[2] While resilience is related to aspects of both reliability and security, it incorporates a dynamic response capability to reduce the magnitude and duration of energy service disruptions under stressful conditions.[3] Infrastructure planning and investment strategies that account for resilience typically broaden the range of risk-reduction options and improve national flexibility through activities both pre- and post-disruption, while also focusing on the electricity-delivery outcomes for the consumer.

U.S. policies, markets, and institutional arrangements must evolve to reflect new electricity system realities and trends—continuing to enable and enhance the reliability, security, and resilience of the electric grid. The Department of Energy (DOE), the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), regional planning authorities, utilities, power system operators, states, and other organizations work together to ensure the reliability of the U.S. power system through the implementation of reliability standards, timely planning and investment, and effective system operations and coordination.

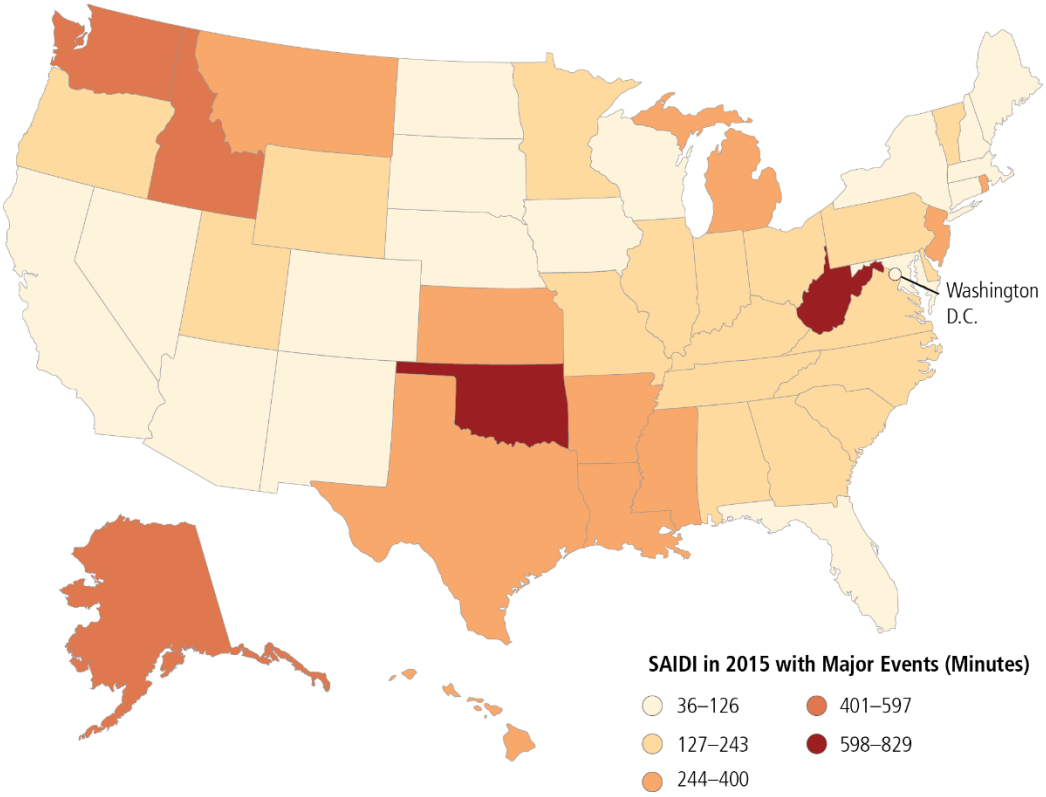
4.2 The Changing Nature of Reliability

Electricity customers have high expectations of electricity reliability from their utility providers. Virtually every sector of the modern U.S. economy depends on electricity—from food production, to banking, to health care. Critical infrastructures like oil, gas, transportation, and water all depend on electricity, and the electric system depends on them. This places a high premium on reliability.

4.2.1 Standard Measures of Reliability

A brief review of how reliability is measured today will help define the playing field and the associated value at stake. From the utility industry perspective, reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent. Reliability within the utility industry is managed to ensure the system operates within limits and avoids instabilities or the growth of disturbances. These practices are not static, and utilities continue to improve their reliability practices and implementation methods to reflect increased consumer expectations. Typical approaches to reliability include hardening, investment, and redundancy to prevent disruptions from reasonably expected hazards.

Figure 4-1. System Average Interruption Duration Index (SAIDI) in 2015 by State[4]



States experienced varying levels of reliability in 2015. A reliable bulk power system does not necessarily mean reliable end-user electricity service because outages often originate on local distribution systems, as reflected in the SAIDI measurements in the above map.

Most state and Federal regulators have significant experience addressing system reliability and currently consider the issues of resilience and security through the lens of existing reliability tools, approaches, and metrics. One metric applied with the goal of improving system performance with respect to reliability indicators is the System Average Interruption Duration Index (SAIDI). SAIDI measures the total duration of an interruption for the average customer given a defined time period. Typically, it is calculated on a monthly or yearly basis. Another metric, the Customer Average Interruption Duration Index (CAIDI), measures how long it takes to restore the system once an outage occurs. And, the System Average Interruption Frequency Index (SAIFI) measures the average number of times that a customer experiences an outage during the year. SAIFI is calculated by dividing SAIDI by CAIDI. As most outages occur on the distribution system rather than the bulk system, these reliability indices are commonly used to measure distribution level reliability. NERC uses a number of bulk power system reliability indices.[5]

Based on these reliability measures, the average customer experiences 198 minutes of electric power unavailability per year,[a, 6] although there is significant variability among states and utility providers. The best-performing state had a SAIDI level of 85 minutes a year. In contrast, as shown in Figure 4-1, one state had a SAIDI statistic in 2015 of nearly 14 hours of outage for the year, with an availability level of 99.84 percent. Even this state level of aggregation masks some outliers in the data. There were several utilities with a SAIDI index below 1 minute of outage for the year.

[a] Analysis is based on 2016 Energy Information Administration (EIA) data. Information reported to EIA is estimated to cover approximately 90 percent of electricity customers.

There are, however, caveats to these findings. First, the variability of reliability performance is a function of a myriad of factors, including regional differences, varying regulatory standards, costs, system configuration, customer density, hazard exposure, and other. Also, utilities have historically reported SAIDI, SAIFI, and CAIDI statistics in inconsistent ways; for example, some utilities include data associated with "major events" in their public reporting to public utilities commissions, while others do not.[7] Utilities also take inconsistent approaches to defining "major events."[8] The lack of uniform national data inhibits more sophisticated analysis of macro trends in distribution reliability—something that is important to remedy in an electricity sector that is increasingly data intensive.

Also, although the predecessor to today's NERC was first formed in 1968 to address system reliability, the Institute of Electrical and Electronics Engineers (IEEE) Standard 1366 only formally defined industry reliability metrics in 1998.[9] The Energy Information Administration (EIA) began collecting distribution-level reliability data, including SAIDI and SAIFI information, in 2013—marking increased attention and effort on the reliability front. Yet, even today, only 33% of utilities report these statistics, covering 91% of the electricity sales in the nation, which indicates that there is room for improving reliability reporting practices.[10]

There are other reliability measures and associated government reporting requirements as well. NERC, for example, collects the additional data it needs to promulgate reliability and security standards, but it does not make all of these data available to government agencies. Beyond reliability, a number of resilience metrics and measures have been proposed; however, there has not been a coordinated industry or government initiative to develop consensus or implement standardized resilience metrics, though the Grid Modernization Laboratory Consortium is launching the Foundational Metrics Analysis project to develop some resilience metrics.[11]

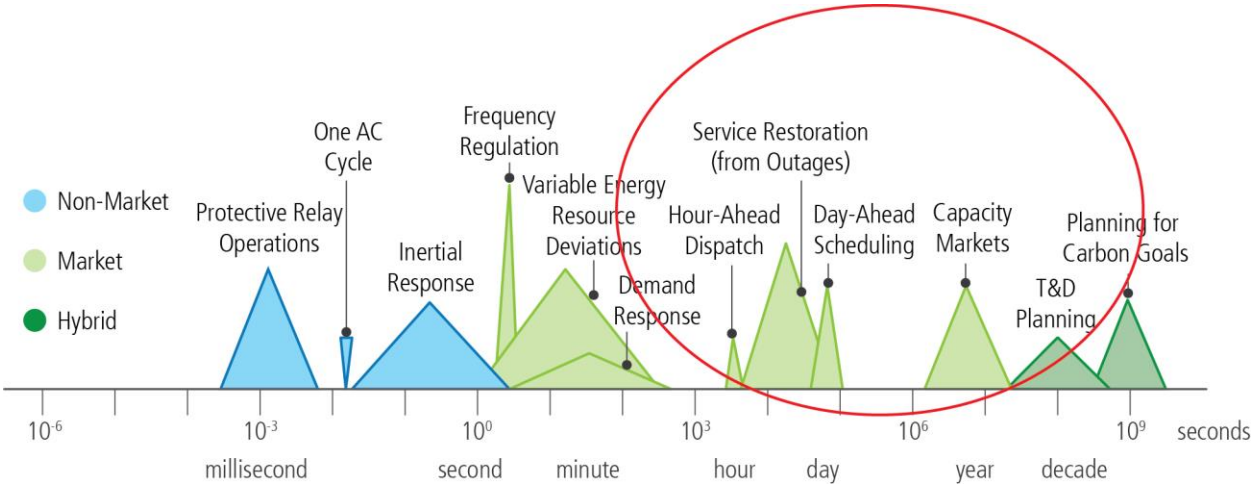
4.2.2 Time Scales and Grid Reliability

Throughout the 20th century, the design of power systems and early metrics (such as the loss of load expectation) focused on periods of maximum consumer electricity use. With more controllable loads, more variable generation, new technologies (such as storage), and the increasing importance of power system reliability, reliability is becoming a more complex concept, and reliability metrics and criteria must evolve accordingly.

Adequacy of generation resources is measured by a utility's reserve margin and has traditionally meant the extent to which utilities have adequate infrastructure to generate electricity to meet customers' needs. Generation reliability criteria is focused on installed generation to meet customer demand; the role of the customer as a system resource was not a consideration.

For vertically integrated systems, grid operators manage the entire electricity supply chain from end (generation) to end (delivery service). When new market structures were created across many U.S. regions in the form of independent system operators (ISOs) or regional transmission organizations (RTOs), end-to-end management was replaced with competing power generators. In these markets, variable generation may be the lowest cost generation; , generation from certain power stations may not be accepted to run because they are not cost competitive for a specific day's operations. However, if a generator is deemed critical to system integrity, power stations can get "reliability must run" payments. These out-of-market payments, in turn, lower power market prices, which has been especially problematic for certain types of generation such as nuclear, which already faces challenges from low power prices due to the relatively low capital, operations, and fuel costs of natural gas-fired generators.

Figure 4-2. System Reliability Depends on Managing Multiple Event Speeds[12]



Markets are used for traditional grid operations, including hour-ahead, day-ahead, and capacity markets. Long-term planning reaches byond typical market and financial signals.

Supply variability[b] is an important part of system operations, where ISOs/RTOs must ensure that risks of unexpected loss or variability of supplies are hedged by having some power plants immediately available (spinning reserves) and other plants able to supply power with short-term notifications of need (non-spinning reserves).

These adjustments to power flow management occur within the general framework of grid operations. This framework has historically been well understood by grid operators because the time dimensions of operations have not changed significantly, even when ISOs/RTOs were given responsibility for transmission system management. These dimensions, which operators have historically understood well, are seen in

[b] As used here, variability refers to the difference between the expected and actual load or generation.

Figure 4-2 on the right side of the continuum, where the time scales of capacity markets, day-ahead, and hour-ahead products are depicted. For out-years beyond capacity contracts, traditional transmission and distribution system planning methods work to map and price investment requirements to ensure long-term grid reliability. Planning for decarbonization and climate resilience reaches beyond typical planning horizons for grid operators.

4.2.2.1 Changing Time Dimensions, Grid Topology, and Emerging Grid Management Challenges

Variable energy resources (VERs) provide a range of benefits to utilities and their customers, including avoided fuel costs, greenhouse gas emissions, and costs associated with environmental compliance.[13, 14] In some cases, distributed VERs are also credited with providing electric reliability and resilience benefits, particularly in the context of microgrids.[15]

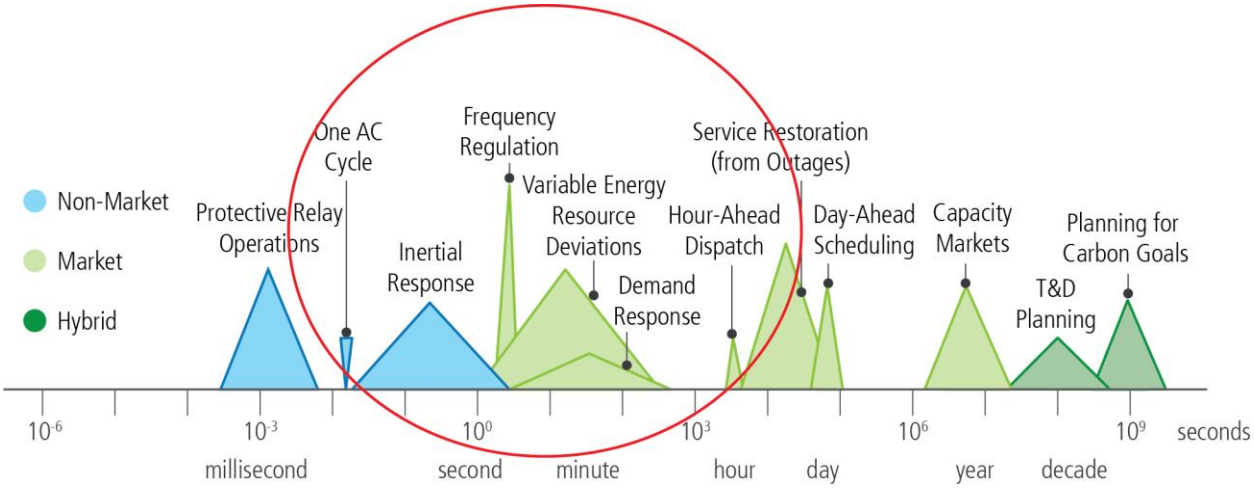
However, the widespread integration of VERs at both utility scale and distributed across all consumer segments significantly expands the time dimensions in which grid operators must function, and it complicates operations. It underscores the need "to coordinate time and space within the electric grid at greater resolution or with a higher degree of refinement than in the past."[16] A recent White House report noted, "The distinctive characteristics of [VERs] will likely require a reimagining of electricity grid management."[17]

Impacts on transmission and distribution systems and integration options vary by scale. For instance, utility-scale solar power flowing onto high-voltage transmission lines can be smoothed and firmed up at the point of production by using smart inverters and storage. When onshore wind plants are integrated at a large geographic scale, lower correlation factors can smooth out variability. Assuming these aggregations are visible to grid operators to adequately assess both their costs and benefits, many aggregated distributed solar installations can smooth out the random variations from individual installations.

The time dimensions in which grid operators must function to accommodate the unique characteristics of VERs and distributed energy resources (DERs) are identified in the hourly, to minute, to second intervals (see

Figure 4-3). While grid operations are successfully managed today in some markets with relatively high levels of VER penetration,[18] this can complicate grid management. Consider a generic example of utility-scale generation portfolio management in a high VER supply system. Power supplied from solar stations has two types of variability to manage: minute-to-minute fluctuations and the dramatic drop in power supplied from solar as the sun goes down. This drop can be precipitous and occur within an hour or less.

Figure 4-3. System Reliability Depends on Managing Multiple Event Speeds[19]



Markets are used for grid operations on the order of seconds to minutes, such as frequency regulation and demand response. Some essential reliability capabilities, such as inertial response, occur faster than typical market signals.

Grid dispatch (actions that operators take to engage power suppliers to provide power to the grid) occurs around load changes, traditionally referred to as load-following activities. In grids with wholesale markets, economic dispatch occurs based on which generators win daily auctions and produce power for the grid. ISOs/RTOs also load follow for grid management, and in regions with high VER production, load following and load shaping may provide linked challenges.

By calling or not calling on generators to produce electricity, grid dispatch determines the value that power producers obtain from their assets. Grid dispatch ensures system reliability through management of operating generators, as well as those waiting to be called if needed. In a world of sub-second decision making, dispatch effectiveness will require the integration of automated grid management, with continuing human oversight. The pace of change may dictate faster adaptation times for grid operators, but grid reliability may dictate a more methodical consideration of operating protocol changes, which are driven by changes in the types, scale, scope, and location of power supplies. Continuous engagement of grid dispatchers in planning for the 21st-century grid is essential.

VER fluctuations on the bulk power side of the equation can be mitigated by regulating power flows onto the grid—both up and down and from minute to minute. Mitigating power flows can occur with resources and services such as regulation that respond in one to several seconds; through process-flow techniques involving ramping up and throttling down generation plants; via transmission system blending with flexible resources such as hydro; and through demand response (DR) (including advanced water infrastructure),[20] which can be used to align demand with supply variations for grid services, including frequency regulation.

Variability is managed through geographic diversity and aggregation. FERC (through NERC) requires balancing authorities to constantly match supply and demand within their respective balancing areas.[c, 21] Larger balancing areas could help manage variability by sharing generation resources to smooth out

[c] A balancing authority "integrates resource plans ahead of time, maintains Demand and resource balance within a Balancing Authority Area, and supports Interconnection frequency in real time." The Balancing Authority Area (shortened here to Balancing Area) is the "collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority." From North American Energy Regulatory Commission (NERC), "Glossary of Terms Used in NERC Reliability Standards," NERC, last updated November 28, 2016, http://www.nerc.com/files/glossary_of_terms.pdf.

supply. A recent National Renewable Energy Laboratory analysis concluded that, "consolidated operations of two or more balancing authorities fully captures the benefits of geographic diversity and provides more accurate response."[22] For example, the integration of PacifiCorp into the California ISO Energy Imbalance Market reduced the amount of required flexibility reserves by about 280 megawatts (MW), or 36 percent.[23]

While there is ramping associated with all generation technologies, because of their variability, baseload generators must ramp more frequently to accommodate VERs. Ramping to match supply and demand can reduce the efficiency of baseload generators, possibly decrease their ability to recover capital costs, and increase fossil unit emission rates. Innovation to improve baseload generators' ramping capability is an important need that will become more important at high levels of VERs. Recent analysis suggests that "…High renewable energy penetrations could significantly change dispatch requirements and use of conventional generators."[24] Also, price suppression is occurring in RTO/ISO wholesale markets, with noticeable amounts of wind and solar generation (and low-cost gas generation). While passing on savings to consumers is desirable, in some regions, these low prices have put pressure on baseload units, particularly zero-carbon emissions nuclear generation.

Better forecasting has also reduced VER integration costs. Most North American power markets dispatch wind plants along with conventional power plants based on current grid conditions and economics.[25] Setting wind generator schedules as close as possible to the dispatch time minimizes forecast errors, and using wind forecasting can greatly facilitate wind integration and reduce costs from carrying reserve capacity.[26]

Another complication, as noted earlier, is that system operators dispatch the least-cost mix of generation needed to meet load, and the least-cost sources are often VER sources, which are fueled by the sun or the wind and therefore have low or zero marginal cost of production. In New England, as additional variable resources have come online, there has been "more frequent localized [transmission] congestion."[27] In the past, congestion was reduced by the system operator "through manual curtailment instructions that [were] not reflected in Real-Time Prices," causing a "mismatch" of signals, when generators who would normally respond to high prices by increasing output were instead told to decrease output in order to maintain reliability.[28] The system operator has undertaken several steps to address these challenges, and in April 2016, wind and hydro resources were designated as automated dispatch.[29] Going forward, the system operator will require a series of actions to further integrate VER sources.[30] Specifically, on October 12, 2016, ISO New England filed proposed revisions to its Transmission, Markets, and Services Tariff with FERC, which in part were made to "more directly incorporate non-dispatchable, intermittent power resources into [market pricing]", and on December 12, 2016, FERC issued an order accepting the proposal.[31] [32]

Another example of the changes to grid management made in response to increasing penetrations of VERs is seen in the California market. Under existing operations, the California ISO found that "the fleet of resources committed…to provide energy often does not provide sufficient flexible ramping capability…to meet the actual changes in net load."[33] As a result, the operator must "dispatch units out of economic sequence, or dispatch units that are not in the market," imposing "additional costs on the system" and creating "prices [that] do not reflect such marginal costs."[34] In California, the ISO addressed this issue by amending its tariff to "enhance the CAISO ability to manage the ramping capacity necessary to meet changes in net load—both forecasted and unexpected."[35]

Real-time wind penetration in the Southwest Power Pool (SPP) has, at times, approached 40% of generation.[36] Between March 2016 and May 2016, wind accounted for 21.5% of all energy generated in SPP.[37] In examining scenarios with significantly more VER, SPP found that new procedures "would enable the SPP transmission system to reliably handle up to…60% wind penetration" [38] while lowering overall

costs and reducing price volatility. [39] These new procedures include increasing the dispatchability of renewable resources, additional transmission capacity, enhancements to ancillary services, and new tools to manage inter-hour ramps.[40]

In the Pacific Northwest, an increase in wind generation has meant that the operator must "dispatch units out of economic sequence, or dispatch units that are not in the market," imposing "additional costs on the system" and creating "prices [that] do not reflect such marginal costs."[41] Additionally, an increase in wind generation has meant that "utilities must hold more resources in reserve to help balance demand minute-to-minute," increasing "the need for system flexibility."[42] The Northwest Power and Conservation Council anticipates, however, "that the region will have sufficient generation and demand side capability on its existing system to meet balancing and flexibility reserve requirements over the next six years if [the region's] energy efficiency and demand response development goals are achieved."[43]

Hydropower provides a variety of essential reliability services that are beneficial to the electricity system. One example is regulation and frequency response (including inertia), in which hydropower generators can quickly respond to sudden changes in system frequency, making hydro a very suitable complement to wind generation. Other essential reliability services include spinning and supplemental reserves enabled by high ramping capability, reactive power and voltage support, and black start capability.

Despite the technical ability of hydropower to provide essential reliability services, these services provided by hydropower are not always explicitly compensated by existing market structures. For example, hydropower is one of the main providers of inertia and primary frequency response in the Western Electricity Coordinating Council, but it is not explicitly compensated for either service.[44] Some recent market advances have been made that allow greater ancillary service participation. For example, FERC now requires ISOs to better compensate generators for frequency regulation services based on their response speed and flexibility to respond to a range of situations.[45] In addition, in June 2016, FERC issued Order No. 825, requiring all regional transmission organizations (RTOs) and ISOs to implement sub-hourly settlements, allowing more accurate alignment of the services provided with the prices paid for them. Market rules governing participation of flexible resources, such as hydropower and pumped storage, could be reviewed to determine if additional changes could allow these resources to participate more effectively and ensure just and reasonable compensation.

Part of the challenge facing hydropower lies in the difficulty of optimizing the limited generating ability of hydro resources due to non-market environmental and competing use constraints. Determining the best use of hydro resources through manual dispatch or market-based bidding process can be difficult because the value of essential reliability services can change quickly due to a number of factors, including location, day, time, regulatory constraints, and interaction with other generators. Moreover, in the long term, the best use of hydro resources may evolve as the generation mix changes.[46] Essential reliability services are, however, undervalued in some existing market structures.

On the consumer side of the utility meter, consistent growth in DERs (of which distributed VERs are a subset) has also changed how grid operators sustain high system reliability at both the distribution and transmission levels of electricity delivery. DERs represent a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid, and they include distributed generation (DG) and storage technologies, as well as DR.[47] Consumers with rooftop solar may influence their demand frequently and in diverse ways. This can impact total load (tending to reduce it) but may not be directly controlled by grid operators. Other DERs, such as truly dispatchable DR, can be directly managed and called by grid operators when needed.

Deployment of distributed VERs places additional design and operational requirements on distribution grid operators. Currently, distribution systems are predominantly radial networks (feeders) delivering

grid-supplied power to customer premises. With significant penetration of distributed generation, some distribution utilities are facing new demands to interconnect multiple feeders together to accept customer-generated power and to be able to balance generation and demand. The new structure and roles of distribution systems will require development of advanced distribution circuits and substations to enable significant two-way power flows, new protection schemes,[d] and new control paradigms.

Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii

Hawaii leads the United States in the portion of its electricity that is produced from variable renewable sources, and as an island state, it cannot rely on neighbors to help balance generation and load. Hence, the Hawaiian Electric Companies are currently experiencing the bulk system frequency stability impacts that mainland U.S. power systems will experience in the coming years and decades.[48] The Grid Modernization Laboratory Consortium will develop, simulate, validate, and deploy practical solutions that enable distributed energy resources (DERs) to help mitigate bulk system frequency contingency events on the fastest time scale (milliseconds to seconds).[49] The project will examine the ability to leverage the fast response capability of power electronics to enable photovoltaic inverters and storage inverters to support grid frequency starting a few fractions of a second after the appearance of a frequency event. The capabilities of currently available products to provide rapid frequency response will be characterized, and new capabilities will be developed with a goal of maximizing DERs' ability to support grid frequency stability.

California's recent experience with its requirements for 20,000 MW of small renewable generation (under 20 MW) by 2020 is instructive for both valuation and grid management. To make these volumes both visible to the ISO and valuable to consumers, aggregators, and grid operators, market designers at the California ISO allowed bids of at least 0.5 MW into day-ahead, energy and ancillary markets. Similar efforts are underway in Texas and New York.[50]

The electricity system is also experiencing an increasing array of "sub-second" events that require response times that are far too short for humans to react. One of the driving forces making smart grids necessary is the proliferation of smart devices; each one is capable of microscopic frequency disruptions, which cumulatively present an unprecedented new challenge for system operators. Many consumer electronic devices (such as mobile phones, Wi-Fi-based home automation solutions, and smart entertainment devices) represent "endpoints" that can impact system operations. In addition, Internet of things (IoT) devices function at microsecond "clock speeds." In the aggregate, these devices represent a new source of variability at speeds far faster than what grids have traditionally managed. The solution must take the form of protective relays and synchrophasors operating more-or-less autonomously in real time. The upside implications going forward include the need for integrating machine learning into grid operations (i.e., as positive solutions for mitigating unprecedented grid disruptive forces); on the downside, digitizing grid operations deep into sub-second operations raises new cyber vulnerabilities.

The kinds of anomalies affecting wholesale markets and grid operators noted above suggest the need for frequent adjustments to market designs to accommodate new technologies, changing consumer preferences, and security needs. The Nation's ISOs/RTOs, FERC, and NERC are continuously engaged in analysis, evaluation, and design modification processes—working to ensure that the present scoping and pace of regulatory change is aligned with the scale and speed of change occurring as a result of continued VER deployment. In September 2016, FERC approved new requirements for the quality of real-time monitoring and analysis capabilities for system operators,[51] and NERC has made a number of improvements that have significantly reduced the time it takes to develop a standard. This is an ongoing process: both state and Federal regulators face complicated and evolving challenges that grid operators

[d] Protection schemes identify coordinated corrective actions to detect and address abnormal system conditions (e.g., faults).

must address in a timely fashion while simultaneously operating under existing performance standards and system requirements.

4.2.2.2 Grid Operation Impacts of the Internet of Things

Grid control systems now handle, sense, and control endpoints numbered in the thousands. Widespread DER/DR penetration implies that future grid control systems may have to coordinate millions of end point control devices to support grid functions. These devices vary in type, from digital sensors and smart boards built into transformers, to mobile devices used by field operators and grid control managers.

Current grid control systems are not structured for large-scale optimization of millions of devices and they are not equipped to handle increasingly large volumes and types of data. End-users (consumers, as well as aggregators controlling multiple demand profiles) may wish to perform optimal local controls to meet their desired requirements that may be in conflict with optimal *system-wide* control.

Grid control systems must evolve from being centralized to a hybrid of central and distributed control platforms. The need for flexible grid operations is challenging basic assumptions about grid control, which will require changes in standards and operating protocols. Bulk power systems operations are the purview of both FERC and NERC, but grid security and reliability assurance concerns mean that Federal authorities must be included in designing 21st-century grid control systems.

Overview of DHS Strategic Principles for Security of the Internet of Things (IoT)

The Department of Homeland Security (DHS) developed strategic principles, published on November 15, 2016,[52] to mitigate vulnerabilities introduced by the IoT through recognized security best practices. These principles are intended to offer guidance to stakeholders as they seek to manage IoT security challenges.

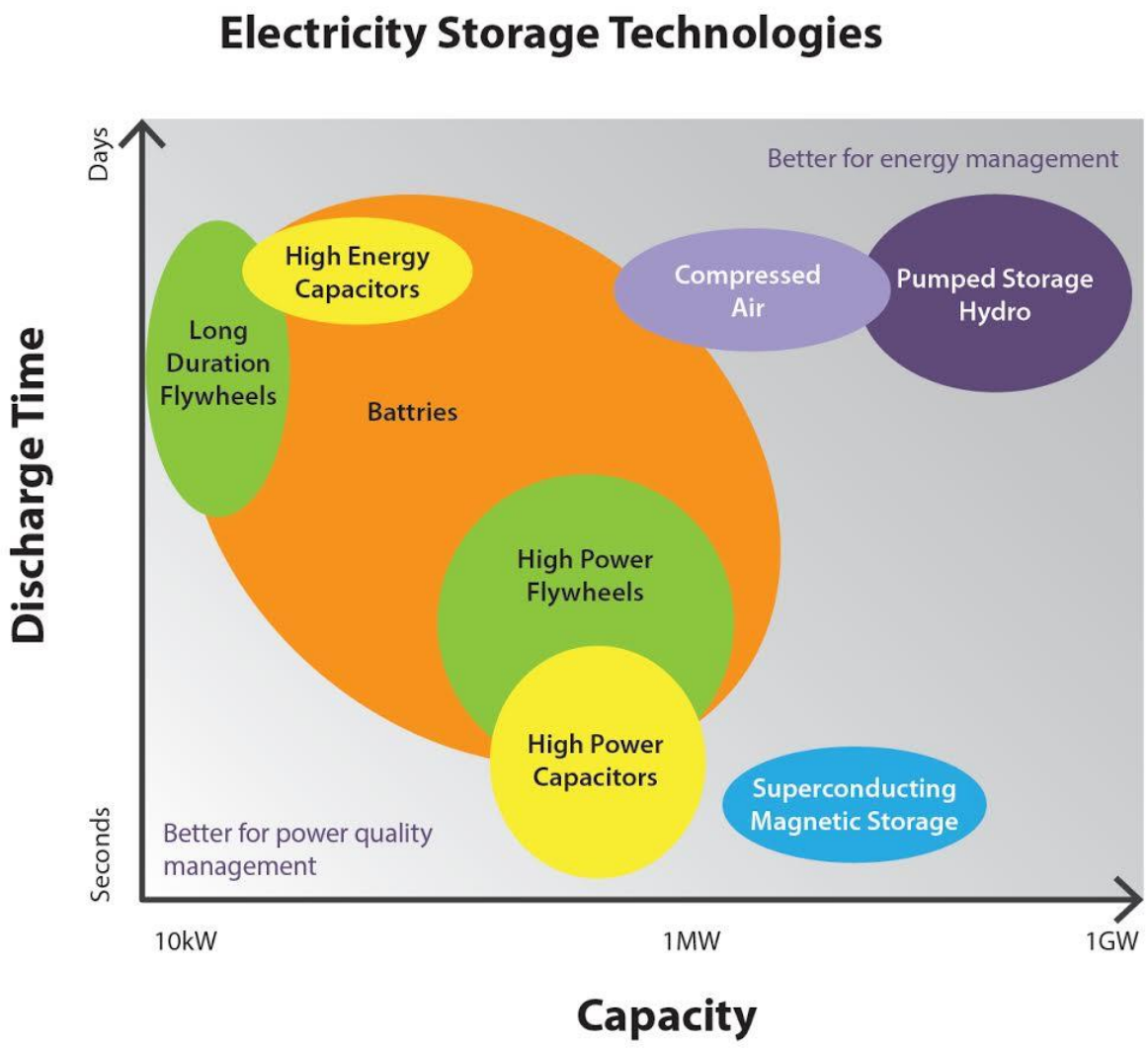
Strategic Principles for Securing IoT:

1. Incorporate security at the design phase—building in security at the design phase reduces potential disruptions and avoids the much more difficult and expensive endeavor of attempting to add security to products after they have been developed and deployed.
2. Advance security updates and vulnerability management—vulnerabilities may be discovered in products after they have been deployed. These flaws can be mitigated through patching, security updates, and vulnerability management strategies.
3. Build on proven security practices—many tested practices used in traditional information technology and network security can be applied to the IoT, helping to identify vulnerabilities, detect irregularities, respond to potential incidents, and recover from damage or disruption to IoT devices.
4. Prioritize security measures according to potential impact—risk models differ substantially across the IoT ecosystem, and the consequences of a security failure across different customers will also vary significantly. Focusing on the potential consequences of disruption, breach, or malicious activity across the consumer spectrum is therefore critical in determining where particular security efforts should be directed and who is best able to mitigate significant consequences.
5. Promote transparency across the IoT—increased awareness could help manufacturers and industrial consumers identify where and how to apply security measures, build in redundancies, and be better equipped to appropriately mitigate threats and vulnerabilities as expeditiously as possible.
6. Connect carefully and deliberately—IoT consumers can also help contain the potential threats posed by network connectivity, connecting carefully and deliberately, and by weighing the risks of a potential breach or failure of an IoT device against the costs of limiting connectivity to the Internet.

4.2.2.3 Utility-Scale and Distributed Storage

Electricity remains unique among commodities in its limited capability available for storage. There are few viable ways to store electrical energy (e.g., batteries, or pumped storage solutions), and there are other more exotic possibilities like superconducting magnet rings. Inventory options tend to narrow the amount and duration of ready access electricity. The graphic depiction in Figure 4-4 summarizes the power and duration capabilities of various storage technologies.

Figure 4-4. The Storage Technology Development Map[53]



Most electricity storage is water that fuels turbines that produce electricity. Currently, the largest storage capacity is pumped hydro. Electrochemical batteries have been the fastest growing new storage technology. Batteries in the form of fuel cells can be used for continuous power production and the scaling capabilities of fuel cells make them attractive for fitting load shapes to specifically sized power supplies. Other technologies for energy storage include compressed air, flywheels, and capacitors.

Utility-scale battery storage and distributed battery storage vary by scale and duration, but perform consistently at any scale from a grid management perspective. When distributed storage is aggregated, it can offer to local grid operators greater flexibility for managing system reliability and power quality than utility-scale resources. Aggregation can be scaled to fit specific local needs in distribution systems

An example of grid reliability applications of energy storage is seen in California, where the building of about 60 MW in new battery storage capacity is underway.[e, 54, 55, 56] These installations are being built to

[e] Upon commissioning, the 20 MW/80 MW-hour SCE Mira Loma project will be the largest battery in operation. The 37.5 MW/120 MW-hour San Diego Gas & Electric Escondido project will then overtake Mira Loma as the largest battery when it is

resolve reliability issues caused by the Aliso Canyon leak[57] (for more information on Aliso Canyon, see "Underground Storage Leak in California Driving Natural Gas Storage Safety and Reliability Improvements" text box in section 4.3.3) and the San Onofre Nuclear Generating Station outage,[58] and they will help level out electricity supply in California by moving energy from the afternoon production of solar to the evening peak.[59] While region-specific critical reliability requirements can drive storage deployment, additional incentives can help accelerate these benefits ahead of a major disruption.

Public investment and policy have been key to electricity storage technology development; the American Recovery and Reinvestment Act is the most commonly identified funding source for storage projects.[60] By 2015, through a combination of regulatory reforms, innovation, and cost reductions, lithium-ion batteries emerged as a dominant battery design for frequency regulation and renewables integration; lithium-ion batteries made up 95% of deployed capacity in 2015, with 80% of this capacity located in the PJM Interconnection territory, attracted by its pay-for-performance frequency regulation market.

The evolution of storage technology is likely to take the electricity sector into new realms. "Hybridizing" storage solutions with solar and wind power sources may redefine what is meant by "power plant," and alter how the grid is understood and used. If hybrids can "self-power" even a portion of a significant load, then tomorrow's future electricity sector will be able to achieve national objectives for clean, secure, and affordable electricity supplies in a system that is imminently flexible and considerably resilient.

4.2.2.4 Demand Response Can Aid Grid Management

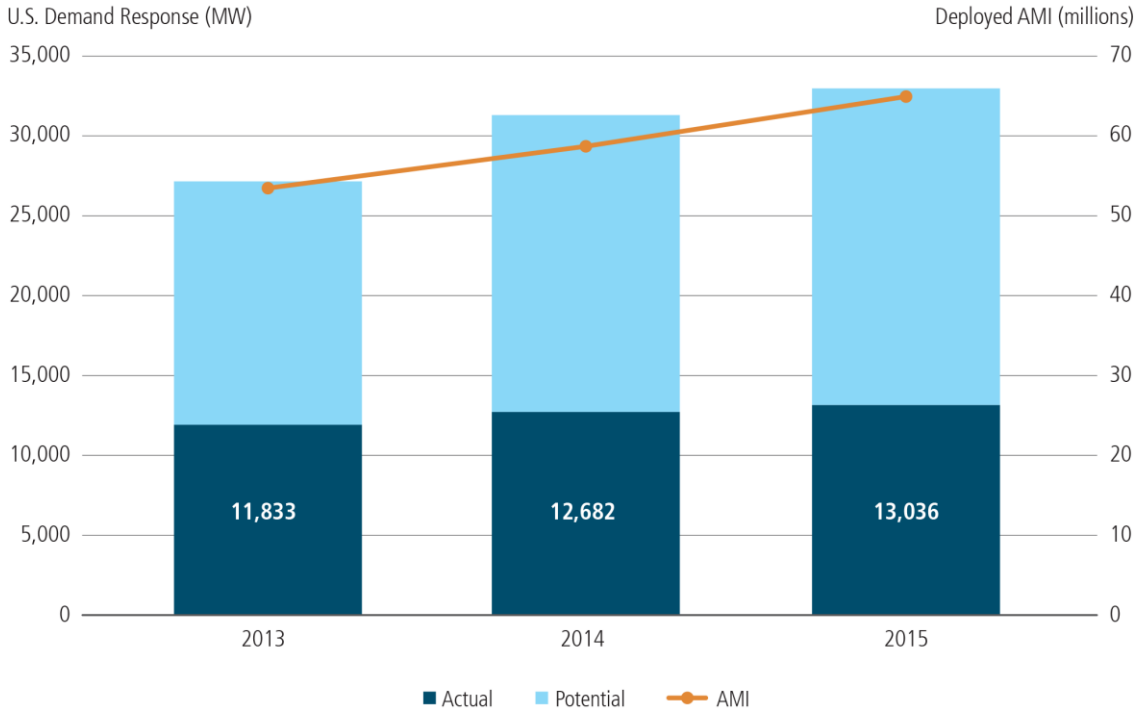
DR empowers consumers to change their normal electricity consumption patterns; it is a particularly flexible grid resource, capable of improving system reliability, reducing the need for capital investments to meet peak demand, as well as electricity market prices. DR can also be used for load reduction and load shaping, as well as to help grids mitigate generation variability, including from VERs. A variety of DR programs exist, some of which are offered directly by utilities, while other programs are offered by the grid system operators, retail competitors, and aggregators. DR challenges the view that a utility's generation adequacy, measured by its reserve margin, is "steel in the ground". DR can offset "installed capacity" and currently provides nearly 30 gigawatts (GW) of peak reduction capability nationwide;[61] this accounted for 3.9 percent of U.S. peak demand in 2016[62] and exceeded 10 percent in some regions.[f, 63, 64] Future DR growth—FERC scenarios show 82 GW to 188 GW in possible DR capacity by 2019[65]—along with other DER could significantly shift customer demand from peak to off-peak periods.

A key driver of today's DR programs has been the growth of advanced metering infrastructure (AMI), now deployed for nearly 65 million customers in the United States (see Figure 4-5).[66] AMIs typically include two-way communications networks that utilities can leverage to improve electric system operations, enable new technological platforms and devices, and facilitate consumer engagement. More than half of deployed AMIs are in five states, with California, Florida, and Texas accounting for over 40 percent of the total.[67] AMI investments have been largely driven by state legislative and regulatory requirements and ARRA funding.[68]

commissioned. In addition to their titles as largest yet in operation, both projects were built quickly: about six months from contract award to commissioning. These projects show how new technologies, many of which benefitted from early publicly supported demonstrations, can provide rapid solutions for reliability, resilience, and security.

[f] For example, in PJM Interconnection, demand resources account for over 10 GW out of the 167 GW from all capacity resources in the 2019/2020 delivery year. See references for more information.

Figure 4-5. Advanced Metering Infrastructure Growth Has Contributed to Expanded Role of DR Programs[69]



A key driver of today's demand response programs has been the growth of advanced metering infrastructure (in orange). In 2015, approximately 65 million customers in the United States had advanced metering infrastructure installations.

State Regulatory Actions That Have Impacted DR[70]

- The California Public Utilities Commission will require default time-of-use (TOU) rates for residential customers in 2019, and it is working with California Independent System Operator and the California Energy Commission to create a market for demand response (DR) and energy efficiency resources.[71]
- In 2014, Massachusetts ordered its electricity distribution companies to file TOU rates with critical peak pricing as the default rate design for residential customers once utility grid modernization investments are in place.[72]
- In 2015, the Michigan Public Service Commission directed DTE Electric to make TOU and dynamic peak pricing available on an opt-in basis to all customers with advanced metering infrastructure by January 1, 2016. Similarly, Consumers Energy must make TOU available on an opt-in basis by January 1, 2017.
- Also in 2015, the New York Public Service Commission released a regulatory framework and implementation plan (Reforming the Energy Vision) to align electric utility practices and the state's regulatory framework with technologies in information management, power generation, and distribution. A related measure in 2014 approved a $200 million Brooklyn-Queens demand management program, which includes 41 megawatts (MW) of customer-side measures, including DR, distributed generation, distributed energy storage, and energy efficiency, to cost-effectively defer approximately $1 billion in transmission and distribution investment.
- In June 2015, the Pennsylvania Public Utility Commission set a total peak demand reduction of 425 MW for electric distribution companies by 2021, against a 2010 baseline.
- In Rhode Island, DR is continuing to be tested in pilot programs by National Grid and will be incorporated in analysis for "non-wires alternatives" to traditional utility infrastructure planning.[73]

The legal and regulatory environment for DR is highly dynamic and evolving at both the national and state levels. On January 25, 2016, the U.S. Supreme Court upheld FERC's authority to regulate DR programs in wholesale electricity markets (FERC Order No. 745).[74] While this decision provides final policy clarity, it was made almost 2 years after the Appeals Court issued the opposite decision; in the intervening time, the markets were operating under the lower court's interpretation that FERC's DR order was encroaching on each state's exclusive right to regulate its utility markets. As affirmed by the Supreme Court, the FERC order ensures that DR providers are compensated at the same rates as generation owners. This ruling is also expected to provide a more favorable environment for DR market growth by facilitating the participation of third parties in the aggregation of DR resources.

As noted, total DR capacity varies widely by region, reflecting the diversity in utility, state, and regional policies toward DR and other forms of demand-side management. Regions where DR is installed directly in multiple electricity markets (e.g., capacity and essential reliability services) generally have greater total DR capacities and can reduce a larger proportion of their peak demand by using DR.[75]

Table 4-1. Potential Peak Reduction from Retail DR Programs, by Region and Customer Class[76]

NERC Region	Total DR Capacity (megawatts)	Residential	Commercial	Industrial	Transportation
Alaska	27	19.0%	48.0%	33.0%	0.0%
Florida Reliability Coordinating Council	1,924	42.0%	39.0%	19.0%	0.0%
Hawaii	35	57.0%	43.0%	0.0%	0.0%
Midwest Reliability Organization	4,264	44.0%	19.0%	37.0%	0.0%
Northeast Power Coordinating Council	467	8.0%	55.0%	34.0%	3.0%
Reliability First Corporation	5,362	29.0%	13.0%	58.0%	0.0%
SERC Reliability Corporation	8,254	16.0%	10.0%	74.0%	0.0%
Southwest Power Pool	1,594	13.0%	20.0%	66.0%	0.0%
Texas Reliability Entity	459	19.0%	74.0%	7.0%	0.0%
Western Electricity Coordinating Council	4,681	22.0%	24.0%	50.0%	3.0%
Unspecified	28	100.0%	0.0%	0.0%	0.0%
Totals	27,095	25.8%	18.9%	54.6%	0.6%

Demand response (DR) resources tend to be drawn principally from industrial and commercial customers of utilities, although three regions—Florida Reliability Coordinating Council, Hawaii, and Midwest Reliability Organization—exhibit high-residential DR capacity. Variability among segments within and between regions is a function of DR program characteristics and requirements—whether penalties for non- or under-performance apply, the frequency with which DR resources are called, and the purpose for which DR is used, such as peak mitigation or frequency regulation. Capacity estimates must be adjusted for value and reliability of delivery based on operational outcomes, as well. DR, when called, may not sustain for a complete event period; only a portion of what is called may show up; resource availability may vary over an event period; and sometimes the "snap back" at the end of an event can create "echo effects" of peak mitigation problems, as well.

It is important to note that the potential peak reduction in Table 4-1 may not all be reduction in "real capacity." There are significant challenges to making DR resources reliable, predictable, and sustainable so that they may function as "proxy generators." Also, the terms related to non-delivery or partial delivery of DR that is called into service by grid operators tend to have highly variable penalty clauses from region to region and from utility to utility' grid operators generally favor more reliable and predictable resources over DR. Until there are consistent standards across regions that ensure data accuracy and validity, data on DR capacity will tend to be discounted by grid operators—an estimated 100-MW DR resource that *can*

be called does not mean that 100 MW will show up *when* called. Real-time visibility of these resources is important to grid operators and essential for maximizing the value of DR.[77]

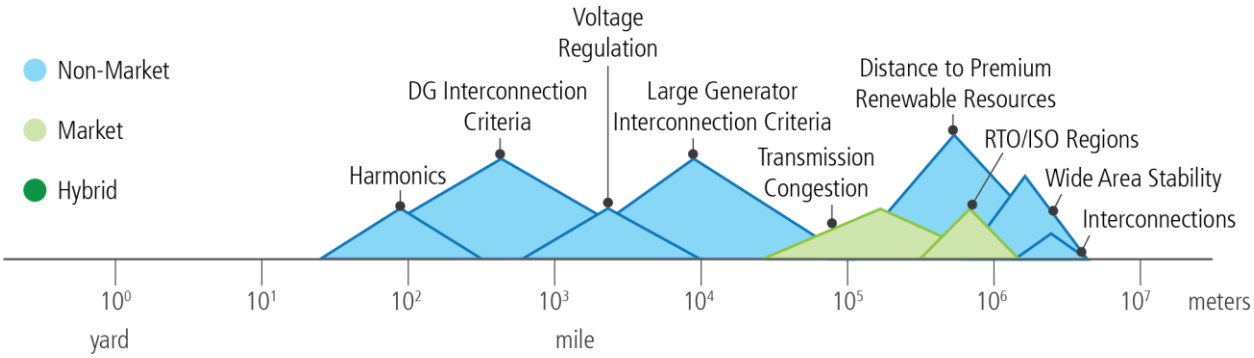
4.2.2.5 Topography and Geography are also Important to Grid Operators

Topography and geography are additional and important aspects of core grid management challenges (see Figure 4-6). Geography is the physical area covered by the grid; topography is the type of geography (e.g., flat, hilly, mountainous, etc.). Figure 4-6 illustrates how physical distances can influence system structure and operational challenges.

An example of why these features are important is that information and communications technology (ICT) infrastructure and reliability for smart meters and smart grid assets are less effective when mountainous terrain and urban infrastructure disrupt reliable wireless signal strength. Smart grid designers must and do build in redundancy to deal with certain topographic asymmetries by using multiple ICT channels.

As another example, the concentration of distributed VERs in a specific urban geography can lead to stresses on local infrastructure, including transformers and substations. This can present more disruptive problems for local grid operators than non-clustered dispersion of VERs. System operators must watch for grid impacts in more granular ways, and grid design changes to mitigate clustering effects will become important new paths for adapting to consumer-side influences on grid operations. Because consumer behavior can change quickly, new grid design processes must be made to function faster, from core architecture to actual deployment. In turn, regulators must become nimble in considering incremental system costs that are compelled by grid operators anticipating problems and acting to mitigate them before they lead to grid interruptions.

Figure 4-6. Network Geography and Topography Impact Real-Time Operations Management and Influence How System Planning Is Done for Grid Operations and Related Markets[78]



A variety of grid services are managed across different distance scales, and markets can be used to integrate some necessary services.

4.2.3 The Growing Role of the Consumer in Grid Reliability

Reliability is increasingly a two-way proposition between grid operators and consumers, and grid reliability, while remaining true to its longstanding commitment to ensure high system "uptime," now abuts an emerging "consumer reliability." Reliability has typically been synonymous with "grid reliability" or "system reliability." Consumer reliability derives from a series of initiatives over several decades; the continuous improvement in energy efficiency; the value of DR to both the grid and consumer; emerging new consumer value creation from IoT development; and the shifting priority of consumers (especially the commercial segment) for uninterruptible power services. The growing interdependence between grid operators and consumers—the two-way flow of information and power—means that grid reliability can be made more efficient and more robust if consumer integration into grid operations occurs.

4.2.3.1 Customer Engagement in Demand-Side Management

Today, many customer categories and segments are interacting with the grid in some way. Customers now have the tools to alter their consumption patterns in response to price signals or requests from grid operators. This significant change—from a customer that is a passive load to one that is more actively engaged in demand management—may trend toward greater customer participation in the future. Within 10 to 15 years, many of the new devices likely to become part of our electricity system—from power plants to rooftop solar systems, from batteries to street lights, from transformers to electric vehicles—will also be digitally communicating with the grid.[79] Most of these new devices will be able to "see" others on the grid, as well.

This kind of connectivity with customers may lead to more fully integrated customer participation in grid operations on either an active level—where customers respond to time-of-use or real-time price signals—or a passive level—with devices encoded to reflect customer preferences that are responsive to system prices and operating signals. Visibility of this connectivity is however, key to grid operations and management and essential for both customer and system reliability.

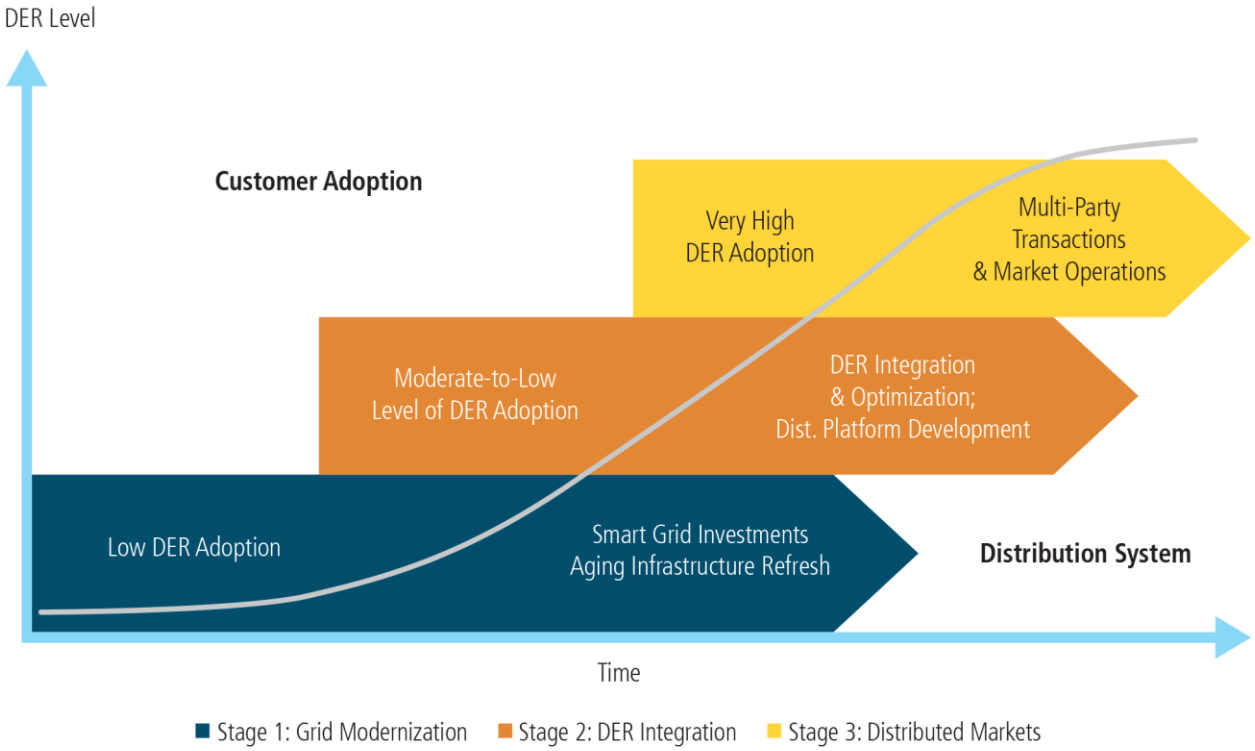
Consumption response to system signals can be more precise, timely, and predictable thanks to improved ICT enablers and better grid-side analytics focused on managing overall system reliability, not just peak mitigation. DOE, through its laboratories, for example, has developed a platform that "enables mobile and stationary software agents to perform information gathering, processing, and control actions and independently manage a wide range of applications, such as HVAC [heating, ventilation, and air conditioning] systems, electric vehicles, distributed energy or entire building loads, leading to improved operational efficiency." This platform provides the capabilities for real-time, scalable distributed control and diagnostics that we need for security and reliability and "…the integration of today's new energy system."[80]

4.2.3.2 Customer Engagement in Generation and System Reliability

In addition to the potential for increased customer participation in demand side management, there have been dramatic increases in distributed generation, such as rooftop solar, which enable customers to produce power that is sold back to the grid by the customer or aggregators acting on behalf of the customer. The result is that both electricity and information can now flow in two directions across the distribution grid, enabled by smart meters and/or Internet platforms. This two-way engagement has become more complex as distributed generation continues to penetrate industrial, commercial, and residential delivery service segments.

Most utilities are in the low distributed generation adoption phase, with some states approaching moderate levels.[81] The growth will be driven by regulatory characteristics within each state, for example, through rate design and utility regulation as set by a public utilities commission. Figure 4-7 shows the conceptual growth of DG/DER in three phases, from low to high adoption. Such conceptual forecasts are helpful in posing policy issues and assisting investors in seeing new opportunities. However, structural and systems outcomes depend as much on actual results of markets, regulators, and various jurisdictions co-evolving into the future.

Figure 4-7. Major Technology, Policy and Infrastructure Enablers of DER Adoption[82]



This figure shows a three-stage evolutionary framework based on an assumption that the distribution system will evolve in response to both top-down policy and bottom-up customer drivers. Each level includes additional functionality to support greater amounts of distributed generation/distributed energy resource (DG/DER) adoption and complexity building upon the earlier level. Most of the U.S. distribution system is at stage 1; the speed and nature of DG/DER adoption will vary by region based on top-down and bottom-up drivers.

Currently, around 4 percent of U.S. generation is from DG, although this varies widely by region.[83] Low levels of DG penetration generally require modest, though critical, levels of planning and operational considerations. Under high DG adoption rates, grid operations and market structures will most likely require significant modification. In a future grid where DG comprises a larger portion of the resource base, disruptions of system dispatch and control signals that could result from higher levels of DG penetration will increase the risk of disturbing grid stability and reliability. In its *2015 Long-Term Reliability Assessmen*t, NERC noted the complications DG/DERs create for grid operations and how these issues might be resolved:

> "Operators and planners face uncertainty with increased levels of distributed energy resources and new technologies. Distributed energy resources (DERs) are contributing to changing characteristics and control strategies in grid operations. DERs are not directly interconnected to the BPS [bulk power system], but to sub-transmission and distribution systems generally located behind customer metering facilities. Visibility, controllability, and new forecasting methods of these resources are of paramount importance to plan and operate the BPS—particularly because the majority of DERs are intermittent in nature and outside the control of the System Operator. As more DERs are integrated, the supply of control to System Operators can decrease. However, distribution-centric operations can reliably support the BPS with adequate planning, operating and forecasting analyses, coordination, and policies that are oriented to reliably interface with

> the BPS. Coordinated and reliable integration of DERs into the BPS can also present opportunities to create a more robust and resilient system."[84]

At high penetration levels, distribution system changes to enhance DG/DER value to grid reliability will require developing advanced distribution circuits and substations that allow for two-way power flows, new protection schemes, and new control paradigms. There are digital solid-state technologies combined with ICT, such as smart inverters, power electronics, and smart energy storage that can provide grid operators the flexibility needed to manage a mixed set of DERs and deal with inbound impacts from utility-scale VERs upstream as well. The introduction of new grid control and optimization algorithms taking advantage of distributed generation and load flexibility in the United States could also contribute to grid reliability and related benefits, such as reduction of renewables curtailment, peak load mitigation, and transmission and distribution (T&D) congestion management. Development of new technologies could enable DGs to provide voltage or reactive[g] control resources.

Currently, customer reliability investments and interests are not necessarily contributing to supporting and enhancing overall grid system reliability. In cases where DGs are part of the equation, particularly distributed VERs, customer actions can increase reliability risk. The electricity sector has a range of choices to adapt to these challenges and demands, many of them coming from new generators and consumers. The path that is chosen will shape future sector value-creation potential and the long-term relevance of utilities to electricity service delivery. Technology innovation, along with market forces, are redefining "grid reality," the management space where high system reliability is sustained under the aegis of critical national goals for a clean, secure, and competitive electricity sector.

Increased penetration of DGs and increased interconnectivity also bring increased vulnerabilities to malicious attacks on customer assets and on the grid. Public networks carry with them risks of being conduits through which cyber attacks can be executed—where impacts can spread through grids as well as through customer assets that are part of the IoT. There are policy gaps at the interface of electricity and information that require new policies that both promote value creation through connectivity and protect critical infrastructure against cyber attacks.

4.2.3.3 Valuation of DERs: System Benefits and Costs

The growth of DERs, where significant, will require additional valuation efforts in both planning and market design to capture the value of these new systems and services, as well as to avoid uneconomic or unintended issues. Valuation can be developed based on different cost perspectives, such as private costs that affect the ratepayers' cost of service or social costs that include the private cost of service and externalities. Valuation efforts need to be performed for system as a whole as well as for planning and compensation structures (e.g., rate design).

It is important to consider both the system cost and benefits when valuing DERs. Factors that influence DER value include constraint reduction, loss reduction, voltage control, investment deferral, environmental benefits, and reliability. These factors can vary significantly based on the size and location of the DER. Accurate valuations will depend on evaluations at a finer level or resolution than has been considered historically.

[g] NERC requires transmission operators to ensure that resources capable of providing "reactive power" or "voltage control" in addition to electricity are online or can be scheduled because these reactive power or voltage control services regulate voltage levels that maintain grid stability.

4.2.4 Flexibility and Management of DERs, VERs, and Two-Way or Multi-Directional Flows

Resilience and flexibility might be considered complementary factors of grid modernization. Grid modernization planning should take flexibility of resources, as well as grid operations techniques, into account; architecting a flexible grid may require distinctive configurations of ICT and physical assets on the grid side, as well as the customer side, of the utility meter. Flexibility is not only a generation matter; it bears directly on the core reliability challenges of maintaining balance between generation and load.

Solar and wind (which are not synchronously connected to the grid) contribute to a net decrease in system inertia (loss of frequency control). System frequency[h] must be managed tightly around 60 Hertz; it measures how well the supply and demand of electricity are in balance, which has significant implications for how resources are deployed literally minute-to-minute. Conventional generation, such as nuclear facilities or coal-fired power stations, serve as baseload resources and as spinning reserves. These resources are synchronously connected to the grid and provide system inertia.[i] Deviations in frequency are corrected by the spinning mass and governor controls of conventional generators, which automatically adjust electricity output within seconds to correct out-of-balance conditions.

In contrast, conventional solar photovoltaic (PV) generators, storage devices, and non-frequency responsive loads do not have inertial value for grid operators. As wind and solar power (and other non-synchronous DERs) replace conventional synchronous generation, total system inertia is reduced along with the number of units available to provide frequency response services. In other words, system flexibility could be compromised in the absence of intentional mitigating actions that preserve or boost frequency response capabilities. Power electronics and advanced inverters that simulate inertia are available to add to wind and solar generators, providing a version of frequency response; but, development and deployment of these technologies may be hindered without additional policies prioritizing or enabling frequency response service.[j, 85]

Steep ramping resources will become more important as more VERs come online and increase their share of power supply. Ramping is used to follow load patterns to ensure that resources match the loads on the system. VERs expand the role of ramping from being primarily load focused to more of a role in matching increasing supply variability. For example, in California in 2015, grid operators were required to bring on approximately 10,000 MW within a 3-hour period at the end of each workday to compensate for the reduction in PV output as the sun was setting. Over time, more ramping will be needed as variable resources continue to grow.[86] There is not yet an established method for calculating the type of flexibility required to ensure reliability, especially in circumstances with high penetration of variable or DG.

Distribution systems were designed to deliver power to customers rather than receive power from them. When the same grid assets are tasked with handling power delivered to the grid, as well as power delivered to customers, the settings on many field devices (such as capacitors, feeder switches, and relays) need to be adjusted to handle multi-directional power flows. Where deployment of PV on distribution feeders may significantly exceed real-time demand, distribution system upgrades will be required. However, upgrades cannot be determined simply by evaluating grid requirements but must be configured

[h] Frequency is the number of times per second that the electric charge reverses direction. "Electric Systems Respond Quickly to the Sudden Loss of Supply or Demand," Energy Information Administration, Today in Energy, November 21, 2011, http://www.eia.gov/todayinenergy/detail.php?id=3990.

[i] NERC defines inertia as "the ability of a machine with rotating mass inertia to arrest frequency decline and stabilize the system." See http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF_Draft_Concept_Paper_Sep_2014_Final.pdf.

[j] FERC issued a Notice of Inquiry on February 18, 2016, seeking comment on whether it should require all generators, including wind and solar, to provide frequency response service. See https://ferc.gov/whats-new/comm-meet/2016/021816/E-2.pdf.

to deal with existing and potential increases in PV deployments. Thus, the concept of "hosting capacity," much in the same way that Internet services calculate capacity requirements to serve Internet loads, will become a key decision criterion for future grid upgrades. Regulators will need to learn how hosting capacity is a relevant measure for grid planning and how cost justifications for rate purposes should be framed.

As noted, consumers are adopting renewable technologies and devices that enable them to manage their electricity use (e.g., through smart meters and energy management systems). Proactive consumers reduce demand pattern predictability, particularly when remote control of loads is involved. This complicates very near-term system planning, which, in turn, increases the need for redundancy to hedge the unexpected drops and surges in consumption that can happen. Discussion of these circumstances and policy implications can be found in Chapter II (*The Electricity Sector: Maximizing Economic Value and Consumer Equity*).

4.2.5 Visibility Is Key to Addressing the Changing Nature of Reliability

Flexibility in grid operations requires visibility into connected resources. Visibility—knowledge of "which resources are interconnected, as well as their locations and current capabilities"[87]—is a key attribute for managing the electricity system. Visibility is a necessary condition for managing rapidly changing and complex grid conditions and for providing awareness of incursions, as well as foresight for planning.

Advanced communication and information technologies facilitate visibility. Visualization requires data collection; analysis (e.g., modeling, business cases, etc.); transparency (i.e., sharing data and results); modeling (with both existing and new models); and deploying various sensing technologies, such as synchrophasors and smart meters. Creating foresight for transformation requires increasing visibility across many dimensions:

- *Temporal*—real time to planning
- *Geographic*—such as seams between balancing areas in the bulk electric system
- *Analytical*—identification and specification of computer models needed to evaluate the path to the future grid (such as finance tools, transmission planning tools, etc.)
- *Price*—the single most important mechanism for conveying information to customers and suppliers
- *Societal impacts*– associated risks taken on by the consumer may not be accounted for in price
- *Business*—business models and business-use cases for incumbent service providers and new technology providers
- *Technological*—including characteristics of new technologies and grid elements
- *Regulatory*—between different layers of jurisdiction and many different types of entities that must be synchronized to make the future grid work
- *Vertical industry boundaries*—between distribution and bulk system operations.

Integration of DER resources with ICT and other enabling technologies that provide visibility in the distribution system can give system operators the ability to react and respond to critical events with a level of efficiency and accuracy that is currently unavailable. Policies that comprehensively assess and manage DERs could help reduce associated reliability challenges. At some level of DER penetration, these policies may merit extending to encompass the interstate bulk power system. Data requirements and visibility of assets (possibly including tracking production) are important policy issues for state regulators.

The deployment of innovative visibility technologies face multiple barriers that can differ by technology and the role each technology plays in T&D systems. For example, synchrophasors are an important new technology that increase T&D operator visibility, but technology dissemination is being limited by utility concerns about vulnerabilities associated with sharing data and the fact that current regulations do not necessarily encourage investments in new technical solutions. This suggests that there is a role for the Federal Government in working with stakeholders and state regulators to identify, analyze, and develop recommendations for removing barriers to the deployment of value enhancing advanced technologies.

4.3 Growing Vulnerabilities for the Electric Grid

The electricity system requires management of risks from a wide variety of threats, each with different characteristics, not all of which are considered in a comprehensive way by decision makers. Threats and hazards to the electricity system represent anything that can cause disruption and outages, while vulnerabilities are points of weakness within a system that increase susceptibility to such threats. The physical vulnerabilities and specific risks to the electric power system vary among infrastructure components and by geographic location.

Significant Cost of System Outages

A National Research Council study of the 2003 blackout in the Midwest, Northeast, and Canada concluded that "the economic cost of the 2003 blackout came to approximately $5 per forgone kilowatt-hour, a figure that is roughly 50 times greater than the average retail cost of a kilowatt-hour in the United States."[88] Data suggest that electricity system outages attributable to weather-related events are increasing, costing the U.S. economy an estimated $20 billion to $55 billion annually.[89]

4.3.1 Grid Reliability Risk

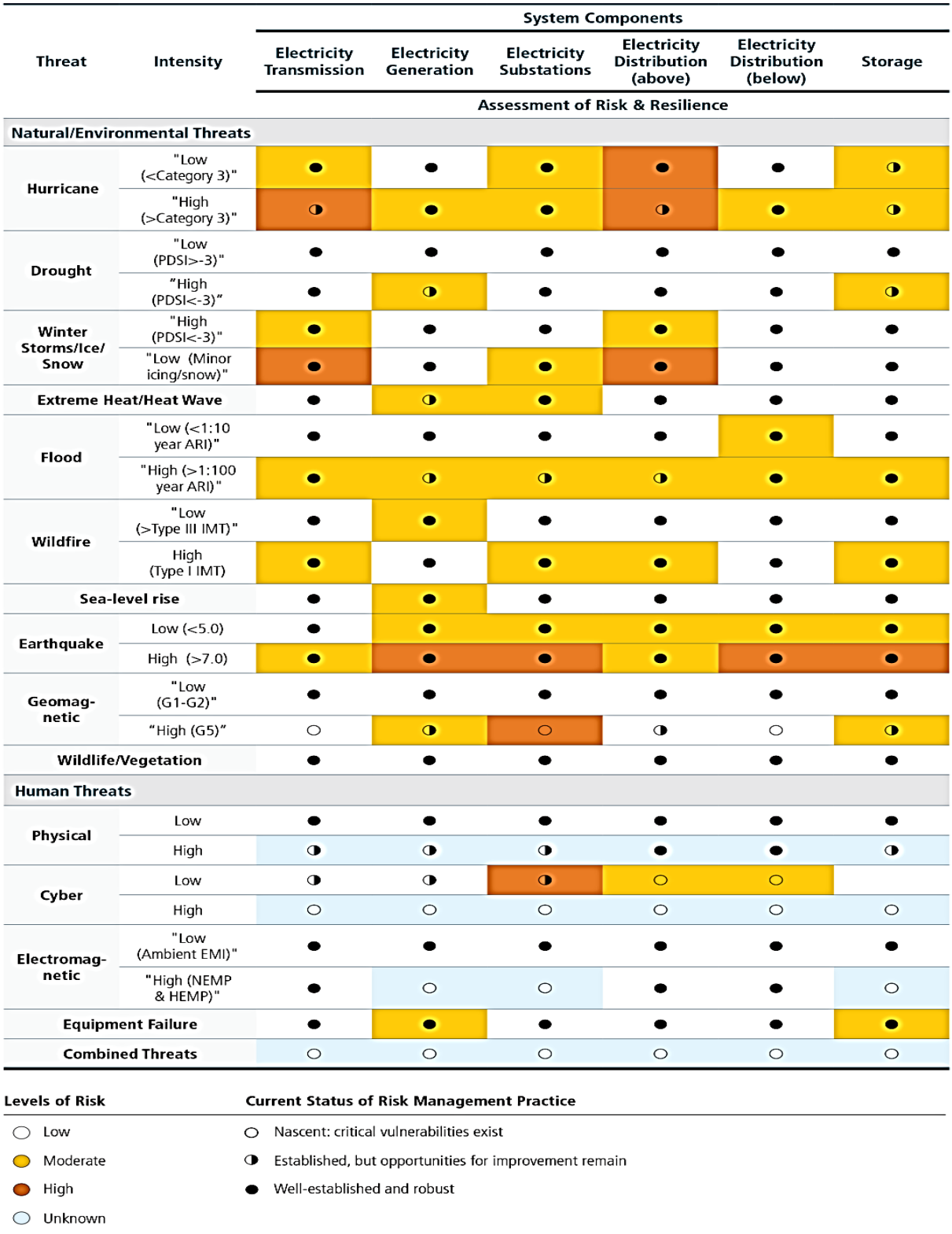
Reliability risk is a complex mix of natural and human threats. Risk mitigation includes developing future grid designs that maximize flexibility, as well as making investments in structural, process, and technology solutions, which increase grid resilience to reduce outage events. Some strategies can help reduce risks with respect to a variety of threats, while other strategies are more threat specific. Specific measures fall into a few broad categories—such as hardening (e.g., protection from wind and flooding), modernization (e.g., investment in sensors, automated controls, databases, and tools), general readiness (e.g., equipment maintenance, vegetation management, stockpiling of critical equipment), and analytics and security upgrades.[90, 91, 92]

Grid owners and operators are tasked with managing risks from a broad range of threats, defined as anything that can disrupt or impact a system—natural, environmental, human, or other. Many threats to critical electricity infrastructure are universal (e.g., physical attacks), while others vary by geographic location and time of year (e.g., natural disasters). Threats also range in frequency of occurrence, from highly likely (e.g., weather-related events) to less likely (e.g., electromagnetic pulse). Electric utilities have long prepared for specific hazards. However, hazards that evolve over time, or combinations of hazards that occur simultaneously, require enhanced or new measures for prevention or mitigation.[93]

Cyber attacks are emerging and rapidly evolving threats that may increase the vulnerability of utilities' system operations. Understanding the various established and emerging risks to the electricity system, including characterization of historical trends and future projections, as well as the predictability of different threats, has important implications for threat mitigation and resilience.[94] Figure 4-8 depicts the scope and severity of risks where probabilities of occurrence of each threat can change significantly "without notice." This Figure illustrates the status of risk management with respect to current threats, some of which are expected to worsen in the future, suggesting a need for new risk management

strategies. Current risk management practices are well suited to address common threats for most system components; however, the picture is mixed, particularly with respect to emerging threats, where there is limited data and experience. Figure 4-8 includes the current risks of system disruption (color coding) for electricity system segments (columns across) to various threats (by rows). The threats are further broken out by incidents of low and high intensity (rows). While the sector has well-established risk management practices for many current threats (indicated with filled circles), practices for other types of threats are nascent (open circles).

Figure 4-8. Integrated Assessment of Risks to Electricity Sector Resilience from Current Threats[95]



Electricity system owners and operators must manage risks in a comprehensive manner for a broad range of threats. This chart provides an integrated portrait of current risks to the electricity system and the maturity

of current risk management practices. The sector generally has well-established practices for managing familiar threats (e.g., wildlife), but much more work is needed to effectively manage risks from high-impact, low-frequency events (e.g., high-intensity hurricanes), combined threats, and unfamiliar threats for which information is lacking or unknowable (e.g., cyber and physical attacks). Additional attention is needed to reduce risks for above-ground distribution systems, substations susceptible to large-scale geomagnetic disturbances. This assessment does not reflect the status of risk management with respect to threats that are expected to worsen, such as extreme weather and cyber attacks.

4.3.1.1 Grid Operator Reliability Risk Management Is Increasingly Important

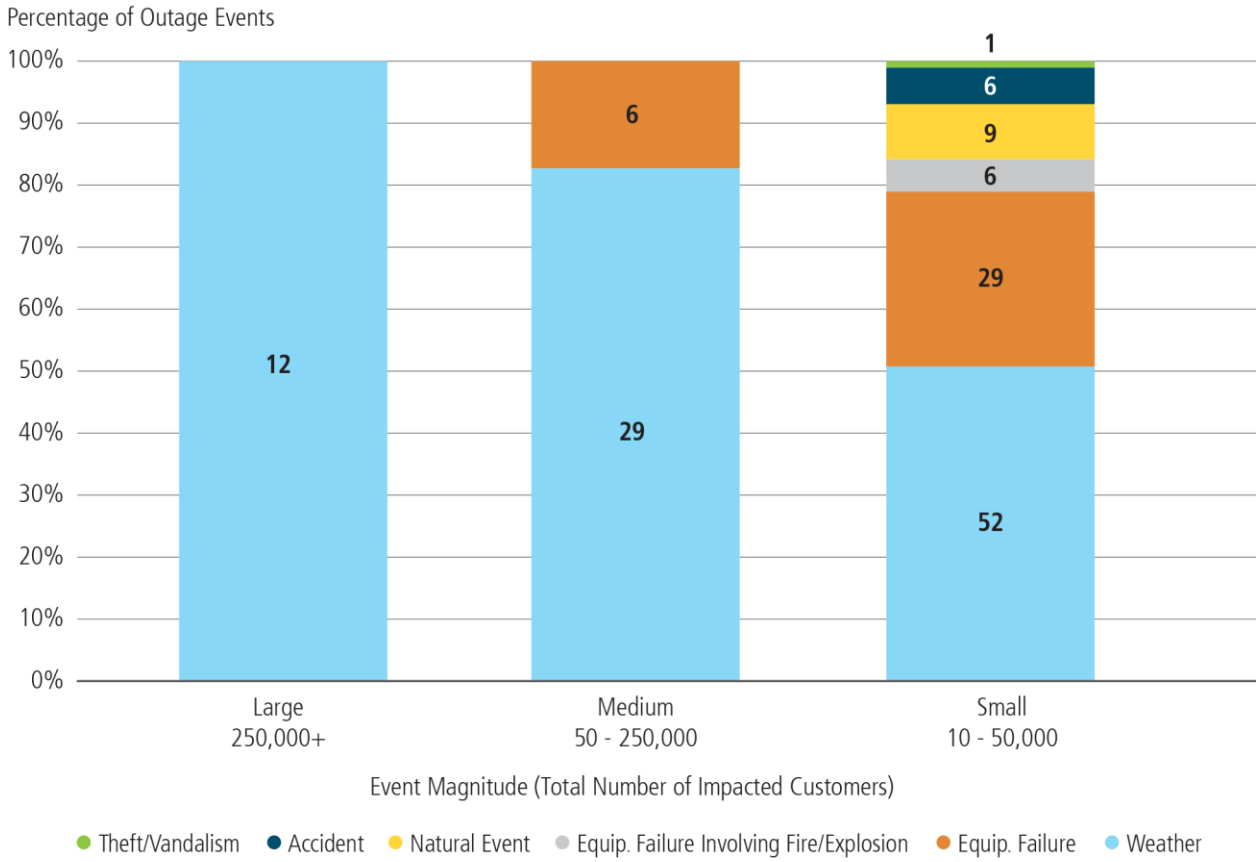
Delivery system reliability remains high and robust in today's world, but emerging threats create a higher risk profile that, in turn, creates challenges for ensuring sustained high delivery system reliability. There are many electricity sector risks that are continuously managed, such as investment risks, regulatory risks, and grid operational risks. Operational risks encompass all variables that can produce outages or disrupt frequency and voltage—from new types of power generation, to changing customer behavior, to extreme weather. Despite risk management practices, the risk of system disruption remains particularly high to certain system segments (e.g., above-ground distribution systems) or threats (e.g., large-scale earthquakes). Further, there remain evolving or dynamic threats for which the levels of risk are unknown and the risk management practices could be improved (e.g., high-intensity physical attacks, high-intensity cyber attacks, or combined threats).

Key policy questions include how investments should be prioritized, how cyber threats to ICT infrastructure should be managed, how emerging climate threats should be mitigated and planned for, and whether a highly dispersed power supply system contributes to a more resilient and secure electricity sector. Finally, longstanding high-voltage transmission and baseload power supply assets now must be analyzed as possible insurance assets for reliability

4.3.2 Extreme Weather Is a Leading Threat to Grid Reliability

Some types of extreme weather are becoming more frequent and intense due to climate change, and these trends have been the principal contributors to an observed increase in the frequency and duration of power outages in the United States between 2000 and 2012.[96] Figure 4-9 summarizes the main sources of contemporary outage events in 2015, excluding consideration of cyber-related effects.

Figure 4-9. US Electric Outage Events by Cause and Magnitude, 2015[97]



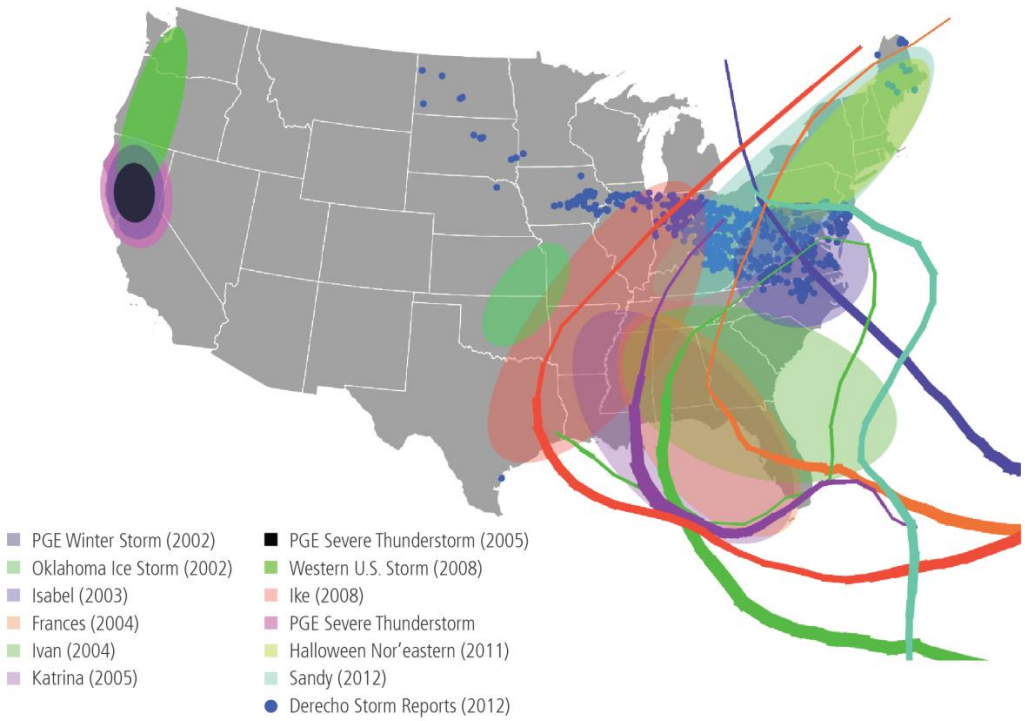
There are regional variations in weather-related outage causes in the United States. While the East and Gulf Coast regions are subject to hurricanes, large, weather-related outages in the West are more often caused by winter storms. Major outages from weather events are more common than from cascading failures.

Superstorm Sandy demonstrated the severe impacts of a large storm and the interdependencies of electricity and other infrastructures. The storm knocked out power to 8.66 million customers from North Carolina to Maine and as far west as Illinois and Wisconsin. Electric utilities deployed over 70,000 workers to the affected areas, the largest-ever dispatch of utilities workers.[98] The nearly 1,000-mile-diameter storm caused flooding and power outages that shut down many other major infrastructure components, illustrating the dependence of other critical infrastructures on electricity.[99] Oil refineries were shut in, as well as many East Coast product import terminals—which act as the primary back-up method for securing bulk product supplies during refinery outages—due to the loss of power. A week after the storm, product deliveries in New York Harbor had returned to only 61 percent of pre-storm levels, and less than 20 percent of gas stations in New York City were open for business. The Department of Defense provided 9.3 million gallons of fuel, though fuel shortages still greatly hindered the ability of emergency response personnel to respond to the crisis.[100]

Weather-related events, including lightning and storms, have historically posed the greatest operation risk to the electricity system.[101] Strong winds, especially hurricane-force winds, are the primary cause of damage to electric T&D infrastructures. Failures on the distribution system are typically responsible for more than 90 percent of electric power interruptions, both in terms of the duration and frequency of outages.[102] Damage to the transmission system, while infrequent, can result in more widespread major

power outages that affect large numbers of customers and large total loads.[103] Figure 4-10 summarizes major weather-induced reliability disruptions from 2002 to 2012.

Figure 4-10. Major Weather-Related Outages Requiring a National Response, 2002–2012[104]

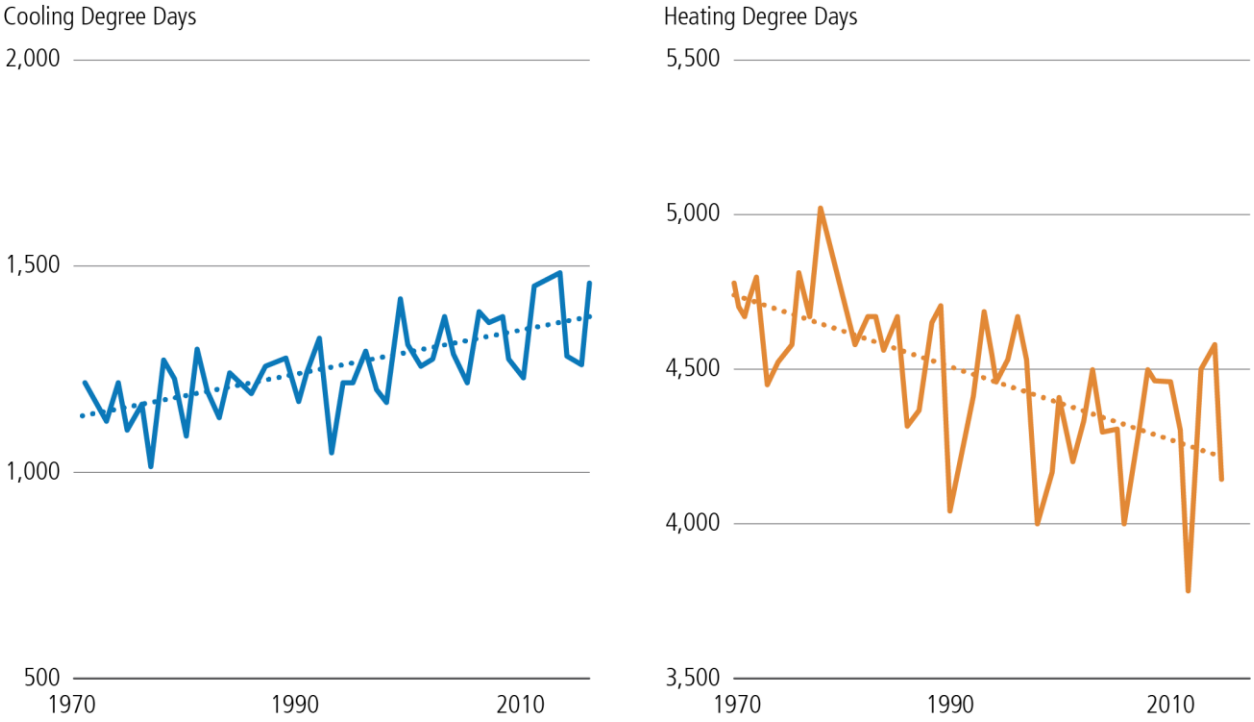


There are regional variations in outage causes in the United States. While the East and Gulf Coast regions are subject to hurricanes, large, weather-related outages in the West are more often caused by winter storms. Major outages from weather events are more common than from cascading failures.

Further, 2016 is on track to be the third consecutive year of record-breaking global temperatures.[105] Cooling degree days[k] have already increased in the United States by roughly 20 percent over the last few decades (see Figure 4-11), and this trend is projected to continue in the future.[106] These changes in temperature are expected to result in increased electricity use, particularly during the mid- to late-afternoon peak hours, primarily to meet rising demand for air conditioning.[107]

[k] The number of degrees that a day's average temperature is above 65° Fahrenheit, indicating that consumers need to use air conditioning to cool their buildings, and there is an increase in electricity demand.

Figure 4-11. Heating and Cooling Degree Days in the Contiguous 48 States, 1970–2015 (Fahrenheit)[108]

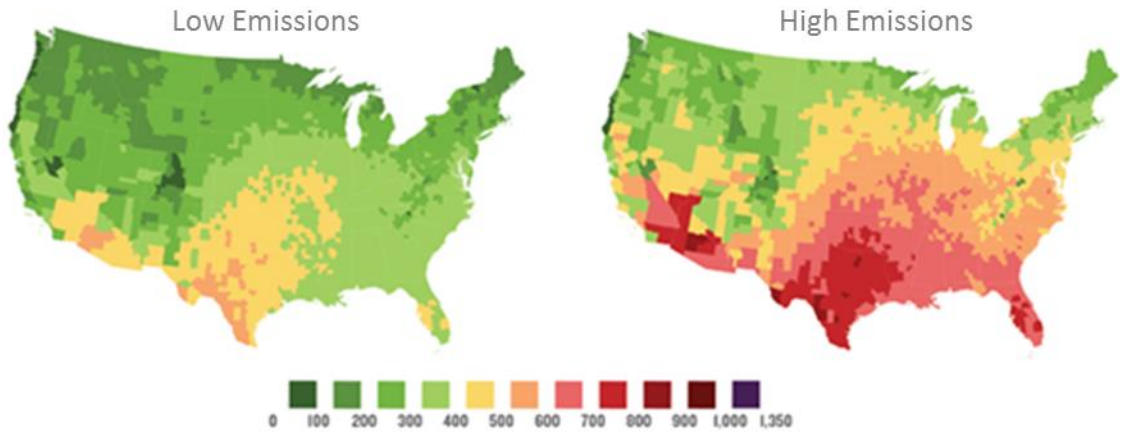


As air temperature continue to rise, since 1970, the number of cooling degree days has increased in the United States by roughly 20 percent, while the number of heating degree days has declined.

The maps in Figure 4-12 show projected median changes in cooling degree days by 2040 under two global greenhouse gas emissions scenarios, based on analysis of output from several global climate models,[I] which were downscaled to the county level.[109] This analysis found that while the average American has historically experienced around 2 weeks of days over 95°F each year, this could rise to 3 to 6 weeks, on average, by 2040.[110]

[I] To account for uncertainty surrounding future emissions pathways, the study cited here uses a plausible range of scenarios developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The highest emissions scenario corresponds to a world where fossil fuels continue to power global economic growth. The lowest emissions scenario reflects a future in which global greenhouse gas emissions are reduced through a rapid transition to low-carbon energy sources.

Figure 4-12. Median Change in Cooling Degree Days from Historical (1981–2010) Average for Average Year between 2030 and 2049 under Two Emissions Scenarios[111]



The average number of cooling degree days are expected to increase significantly by 2040, particularly in southern parts of the country. Projected changes for the higher emissions scenario (*right panel*) are much greater than under the lower emissions scenario (*left panel*).

Power-sector system costs increase with higher temperatures, particularly as additional capacity is built to meet higher peak demand. Higher air temperatures also reduce the generation capacity and efficiency of thermal generation units. Both of these factors were taken into consideration by modeling conducted for the QER. Models showed the likely range of total power system costs[m] increasing by 2 percent to 7 percent (with a median value of 4.5 percent) under the lowest greenhouse gas emissions scenario, rising to 4 percent to 11 percent under the highest emissions scenario.[112] The scale of these modeled costs illustrates why electricity system planners should consider how best to incorporate possible weather changes into load forecasting and other considerations that affect investment planning for the electric power sector. Increased earth observation and modeling of local-scale climate effects to improve forecasting would benefit electricity system planning and could reduce costs.

Extreme temperatures also increase the potential for electrical equipment to malfunction. For example, transformers do not last as long when overloaded to meet peak demand, particularly when they are simultaneously exposed to high temperatures that exceed the heat ratings for which they were designed.[113] When planning for future investments, it may become important for utilities to proactively invest in transformers with higher heat ratings to reduce the potential for overloading under future, warmer conditions.

A continuation of sea-level rise, in conjunction with storm surges caused by tropical cyclones, hurricanes, and nor'easters, will increase the depth and the inland penetration of coastal flooding, thus increasing the frequency with which electricity assets are exposed to inundation during storm events.[114] These challenges are exacerbated by the fact that some coastal areas may be experiencing load growth—rapid population growth and development in coastal areas—which is expected to continue in the coming decades.[115, 116]

Another aspect of uneven impacts is that low-income and minority communities are disproportionately impacted by disaster-related damage to critical infrastructure.[117] These communities often do not have

[m] Calculated in net present value terms, between 2016 and 2040, using a 5 percent discount rate.

the means to mitigate or adapt to natural disasters and disproportionately rely on public services, including community shelters, during disasters. As a result, there may be a Federal role in providing technical and financial resources to help states and localities prioritize resilience investments in critical public infrastructure that would protect the most vulnerable communities.

4.3.3 Electricity and Natural Gas System Interdependencies

A key interdependency (and vulnerability) for all economic sectors and critical infrastructures is reliance on electricity, making its reliability a fundamental need and requirement across the entire economy. Many of these interdependencies are growing, such as the interdependency of electric and natural gas systems.

The reliability of the Nation's electricity system is increasingly linked to the reliability of natural gas pipelines and associated infrastructure. On May 24, 2016, NERC released a special assessment of gas-electric interdependencies, which included an investigation of the potential reliability risks to the Nation's bulk power system due to increased reliance on natural gas. NERC found that areas with growing reliance on natural gas-fired generation are increasingly vulnerable to gas supply disruptions. These concerns were reinforced by NERC's latest long-term reliability assessment, which was released in December, 2016.

Unlike other fossil fuels, natural gas is not typically stored onsite and must be delivered as it is consumed.[n] In many regions, sufficient gas infrastructure is a key requirement for electric reliability. An interruption in natural gas deliveries could result from extreme weather or *force majeure* events, as well as from low-probability events that could unexpectedly remove infrastructure from service, such as a well malfunction, as seen in the underground storage leak in Aliso Canyon, California. Extreme weather events, such as in the Southwest outages of 2011, can simultaneously increase energy demand for gas and electric heating, while reducing supplies in the affected region.[118] Operators may be able to respond to disruptive events by rerouting gas onto other pipelines, as was the case during a 2016 disruption to the Texas Eastern Pipeline.[119] Electric curtailments also have the potential to reduce gas available to gas-fired generators. For example, in 2011, power outages disabled electric-powered gas compressors on well gathering lines, which reduced supplies of natural gas to New Mexico.[120] In addition to physical natural gas disruptions' impact on the electricity system, the electricity sector's increasing reliance on natural gas raises serious concerns regarding the need to secure natural gas pipelines against emerging cybersecurity threats. Thus, the adequacy of cybersecurity protections for natural gas pipelines directly impacts the reliability and security of the electric system.

The vulnerabilities due to natural gas and electric system interdependency are the subject of ongoing regulatory reforms, physical upgrade efforts, and industry collaboration. Some ISOs have undertaken surveys of critical gas facilities to ensure that these facilities are exempt from potential load-shedding plans in the event of a system emergency, and FERC has allowed communication of proprietary and other non-public operational information between the gas and electric industries to continue in order to facilitate further sharing of critical reliability issues.[121] To date, many stakeholders have performed extensive analysis to improve real-time and near-term operations and planning in order to address natural gas-electricity interdependencies. One result has been FERC issuing a final ruling requiring interstate natural gas pipelines to change their pipeline nomination schedules to better conform to dispatch

[n] Some natural gas power plants also have the ability to operate on alternatives to pipeline-delivered natural gas, such as fuel oil and local stores of liquefied natural gas or liquefied petroleum gas. In addition, note that potential deliverability challenges for coal have also been documented. For example, see Energy Information Administration, "Coal Stockpiles at Coal-Fired Power Plants Smaller than in Recent Years," Today in Energy, November 6, 2014, http://www.eia.gov/todayinenergy/detail.cfm?id=18711. See also Department of Energy (DOE), *Natural Gas Infrastructure Implications of Increased Demand from the Electric Power Sector* (Washington, DC: DOE, 2015), v, http://energy.gov/epsa/downloads/report-natural-gas-infrastructure-implications-increased-demand-electric-power-sector.

scheduling in organized electricity markets.[122] Most coordination efforts have been focused on short-term planning and operations. Mid- and long-term planning coordination is also being explored to properly plan for long-term assets like electric transmission and natural gas pipelines. However, coordinated long-term planning across natural gas and electricity can be challenging as the two industries are organized and regulated differently.

Underground Storage Leak in California Driving Natural Gas Storage Safety and Reliability Improvements[123]

On October 23, 2015, the largest methane leak from a natural gas storage facility in U.S. history was discovered by the Southern California Gas Company at well SS-25 in its Aliso Canyon Storage Field in Los Angeles County. The leak continued for nearly four months until it was permanently sealed on February 17, 2016. In the interim, residents of nearby neighborhoods experienced health symptoms consistent with exposure to odorants added to the gas; thousands of households were displaced; and the Governor of California declared a state of emergency for the area. Approximately 90,000 metric tons of methane were released from the well, although estimates vary, and the State of California is continuing its analysis. The incident also created serious energy supply challenges for the region and prompted broader public concerns about the safety of natural gas storage facilities.

From an electric reliability perspective, the continued shutdown of this facility has been significant because it is a key component of the Southern California gas system serving customers in the Los Angeles Basin and San Diego, particularly many gas-fired power plants. Curtailments of gas deliveries were expected to cause electric reliability problems in the summer of 2016. Such disruptions were avoided, however, due to the combined effects of comparatively mild summer weather, intensified electric demand response efforts, coordinated maintenance programs, and extraordinary management of the region's gas delivery system. The possibility of gas and electric delivery problems remains a concern, however, for the winter of 2016–2017, and additional preparation and coordination are required in order to avoid gas and electric curtailments.

In April 2016, the Obama Administration convened an Interagency Task Force on Natural Gas Storage Safety to support state and industry efforts to ensure safe storage of natural gas. Congress codified the Task Force through the Protecting our Infrastructure of Pipelines and Enhancing Safety Act, which was signed into law by President Obama in June 2016. The legislation created a task force established by the Secretary of Energy that consists of representatives from the Department of Transportation, Environmental Protection Agency, Federal Energy Regulatory Commission, and the Department of the Interior. The Protecting our Infrastructure of Pipelines and Enhancing Safety Act tasked the group with performing an analysis of the Aliso Canyon event, making recommendations to reduce the occurrence of similar incidents in the future, and required that Pipeline and Hazardous Materials Safety Administration promulgate minimum safety standards for underground gas storage that would take effect within 2 years.

In October 2016, the Task Force released a report, called *Ensuring Safe and Reliable Underground Natural Gas Storage*, and 44 recommendations. These recommendations address concerns regarding the integrity of wells at underground natural gas storage facilities, public health and environmental effects from leaks like the one at the Aliso Canyon facility, and energy reliability concerns that could arise in the case of failures at such facilities in the future.

4.3.4 Combined Threats to the Grid

The stochastic nature of certain events such as hurricanes and earthquakes makes the probability of two closely spaced, co-located events very low. However, an intelligent attacker may plan to use the occurrence of one naturally occurring, high-intensity, and low-frequency event to amplify the impact of a physical, cyber, or electromagnetic pulse attack.[124] While electric power systems are generally resilient and quick to recover from failures caused by most natural and accidental events, the National Academy of Sciences concluded that an intelligent multi-site attack by knowledgeable attackers targeting specialized components, like power transformers, could result in widespread, long-term power outages from which it could take several weeks to recover.[125] Another combined threat is the simultaneous

occurrence of a severe heat wave during a prolonged drought, which is expected to become increasingly likely in certain regions, such as the U.S. Southwest.[126]

4.3.5 Physical Attacks on the Grid

Incidents such as a series of as-yet unexplained attacks on exposed electricity substations—including the Metcalf incident in California and the attack on the Liberty substation in Arizona—have raised the public's consciousness about the vulnerability of the U.S. electricity grid and the need for the United States to address these vulnerabilities. With an increased focus on physical security, NERC developed Critical Infrastructure Protection (CIP) Standards (CIP-014) in 2014 to address the physical security risks and vulnerabilities of critical facilities on the bulk power system.[127] The Reliability Standard requires transmission owners that meet specific voltage criteria to identify and then protect facilities that, if rendered inoperable or damaged, could result in instability or uncontrolled separation within an interconnection. Transmission owners must also complete third-party verification of their analyses and mitigate the identified areas of concern. Per NERC, the initial risk assessments of critical facilities (including transmission stations, substations, and control centers) were completed by October 1, 2015, while the third-party review of proposed changes to security plans and mitigation strategies was to be completed by November 24, 2016.[128] All entities subject to NERC CIP-014 Standards must retain data and/or evidence of compliance, as described by NERC guidance.[129]

4.3.6 Evolving Cyber Threats to the Grid

The integration of cyber assets to electricity infrastructure presents unique and significant challenges for maintaining and planning for reliable and resilient grid operations. The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities juxtaposed against the slower-moving prioritization and deployment of defense measures. This gap is exacerbated by difficulties in addressing vulnerabilities in operational technologies that cannot easily be taken offline for upgrades, and the presence of significant legacy systems, as well as components that lack computing resources to incorporate new security fixes. Also, any operational changes must be implemented by the thousands of private companies that own and operate electricity infrastructure.

Sector transformation based on a two-way flow of energy and information between grids and consumers brings to the foreground the importance of Federal Government engagement in helping to manage and mitigate vulnerabilities inherent in 21st-century modernization. Interoperability standards, in particular, have the potential to enhance cybersecurity. Improved tools, analytic methodologies, and demonstrations would serve to clarify the circumstances where improved interoperability can improve grid cybersecurity by standardizing security solutions such that utilities can select 'plug-and-play' options to mitigate cybersecurity issues. To this end, there is a role for the Federal Government to facilitate state and utility adoption of interoperability standards that provide high societal net benefits through providing high-quality and trusted information to decision makers.[130]

While cyber attacks on the U.S. grid and affiliated systems have had limited consequences to date, attacks elsewhere in the world on energy systems should be seen as an indicator of what is possible. Threats can emerge from a range of highly capable actors with sufficient resources, including individuals, groups, or nation-states under the cloak of anonymity.

As noted, the 2015 cyber attack on the Ukrainian electric grid was the most sophisticated cyber incident on a power system to date. On December 23, 2015, Ukraine experienced widespread power outages after malicious actors remotely manipulated circuit breakers across multiple facilities in a series of highly coordinated attacks.[131] The event compromised six organizations, including three electric distribution

companies; disconnected seven 110 kilovolts and 23 35-kilovolt substations (which would straddle Federal and state jurisdiction in the United States); rendered equipment inoperable; overwhelmed the call center with a denial-of-service[o] event to prevent people from reporting outages; and left 225,000 without power for 1 to 6 hours.

4.3.6.1 Grid Communication and Control Systems

Deploying smart grid technologies can support increased grid systems' observability and reliability by allowing more real-time awareness via sensors, which enable self-healing systems like fault location and service restoration. At the same time, deployment of smart technologies and DERs can provide new vectors for cyber attacks. While not yet a significant issue, this is a growing and significant concern in a grid with two-way, end-to-end flows of electricity. While the likelihood that a malicious actor could bring down large regions of the electric grid by manipulating distributed energy and behind-the-meter equipment is currently low, the risks may change as distributed energy and other advanced technologies increase in number, are operated in aggregation, and are used by the bulk power system to manage and shape load. Smart meters track detailed power usage and allow for two-way communication between the utilities and end users via smart grid technology, which can include remote customer connection and disconnection. Hackers targeting this technology could cause erroneous signals and blocked information to cut-off communication, cause physical damage, or more, and disconnect large numbers of customers to disrupt the grid.

Recently, some utilities have been moving toward combining their physical security and cybersecurity business centers to create a "centralized operations center" organized under a chief information security officer responsible for cybersecurity.[132] These centralized operations centers generally work toward meshing informational technologies with physical operational technologies. Other utilities have their cybersecurity risk management program located in existing information technology (IT) security departments.[133] However, some utilities suffer from a lack of practical cyber expertise. A recent survey showed that 37 percent of utilities surveyed make cybersecurity decisions at the executive level, 47 percent at the management level, and only 16 percent by professional staff.[134]

Reported cybersecurity incursions into industrial control systems (ICS) within the U.S./Canadian energy sector, have decreased slightly, from 111 reported incidents in 2013,[135] to 79 incidents in 2014,[136] and 46 in 2015.[137] This is occurring despite an overall increase in the number of reported ICS incidents across the broader economy, and so far, these incursions have been unsuccessful at inhibiting or disrupting power system operations.[138] Typical cybersecurity events impacting the grid have been mainly limited to gaining access to networks through phishing emails or infecting flash drives with the hope that they will be connected to a network. Russian hacking of utility systems as seen in the Ukraine incident, however, underscores that such events should not be viewed simply as information theft for business purposes. The more common cyber intrusions impacting the electricity subsector today could be preparatory activity for disruptive attacks in the future.

4.3.6.2 Mitigation of Threats to the Grid

Detecting anomalies and sharing information across organizations are critical measures to enhance grid security; this covers everything from prevention to mitigation and recovery from cyber attacks. However, it is difficult to identify cyber intrusions when no changes or disruptions to system operations are evident or detectible. Furthermore, utilities report a lack of intrusion detection systems,[139] which allow security personnel to identify anomalies in cyber systems and to obtain forensic data.[140] Organizations vary

[o] Distributed denial of service refers to the prevention of authorized access to multiple system resources or the delaying of system operations and functions.

monitoring systems, and nearly every utility will require distinct intrusion detection system specifications due to utility-specific IT and operational technology system configurations.[141, 142]

Even in optimized detection environments, programs and institutions that wish to facilitate sharing within and across industry and government face challenges, including human delays in sharing information, procedural barriers related to classified information, and liability and privacy concerns from industry that inhibit sharing. For example, Federal agencies maintain classified information related to cyber and physical security threats. While some of this information is shared via existing mechanisms, including the Electricity Information Sharing and Analysis Center and DOE's Cybersecurity Risk Information Sharing Program,[p] sector representatives routinely ask for more in-depth, synthesized, and timely security information.

When digital components of the grid have been compromised, manual operations[q] can be a temporary alternative. Utilities may need to maintain mechanical controls to prevent degradation and loss of operability.[143] Some subject matter experts suggest utilities are also leveraging decades of experience with mutual assistance agreements to set up cyber assistance in the event of a cyber attack, but response and recovery from cyber attacks pose distinct challenges that are generally not covered by existing mutual assistance programs. The Electricity Subsector Coordinating Council established the Cyber Mutual Assistance Task Force to convene industry experts and develop a cyber mutual assistance framework. The Federal Government could play a convening role for the electricity sector and thereby accelerate efforts to design and employ cyber mutual response programs and ensure swift grid recovery after a cyber attack.

4.3.6.3 Grid Cybersecurity Workforce Gaps

A shortage of skilled cybersecurity personnel across government and electricity industry presents challenges to meeting response and recovery needs in the aftermath of a large, disruptive cyber event. The power grid is a cyber-physical system, requiring a cross-disciplinary workforce dedicated and trained to design, manage, and protect such complex systems.[144] Companies face challenges in designating sufficient personnel for system security.[145] In addition to the challenge of incorporating sufficient cyber and physical security expertise into their businesses, recruiting and maintaining a workforce that is adequately trained is a growing challenge. To address emerging cybersecurity risks, the United States requires a workforce adept in a variety of skills, such as risk assessment, behavioral science, and familiarity with cyber hygiene.[r]

4.3.6.4 Smart Grids and Related Risk

Deployment of smart grid technologies—sensors and the ability to collect and analyze more data faster—supports increased observability of grid systems and thereby contributes to increasing grid reliability. However, in the absence of adequate cyber protections, deployment of smart technologies and DERs could increase system vulnerabilities. Because the deployment of these technologies is still in the

[p] In partnership with industry, the Department of Energy's Office of Electricity Delivery and Energy Reliability has been supporting the Cybersecurity Risk Information Sharing Program (CRISP), which is a collaborative effort with private energy sector partners to facilitate the timely sharing of threat information and the deployment of situational awareness tools to enhance the sector's ability to identify threats and coordinate the protection of critical infrastructure. In August 2014, the North American Electric Reliability Corporation and the Electricity Subsector Coordinating Council agreed to manage CRISP for its sector.

[q] Use of mechanical switches and controls rather than computer-based controls.

[r] Cyber hygiene is a set of practices designed to maintain cyber security and keep out the "bugs" from a digital system. Just as hand washing keeps germs from entering the body, practices such as deleting data from cloud storage when it is no longer needed or prohibiting the download of non-essential applications, which might contain viruses, are intended to keep intrusions out of a computer system.

relatively early stage, electricity regulatory bodies should ensure that cyber protection planning includes advanced cyber protection protocols when execution occurs.

Automated smart meters, for example, are increasingly relied on to track actual power usage and allow for two-way communication between the utilities and end users. Hackers targeting this technology could cause disrupted power flows, create erroneous signals, block information (including meter reads), cut off communication, and/or cause physical damage. Also, some supervisory control and data acquisition (SCADA) systems rely on modern communication infrastructure or a blend of modern and conventional, (i.e., telephone lines communication channels to achieve the same ends), which could make SCADA communications more accessible to hackers and more vulnerable to disruptions. Hacking may come through access to hardcoded passwords,[s] system backdoors,[t] passwords in clear text,[u] lack of strong authentication,[v] and firmware vulnerabilities.[w, 146, 147]

Development of Security Metrics

A major impediment to common metrics is variation in how to measure benefits (or conversely, the cost of interruptions), such as "freight cost per mile" or "value at risk." After the attack on the Metcalf substation in April 2013, the California Public Utilities Commission analyzed methods of quantifying distribution system security.[148] Metrics included copper theft, successful or unsuccessful intrusion or attack, and false or nuisance alarms; the condition of all monitoring equipment and the performance of security personnel in training exercises and on tests; results of substation inspections; instances of vandalism or graffiti; and problems with access control, number of malfunctions of security equipment, or camera coverage.

4.3.6.5 Comprehensive Vulnerabilities Assessments

Reliability requirements in the face of human and natural threats require enterprises, as well as state and Federal entities, to seriously assess vulnerabilities and prioritize investments to ensure that highly reliable service continues. These entities diligently work to identify and mitigate risks to grid reliability. However, given the scope and complexity of risks, especially related to new vectors such as cyber attacks, there may be a need to improve coordination not only around assessing event outcomes, but also around maintaining contemporary assessments of vulnerabilities, their associated risks, and professional estimates of their likelihood.

4.3.7 Gaps in National Reliability, Security, and Resilience Authorities and Information

The primary Federal entities with roles related to security and resilience of the electric grid under normal and emergency conditions are DOE, the Department of Homeland Security (DHS), the Department of Commerce, and FERC.[149] These entities' roles span research and development, standards and guidance, information-sharing mechanisms, and the coordination of resource deployment during emergency events.

Existing authorities cover a wide breadth of Federal Government responsibilities, yet certain gaps remain in implementing comprehensive reliability, security, and resilience measures. For example, the Fixing America's Surface Transportation (FAST) Act granted the President new authorities to protect critical infrastructure against electromagnetic pulse, cyber, geomagnetic disturbances, and physical threats, but not to take anticipatory action for natural disasters and extreme weather. Nevertheless, certain extreme

[s] Passwords that cannot be changed by the user

[t] Alternative access (to secure data or functions) that bypass normal security procedures

[u] Passwords stored without encryption

[v] Not scrambling login information, which enables a digital eavesdropper to capture passwords

[w] Generic catch-all for hardware-based exploits (rather than software-based)

weather events (e.g., heat waves, hurricanes) can be easier to anticipate,[150] and to date, they have caused significantly more direct physical harm to the electric grid than have malicious acts. Taking actions in advance of an impending threat can have significant positive effects in reducing power outages,[151] so extending this authority for all hazards would be a great benefit for protecting the grid.

The lack of access to data represents another challenge to Federal agencies to enhance the security and resilience of the grid. Given that the majority of electricity infrastructure is privately owned, the Federal Government must rely on industry data collection activities to understand the vulnerability and security landscape of the electric grid**.** Furthermore, as noted earlier, utilities report SAIDI, SAIFI, and CAIDI statistics in inconsistent ways,[152, 153] limiting the ability of governments to independently conduct robust risk assessments of the grid. DOE and FERC in particular lack access to data on critical grid assets and their vulnerabilities. In order to support the President in executing new anticipatory security authorities under the FAST Act, addressing this information deficit is a priority.

NERC collects certain data, in its role of performing grid reliability assessments and supporting the development of reliability and security standards, but NERC does not make all of that data available to government agencies. DOE has some limited visibility into critical electricity infrastructure through tools like EAGLE-I[x]; additional system data, to determine, for example, where there are critical vulnerabilities, are needed to exercise the new emergency authorities granted to the President and the Secretary of Energy under the FAST Act.

One of the most prominent examples of this data gap is a lack of information on risk mitigation practices at the utility level, including information regarding participation in risk mitigation programs, a utility's specific risk mitigation practices, and spare equipment specifications and numbers for critical infrastructure, such as transformers. Without with enhanced and appropriately protected data on utility practices, component part reserves, and an increase in awareness on a range of additional topics—such as transformer configuration, the direct current resistance of various components, and substation grounding resistance values—DOE's ability to understand the extent to which infrastructure will be improved, enabling DOE to better fulfill key statutory and executive responsibilities.

4.4 Markets and Their Impact on Reliability and Resilience

Organized wholesale markets are recent innovations in the century-plus life of the electricity sector. They were developed and implemented beginning in the 1990s on the heels of state legislative and regulatory direction, but are considered Federally regulated structures that adhere to rules set by FERC and reliability standards set by NERC. Organized markets operated by ISO/RTO include time-delineated markets (e.g., day-ahead, hour-ahead, and real-time), as well as system support services such as spinning reserve and non-spinning reserve, often referred to as Ancillary Services. Commodity exchanges, such as the Intercontinental Exchange (ICE) and the New York Mercantile Exchange, offer future contracts for location-specific electricity trading (referred to as hubs in U.S. markets). These short-term markets are designed to provide price discovery on the marginal cost of power production and delivery.

Seven U.S. regions have operating ISOs/RTOs that manage centrally organized wholesale markets for energy trades (i.e., MW-hour only, as compared to capacity trades that are for MW-only transactions). Together, these trades play an important role in operating and economically optimizing regional grids and

[x] EAGLE-I, which stands for *Environment for Analysis of Geo-Located Energy Information*, is an interactive geographic information system (GIS), created and managed by DOE. It allows participants to view and map the nation's energy infrastructure and obtain near real time informational updates concerning the electric, petroleum and natural gas sectors within one visualization platform.

ultimately delivering fair-priced electricity to the Nation's consumers. Aspects of the bilateral model exist in the RTO/ISO regions, particularly in the SPP and Midcontinent ISO. Also, several RTO/ISOs operate ancillary services markets and some run capacity markets designed to help ensure that total electricity resources will be sufficient to meet the immediate demand for electricity.

Wholesale electricity trade occurs through bilateral transactions, as well. These transactions vary in duration of contract, as well as in volume, daily timing, and duration of delivery. Trade differs regionally as a function of distinctive characteristics of regional grids. Bilateral trade volumes tend to be much larger than daily trade in ISO/RTO markets short-term markets.

There are many reasons that wholesale markets developed—from requirements for open-access transmission systems, which enable development of competitive power generation, to the need to value resources in more refined ways, which help ensure that system reliability is maintained across a broad spectrum of possible disruptive situations. For example, peak mitigation requires generators to perform differently than a traditional baseload production model might specify, and therefore, it may be more valuable than day-ahead committed baseload generation. Increasingly, frequency regulation is as important as peak mitigation, but frequency regulation methods may differ at the transmission level compared to the distribution level. For example, increasingly, distribution frequency regulation occurs at much faster millisecond speeds compared to transmission frequency regulation.

As noted, an array of new and evolving business models—aggregators, consumer generators, and an evolving generation mix—have emerged from the adoption and integration of new technologies and their associated economics. These developments are raising jurisdictional and market questions. For instance, at the bulk power (wholesale) level, short-run markets are deemed by regulators to be workably competitive, but concerns have been raised about the ability of short-run markets to address longer-term issues, such as ensuring that adequate capacity will be available when needed. Also, wholesale markets have successfully integrated independent generation into system operations, and efforts have been underway for some time to make individual DER providers (principally DR) and aggregators of DERs (also principally DR) active market participants. More visibility of and reliance on these potential resources is needed, however, to maximize their value.

At the local and utility level (retail), electricity choice markets that are intended to bring new services and lower prices to consumers have seen minor successes, and consumer demand for these services is a significant driver of change. Some states are exploring new structures that would open retail commodity trade to emulate wholesale markets. These models are under consideration in the State of New York, for instance, and are often referred to under the rubric Distribution System Operator models.

4.4.1 Organized Wholesale Markets and Reliability

Electricity production and delivery have traditionally been organized around large centralized power stations and high-voltage transmission lines. Power is shipped over long distances before voltage is stepped down to flow through distribution systems for delivery to consumers. This system often is referred to as the "bulk power system." Organized wholesale markets are structured to provide price discovery of wholesale electricity costs in the bulk power system. Costs relating to bulk power are more than half—and up to two-thirds—of most customers' electricity bill. The significance of costs to customers and the associated economic value of electricity to them is why the functioning of wholesale markets is so important to the overall operation of the electricity supply chain.

High-voltage transmission infrastructure tends to be much more networked than distribution systems. Networked infrastructure increases system resilience by enabling grid operators to reroute power flows when a single line or multi-line pathway is compromised. Transmission infrastructure already is

significantly automated (through such tools as Automated Generator Control and advanced SCADA systems) and information intensive. New tools, such as highly granular system visualization solutions, synchrophasors, smart relays, and smart inverters increase network resilience. While changing weather patterns and storm intensity are impactful, the structure of most transmission networks is already hardened against such disruptive factors. What remains to be addressed more comprehensively is how transmission grids can resist cyber incursions that could paralyze wide areas of a large-scale interconnect, such as the Western or Eastern Interconnection. These considerations were discussed in the preceding section.

Stakeholder input as part of the QER process, FERC dockets, National Association of Regulatory Utility Commissioner meetings, and other venues have consistently raised the following issues as part of ongoing grid operations and planning efforts: [154]

- The roles of mandatory capacity markets in PJM, ISO-New England, and parts of New York ISO
- The ability of bulk power markets, especially in RTO/ISO markets, to incentivize new generations in addition to natural gas and state-Renewable Portfolio Standard mandated renewables, thus helping with resource diversity, resource adequacy, and long-term decarbonization
- The incorporation of state policy and environmental goals in RTO/ISO markets
- The ability to integrate increasing wind and solar generation at lower costs, while allowing remaining traditional sources of generation to earn sufficient revenue to continue to provide needed generation and reliability services
- The ways to address the increasing changes occurring at the distribution level
- The continued evolution of transmission planning and seams issues between major bulk power market regions.

In addition to the issues noted above, analysis of markets with high volumes of VERs, notably California, point to emerging impacts, which eventually will affect other regions as their VERs increase as an overall share of the resource mix. It is in these emerging issues that new resilience and flexibility considerations come into focus. A 2014 study, "Investigating a Higher Renewables Portfolio Standard in California," which involved Los Angeles Department of Water and Power, Pacific Gas & Electric, Sacramento Municipal Utilities District, Southern California Edison Company, and San Diego Gas & Electric as sponsors. The study identified emerging operations and planning issues under a 50% RPS standard (note that CAISO already consistently handles up to 40% renewable resources on its system).[155] Concerns in the study included over-generation as a critical management challenge that occurs when "must-run" generation—non-dispatchable renewables, combined-heat-and-power, nuclear generation, run-of-river hydro, and thermal generation that is needed for grid stability—is greater than loads plus exports. The principal mitigation for over-generation in many current systems is curtailing renewable resource contributions to the overall resource mix. Future systems may increase the role of storage, DR, and flexibility to manage over-generation. Second, renewable resources can change supply patterns suddenly, and as the sun sets, significant solar production disappears, requiring a need for fast ramping generation to fill in for lost solar resources.

The study also found that a variety of integration solutions can reduce the cost of a high renewable scenario. Improvements in regional coordination—which address jurisdictional challenges when state regulation cannot reach beyond state borders, and Federal regulation cannot easily reach into distribution systems—could improve integration. DR, especially advanced practices that increase overall DR reliability, can support higher levels of VER integration. Energy storage is an important technology that must be developed and deployed as a key tool for VER impact mitigation. Finally, VER portfolio diversity is a key success factor as more VER volume impacts grids.

Resilience is an important transmission network matter, but its traditional treatment has occurred as part of ongoing, FERC-approved investments to meet NERC standards and to ensure reliable operations in regionally distinct conditions. The emergence of VERs and their growing contribution to resource mixes in some U.S. regions bring with them a need to more robustly differentiate reliability investments from resilience investments. As noted, resilience in transmission networks with high VERs requires behavioral changes in system operations, as noted above. In bulk power systems with wholesale market overlays, resolving valuation matters where curtailment of VERs is a valid resilience methodology is a serious matter. To avoid complex issues of how to compensate curtailed VERs adjustments in market designs and new market developments are required. For example, in California, one element in an overall VER management model is the Energy Imbalance Market created by CAISO, which involves PacifiCorp, a large multi-state utility based in the Pacific Northwest. These initiatives tend not to be considered resilience efforts when in fact they are important contributors to both system reliability and longer-term resilience in high VER systems. In short, as resource mixes change with decarbonization efforts of grid operators and power producers, the role of resilience grows more important as a distinct compliment to established reliability management investments and techniques.

4.4.2 The Role of Markets in Downstream Electricity Delivery Services

Presently, downstream electricity delivery services provided by investor-owned and public utilities—whether integrated with retail customer service or separated into wires operations and competitive retail services—do not function with organized "retail commodity markets" that emulate upstream wholesale markets. But, there are aspects of market mechanisms that impact grid operations and provide proxies for valuing various types of grid investments for reliability assurance, system flexibility, and network resilience. For example, some distribution systems allow net metering, which involves the sale of power from consumers to grid operators. Pricing of these services is based on state regulatory and ratemaking processes, not auction platforms like those used by ISOs/RTOs. Energy Service providers, retail competitors, and aggregators compete through various sales channels for consumers interested in controlling and/or reducing energy costs, deploying onsite power generation, and adopting microgrids that optimize sources and uses of electricity as an integrated onsite system.

Downstream electricity markets may not yet value commodity electricity in a manner that allows for effective pass-through of wholesale clearing prices in real-time to end-use consumers. Wholesale and retail linkages may develop over time; the New York Reforming the Energy Vision process and consideration of distribution system operator models may provide meaningful guidance for such evolution. Whether realized or not, under appropriate and necessary requirements for visibility of such generation, downstream electricity delivery services achieve enhanced resilience by systematically promoting and integrating advanced DR and energy storage solutions into local grid operations.

Similar to wholesale markets and resilience considerations, distribution system resilience measures can be enhanced by incorporating behavioral systems and processes into specific asset-based investments that harden systems against severe weather-related impacts, physical threats, and cyber-attacks.

4.4.3 Electricity Markets, Reliability, and Resilience

Reliability investments are typically incorporated into ratemaking processes in both investor-owned and public utility institutions. Supplementary investments for recovery from outage events also are handled through established ratemaking processes. Resilience requirements tend to be valued as contributions to reliability and incorporated as part of ratemaking processes. These processes are more easily executed in structures that are traditional end-to-end, vertically integrated electricity delivery services; other market

structures complicate reliability and resilience investment decision-making. Short-run markets may not provide adequate price signals to ensure long-term investments in appropriately configured capacity. Also, resource valuations tend not to incorporate superordinate network and/or social values such as enhancing resilience into resource or wires into investment decision making. The increased importance of system resilience to overall grid reliability may require adjustments to market mechanisms that enable better valuation.

4.5 Grid Operations Planning and Resilience

Resilience of the electricity system is increasingly important. Recent weather extremes, climate change impacts, physical security and cybersecurity threats, and a changing workforce have added to the challenges faced by electric utilities, prompting industry to develop new multidisciplinary all-hazards approaches for managing these issues and making the grid more resilient.

Resilience Measures Expedited Restoration after Hurricane Matthew[156]

Hurricane Matthew began impacting the southeast United States on Thursday, October 6, 2016, and the flooding caused by the storm continues to affect North Carolina and South Carolina. The initial effects of the storm were felt from Florida to Virginia, with increased rain and wind causing damage to energy infrastructure. Industry efforts to restore that damaged infrastructure are ongoing and have involved mutual assistance from utilities from across the country. More than 99 percent of customers who lost power had their power restored within 8 days, by 11:00 a.m., on October 14, 2016.

Florida Power and Light has invested $2 billion over the last 10 years, leveraging $200 million in Federal investment through the American Recovery and Reinvestment Act of 2009, to advance smart grid functionalities with technologies, such as advanced smart meters, distribution automation, and advanced monitoring equipment, for the utility's transmission system. Early damage assessments suggest that investments in resilience measures expedited Florida Power and Light's restoration timeline; without these new technologies and functions, it is estimated that restoration efforts would have taken 10–15 days. Florida Power and Light reports that 98 percent of the 1.2 million customers who lost power had their power restored within 3 days.

Government, industry, and the various state energy offices helped coordinate the national effort to restore power following the storm. Government responders helped industry crews access impacted areas, facilitated waivers requested by utilities to use unmanned aerial systems for damage assessments, and provided energy-sector situational awareness reports that informed decisions about where to place limited Federal and state resources. Government responders remained in Georgia, as well as North Carolina and South Carolina, providing assistance until restoration was complete. The response effort built on lessons learned from Hurricane Sandy of 2012.

Resilience enhancement initiatives are generally focused on achieving at least one of three primary goals: (1) preventing or minimizing damage to help avoid or reduce adverse events; (2) expanding alternatives and enabling systems to continue operating despite damage; and/or (3) promoting a rapid return to normal operations when a disruption occurs (i.e., speed the rate of recovery). Resilience relates both to system improvements that prevent or reduce the impact of risks on reliability and to the ability of the system to recover more quickly.

Unlike reliability, there are no commonly used metrics for the resilience of the electric grid, and threats to system resilience are typically associated with disasters or high-intensity and low-frequency events. An additional complication is that the responsibility for maintaining and improving grid resilience lies with multiple entities and jurisdictions, including Federal and state agencies and regulatory bodies, as well as multiple utilities. For investments in electricity sector resilience, approval is generally up to the discretion of state public utilities commissions or equivalent bodies, which are balancing competing, more near-term

interests. Furthermore, from the societal perspective, building resilience of critical infrastructure to future disasters involves decision making that also considers social, cultural, and environmental issues, which have both qualitative and quantitative value, from a risk assessment standpoint.[157] Therefore, building resilience to disasters depends upon close coordination among multiple entities, which have varying approaches to measuring electricity system performance and outcomes for society.

Perhaps most relevant is the underlying barrier to prioritizing investments in reliability and resilience that utilities and regulators face.[158] There is no established method for quantifying the benefits of investments, which depend on the occurrence of some events with low probabilities. One exception to this is an order recently released by the New York State Public Service Commission;[159] however, there is a clear need for a set of commonly used methods for estimating the costs and benefits of reliability and resilience investments.

4.5.1 Real-Time Electricity System Monitoring Enhances Situational Awareness

Maintaining situational awareness is an important aspect of overall resilience management in service to maintaining high electricity system reliability. Utilities rely on field personnel to assess and report grid system conditions through site inspections. During emergency situations, utilities' abilities to assess and communicate system status after a large disruption tend to be significantly degraded. Where there is a widespread disruption beyond electricity infrastructure damage, personnel may be responding to a specific emergency situation, which limits work scope. Transportation challenges, such as road blockages and traffic, may also prevent the movement of utility personnel and equipment to assess electricity infrastructure throughout the affected area. Furthermore, wide communication system outages will also limit utilities' ability to assess system conditions. These initial assessment limitations then impede response and recovery planning.[160]

When distribution-level SCADA pairs with a distribution management system, operations can be conducted remotely, increasing the speed at which a utility can identify and locate faults on the distribution system and restore service, as well as manage voltage and reactive power to reduce energy losses and integrate distributed generation and storage technologies.[161]

Analyses of the August 2003 Northeast blackout concluded that it was preventable and that the reliability of the U.S. and Canadian power systems needed an immediate and sustained focus on investments in technologies to promote "situational awareness" and adequate responses to major disturbances.[162] New institutional structures and processes were developed to coordinate information among power pools for improved coordination across systems and across NERC regions for improved coordination of system resource adequacy requirements.

4.5.1.1 Grid Operations and Communications Redundancy

With the increasing interdependence between communications and electricity, redundancy in communications systems is essential to continuity of grid operations. Some utilities have expanded satellite communications capabilities with mobile satellite trailers that can be deployed to field staging areas and include full capabilities for email, Internet, outage management systems, voice-over Internet protocol telephones, and portable and fixed satellite phones. Others have redundant and diversely routed dedicated fiber-optic lines to enable continued operations.[163, 164]

4.5.1.2 Dynamic Line Rating Systems for Transmission Systems

Current transmission system operations rely on fixed ratings of transmission line capacity that are established to maintain reliability during worst-case conditions (e.g., hot weather). Line ratings may also

be reduced if ambient conditions are abnormally hot and still. There are times when the conditions associated with establishing line ratings are not constraining, and transmission lines could be operated at higher usage levels. Dynamic line rating systems help operators identify available real-time capacity and increase line transmission capacity by 10 percent–15 percent. Dynamic line rating systems can help facilitate the integration of wind generation into the transmission system.[165] This real-time information about overhead conductors can help further enhance situational awareness, while simultaneously providing economic benefits. Incremental investments that increase the capacity of the existing transmission system can provide a low-cost hedge, as well as enhanced real-time awareness. However, economic, financial, regulatory, and institutional barriers limit incentives for regulated entities to deploy these low-capital cost technologies that could increase transmission capacity utilization.[166] NERC has an important role to play in setting relevant standards, which would drive increased operational focus on dynamic line ratings as part of overall response and recovery planning and execution.

4.5.2 Information Collection and Sharing Can Mitigate Threats to the Grid

The Federal Government has established programs and launched pilots to analyze cyber and physical threat information, share information with industry, and provide technical assistance to state and utility decision makers in their mitigation efforts. The electric sector utilizes resources and participates in these programs, while also collaborating with one another through industry-led initiatives.[y] While several Federal programs facilitate the sharing of threat information with industry, challenges remain with respect to the Federal Government's ability to provide data quickly enough to be useful. Several factors limit timely and effective exchange of information, including human delays in sharing information, procedural barriers related to classified information, and liability and privacy concerns from industry.

One particular challenge is that some government intelligence on threat indicators and vulnerabilities is classified, preventing power sector owners and operators who lack the appropriate security clearances from accessing relevant information. Many sector owners and operators and Federal employees often lack the security clearances to access this information.

Another important information gap is a national repository for all-hazard event and loss data, which would help utility regulators, planners, and communities analyze and prioritize resilience investments. In 2012, the National Academy of Sciences recommended the establishment of such a database[167] to support efforts to develop more quantitative risk models and better understand structural and social vulnerability to disasters.

4.5.3 The Grid and Emergency Response

As not all hazards to the grid can be prevented, local authorities and stakeholders focus on failing elegantly and recovering quickly. Response options can leverage existing capabilities, tools, and equipment to act immediately before, during, and after a disruptive event. Emergency response resources can be provided by public and private sectors and can include mobile incident management and command centers, mutual aid agreements, and access to specialized materials.[168]

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[y] For example, in 2011, Edison Electric Institute, in conjunction with private-sector experts and its member utilities, initiated the Threat Scenario Project to identify threats and practices to mitigate these threats. Identified threats included coordinated cyber attacks, as well as blended physical and cyber attacks. The project established common elements for each threat scenario, including likely targets, potential threat actors, specific attack paths, and the likely impacts of a successful attack. Edison Electric Institute, "EEI Business Continuity Conference Threat Scenario Project (TSP)," (presentation, April 4, 2012), 1, http://www.eei.org/meetings/Meeting_Documents/2012Apr-BusinessContinuity-Treat%20Scenario%20Project_Engels.pdf.

A utility's power restoration and business continuity planning includes year-round preparation for all types of emergencies, including storms and other weather-related events, fires, earthquakes, and other hazards, as well as cyber and physical infrastructure attacks. A speedy restoration process requires significant logistical expertise, skilled/trained certified workers, and specialized equipment. Utility restoration workers involved in mutual assistance typically travel many miles from different geographic areas to help the requesting utility to rebuild power lines, replace poles, and restore power to customers.[169]

Lessons Learned from Severe Outages[170, 171, 172]

After the immediate response to manage the adverse effects of an event, recovery activities and programs take place to effectively and efficiently return operating conditions to an acceptable level. This may entail restoring service to the same level as before the event or stabilizing service to a new normal. Recovery measures usually consist of longer-term remediation measures and include access to critical equipment, municipally owned utility activation, and after-action reporting that would make the grid more resilient to future disruptions.

Hurricane Sandy (and Katrina in 2005) caused significant damage to critical national energy infrastructure and stressed Federal capabilities to protect and restore critical infrastructure. In the aftermath, the White House and Federal Emergency Management Agency (FEMA) conducted detailed analyses of the Federal response to identify challenges and lessons learned and to make recommendations for future disaster preparedness and response efforts. Several common themes emerged about response and recovery:

Ensure mutual aid in the utility sector. In response to Hurricane Sandy, electric utilities mobilized the largest-ever dispatch of mutual aid workers (totaling approximately 70,000), primarily from the private sector but including some government workers.

Grant energy sector restoration crews the appropriate credentials to enter damaged work zones and have priority for fuel distribution. In the storm response, some energy sector repair crews were designated as first responders, giving them priority access to fuel and expediting travel into affected areas. However, not all energy infrastructure repair crews had this status or access. After Hurricane Sandy, the Department of Energy's (DOE's) Office of Electricity Delivery and Energy Reliability recommended that electrical workers, as well as refinery and terminal repair crews, be given appropriate credentials to enter damaged work zones quickly.

Coordinate Emergency Support Function (ESF) 12 functions across Federal agencies. ESF-12, under the National Response Framework, is an integral part of the larger DOE responsibility of maintaining continuous and reliable energy supplies for the Nation through preventive measures and restoration and recovery actions in coordination with other Federal Government and industry partners. In the "Hurricane Sandy FEMA After-Action Report," FEMA noted that ESF-12—coordinated by DOE—struggled to fully engage supporting Federal departments and energy sector partners in addressing energy-restoration challenges. A DOE report on the response to Sandy recommended that DOE permanently deploy DOE/ESF-12 responders to the states and regions so they could provide on-the-ground situational awareness of energy disruptions, establish relationships with State and local energy sector partners, and gain first-hand system knowledge to better coordinate energy preparedness efforts with state and local public and private sector partners.

State governments play a major role in coordinating and directing response and recovery efforts to electricity disruptions. These responsibilities received a boost through DOE grants to states and local governments to support a State Energy Assurance Planning Initiative. Grants were awarded under this initiative in 2009 and 2010 to 47 states, the District of Columbia, 2 territories, and 43 cities.[173] The grants were used over a 3–4-year period to improve energy emergency preparedness plans and to enable quick recovery and restoration from any energy supply disruption. States also used these funds to address energy supply disruption risks and vulnerabilities, with the aim of mitigating the devastating impacts that such incidents can have on the economy and on public health and safety.[174]

Each state under the Energy Assurance Planning Initiative was required to track energy emergencies, to assess the restoration and recovery times of any supply disruptions, to train appropriate personnel on energy infrastructure and supply systems, and to participate in state and regional energy emergency exercises that were used to evaluate the effectiveness of their energy assurance plans. States were also required to address cybersecurity concerns and to prepare for the challenges of integrating smart grid technologies and renewable energy sources into their plans. Because of the initiative, nearly all state and territory governments and select local governments have Energy Assurance Plans in place. A review of the State Energy Assurance Plan was recommended to occur every 2 to 3 years, and to date some states have undertaken update efforts.[175]

4.5.4 Back-Up Power and Spare Transformers for Emergency Response

During outages and emergencies, fast but safe system recovery is the mission of a utility. Part of the effort to maintain service while power is being restored involves the use of back-up power along with speedy deployment of equipment spares that may have failed.

Back-up power sources can be used to bypass existing distribution service lines until they are restored, and they are used by customers in lieu of utility service. Critical facilities, such as hospitals, maintain robust back-up power systems. Microgrids offer islanding solutions for large facilities and campuses by their integration of DG, storage, and demand side management solutions. According to an Argonne National Laboratory report, "One hundred percent of the following assessed facility groups have an alternate or back [-up] power in place: Banking and Finance; Critical Access Hospitals; Private or Private Not-for-Profit General Medical and Surgical Hospitals; State, Local, or Tribal General Medical and Surgical Hospitals."[176] More than 75 percent of other users, including manufacturing, wastewater, hotels, arenas, retailers, offices, and law enforcement offices, also maintain some form of alternate or back-up power source.[177] Critical data centers and server centers also have robust back-up systems that enable islanding from the impacts of grid failures.

It is also important to ensure that key grid components are available in the event of emergencies. Utilities have robust supply chains and inventory management systems that help ensure that spare transformers, including the stocking of interchangeable spare transformers,[178] the ordering of conventional spares in advance, and the early retirement of conventional transformers for use as spares. Conventional spares are typically used for planned replacements or individual unit failures; but these transformer spares can also be used as emergency spares. Under this approach, the spares are identical to those transformers that are to be replaced and often stored at the substation next to existing transformers—which allows for quick energization without the transformer being moved. The close proximity of such spares to the existing transformers can lead to potential high-intensity and low-frequency physical attacks or weather events. Some utilities retain retired transformers to repurpose them as emergency spares.[179] These are transformers that have retired but not failed, which would allow their use as temporary spares until a new transformer is manufactured and transported.[180] Utilities also use mobile transformers and substations to temporarily replace damaged assets, much in the way that mobile power is used for resilience and repowering efforts.

Nuclear Regulatory Commission Requirements

The Nuclear Regulatory Commission has issued several cyber and physical security regulations for nuclear power plants covering cybersecurity plans, response and recovery strategies from aircraft crashes, and training for security personnel, among other measures. For example, 10 Code of Federal Regulations § 73.54 stipulates that licensees provide "…high assurance that digital computer and communication systems and networks are adequately protected against cyber-attacks…" Each nuclear power plant must submit a cybersecurity plan and implementation schedule, which is then reviewed by the Nuclear Regulatory Commission.[181] Additionally, the Nuclear Regulatory Commission is also required to conduct "force-on-force" exercises at nuclear power plants at least once every three years. These security exercises deploy a mock adversary force attempting to penetrate a plant's critical locations and simulate damage to target safety components. These exercises provide an evaluation of power plant security and identify deficiencies in security strategy, plans, or implementation. When these deficiencies are identified, additional security measures must be promptly implemented.[182] These regulations have led to significant investments by nuclear power plant operators.

Some utilities retain retired transformers to repurpose them as emergency spares. These are transformers that have retired but not failed, which would allow them to be used as temporary spares until a new transformer is manufactured and transported.[183] Utilities also use mobile transformers and substations to temporarily replace damaged assets. "A mobile substation includes a trailer, switchgear, breakers, emergency power supply, and a transformer with enhanced cooling capability. These units enable the temporary restoration of grid service while circumventing damaged substation equipment, allowing time to repair grid components. Mobile transformers are capable of restoring substation operations in some cases within 12–24 hours."[184]

Finally, utilities preparing for response after cyber disruptions are also taking measures to build redundancies for cyber infrastructure. Some of these measures include building back-up control centers for full functionality and developing independent, secured control mechanisms that would provide limited vital functions during an emergency.[185] NERC CIP standards require utilities to maintain back-up energy management systems to manage bulk electric system generation and transmission assets.[186]

4.5.4.1 Equipment Constraints on Speedy Restoration: Large Power Transformers

The shortage of critical electrical equipment can cause significant delays for power restoration. Specifically, the loss of multiple large power transformers (LPTs) may overwhelm the system and cause widespread power outages, possibly in more than one region, increasing vulnerability and the potential for cascading failures.

Replacement of multiple, failed LPTs is a challenge, due to the cost and complex and lengthy process involving the procurement, design, manufacturing, and transportation of this equipment. These processes can take months, depending on the size and specifications of the needed LPTs, even under an accelerated schedule and normal transportation conditions. Utilities mitigate the risk of losing LPTs through several strategies, including adopting measures to prevent or minimize damage to equipment, purchasing and maintaining spare transformers (conventional spares), identifying a less critical transformer on their system that could be used as a temporary replacement (provisional replacement transformer), and/or setting up contracts to procure a transformer through a mutual assistance agreement or participation in an industry sharing program.

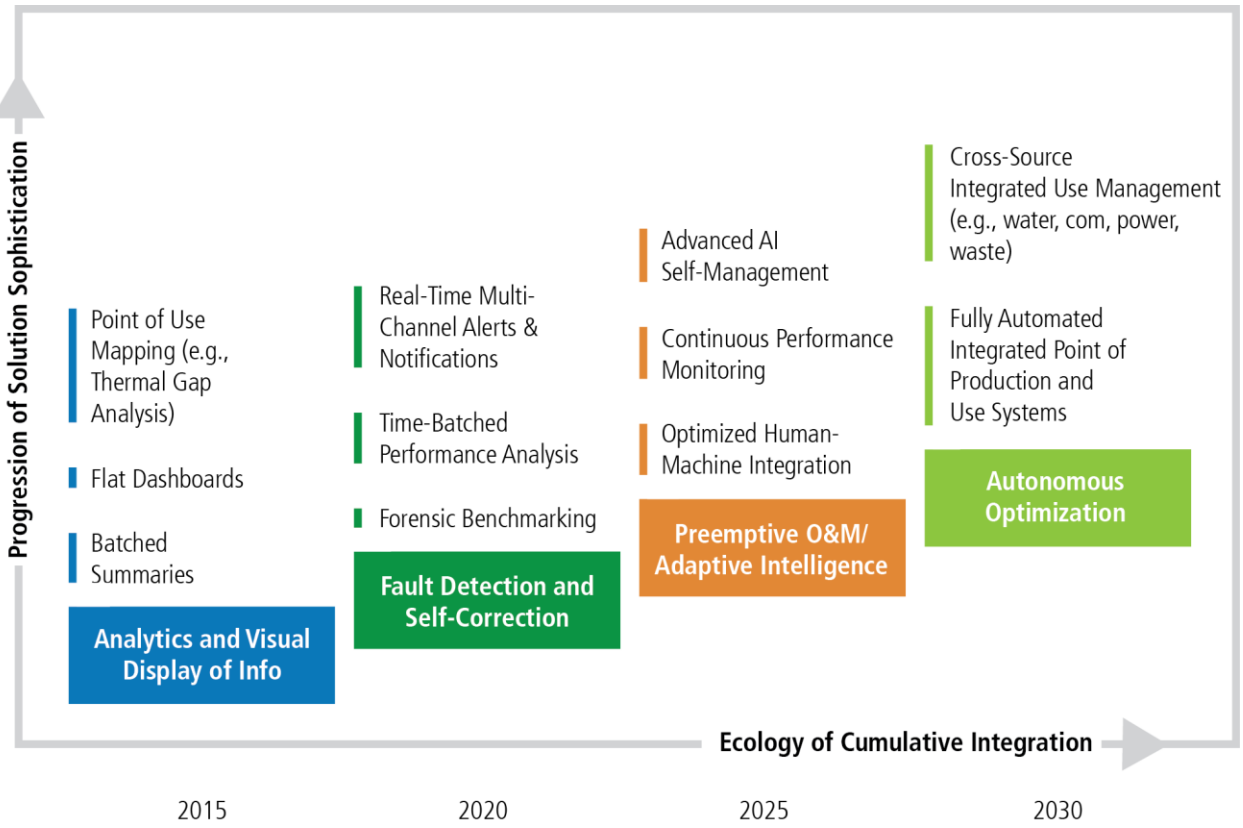
There are currently three key industry-led, transformer-sharing programs in the United States—NERC's Spare Equipment Database program, Edison Electric Institute's Spare Transformer Equipment Program, and SpareConnect. Another program, Recovery Transformer, developed a rapidly deployable prototype transformer designed to replace the most common high-voltage transformers, which DHS successfully funded in partnership with Electric Power Research Institute and completed in 2014.[187] As of December

2016, three additional programs—Grid Assurance, Wattstock, and Regional Equipment Sharing for Transmission Outage Restoration (commonly referred to as RESTORE)—are in development. QER 1.1 recommendations noted that DOE should "analyze the policies, technical specifications, and logistical and program structures needed to mitigate the risks associated with the loss of transformers."[188] In December 2015, Congress directed DOE to develop a plan to establish a strategic transformer reserve in consultation with various industry stakeholders in the FAST Act. To assess plan options, DOE commissioned Oak Ridge National Laboratory to perform a technical analysis that would provide data necessary to evaluate the need for and feasibility of a strategic transformer reserve. The objective of the study was to determine if, after a severe event, extensive damage to LPTs and lack of adequate replacement LPTs would render the grid dysfunctional for an extended period (several months to years) until replacement LPTs could be manufactured. DOE's recommendations will be published in the report to Congress in early 2017.

4.5.5 Grid Analytics and Resilience

Both grid reliability and resilience increasingly depend on highly granular data about what is happening on grids in real time. Data analysis is an important aspect of today's grid management, but the granularity, speed, and sophistication of operator analytics must increase as greater distribution system complexity occurs. Regional differences may matter, but the core analytic engines that must be developed and configured for grid operator use will be the same across regions and systems.

Figure 4-13. Information Drives Solution Sophistication, which Drives New Benefit Realization for Grids[189]



Grid information systems are expected to evolve over time, growing increasingly autonomous and self-managing. Increased autonomy and self-management also involves increased system integration, which amplifies the complexity systems and requires a degree of human-machine interdependence that is unprecedented for grid operations.

4.5.6 Smart Grid and System Resilience

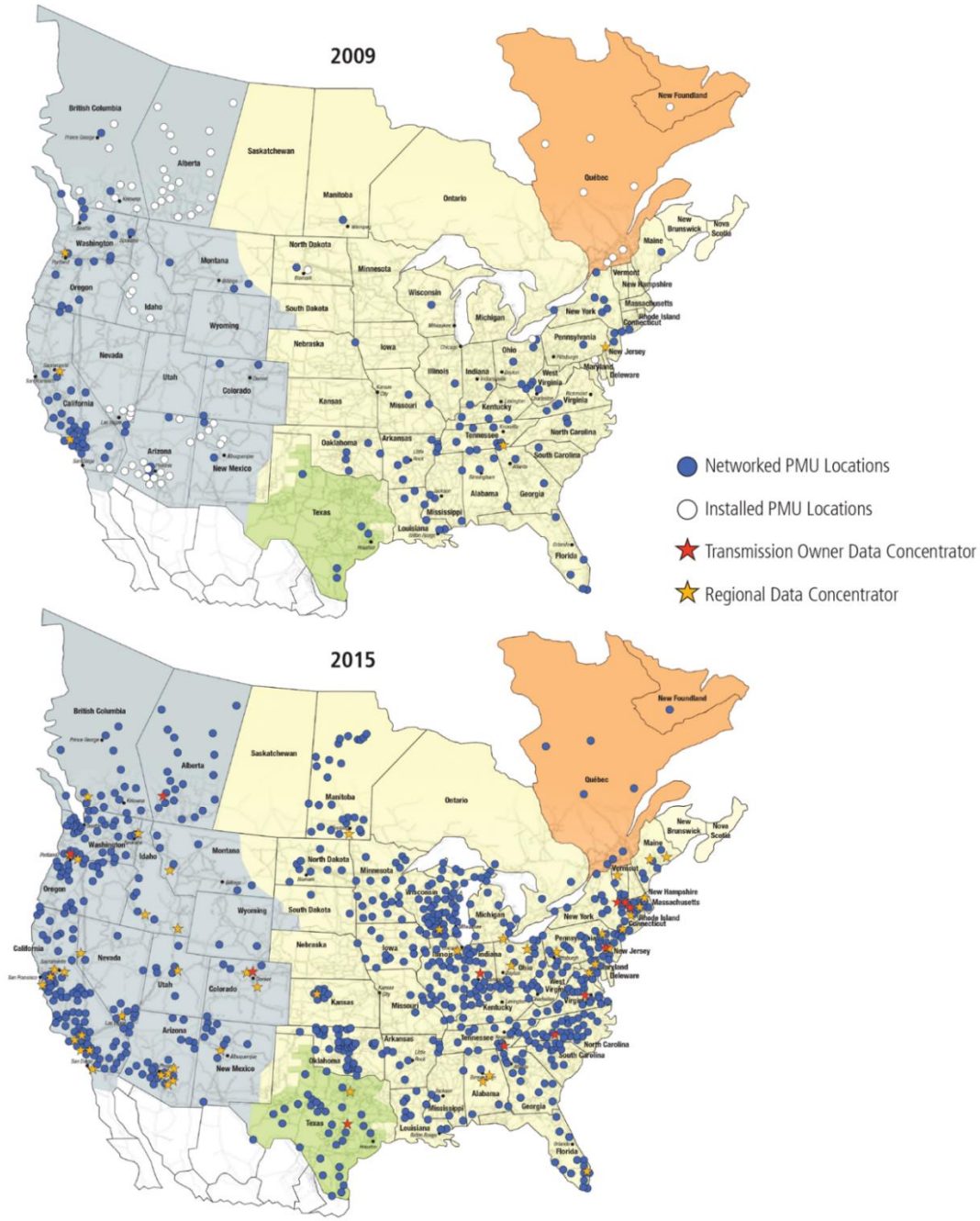
The installment and implementation of advanced meters and smart grid technology can make significant contributions to system resilience. Advanced smart grid systems can be used to expedite information flow; remotely monitor demand, performance, and quality of service; enhance system efficiency; and improve outage detection and restoration by identifying the location and description of damaged equipment. Real-time system monitoring can support hourly pricing and reactive power and/or DR programs, which allow utilities to make same-day operational decisions, near-term forecasts, and scenario evaluations. Historical data, coupled with predictive modeling of extreme weather events and the related effects on electric infrastructure, can also be used to inform management decisions, identify areas of greatest risk, ascertain system vulnerabilities, allocate resources, and help prioritize investments.

Still, system managers need better real-time information about system trends and changes, including the growth in VERs, the rise of the "prosumer," two-way electricity and information flows, and real-time load management data—which means that demands on and expectations of SCADA systems are only increasing. Grid modernization requires changes in operational systems and processes, and in the way that system planners design for grid evolution. Critical to smart grid realization is systems engineering to determine the requirements for ICT infrastructure, which includes how latency factors (communications delays) and bandwidth requirements are embedded in operations to accommodate the proliferation of intelligent assets from relays to whole substations to automated customer DR controls that grid operators can access and use.

Fortunately, as the complexity of the electricity system increases, so do computer- and network-based capabilities. The growing electricity-ICT interdependence is enabled in part by new technologies, such as sensors and software that can provide greater situational awareness of grid conditions and operational efficiencies (although much more work is needed).[190] Large volumes of data are, however, unwieldy, and developing additional ways to translate data into usable and timely information is essential. Networks are evolving to include cloud computing and IoT technologies to help reduce costs, increase efficiencies, and increase system integration.[191, 192] Smart meters, synchrophasors, and other devices have also been deployed across the grid. Even electromechanical devices, like voltage regulators, are adopting digital control interfaces.

On transmission networks, SCADA systems traditionally have been used to monitor and control power systems by measuring grid conditions every 2 to 4 seconds. Synchrophasor technology, which addresses the lack of situational awareness provided by conventional instrumentation, uses high-resolution phasor measurement units (PMUs) that provide time-synchronized data at a rate of more than 30 times per second to detect destabilizing network oscillations that would otherwise be undetectable. Strategically located PMUs connected by high-speed communications networks provide grid operators with wide-area visibility to better detect system disturbances, improve the grid's efficiency, and prevent or more quickly recover from outages. In 2009, there were 166 PMUs in the United States—there are now over 1,700 PMUs located around the country (see Figure 4-14).[193] The impact of this deployment is that it now takes 16 milliseconds for PMUs in the Western Interconnect to send signals over a dedicated fiber-optic system to transmission operators in control centers throughout the system—a system that covers western North America from Mexico to western Canada, from east of the Rockies to the Pacific Ocean.

Figure 4-14. Phasor Measurement Units, Technologies that Enable Superfast Network Management across Large Interconnected Systems, Are Being Deployed to Improve Grid Operations[194]



Note the concentration of phasor measurement units (PMUs) in regions and interconnected systems where ISOs and RTOs dominate transmission service. PMU deployment can be interpreted as a first mover in the development of smart grids and as evidence that upstream transmission systems are advancing more consistently and at a faster pace toward smart grid realization than local distribution systems, although recent rate cases and public utility budgets for larger investor-owned utilities and public power indicate that smart grid investments are beginning to ramp up quickly. However, it should not be assumed that PMU deployment at the distribution level will mirror that at the transmission level because distribution smart grid deployment is much more complex in scale and scope. Note that the Western Interconnect is in gray.

The electricity sector has also been relying on a variety of redundant communications networks for operations since its inception. Internet Protocol-based communications (networking) systems—whether fiber-optic, radio, or other means for conveying data—can be owned by utilities or provided by telecommunication firms. Utilities have invested heavily in these ICT networks over the last decade, in part spurred by funding Congress provided through ARRA. Roughly one-third of customers are connected to the distribution grid by the 60 million smart meters that serve as an essential building block to grid digitization.[195] Smart meters send data to utility control systems every 15–60 minutes through communications networks and can provide information back to customers in real time, often through the Internet. These meters enable remote meter reading, connections, and disconnections, and they allow for improved outage management and restoration. During Superstorm Sandy, smart meters reduced PECO Energy's restoration time by 2–3 days. Florida Power and Light has developed a tablet-based application for its field crews using AMI and geographic information systems data to improve emergency response; this was recently used to increase the speed of power recovery after Hurricane Matthew. Smart meters have an additional benefit—they give customers price information that enables them to respond to market conditions and reduce their electricity bills.States and RTOs/ISOs will continue in their traditional regulatory roles as the system evolves. Given the increasing technical sophistication of grid operations, state regulatory staff may need additional support from the Federal Government in evaluating technical proposals from utilities as they seek to modernize their grids. Of concern are grid security standards across distribution delivery services. Proactive planning should be considered, as well as emergency response. The impetus to invest in mitigation and preparedness may only occur following a catastrophe, but proactive investments can prevent catastrophe and ultimately benefit ratepayers in the long term. However, distribution utilities face various challenges to implementing cybersecurity measures, including outdated legacy equipment, budgetary constraints, workforce readiness, and technology availability. Recent electricity response exercises demonstrate the nascent status of coordinated industry and government efforts to jointly respond to potential cyber incidents. The electricity industry has a long history of employing mutual assistance agreements to recover from most disruptions, and the Nation would benefit from the development of appropriate mechanisms for addressing cybersecurity disruptions.

4.5.6.1 Underinvestment in Research, Development, Demonstration, and Deployment, and Implications for System Resilience

This chapter has emphasized the importance of resilience to overall grid reliability. From an investment perspective, high grid reliability is a key factor in the treatment by investors of utilities (both public and private) as low risk investments with predictable returns. Analysis suggests that in an increasingly complex grid management environment, more focused investments are needed to ensure continued high system reliability and resilience. Future investments must focus on innovations that help mitigate new sources of system disruption, including VERs, extreme weather, and physical and cyber attacks; these investment must occur in an environment that does not necessarily favor increased utility funds being used for research, development, demonstration, and deployment (RDD&D).

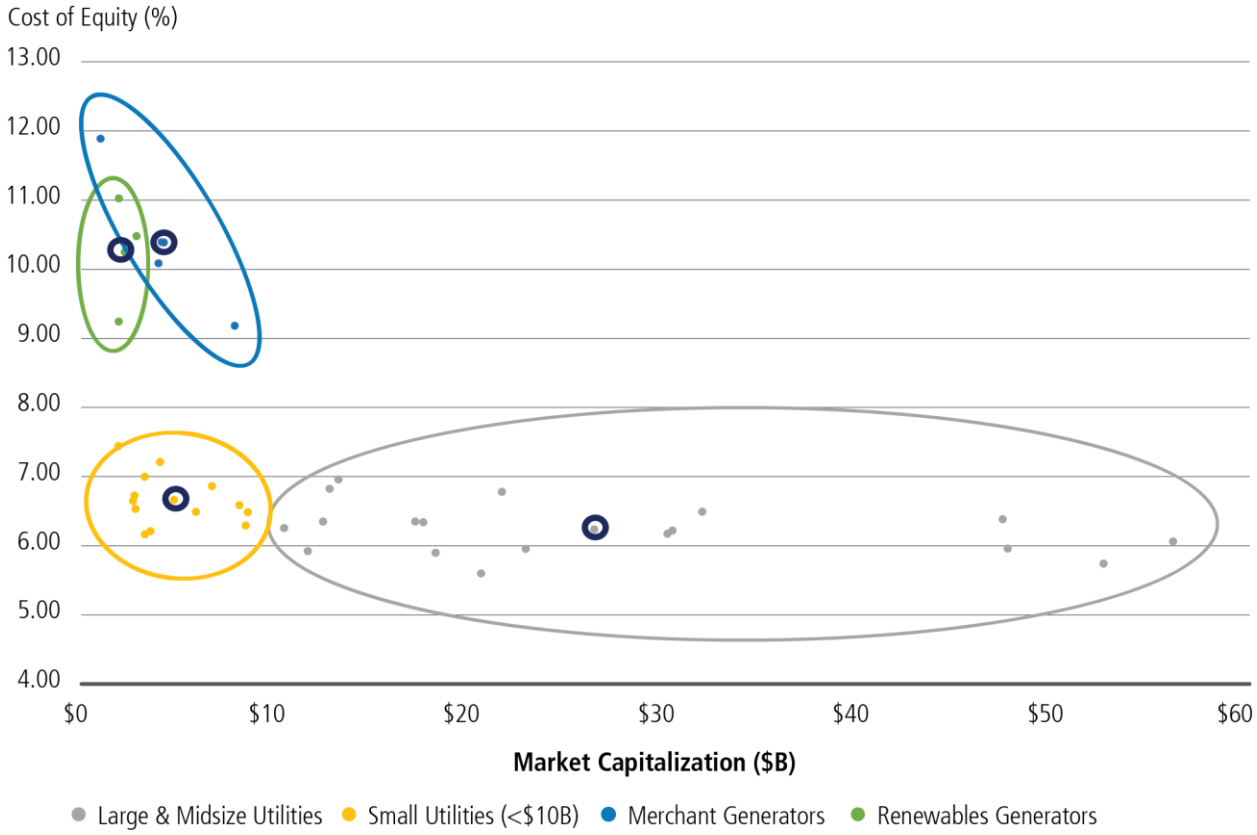
Despite existing RDD&D funding and activity in the electricity sector, there is systemic underinvestment in RDD&D of technologies, as described in 3, *Building a Clean Electricity Future.* Also, private industry serving the electricity sector lacks incentives for investments in infrastructure resilience, in part, due to uncertainties in emerging risks.[196] Utilities acquiring resilience assets and solutions face rate proceedings that have an inherently conservative perspective on new technologies and approaches, which limits the ability to test new approaches in a timely manner and move to deploy successful efforts at an accelerated pace compared to traditional electricity sector norms. The lack of incentives, and preference for existing methods, constrains the innovation options that are pursued and tested, then enter the innovation

process supply chain. These characteristics drive the need for additional Federal RDD&D opportunities to improve the resilience of electricity systems, as well as system security, rapid response, and recovery from disruptions.

Entities that operate distribution systems—the grid components most critical to reliability, security, and resilience—operate almost universally on the basis of cost-of-service. The combination of stable revenues and low operational risk enables these entities—investor-owned utilities, Munis, Coops, and other entities—to acquire capital at lower rates (see Figure 4-15). Investors view these entities as relatively low-risk investments compared with other electricity sector opportunities that face more competitive pressures.

As the operational characteristics of the industry evolve, traditional utility returns may not be compelling for investors, if sector transformations cause utilities to take on more or different types of risks. New types of regulatory structures may be needed to provide appropriate incentives to plan for an increasingly uncertain and more complex risk environment, as well as incorporate new approaches and technologies, which enable the kind of resilience investments that may be needed but not otherwise funded.

Figure 4-15. Cost of Equity by Company Type and Size for Sampled Power Sector Companies[197]



Regulated utilities, with their predictable revenues and low risks, tend to be viewed as safe investments, exhibiting a low cost of equity compared to the rest of the sector. As the industry addresses increasing risks and uncertainties, existing regulatory structures may evolve to meet risk appetite.

4.5.7 Planning Is Essential for System Reliability and Resilience

The responsibility for maintaining and improving grid reliability and resilience resides with a complex mix of entities with overlapping and sometimes inadequate jurisdictional responsibilities, which include Federal and state agencies and regulatory bodies, regional and national reliability organizations, and multiple utilities with various business models.

There are many existing planning platforms for reliability planning that are well understood by utilities, stakeholders, and other responsible entities. New, value-added planning contributions can help grid operators make tradeoffs among multiple investment options, strengthen the system, and help ensure resilience and reliability, which are needed for transforming a dramatically changing electricity system. Rigorous tradeoff analysis implies and includes rigorous risk analysis. Planning elements that should be added to existing platforms to accommodate system changes, challenges, threats, and opportunities include the following:

- Regional integrated resource planning that includes both T&D
- Integration of end-to-end options for optimal resource mix and operational integrity into existing planning
- Analyses with proposals for how to mitigate vulnerabilities.

In many parts of the country, investor-owned utilities conduct integrated resource planning in accordance with state requirements that were established through legislation or regulatory actions. While more than half of states in the Nation have integrated resource planning requirements, other states have adopted "Long-Term Procurement Planning" or other similar processes.[198, 199] Only a small number of distribution utilities conduct planning[200] in response to state policies,[201] aiming to increase resilience to extreme weather events or stressful system conditions. Also, with few exceptions, very few utilities take emerging threats from climate[202, 203] or cyber attacks into consideration when conducting integrated resource planning and distribution planning.[204]

In most cases, cybersecurity efforts are often funded out of the overall rate base. This means that funding for cybersecurity comes at the expense of profit or other investment needs, which may have a disproportionate budgetary impact on smaller distribution utilities. In rarer cases, distribution utilities have a separate security recovery factor in their rate structure.

4.5.7.1 Integrated Planning Considerations

The changing role of the consumer that drives the transformation of distribution also drives a need for new distribution planning approaches and tools to effectively integrate DERs into the grid and to understand the benefits and costs for developing forward-looking investment plans. New solutions like smart inverters bring important issues to center stage, like whether such solutions can be fully valued prior to deployment. Because consumer preferences and needs are changing faster than the pace of grid planning, there may be misalignment of operating circumstances. Whatever investments are planned are likely to require revisions as actual events diverge from what is planned in advance. Continued and rapid changes on the customer side of the meter may require adjustments in regulatory processes to assist grid owners and operators in keeping systems up to date.

Methods are under development in leading states (e.g., California and New York) to incorporate DERs, and the growing role of ; “prosumers” -- consumers that produce power for the grid; and third parties into the distribution system planning processes. Important considerations for the development if such methods should include hosting capacity of distribution feeders for DERs and probabilistic DER growth scenarios, as well as balance utility investments in system upgrades versus the services provided by DERs

(e.g., in energy supply, supply/load balancing, storage, and support of both frequency and voltage regulation). These planning processes will need sufficient transparency to permit all stakeholders, including DER service providers, to participate in supporting long-term capacity and energy requirements. Contractual provisions between utilities and DER service providers will need to be established to ensure grid reliability and security, which might benefit from the development of standard offer DER contracts. As capacity and energy are increasingly being delivered at the distribution system level, distribution- and transmission-level planning will need to be integrated.

4.5.7.2 Integrated Probabilistic Planning as an Emerging Tool

Typically, reliability decisions are based on a deterministic, binary decision—a new facility is approved if it resolves a violation of a reliability standard. In contrast, economic decisions are based on a scenario framework, where the expected value of a facility is evaluated across a range of likely scenarios. The changing system topology, uncertain regulatory frameworks, decentralized market decisions, and evolving vulnerabilities introduce economic and reliability uncertainties and risks that cannot be adequately assessed through a deterministic framework.

Probabilistic risk assessment (PRA) methodologies offer a framework to consider underlying uncertainties and risks. PRA methods in transmission planning are still at a research stage and are not implemented widely. Currently, PRA is used to model topological changes, such as variations in renewable generation levels; variations in load level due to weather and DER output; generation and transmission equipment performance; variations in hydro-generation; and physical threats like weather.[205] However, considerable barriers to implementation of PRA approaches in transmission planning include the following:

- Tradition of planning for worst-case scenarios using a deterministic approach
- Lack of industry-wide accepted approach for reliability indices in PRA framework
- Lack of standardization and availability of historic reliability data
- Lack of qualified workforce, skillset, and awareness of PRA approaches
- Lack of modeling tools for implementing PRA methodologies
- Lack of commercial tools for system security assessment under PRA framework.[206]

4.5.8 The Grid of the 21st Century

The electricity sector's long history is one of managing continuous, albeit slow, change while sustaining the same high reliability year in and year out. The stock of the sector is incrementally refreshed as needed, but changes highlighted in this chapter and other chapters of QER 1.2 call attention to several factors that place new emphasis on the sector's effort to sustain high reliability, security, and resilience.

A transformed 21st-century grid is likely to be one that invests more in flexibility and resilience to achieve the same desired outcome that is the prime directive of grid operators—sustained, high-service reliability. How the grid is managed depends on the capabilities built into the stock of assets that make up the end-to-end supply chain, but managing real-time operational flows also requires specific systems and processes to continuously succeed. The complexity of grid operations requires grid control tools that enable granular visibility and certain operational algorithms that help grid operators stay on top of second-to-second and millisecond-to-millisecond changes. The era of enhanced grid operations through artificial intelligence is here. Execution, however, must occur in a context that assiduously assures deflection of cyber attacks that could cripple grids; it must also occur through market mechanisms to help value and ensure cost-effective outcomes.

State and Federal regulatory bodies and policymakers play key roles in helping ensure system integrity, safety, and the ongoing financing of the electricity sector. Planning, which is central to ensuring long-term

stock and flow integrity, must evolve as the sector itself evolves. More robust modeling, improved risk analysis, and better optimization realization at the two-way interface of information and energy flows between consumers and grid operators are important improvements that are likely to be significant contributors to enabling a transformation that ensure today's service reliability and quality can continue, if not improve.

This is the state of sector grid management as the Nation continues its march deeper into the 21st century. The scope of transformation required to adapt to new security concerns, coupled with the organic evolution of a sector that is qualitatively changing as consumers have more direct and indirect influence on grid reliability, are non-trivial costs that must be financed and paid for. There are many ways to facilitate transformation and assist grid operators and other stakeholders in the sector in adapting to the sector's changing physical and cyber "topography." QER 1.2 turns now to addressing the "how to" question in the final chapter, where recommendations designed to assist the Nation in maintaining a highly reliable electricity sector are mapped for consideration by policymakers and sector leaders alike.

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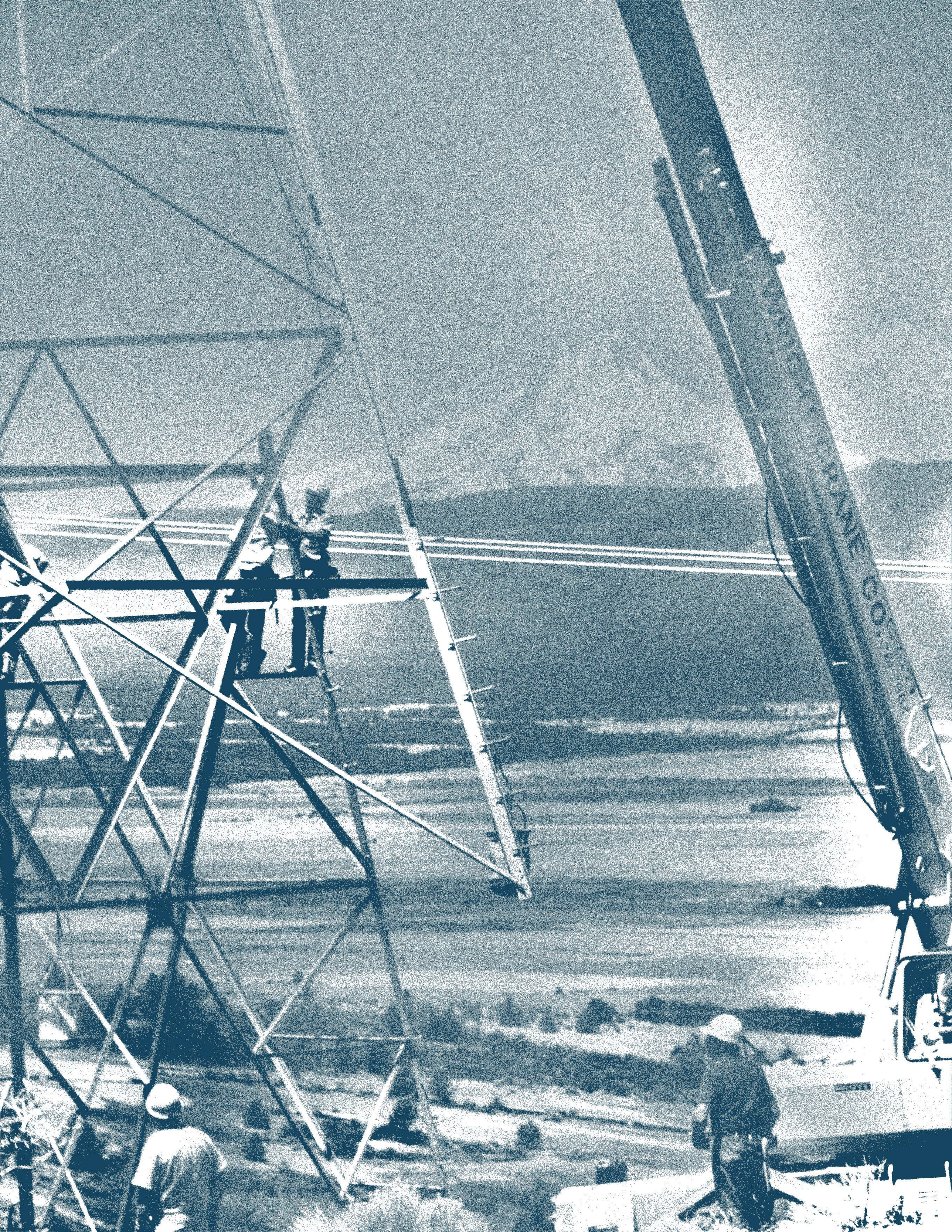
[206] EPSA Analysis: ICF International, "Transmission Analysis: Planning, Operations and Policy," forthcoming.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V The Electricity Workforce: Changing Needs, New Opportunities

This chapter provides an overview of current and projected employment in and related to the electricity sector, and it discusses options to assist workers and develop a workforce that has the skills to build, maintain, and operate the electricity system of the future. The chapter begins with an overview of the current workforce and key trends that have shaped employment in this sector. It then discusses the demographics of the sector, including the underrepresentation of women and minorities in employment and leadership. Next, the chapter identifies challenges to replacing retiring workers, the incompatibility of available worker skills and electricity workforce needs, and possible approaches to developing a skilled workforce for future sector demands.

Key Findings

The broader changes in the electricity industry have created both new opportunities and new challenges for the electricity industry workforce. Opportunities include new workforce potential in the renewable energy industry and information and communications technologies; challenges include the skills gap for deploying and operating new technologies, the shift in the geographic location of jobs, and the need to recruit and retain an inclusive workforce. The electricity industry is the dominant consumer of coal, natural gas, and renewable energy technologies, so changes in electricity industry demand for these resources can cause regional and sectoral dislocations in these industries. Each industry has distinctive workforce skills requirements and geographic concentrations, so employment gains in one industry do not always translate to opportunities for workers affected by employment loss in other industries that may be geographically distant and require different skills.

- Over 1.9 million people are employed in jobs related to electric power generation and fuels, while 2.2 million people are working in industries directly or partially related to energy efficiency.[1]
- Job growth in renewable energy is particularly strong. Employment in the solar industry has grown over 20 percent annually from 2013 to 2015. From 2010 to 2015, the solar industry created 115,000 new jobs. In 2016, approximately 374,000 individuals worked, in whole or in part, for solar firms, with more than 260,000 of those employees spending most of their time on solar. There were an additional 102,000 workers employed at wind firms across the Nation. The solar workforce increased by 25 percent in 2016, while wind employment increased by 32 percent.[2]
- The oil and natural gas industry experienced a large net increase in jobs over the last several years, adding 80,000 jobs from 2004 to 2014.[3] Unlike coal production, natural gas production is projected to increase over the coming decades under a business-as-usual scenario, sustaining natural gas industry employment.[4, 5]
- Employment in the natural gas industry is regionally and temporally volatile; 28,000 jobs were lost between January 2015 and August 2016.[6] Shifts in locations pose challenges for employees and the economies of the areas where they live and work.[7]
- Between 1985 and 2001, coal production increased 28 percent as industry employment fell by 59 percent due to efficiencies gained by shifting production from Appalachia to the West.[8, 9] In 2015, annual coal production was at its lowest level since 1986, and it is forecast to continue declining over the coming decades.[10, 11]
- Aside from a minor employment increase from 2000 to 2011, 141,500 domestic coal jobs were lost between 1985 and 2016, and the industry shrank by 60 percent. As of November 2016, according to BLS data, the coal mining industry employs about 53,000 people.[12,a]
- Despite ongoing economic challenges in the Appalachian region, the non-highway appropriated budget for the Appalachian Regional Commission (ARC), a Federally funded regional economic development agency, has fallen from roughly $600 million in the early 1970s to around $100 million in the 1980s and remained roughly constant until 2016. The ARC budget recently increased from $90 million in fiscal year 2015 to nearly $150 million in fiscal year 2016.[13]
- The Abandoned Mine Lands Reclamation Fund's (AML Fund's) inability to fully support the reclamation of lands disrupted by the coal mining industry has the potential to leave communities in regions with declining local revenues with polluted and unsafe lands and few means to repair the damage. The AML Fund's increased ability to support coal mine reclamation would provide local employment opportunities and help coal communities transition to new industries.
- The continued fiscal difficulties of coal miner pensions threaten the solvency of the Pension Benefit Guaranty Corporation, a Federal agency that insures private-sector pension funds and is funded out of insurance premiums paid by member funds.
- Proliferation of information and communications technology and new technologies like distributed generation, smart home devices, and electric battery storage have led to new businesses and employment opportunities, which will require a wide array of new skills.[14]

[a] The 2017 *U.S. Energy and Employment Report* records 74,084 jobs for Coal Fuels employment in March 2016. The BLS data from November 2016 is relied upon here to illustrate both the recent trends and the historical record over many decades.

- The electricity industry will need a cross-disciplinary power grid workforce that can comprehend, design, and mange cyber-physical systems; the industry will increasingly require a workforce adept in risk assessment, behavioral science, and familiarity with cyber hygiene.[15,16]
- A dip in the number of electricity industry workforce training programs in the 1980s contributed to a currently low number of workers in the electric utilities able to move into middle and upper management positions—creating a workforce gap as the large number of baby boomers retire.[17]
- Workforce retirements are a pressing challenge. Industry hiring managers often report that lack of candidate training, experience, or technical skills are major reasons why replacement personnel can be challenging to find—especially in electric power generation.[18, 19]
- Electricity and related industries employ fewer women and minorities than the national average, but have a higher proportion of veterans.[20, 21] Only 5 percent of the boards of utilities in the United States in 2015 include women, and approximately 13 percent of board members among the top 10 publicly owned utilities were African American or Latino.[22, 23] Underrepresentation in or lack of access to science, technology, engineering, and mathematics educational opportunities and programs contribute to the underrepresentation of minorities and women within the electricity industry.
- From 1995 to 2013, the number of injuries per 100 employee-years in the electricity utility industry decreased from 4.7 to 1.3.[24] However, line workers continue to experience hazardous working conditions. In 2014, electrical power line installers and repairers suffered 25 fatal work injuries—a rate of 19 per 100,000 full-time equivalent workers, which is over five times the national fatal work injury rate.[25]
- While data on energy sector workforce are improving, there are still major shortcomings in the data availability, precision, and categorization of energy sector jobs.[26]

5.1 A Modern Workforce for the 21st Century Electricity Industry

The evolving demands on the electricity industry are causing a number of workforce challenges for the electricity industry, which include large shifts in skills needed and in geographic location of jobs, a skills gap for deploying and operating newer technologies, changes occurring during a period when the industry is facing high levels of retirements, and challenges recruiting and retaining a workforce that reflects the gender and racial diversity of the Nation. At the same time, the evolution of the industry is also creating a number of new workforce opportunities, including jobs in renewable energy, natural gas, and information and communications technology (ICT).

The electricity sector's full potential will only be realized if its workforce is able to appropriately adapt and evolve to meet the needs of the 21st-century electricity system. A skilled workforce that can build, operate, and manage this modernized grid infrastructure is an essential component for the sector's development. Addressing the workforce challenges identified here will create well-paying jobs that contribute to the economic health of local communities, support the increased use of efficiency technologies, reduce injuries and improve worker safety enable employees in the electricity industry to support a modernized 21st-century energy system, and ensure a resilient electricity system.

This chapter provides an overview of the composition of the electricity industry workforce, as well as the challenges the sector faces in maintaining an adequate and skilled workforce for the 21st-century electricity system. This chapter further examines how qualities and characteristics of the electricity workforce are shifting in light of the ongoing transformation of the energy sector, and it provides an overview of how industry and government action can respond to challenges facing the industry.

5.2 Overview of the Electricity Industry Workforce

The electricity system depends on a workforce that fills a diverse set of jobs—from the coal miner extracting fuel from the ground for electricity generation, to the utility worker repairing a distribution line, and everything in between. The following section provides an overview of the number and types of jobs related to the electricity industry.

5.2.1 Workforce Size

The Bureau of Labor Statistics (BLS) reports that nearly half a million people are employed in electric power generation, transmission, and distribution (see Table 5-1).[27] Of the 290,000 employees in the electric power transmission and distribution subsector, over a quarter million are employed with distribution companies. There are an additional 600,000 jobs in extraction and mining industries, though only a portion of those jobs are directly attributable to the electricity industry.[28]

Table 5-1. Direct Employment and Income in Industries Related to Electric Power Supply as Tracked by BLS, 2015[29]

Industry Sector/Subsector	Jobs	Percent Related to Electricity Industry	Average Annual Income
Electric power generation	192,000	100 percent	$116,000
Electric power transmission and distribution	290,000	100 percent	$99,000
Electric power total	482,000	100 percent	$106,000
Coal mining[b]	71,000	~80 percent	$82,817
Oil and gas extraction[c]	540,000	~10 percent to 20 percent	$113,022
Mining and extraction total	611,000	Unknown	$110,000

More than 80 percent of the coal mined in the United States goes to power production.[30] The oil and gas extraction sector is not subdivided and includes many non-power uses. About 35 percent of the natural gas and roughly 1 percent of petroleum usage in the United States is for power production.[31]

In addition to the 482,000 jobs in the electric power generation, transmission, and distribution subsectors, BLS reports that 169,000 people are employed in the Power and Communication Line and Related Structures Construction industry. Some of these employees work constructing transmission lines, substations, and power plants.[32]

The electricity industry is a dynamic industry with changing sources of employment and job categories. As a result, the direct employment figures captured by the BLS job categories provided in Table 5-1 do not include all employment related to the electricity industry, particularly those related to construction, solar, wind, and energy efficiency workers.[33] In 2015, the Department of Energy published the first edition of the *U.S. Energy and Employment Report* (USEER), which provided a broader depiction of electricity industry employment than the BLS data based on supplemental employment surveys. A second edition of the USEER, published in January 2017, finds that about 862,000 people are employed in jobs related to electric power generation. Another 1,082,746 are also employed in jobs related to fuels extraction and mining, although not all of these are directly attributable to the electric power sector (see Table 5-2).

[b] Includes supporting North American Industry Classification System (NAICS) industry categories
[c] Includes supporting NAICS industry categories

Table 5-2. Electric Power Generation and Fuels Extraction and Mining Employment Estimates by Technology, First Quarter 2016[34]

Technology	Electric Power Generation (Employment Estimates)	Fuels Extraction and Mining (Employment Estimates)
Hydroelectric	65,554	-
Coal	86,035	74,084
Natural Gas	88,242	309,993
Nuclear	68,176	8,592
Solar	373,807	-
Wind	101,738	-
Geothermal	5,768	-
Bioenergy	7,980	104,663
Oil	12,840	502,678
Combined Heat and Power	18,034	-
Other	32,695	82,736
Total	**860,869**	**1,082,746**

The *U.S. Energy and Employment Report* (USEER), provides a broader accounting than the BLS data presented above, and finds that as of the first quarter of 2016, over 800,000 people were employed in the electric power generation industry, most of which are related to the construction and buildout of new solar and wind generation capacity. Another 1,082,746 are also employed in jobs related to fuels extraction and mining, although not all of these are directly attributable to the electric power sector. As noted above over 80 percent of coal, 35 percent of the natural gas, and merely 1 percent of petroleum usage in the United States is for power production. [35]

USEER finds that the BLS estimates are particularly low for jobs associated with solar, wind, geothermal, and biomass electric power generation.[36] These low estimates result from classifying many jobs in these industries as construction or business and professional services employment. For instance, most solar company installers are classified as electrical contractors.[37]

Though BLS does not estimate employment in energy efficiency jobs, USEER found that 2.2 million people are working in industries directly or partially related to energy efficiency—more than 2.5 times the number employed by electric power generation. Of those 2.2 million, 1.4 million are in the construction industry.[38] Energy efficiency employment includes both the production of energy-saving products and the provision of services that reduce end-use energy consumption. However, USEER estimates only include work with efficient technologies or building design and retrofits. They do not capture employment related to energy-efficient manufacturing processes. If process efficiencies were included, estimates for the energy efficiency workforce would be even larger.

5.2.2 Skills and Training

The electricity industry offers diverse jobs, which require a variety of skills. Table 5-3 includes job descriptions and educational requirements for selected job categories across the utility portion of the electricity industry. Traditional jobs, such as lineman, will continue to be needed, but the increase of renewable energy, as well as an increased ICT component to the electricity industry, will change the skillset required for many jobs in the electricity system of the 21st century.

Table 5-3. Typical Electricity Workforce Roles and Required Education or Training[39]

		Required Education						
Job Category	**Job Description**	**High School**	**Vocational**	**Apprenticeship**	**Associates**	**Bachelors**	**Masters**	**Doctorate**
Lineman	Responsible for the installation and repair of overhead and underground distribution and transmission lines, poles, transformers, and other equipment.	■	■	■				
Power Plant Operator	Responsible for the maintenance and operation of all primary and auxiliary equipment required to generate electricity or meet natural gas customers' demands.	■	■		■	▨		
Technicians (Transmission and Distribution)	Responsible for the repair of both electrical and mechanical equipment. This includes inspecting and testing electrical equipment in generating stations and substations.	■	■		■	▨		
Technicians (Generation)	Responsible for the construction, assembly, maintenance, and repair of steam boilers and boiler house auxiliary equipment.	■	■		■	▨		
Pipefitters and Pipelayers (Generation)	Responsible for the installation and maintenance of pipe systems and related equipment for steam, hot water, heating, sprinkling, and industrial production and processing systems.	■	■		▨			
Power Engineers	Focus on electrical systems, equipment, and facilities rather than on mechanical systems and other non-electrical systems involved in electric and natural gas energy services. It includes people involved in planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation, transmission, distribution, consumption, and control of electricity.					■	■	▨
All Other Engineers	Focus on non-electrical systems, processes, equipment, and facilities involved in electric energy services. It includes people involved in the planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation/supply, transmission, distribution, consumption, and control of electricity.					■	■	▨

The electricity workforce includes several job categories, each with specific educational requirements (shown in orange). The striped orange boxes show where a specific level of education is sometimes required or infrequently required.

One ongoing challenge for maintaining the electric industry workforce is the amount of time required to train new workers. For example, training to become a journeyman line worker can take up to 7 years.[40] if enrollment in apprenticeships and training programs increases during a period of worker shortage, the new employees would not be prepared for the full range of line worker duties for several years.[41] The electricity industry appears to have made progress on maintaining a pipeline of skilled labor; the number of pre-apprenticeship training programs has more than tripled since the 1990s.[42, 43] Furthermore, skilled workers

coming from related industries—such as construction electricians—may not require as much training and would be ready for duty in a shorter timeframe.

In addition to the electricity workforce job categories shown in Table 5-3, the electricity industry also employs thousands of corporate services employees engaged in jobs such as customer service, finance, management, and human relations. Skills required in these jobs are often more transferable between industries and require less specialized electricity industry training.

Training Programs in the Electricity Industry between the 1980s and Today

The economic outlook of an industry often determines the availability of training programs. During the 1980s and 1990s, the electricity industry experienced much lower demand growth than the decade before. A conservative outlook on demand growth coupled with an increased focus on productivity in anticipation of impending industry deregulation led utilities to scale back hiring and internal training programs.[44]

The 1980s and 1990s also coincided with a shift away from technical education as the primary tool to train the next generation, toward a larger emphasis on four-year college programs. This shift further decreased the interest in technical and vocational training, previously a main pillar of education for the electricity industry workforce, which led to the closure of many technical high schools, shrinking the pool of available applicants for the electricity industry even further.[45] The future workforce is now educated through a variety of means, including community colleges, apprenticeship programs, and certificate programs. This has led to a lack of uniformity of standards and curricula, which is a challenge for electric companies, as they often have to retest skills to ensure that applicants have the necessary education. While the 2000s have seen a rebuilding of some of the training and apprenticeship programs, the dip in training programs in the 1980s contributed to fewer workers in middle management in the electric utilities—creating a gap as the large number of baby boomers retire.[46]

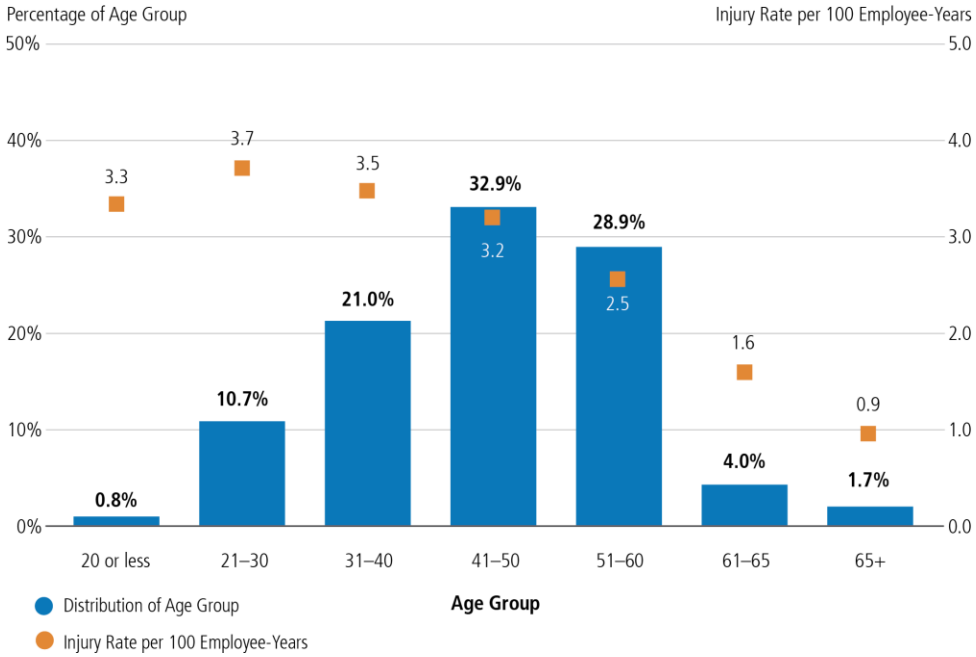
5.2.3 Electricity Utility Worker Health and Safety

The electricity industry has made progress in improving workplace safety. From 1995 to 2013, the number of injuries[d] per 100 employee-years in electricity utilities decreased from 4.7 to 1.3.[47] In 2015, the workplace injury rate across electricity generation, transmission, and distribution companies was slightly more than half the national rate.[48] However line workers continue to experience hazardous working conditions. In 2014, electrical power line installers and repairers suffered 25 fatal work injuries—a rate of 19 per 100,000 full-time equivalent workers, which is over five times the national fatal work injury rate.[49]

For electricity utility workers, the injury rate is highest among the 21–30-year-old age group at 3.7 percent (see Figure 5-1). This segment only makes up 10.7 percent of the sector workforce, but has higher rates of injury due to "fewer years of experience and a higher proportion of young workers employed in higher risk occupations, performing physically demanding or higher risk tasks."[50]

[d] Injury rates reported here are for injuries resulting in a worker missing at least one full day of work after the injury date.

Figure 5-1. Injury Rates and Employee Age Group Distribution for Electricity Utilities, 1995–2013[51]



Overall injury rates are highest among the 21–30-year-old group, although employees between 41 and 50 years of age comprise the largest group of employees, with 32.9 percent.

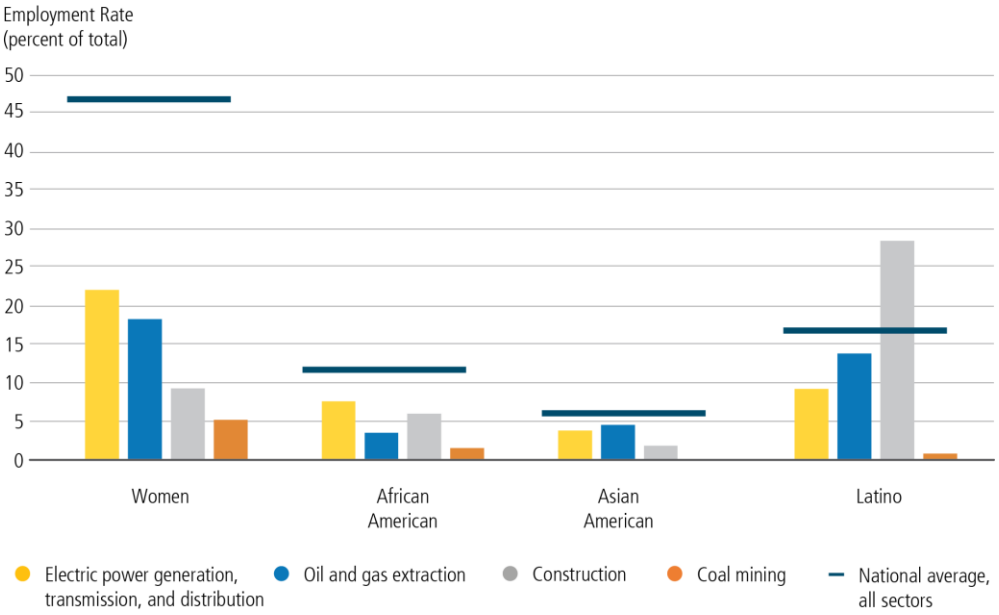
Injury rates for electricity utilities are not only unevenly distributed by age group, they also differ regarding the nature of the job. Welders, line workers, and meter readers accounted for the highest proportion of injuries among all electricity power sector occupations.[52] The specific causes of worker injuries and fatalities can be generally grouped into four categories: a misunderstanding or non-compliance with safety concepts, poor communication, absence of leadership, and/or lack of experience and qualified employees.[53]

As the electricity sector modernizes, there may be opportunities to leverage technological advances to improve worker safety and reduce rates of injury. New equipment, processes, and infrastructure design can complement innovations in training practices to improve workplace safety in the electricity industry through reducing electrical exposures, instances where utilities deploy crews and trucks, as well as instances where crews work at elevated heights.

5.2.4 Electricity Industry Workforce Inclusion

The electricity and related resource extraction industries employ fewer women and minorities than the national average (see Figure 5-2). Women constitute 22 percent of the electric power generation, transmission, and distribution industry workforce, compared to 47 percent of the entire workforce. African Americans constitute just 8 percent of the electricity workforce but are 12 percent of the workforce as a whole. Oil and gas extraction, construction, and coal mining industries employ even fewer women and African Americans. Asian Americans are not statistically represented in the coal mining industry, and again, lag the national average for the other industries surveyed here. Latino employment in the construction industry is the only minority demographic that is higher than the national average for the population groups and industries included here.[54]

Figure 5-2. Electricity and Related Industry Employment Demographic Indicators, 2015[55]



The electricity industry ranks far below the national average in employment of women, African Americans, Asian Americans, and Latinos. The oil and gas extraction and coal mining industries have similar demographic characteristics. The construction industry, where energy efficiency jobs are mostly located, has a higher percentage of employment of Hispanic or Latino Americans.

The lack of diversity in the electricity industry extends to the executive level as well—only 5 percent of the boards of utilities in the United States in 2015 include any women, and approximately 13 percent of board members among the top 10 publicly owned utilities were African American or Latino.[56, 57]

Veterans make up a slightly higher proportion of electricity industry jobs than their representation in the national workforce. A recent study found that veterans make up 8 percent of the current workforce and 10 percent of new hires across the electricity utility, natural gas utility, and nuclear energy industries.[58] The solar industry employed an estimated 16,835 U.S. veterans in 2015, and the percentages of veterans working as solar manufacturers, solar installers, and solar project developers each exceeded the total percentage of veterans in the broader national workforce.[59]

Underrepresentation in or lack of access to science, technology, engineering, and mathematics (STEM) educational opportunities and programs contribute to the underrepresentation of minorities and women within the electricity industry. For instance, African American and Latino students are critically underrepresented in STEM programs in high schools and colleges, and STEM education is often necessary for entry into many positions in the electricity sector. Two-thirds of public high schools with a majority of African American students do not offer calculus, and more than half do not offer physics.[60] These curriculum deficits result in lower STEM college graduation rates among underrepresented communities. In the 2013–2014 school year, African Americans and Latinos received only 7.2 percent and 9.5 percent of all STEM bachelor's degrees, respectively.[61]

While the renewable portion of the electricity industry is seeing dynamic job growth, workforce inclusion in renewable energy also tends to lag behind the national average. Women represented 24 percent of the solar workforce, which is well below the national average workforce participation levels. However, the number of women in the solar industry has been steadily trending upward from 19 percent in 2013. This trend is reversed for African Americans and Latinos, who are trending downward, with African Americans comprising 5.2 percent of the solar workforce in 2015 (down from 5.9 percent in 2013) and Latinos

accounting for 11 percent of the workforce in 2015 (down from 16 percent in 2013). The number of veterans in the solar workforce is also trending downward—9.2 percent in 2013 and 8.1 percent in 2015, but it is still above the national average.[62]

5.3 Electricity Industry Workforce Challenges

The electricity industry is facing several changes that present challenges for maintaining a skilled workforce. New technologies require new and evolving skillsets for industry employees, as high levels of retirees take with them industry experience, and regional mismatches are emerging between the needed and available workforce. These changes could create skills gaps for the industry and workforce, as well as recruitment challenges in attracting appropriately trained and qualified employees. The time required to train new, qualified workers in the sector serves to limit the industry's ability to respond to rapid shifts in the workforce and limit the employment appeal to prospective employees faced with alternative career options. Workforce challenges facing the industry are exacerbated by the lack of robust, reliable data and by forecasts on industry needs and workforce supply—especially as business models evolve. Meanwhile, new technologies like distributed generation, smart home devices, and electric battery storage have led to the proliferation of many new business, job types, and employment opportunities. These new business models are expanding the definition of electricity industry jobs, and they present new workforce development challenges related to skills transferability and uniform safety and security practices and services.

The electricity system of the 21st century will require an adaptable and flexible workforce with additional areas of expertise and capabilities than the current workforce. The integration of variable renewable sources, storage systems, smart grid, and demand management will require new training and skillsets. Sector engineers need to have well-developed expertise in traditional topics such as electrical engineering, while also possessing knowledge of information technology, communications, and other relevant topics. Maintaining existing training programs for the legacy systems while also focusing on the skillsets of tomorrow's workers will be a unique challenge. As an example of these new workforce needs, the increased ICT component in the smart grid of the 21st century requires a wide array of new and different skills. [63]

With the issue of cybersecurity increasingly at the forefront of electricity industry concern, the industry will require a workforce adept in risk assessment and behavioral science, as well as familiar with cybersecurity risk factors.[64] A 2010 report from the President's Council of Advisors on Science and Technology, *Designing a Digital Future*, highlighted challenges stemming from the lack of a dedicated and trained cross-disciplinary power grid workforce that can comprehend, design, and manage cyber-physical systems (CPS).[65] In the future, the electricity industry faces dual challenges of growing a workforce with new requirements and qualifications, while also competing with other industries that are demanding CPS trained workers. Training, curriculum, and education in CPS remains nascent. The shortage of CPS-trained workers could place constraints on the evolution of the 21st-century electricity system. Addressing those ICT and sectoral skills challenges requires a strategic approach to talent management, focused on upgrading skills for existing employees and recruiting new employees with needed skills.

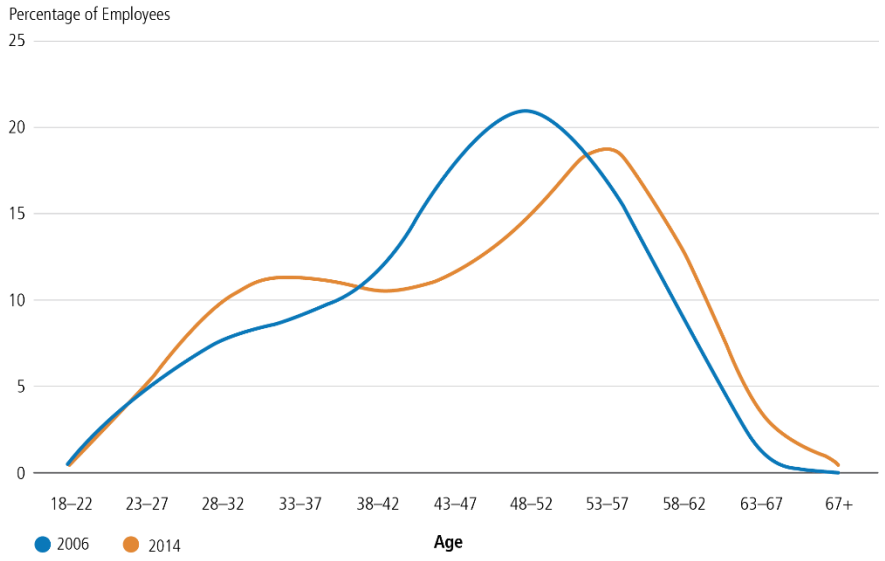
5.3.1 Electricity Industry Capacity Gaps

Much of the utility and electricity sector workforce is nearing retirement. The aging workforce of the electricity sector is not unique in the U.S. economy, yet its specific skills requirements and the importance of the industry to national security and economic prosperity elevate the importance of its workforce management. Electricity utility, natural gas utility, and nuclear generation industry surveys indicate that roughly 25 percent of employees will be ready to retire in the next 5 years.[66] Noting demographic trends within the industry, in 2006, the North American Electric Reliability Council (NERC) raised concerns about

worker and skills gaps among electricity industry employees, stating that "industry action is urgently needed to meet the expected 25 percent increase in demand for engineering professionals by 2015."[67] Spurred by this and other reports, the industry has pursued multiple initiatives and programs to address the looming increase in demand for skilled workforce.

Although the industry has made some progress on recruiting and developing the next generation workforce through hiring (see Figure 5-3), the capacity gap remains stubbornly persistent due to a workforce that continues to age, recruitment difficulties, a rapidly changing industry and specific training and certification needs.[68] A recent industry study forecasts the need for 105,000 new workers in the smart grid and electric utility industry by 2030, but expects that only 25,000 existing industry personnel are interested in filling those positions.[69] The remaining 80,000 employees in this supply-demand mismatch will need to be filled through recruiting and training. However, the industry is not expected to meet the forecasted need with its current recruitment and training rates.[70] In one recent survey, 43 percent of utilities surveyed stated that they see the aging workforce and the increased rate of retirements as one of their top three most pressing challenges.[71]

Figure 5-3. Age Distribution in Electric and Natural Gas Utilities in 2006 and 2014[72]



The age distribution in electric and natural gas utilities has shifted between 2006 and 2014, reflecting both the higher proportion of the workforce that is nearing retirement and industry efforts to address the aging workforce by hiring younger employees.

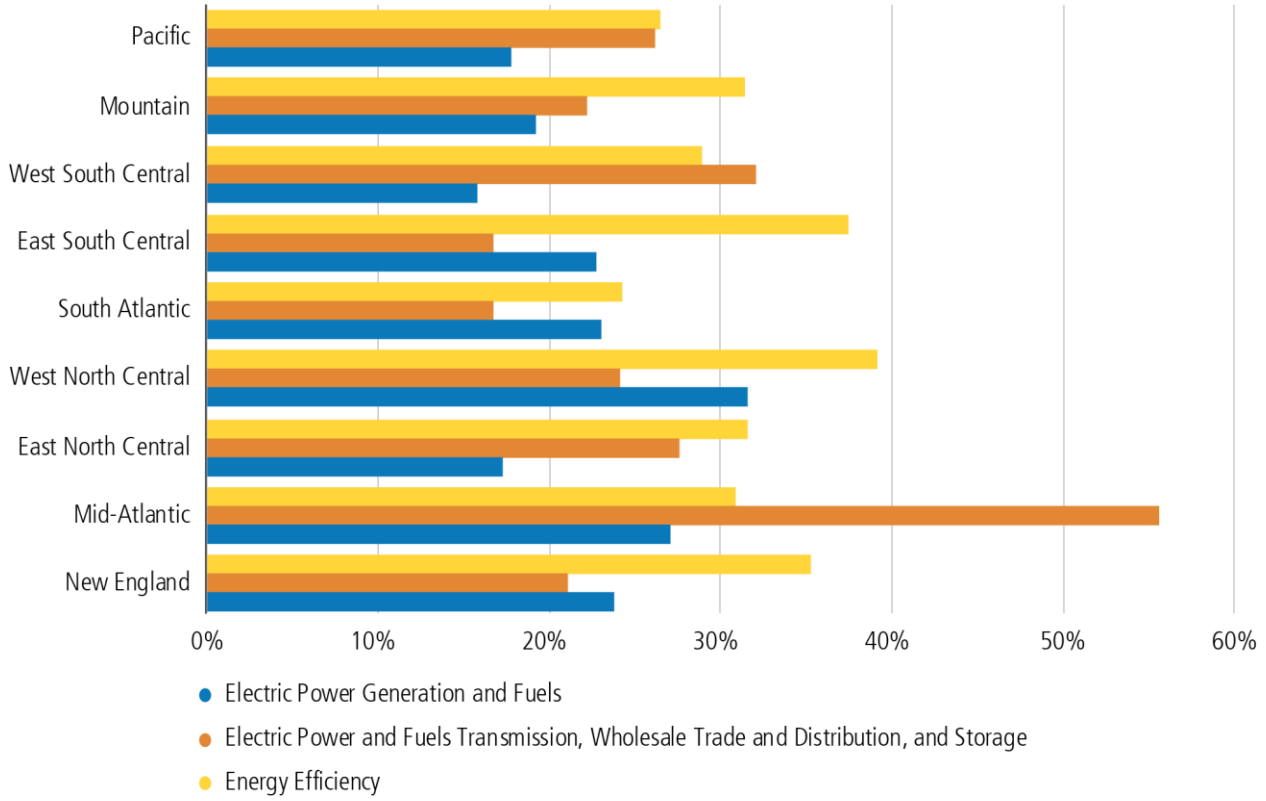
5.3.2 Electricity Industry Employee Recruitment Challenges

As workers retire, the electricity sector is experiencing challenges in hiring replacement personnel. Industry hiring managers often report that lack of candidate training, experience, or technical skills are major reasons why replacement personnel can be challenging to find—especially in electric power generation.[73] This lack of experience can, in part, be attributed to hiring slow-downs in the 1990s and 2000s that have resulted in a current shortage of mid-career professionals with the experience to take on supervisory roles (see "Training Programs in the Electricity Industry between 1980 and Today" textbox).[74]

According to survey responses, over half of employers in the Mid-Atlantic region report very high difficulty with hiring in the electric power and fuels transmission, wholesale trade and distribution, and storage subsector, while no more than 32 percent of employers in other regions reported hiring difficulty in this field (see Figure 5-4). The Mid-Atlantic region, home to more than 40 million people and Washington, D.C.,

also reports among the highest rates of difficulty hiring in the energy efficiency and electric power generation and fuels industries.[75, 76]

Figure 5-4. Percentage of Employers Reporting Very High Hiring Difficulty by Census Region and Subsector (Q4 2015)[77]



Over half of employers in the Mid-Atlantic region report very high difficulty hiring in the electric power and fuels transmission, wholesale trade and distribution, and storage subsector, while no more than 32 percent of employers in other regions reported hiring difficulty in this field. The Mid-Atlantic also reports among the highest rates of difficulty hiring in the energy efficiency and electric power generation and fuels industries.

The employment supply and demand imbalance is already evident in the electric power transmission industry. One analysis finds that 10 states were experiencing a shortage of worker for electric power transmission in 2014. The same analysis projects that the number of states that will experience a shortage of worker supply will grow to at least 12 by 2018.[78]

5.3.3 Training Capacity and Timeline

One of the challenges for maintaining the electric sector workforce is the amount of time required to train new workers in order to respond to changing industry needs. Even if enrollment in apprenticeships and training programs increased today, sector employees would not be ready to enter the job market until several years from now. For example, initial training to become a fully educated lineworker is between 4.5 and 7 years.[79] And, due to the closure of many training programs in the 1980s because of lower need (see "Training Programs in the Electricity Industry between 1980 and Today" textbox), there is also a dearth of mid-career employees within the electricity sector that might otherwise fill these roles (see Figure 5-3).[80]

5.4 Electricity Industry Sectoral and Regional Variations, Training Opportunities

The electricity industry is the dominant consumer of coal, natural gas, and renewable energy technologies, so changes in electricity industry demand for these resources can cause separate regional and sectoral dislocations in these industries. Each industry has distinctive workforce characteristics, skills requirements, and geographic concentrations, which means that employment gains in one industry do not always translate to opportunities to workers affected by employment loss in other industries that may be geographically distant and require different skills.

In many cases, changes in the electricity industry result in new businesses and sources of employment, especially with the growth of natural gas production and the renewable energy industry. In other parts of the country where employment is heavily dependent on a single industry, like coal, the economic consequences of the shifts in the electricity industry can be significant; employment in the coal mining industry has fallen by nearly 70 percent over the last three decades, largely in rural America.[81] Even in sectors experiencing long-term growth, employment can be volatile; the oil and natural gas extraction industry has lost about 14 percent of its workforce since the beginning of 2015 (through August 2016).[82] These changes in employment not only impact the labor force, but also the communities in which they live, work, and contribute to funding public infrastructure and services like roads and schools. While the shift from jobs in coal to natural gas and renewables is a recent example of job dislocation, this issue is not limited to coal or to the energy industry as a whole. Job dislocation has been, and will continue to be, a critical issue across many industries as the Nation's economy grows and changes.

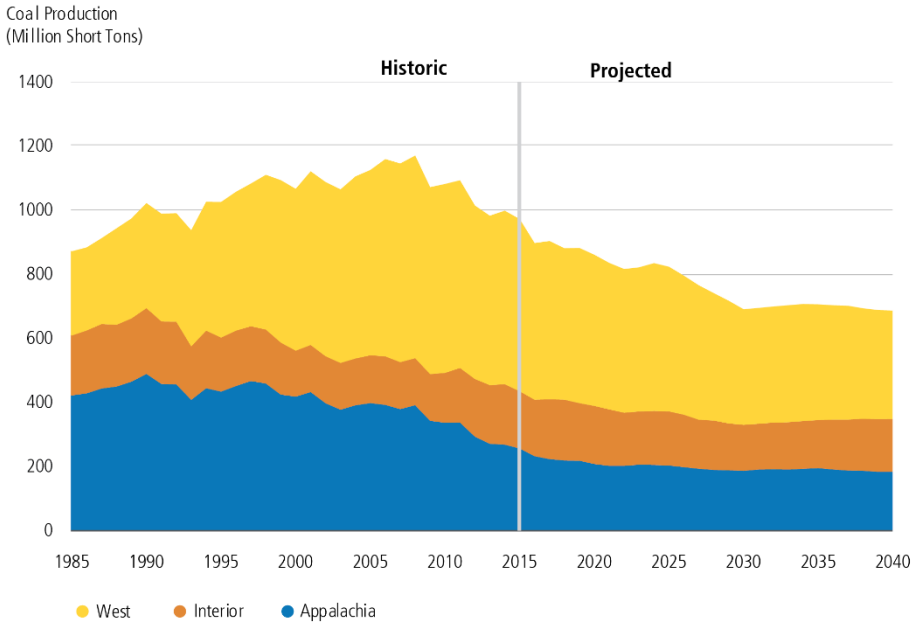
5.4.1 Falling Demand for Coal Has Reduced Coal-Related Employment

In 2015, the electricity industry consumed over 80 percent of domestically produced coal.[83] Recent shifts away from coal for electricity generation and toward natural gas and renewable energy technologies—largely driven by recent reductions in natural gas prices and renewable generation costs—have sharply reduced overall coal demand over the past several years. Annual coal production in 2015 was at its lowest level since 1986.[84] Because of the reduction in electricity industry demand and other shifts in the economy, coal production is forecast to continue declining over the coming decades (see Figure 5-5).

Coal production in the Appalachian region began falling in 1990, even as total U.S. coal production increased through 2007. The primary reason for coal's reduced market share in Appalachia is its higher relative price compared to coal in the western United States; in 2015, the price of coal from West Virginia was four times as much per ton as coal from Wyoming.[85]

Differences in mining efficiency and ownership cause the higher cost for Appalachian coal. Mines in the West tend to be larger and use surface mining techniques, which result in lower production expenses compared to the mix of underground and surface mining used in Appalachia.[86] While most mining in Appalachia occurs on private lands, 80 percent of coal production in the western United States occurs on Federal lands, where companies pay lower royalties and fees.[87] Appalachian coal's relative economic disadvantage is forecast to continue for the coming decades (see Figure 5-5).[88]

Figure 5-5. Historic and Projected Coal Production, 1985–2040[89, 90]



Coal production in the United States peaked in 2008 after a period of decreasing production in Appalachia and increasing production in the West. Production is forecast to continue to fall in the business-as-usual scenario shown here.

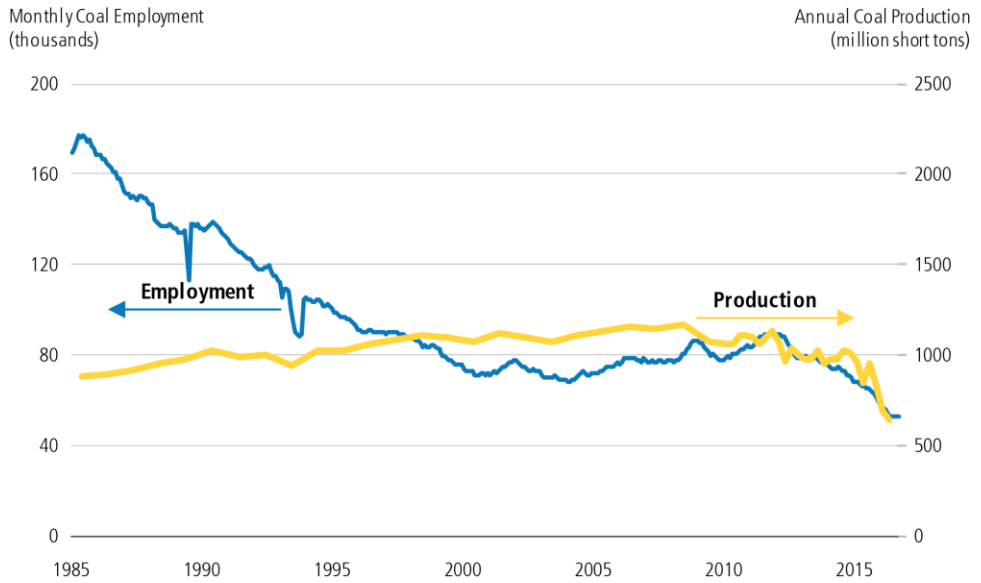
Coal mining jobs in the United States have declined over the last several decades. Between 1985 and 2000, employment in the coal industry shrank nearly 60 percent. During this period, 105,500 domestic coal jobs were lost. While national coal mining employment experienced a minor increase from 2000–2011, 36,000 coal mining jobs were lost between 2011 and September 2016, a reduction of 40 percent.[e] Of these losses, nearly 90 percent were in the Appalachian region. As of November 2016 the BLS reported employment of about 53,000[f] people in the coal mining industry. (see Figure 5-6).[91]

[e] 2011 is used as the base year for this comparison because it was the peak year for domestic coal production this century. Since then, coal mining jobs have been declining, while natural gas and oil extraction jobs have been on the rise overall.

[f] The 2017 *U.S. Energy and Employment Report* records higher Coal Fuels employment numbers in comparison to BLS due to differences in terms, categorizations, and survey methods; reporting 74,084 Coal Fuels jobs in March 2016, as shown in

Table 5-2. The BLS data is relied upon here to illustrate both the recent trends and the historical record over many decades.

Figure 5-6. Coal Industry Employment and Production, January 1985–September 2016[92, 93]

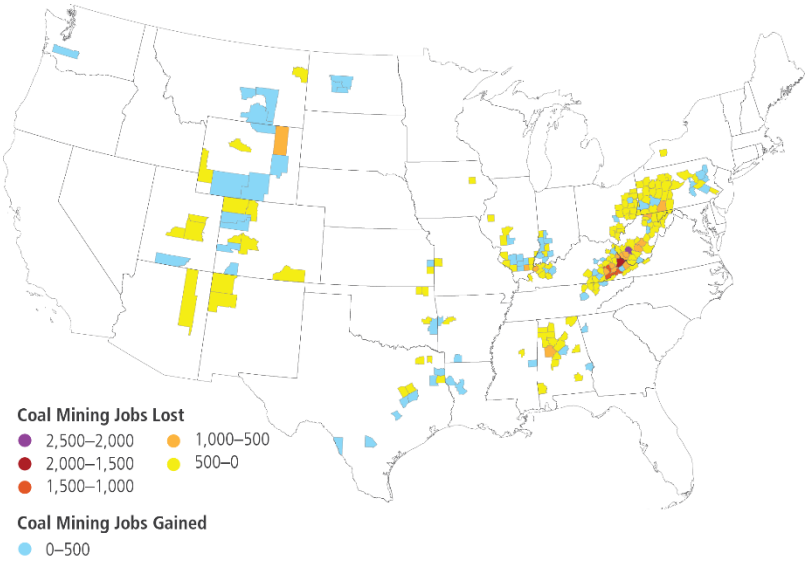


Employment in the coal industry fell from 1985 through 2003, while production increased due to mechanization and a shift to western coal that has much higher labor productivity than Appalachian mines. Over 23,000 jobs were lost between 2011 and 2015; nearly 90 percent of those losses were in the Appalachian region. Note: Data from 2010 to 2016 are quarterly, extrapolated to annual estimates.

This loss of coal jobs can be attributed to increased efficiencies in mining and, later, a reduction in coal demand over the last several decades. Between 1985 and 2001, coal production increased 28 percent, as industry employment fell by 59 percent, due to the increased efficiencies in the industry and by the shifting of production and lower sulfur coal produced by shifting production from Appalachia to the Western U.S., especially within the Powder River Basin.[94, 95] From 2001 to 2015, annual mining productivity in Appalachia ranged from 5,100 tons per employee to 8,100 tons per employee; in the West, it ranged from 35,000 tons per employee to 45,000 tons per employee.[96]

Coal miners provide crucial economic support for communities in which they live, which tend to be concentrated in rural areas. In 2011, at the peak of coal mining employment in this century, coal mining jobs accounted for over 5 percent of employment in 64 U.S. counties and over 20 percent in 12 counties, not including indirect employment supporting the coal sector. Fifty of the counties with over five percent coal mining employment experienced job losses between 2011 and 2015.[97, 98] The total net job loss in the 64 counties was over 20,000 jobs, with 12 counties losing over 10 percent of their entire workforce.[99, 100] These counties that have been hit particularly hard by recent employment declines are located primarily in central and northern Appalachia (see Figure 5-7).

Figure 5-7. Change in Coal Mining Employment by County, 2011–2015[101]



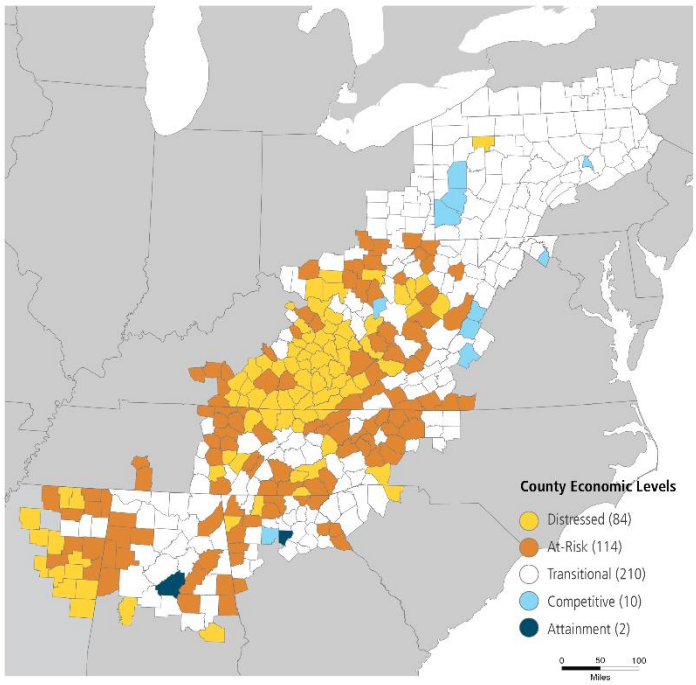
Nationally, 161 counties experienced coal industry job losses between 2011 and 2015, when over 20,000 jobs were lost in total. The most severe job losses are concentrated in central and northern Appalachia, where some regions have a high proportion of their workforce in the coal industry.

Coal mining is a major economic driver within many rural communities. Coal mining jobs pay well relative to other available occupations in those areas; miners earn roughly 40 percent more than the average wage for all U.S. workers.[102] The combination of relatively high income and employment concentration means that many local economies are very sensitive to changes in the industry.[103] A reduction in jobs lowers municipal tax revenues, severely impacting support for public schools, local infrastructure, and public services. Less spending at local businesses depresses the local economy, causing more unemployment, and further reducing public revenue.

There are 1.8 million people living in Appalachian counties with ongoing coal-mining activity and classified as "economically distressed" or "economically at risk" by the Appalachian Regional Commission (ARC) based on a combined index of unemployment, poverty, and income levels.[g, 104] These counties are heavily concentrated in West Virginia, eastern Kentucky, and southern Ohio, largely overlapping with regions facing coal industry employment losses (see Figure 5-8).

[g] The Appalachian Regional Commission ranks all U.S. counties according to a combined index of unemployment, poverty, and income, and considers counties in the bottom decile for the country to be 'distressed' and the bottom quartile to be 'at risk.'

Figure 5-8. Economic Wellbeing of Appalachian Counties, 2016[105]



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More than 45 percent of the mining workforce is over 45 years old.[106] For these employees, finding alternative employment—especially at a similar income level—can be more challenging than for younger workers with more time ahead of them in the labor force.[107] Underfunded pension and retiree healthcare obligations put these older workers, retired miners, and their communities in a particularly vulnerable position. Federal efforts to support economically vulnerable communities and workers are discussed in later sections of this chapter.

Coal-miner pension funds are in financial distress, putting retirees and surviving dependents in jeopardy of losing their planned retirement and healthcare benefits. As coal employment has declined, mine-worker pensions have some of the highest ratios of retirees to current workers of any pension programs in the United States, which can drain the principal balance of the fund faster than it can be replenished. The largest coal-miner pension fund, United Mine Workers of America's 1974 Pension Plan, has 90,000 beneficiaries, with only 8,000 working members still contributing to the fund—a 9 percent ratio of contributing workers to active beneficiaries.[108] On average, 37 percent of pension participants in Federally guaranteed, multi-employer pensions are still working and contributing to their pension funds.[109]

The financial crisis and the bankruptcy of three of the largest coal mining companies in the United States between 2014 and 2016 have further imperiled these pension and healthcare programs. These bankruptcies have allowed several large coal companies, including Patriot Coal and Alpha Natural Resource, to default on some or all of their obligations to these pension and healthcare funds.[110, 111] The miners' pension funds are insured by the Pension Benefit Guaranty Corporation (PBGC), a Federal corporation analogous to the Federal Deposit Insurance Corporation and funded out of insurance premiums paid by member pension

funds. The 1974 Pension Plan is so large that its default could lead to the insolvency of the PBGC, imperiling retirements across the economy.[112] Retiree health insurance programs have no similar Federal guarantee.[113] Typically, a single employer providing retiree health insurance is not required to pre-fund such obligations, and, in bankruptcy, may be relieved of the obligation to fulfill its commitments.[114] Historically, the Federal Government has intervened to support coal miner retiree benefits in times of crisis through legislative and administrative actions.[115] President Obama's fiscal year (FY) 2016 and FY 2017 budgets included the transfer of Federal funds to protect the health and pension benefits of retired coal miners and their families, as did bipartisan legislation in the Senate and House. However, the 114th Congress adjourned at the end of 2016 without passing this legislation and instead only extended healthcare coverage to retired miners and their dependents through the term of the Continuing Resolution (April 28, 2017).

Continued reductions in coal production in Appalachia are also frustrating efforts to protect community health and the environment against land and water degradation from pre-1977 mining activities. Since 1977, the coal industry has taken responsibility for the remediation of the lands and waters affected by mining, as required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). However, prior mining activity has left an estimated $4 billion of high-priority, health-related and safety-related issues with abandoned mine lands in the United States[116] and up to $9 billion of abandoned coal mine sites needing restoration.[117] SMCRA created the Abandoned Mine Lands Reclamation Fund (AML Fund) to reclaim land damaged before 1977 using funds collected through a small per-ton fee—currently less than 1 percent of retail value—on all coal mined in the United States.[118]

Declining coal production has reduced funding for abandoned mine reclamation. AML Fund receipts have declined from a peak in 2007 of $305 million to $197 million in 2016.[119] At this revenue level, it would take 20 years to fully fund the high-priority, health-related and safety-related coal mine reclamation in the United States—the majority located in Appalachia.

The current formula for distributing AML Fund resources poorly matches regional needs. Until 2023, SMCRA requires that 50 percent of the fees collected for AML Fund restoration are spent in the state in which they are collected. Most U.S. coal is produced in the western United States, where little need for pre-1977 mine reclamation remains. Meanwhile, disbursements to Appalachia, the historic heart of coal production where mine reclamation needs are most severe, have fallen due to declining coal production in that region. The President's FY 2016 and FY 2017 budgets proposed to invest $1 billion over five years from the remaining unappropriated balance in the AML Fund. The proposal would allow states and Native American tribes across the country to accelerate efforts to clean up abandoned mine lands and polluted waters, then link those projects with economic development strategies to revitalize coal communities impacted by the downturn of the coal industry. In February 2016, the Revitalizing the Economy of Coal Communities by Leveraging Local Activities and Investing More (commonly known as RECLAIM) Act (H.R. 4456), a bill consistent with the President's proposal sponsored by Congressman Hal Rogers, was introduced in the House and gained a bipartisan group of 27 co-sponsors by the end of the 114th Congress.

Coal Power Plant Closures

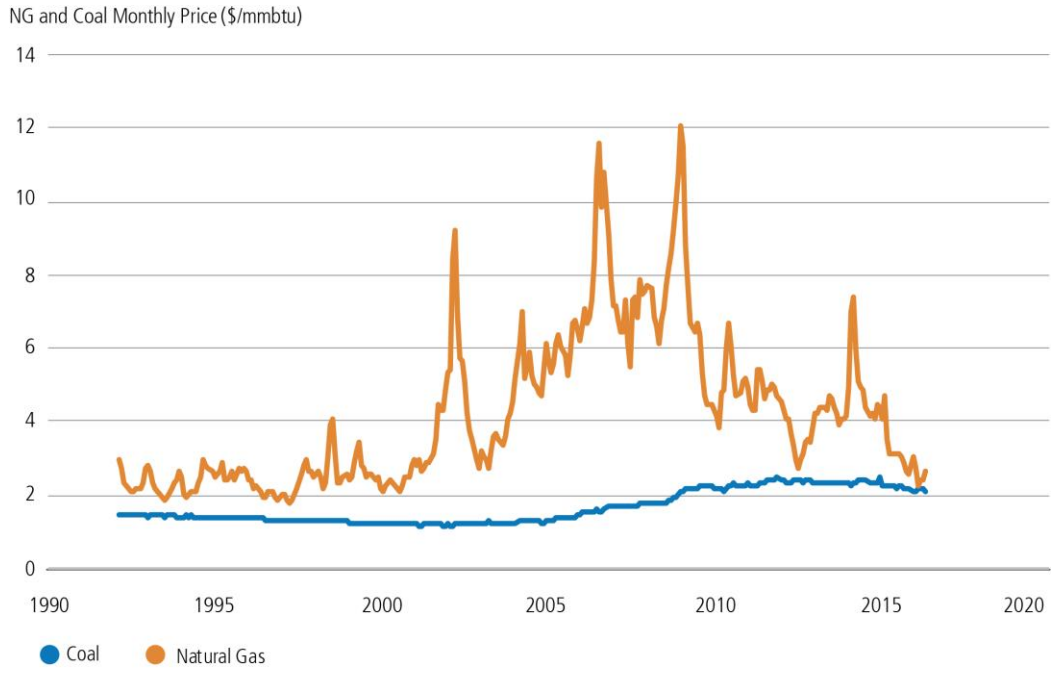
From 2011 to 2015, 345 coal-fired generators were shut down and 20 were added, resulting in a loss of 33 gigawatts, or 10 percent, of the 2011 coal-fired generating capacity.[120, 121] The number of power plants reporting coal as their primary fuel source dropped from 589 to 427.[122] Not all of these numbers represent closures of entire plants—many plants have multiple generating units, and some units have been switched to natural gas rather than shut down, retaining much of their workforce. Nevertheless, fossil fuel electric power generation employment fell 5 percent from 2011–2015.[123] The loss of power plant jobs in rural communities can have effects similar to those described above for coal mining job losses.

Several factors help mitigate, though not eliminate, the effects of coal-fired power plant job losses.[124, 125] For example, in 2012, American Electric Power began planning for plant closures affecting 570 jobs that would occur by 2016. As closures occurred, almost half of the employees moved to positions at other plants. Some retraining occurred, but many employees received similar jobs. Other positions remained vacant after normal retirements, and many employees were retirement eligible at the time of closure due to the advanced age of the workforce.[126] These closures still affected workers and communities, but the utility's planning efforts lessened the effect.

5.4.2 Natural Gas Employment Trends Reflect Shale Boom

Beginning around 2009, the influx of new supply from unconventional sources reduced natural gas prices to pre-2000 low price levels (see Figure 5-9).[127] Low prices relative to coal increased demand for natural gas from the electric power system—now the largest consumer of natural gas in the United States. From 2008 to 2015, electricity generation from natural gas rose 51 percent. [128]

Figure 5-9. Average Monthly Cost of Delivered Fossil Fuels in the U.S. Electricity Industry, 1993-2015[129]

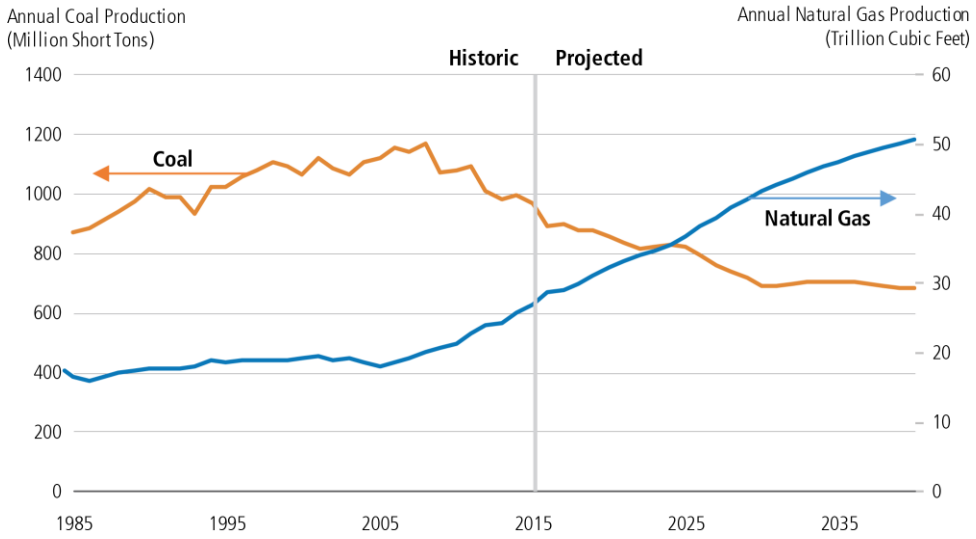


Natural gas prices fell back to pre-2000 prices around 2008. This price drop and increase in the price of coal has made natural gas more competitive than coal in many regions of the country.

The changing relative prices of natural gas and coal and the subsequent change in generation mix led to a large net increase in jobs over the last decade. The natural gas and oil extraction industry added about 80,000 jobs from 2004 to 2014.[130] When support activities, pipeline construction, and associated machinery

construction are included, this number increases to about 400,000.[131] Recently, natural gas and oil extraction employment has declined by around 25,000 jobs between early 2015 through November of 2016.[132] However, unlike coal production, natural gas production is projected to increase over the coming decades, sustaining natural gas industry employment (see Figure 5-10).[133, 134]

Figure 5-10. Historic and Projected Annual Coal and Natural Gas Production, 1985–2040[135, 136, 137]



Coal production is projected to decline in the coming years in the business-as-usual scenario shown here, while natural gas production is forecast to increase substantially. These changes imply the employment prospects within these two industries. Though the oil and gas industry has lost a substantial number of jobs in 2015 and 2016, the industry is forecast to increase production in the long term.

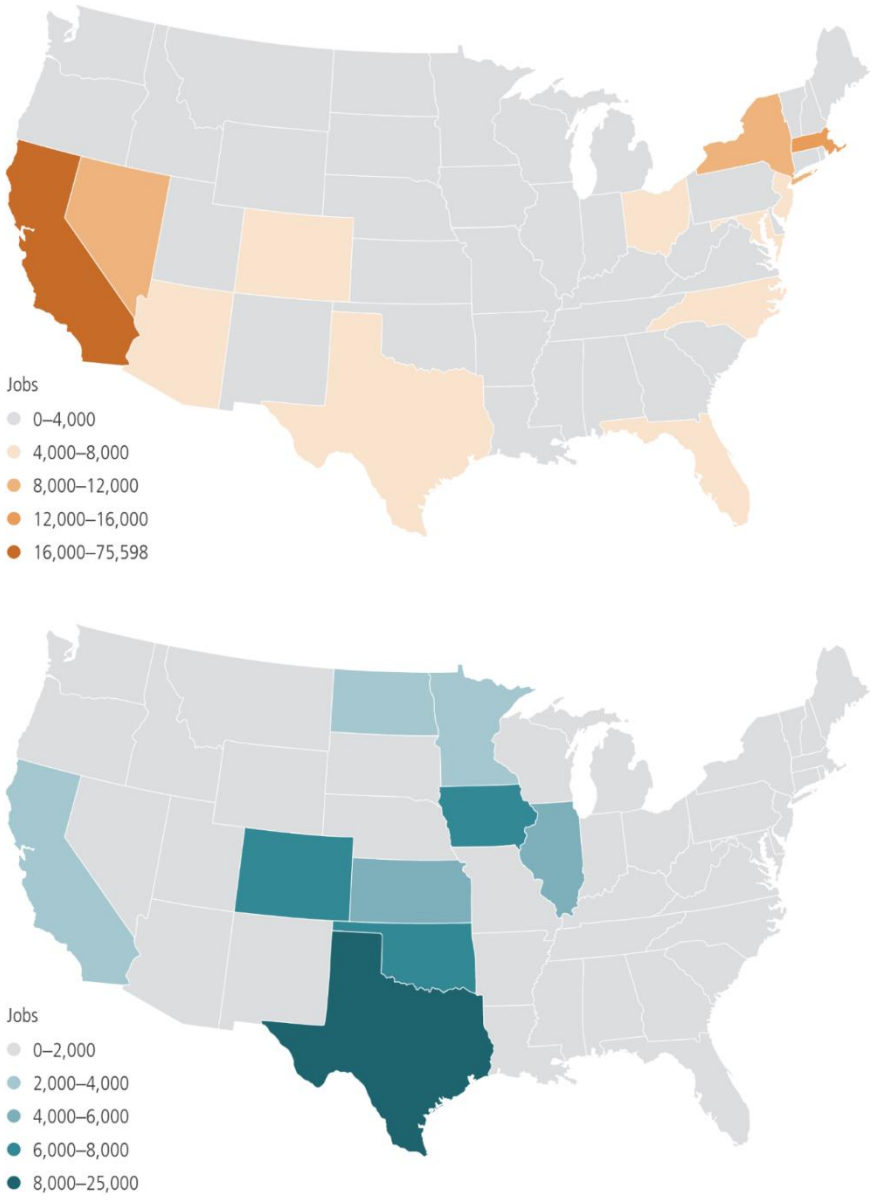
Despite potential employment growth from the expected increase in natural gas production in the coming years, jobs in the natural gas industry pose several workforce challenges. As revealed by the recent shale boom, jobs in the oil and natural gas production industry shift location regularly—posing challenges for employees and the economies of the areas where they live and work.[138] Rapid influx of workers can strain local housing availability, and subsequent outflows of workers can leave partially constructed housing in its wake.[139] While average incomes in oil and gas extraction are high (see Table 5-1), job security is low, as the industry fluctuates in response to global markets and as extraction regions experience boom and bust cycles.[140] These rapid transitions are characteristic of the oil and natural gas industry, while changes in the coal industry have played out over longer periods.

5.4.3 Sector Employment in Renewable Energy Continues to Grow

In 2016, the traditional energy sector employed approximately 4.1 million workers. Of these, electric power generation and fuels technologies directly employed more than 1.9 million workers. And, job growth in the renewable energy industry remains strong. Wind power constituted the largest portion of generation capacity additions in 2015.[141] Employment in the solar industry has grown over 20 percent annually from 2013 to 2015. From 2010 to 2015, the solar industry created 115,000 new jobs. In 2016, just under 375,000 individuals worked, in whole or in part, for solar firms, with more than 260,000 of those employees spending most of their time on solar. There were an additional 108,000 workers employed at wind firms across the Nation. The solar workforce increased by 25% in 2016, while wind employment increased by 32%.[142] Of the 375,000 individuals working in solar, nearly half of these are in the solar installation industry, requiring distinct skillsets compared to traditional generation technologies. Solar industry jobs are relatively high

paying compared to all jobs nationally, with a significant range of earnings across occupations within the industry. Currently, renewable energy jobs are geographically concentrated according to high-value wind and solar resources and state-specific renewable portfolio standards; over half of all the solar jobs in the United States are found in only four states (see Figure 5-11).[143]

Figure 5-11. Distribution of Solar Industry Jobs (*top*) and Wind Industry Jobs (*bottom*) by State, 2015
144, 145



Solar industry jobs are primarily located on the coasts, while wind industry jobs are prevalent in the central United States. Together, wind and solar employment cover much of the United States. Job locations are driven by resource availability and by state policies.

5.4.4 Coal, Natural Gas, and Renewable Energy Shifts Create a Mismatch in Electricity System Job Opportunities

While there is potential for long-term job growth in renewable energy and natural gas extraction and further declines in coal mining, these jobs are not substitutable. Several factors prevent the employment opportunities in the renewables and natural gas industries from reaching those communities most affected by erosion of job opportunities:

- **The geographic locations of electricity sector job losses and gains are currently not well correlated.**

  Job losses from the coal mining industry are largely concentrated in southern Appalachia, while growth in natural gas extraction and the renewable energy industry is located elsewhere.

- **Income discrepancies between industries is a challenge for reemployment.**

  The median wage for solar installers is higher than the median wage across all occupations. It remains more than 20 percent less than the median wage for coal mining jobs, [146] *and solar manufacturing jobs in the United States pay 10 percent less than U.S. manufacturing jobs generally.* [147] *While there is an income discrepancy between coal and solar jobs, solar jobs are rapidly increasing. Retraining and creating more localized solar jobs is important.*

- **The skills required for employment vary between industries experiencing growth and those experiencing decline.**

  Natural gas and coal jobs are largely extraction focused, whereas wind and solar energy jobs are significantly manufacturing-based (almost 50 percent for wind and 40 percent for solar) and construction-based (20 percent for wind and almost 30 percent for solar).[148] *Significant retraining would be required to transition between these jobs.*

Employment in the Nuclear Industry

The *U.S. Energy and Employment Report* finds that 68,000 people are employed in the nuclear generation industry.[149] Employment in the industry may fall as nuclear power plants retire. Since 2013, six nuclear reactors have shut down prior to the end of their existing licenses. Closure announcements have been made for another 10 reactors to cease operation over the next 10 years, 8 will close before the end of their current operating licenses. Recent state actions, pending any legal challenges, may enable four of those to continue operating. However, the net employment impact of plant closures may be mitigated through employee retirements and transfers to other power generation facilities.[150]

Construction of nuclear power plants requires thousands of skilled construction workers.[151] To ensure an adequate supply of highly trained workers for the construction of nuclear reactor units at Plant Vogtle in Georgia, North America's Building Trades Unions and Georgia Power created an apprenticeship-readiness training program under the Helmets to Hardhats initiative. The program focuses on increasing workforce inclusiveness and providing job opportunities to veterans.[152]

Employment in uranium production (mining, milling, and processing) has trended with production levels. Though employment numbers are unknown prior to 1993, uranium production over the last two decades was a fraction of average annual production from 1960 to the early 1980s.[153] The uranium production industry employed 625 people in 2015, down from a 21st-century peak of 1,563 in 2008.[154]

Employment trends in the uranium industry closely mirror resource prices; these have fallen from a peak of over $100 per pound of triuranium octoxide (U_3O_8) in 2007 to below $30 in 2015.Prices are anticipated to remain low due to growing inventories owned by nuclear power owners and operators. Total inventories in 2015 were enough to fuel two years of nuclear power production at use-rate averages over the last decade.[155]

5.4.5 Skills Training and Workforce Development

Companies, industry representatives, and labor unions have pursued a variety of skills training and workforce development programs to overcome workforce skills deficiencies.

Many utilities operate their own line worker schools, joint labor management apprenticeship programs, and other training programs, while others recruit from line worker training schools that offer introductory programs.[156] Additional programs include a uniform nuclear curriculum program and a power plant technology program.[157] In FY 2014, 7,253 apprentices were enrolled in registered apprenticeship programs for line installer/repairers, line maintainers, and line erectors.[158]

In 2006, the major industry trade associations and many leading companies formed the non-profit Center for Energy Workforce Development (CEWD). "CEWD was formed to help utilities work together to develop solutions to the coming workforce shortage in the utility industry. It is the first partnership between utilities, their associations, contractors, and unions to focus on the need to build a skilled workforce pipeline that will meet future industry needs."[159] Today, CEWD includes the five major utility trade associations, the industry's two principal unions, and more than 100 companies that employ over 90 percent of utility workers. CEWD is organized through more than 30 state consortia that are focused on working with local educational institutions, their union apprenticeship programs, and other stakeholders to create a high-quality, diversified workforce.

Construction industry training programs are particularly important for energy efficiency. Nationally, North America's Building Trades Unions operate over 1,600 Joint Apprenticeship Training Committees (JATC) with their construction employers. These JATC's train 74 percent of all construction apprentices in the United States at a cost of $1.3 billion annually.[160]

As the electricity industry relies increasingly on ICT components in creating a smart grid, the labor intensity of the electricity grid of the 21st century may decrease. Critically important industries that face similar challenges have already used redesigned work processes and innovative workforce practices to increase efficiency. The increased use of technology—for example smart meters to reduce the need for meter readers, smart grid components that isolate faults and reduce outages, or aerial inspection technology to improve damage assessments—might also increase workforce efficiency.

Smart Grid Workforce Training and Development under the American Recovery and Reinvestment Act of 2009

In 2010, the Department of Energy awarded nearly $100 million of funding appropriated under the American Recovery and Reinvestment Act of 2009 to support 54 workforce training programs in the utility and electrical manufacturing industries. Funding for these programs was cost-shared with community colleges, universities, utilities, and manufacturers, and it is estimated to have trained approximately 30,000 people.[161]

5.4.6 Electricity System Workforce Outreach and Inclusion Programs

In addition to government programs, private partnerships with non-profit organizations are also focused on increasing the inclusiveness of the energy sector workforce. GRID Alternatives, together with SunEdison, created the Realizing an Inclusive Solar Economy Initiative, which focuses on recruiting members of underrepresented communities for jobs in the solar industry—providing solar installation training, working with the solar industry to identify needed skills for the trainings, linking trained candidates with available employers, and ensuring the retention of a diverse workforce in the industry.[162]

Additional targeted initiatives include the Utility Industry Workforce Initiative, where CEWD joined with the Departments of Energy, Labor, Defense, and Veterans Affairs; the International Brotherhood of Electrical

Workers; and the Utility Workers Union of America to increase hiring rates of veterans in the industry.[163] Helmets to Hardhats, run by the North American Building Trades Unions, also trains veterans for the construction and utility industries.[164]

Department of Energy Workforce Inclusion Programs

Several outreach programs have been established to build a more inclusive work environment in the energy sector. The Department of Energy (DOE) launched the Minorities in Energy Initiative in 2013 to "strive to ensure that our energy workforce more fully reflects the diversity and strengths of the country."[165] The Department, through the National Nuclear Security Agency, also sponsors the Minority Serving Institutes Partnership Program and the Cybersecurity Consortium at Historically Black Colleges and Universities.[166] In 2014, DOE also created the Solar Ready Vets® program through its SunShot Initiative.[167] The program trains exiting service members to become solar installers and has developed a program that provides on-base training through the Department of Defense SkillBridge program during the last six months of service. Other programs are more broadly focused on improving participation among women and minorities in science, technology, engineering, and mathematics (STEM) fields and career pathways. Specific DOE initiatives for STEM outreach include the Clean Energy Education & Empowerment initiative and the Mickey Leland Energy Fellowship Program.[168, 169]

5.4.7 Federal Workforce Data and Coordinated Programs

In response to the lack of high-quality and discrete energy jobs data, the Department of Energy launched the Jobs Strategy Council, which commissioned USEER, making significant strides in improving the availability of data and insights for the energy and electricity industry workforce.[170] The second edition of the report will provide more precise job categorization—particularly for natural gas industry employment estimates—and will be published in January 2017.

Title X of H.R. 6, the 2007 Energy Bill, established the Energy Efficiency and Renewable Energy Worker Training program for the Department of Labor to administer.[171] In addition to the training program, H.R. 6 required the Secretary of Labor to collect and analyze labor market data to track energy-related workforce trends, award competitive National Energy Training Partnerships Grants to implement training for economic self-sufficiency, and develop an energy efficiency and renewable energy industries workforce. Finally, the Secretary of Labor was required to award competitive grants to states to administer labor market research, information, and labor exchange research programs, as well as renewable energy and energy efficiency workforce development programs.[172] To date, this program remains unfunded by Congress.

5.4.8 Support for Communities Experiencing Economic Dislocation

The United States has a long history of providing adjustment and training programs to workers in industries undergoing transition. The Trade Adjustment Assistance program for workers in trade-exposed industries with increased import competition was established in 1962, and the broader Job Training Partnership Act was passed in 1982.[173] The Clean Air Employment Transition Assistance Program, included in the Clean Air Act Amendments of 1990 and subsequently repealed, provided training, adjustment assistance, employment services, and needs-related payments to workers who lost jobs due to a business's compliance with the Clean Air Act.[174, 175] Current changes in the electricity sector are rapid and significant; targeted assistance may aid in addressing this transition. An alternative approach for older workers in regions with few economic opportunities could also provide a financial bridge to retirement in areas of rapid transition.

The Appalachian Regional Commission (ARC) is a regional economic development agency created in 1965 to help the Appalachian region reach socioeconomic parity with the rest of the Nation. ARC funds business development, workforce development, infrastructure investment, and community capacity building through Federal appropriations. Despite ongoing economic challenges in the region, ARC's non-highway

appropriated budget has fallen from roughly $600 million in the early 1970s to below $100 million in the 1980s. Its budget has averaged below $100 million per year until 2016 when it grew to $146 million.[176, 177]

The continued fiscal difficulties of coal miner pensions threaten the solvency of PBGC. Ensuring the continued fiscal health of PBGC would support retired workers and their spouses and provide sources of economic wealth in communities with decreasing sources of local government revenues.

While local governments experience losses in tax revenue, it is essential to ensure that children have access to adequate education. The Federal Government previously assisted in similar situations through the now-expired Department of Agriculture Secure Rural Schools (SRS) program, which provided grants to schools in communities that were suffering from the precipitous decline in logging on Federal land in the 1990s.[178] In FY 2015, the SRS program paid $222 million to localities in 41 states and Puerto Rico to invest in school systems and road infrastructure.[179, 180] The amount of support required in coal communities is likely significantly less than in the SRS program, which reached 9 million children.[181] All of the central Appalachian states spend within 10 percent of the U.S. average of $10,600 per student per year, and fewer than 100,000 students live in counties where at least 1 percent of the population works in coal mining. [182, 183, 184]

The AML Fund's inability to fully support reclamation of lands disrupted by the coal mining industry has the potential to leave communities in regions with declining local revenues with polluted and unsafe lands and few means to repair the damage. Ensuring funding and appropriate design for the AML Fund will help prevent mines that were once a source of prosperity for these communities from becoming sources of sustained financial and community health challenges.

The Partnership for Opportunity and Workforce Economic Revitalization (POWER) Initiative

The POWER Initiative is a coordinated Federal effort designed to assist communities that are negatively impacted by changes in the coal and electricity industries by funding investments in economic revitalization and workforce training in coal communities across the United States. The Appalachian Regional Commission and the Department of Commerce's Economic Development Administration administer the program.[185] Several first and second round grantees provide workforce development and training opportunities for workers displaced by the contraction of the coal industry in addition to economic development planning assistance.[186, 187]

The recommendations based on the analysis in this chapter are covered in Chapter VII, *A 21st-Century Electricity Sector: Conclusions and Recommendations*.

5.5 Endnotes

[1] BW Research, *U.S. Energy and Employment Report* (Washington, DC: Department of Energy, January 2017).

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VI Enhancing Electricity Integration in North America

This chapter details the interconnectivity of the United States', Canada's, and Mexico's[a] electric systems and opportunities for enhancing integration. First, the chapter outlines the existing consensus between the nations to improve integration and the regional variation in transmission capacity that exists. The next two sections explore the integration of the United States with Canada and Mexico, respectively, and provide in-depth discussions of relevant country-specific policies. The chapter concludes with possible policy options to improve integration as well as ongoing and potential opportunities for collaboration.

[a] Due to the nature of electricity system interconnections and for simplicity of terminology, the term "North America" will be used in this chapter to refer narrowly to the continental United States, Canada, and Mexico.

Key Findings

Integration of the power systems of Canada, Mexico, and the United States historically occurred by gradual, ad hoc, and regional adjustments implemented by an array of regional, public, and private stakeholders, reflecting the complex and fragmented jurisdictions in all countries. Many opportunities for enhanced integration have included a collection of stakeholders and were pursued on a subregional basis.[1]

One model for power-sector collaboration across national borders is demonstrated by the reliability planning under the North American Electric Reliability Corporation; however, this engagement has been limited to Canada, the United States, and the Baja California region of Mexico.[2] The Canadian, Mexican, and United States governments have all made significant climate commitments and have indicated a desire to shift toward greater renewable energy penetration.[3] In June 2016, the United States, Canada, and Mexico announced a goal for North America to strive to achieve 50 percent clean power generation by 2025. Greater cross-border integration could be a tool to maximize gains from the deployment of clean energy generation and energy efficiency, but the complexity and current asymmetry of national and subnational policy frameworks may impede implementation.[4]

The design of domestic U.S. clean energy policies, both at the Federal and state level, has implications for cross-border trade and continental emissions reductions. Currently, there are significant disparities between U.S. states' policies for recognition or exclusion of international clean energy imports.[5]

Continued study of the context and levels of integration of each subregional, cross-border interconnection will allow for a deeper understanding of policies that have shaped current levels of cross-border trade (Table 1-1).

Canada has additional hydropower resources that could be exported to the United States to provide a reliable source of firm, low-carbon energy.[6] There are concerns among stakeholders that increased imports of Canadian hydropower could reduce U.S. clean energy competitiveness; however, there are examples of arrangements where Canadian hydropower decreases curtailments of U.S. clean resources.[7]

Trade has been increasing across the North American bulk power system,[8] but cross-border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.[9, 10]

Under a low-carbon future scenario, current modeling results show that transmission with Canada becomes increasingly important for sustaining emissions reductions and has a significant impact on the generation mix in border regions.

While many electricity system models exist for the United States (and in some cases, the United States and Canada), detailed modeling tools to explore the economic, social, and/or reliability impacts of electricity trade across all of North America are currently insufficient to inform opportunities for enhancing integration.

While extensive integration between the United States and Canada can inform the potential for increased future U.S.-Mexico integration, these situations are fundamentally dissimilar in four main ways: (1) the lack of a dominant exporting country on the U.S.-Mexican border; (2) the different regional approaches to integration on the U.S. side; (3) the nascent regulatory framework in Mexico; and (4) the differing legal instruments for open-access transmission agreements and reliability coordination between the United States and Mexico.[11]

Mexico's ongoing electric utility industry reforms could have significant impacts on the future of cross-border integration. The reforms are focused on the overall goal of competitiveness, with the twin objectives of reducing electricity costs and developing more clean energy.[12] A transition in Mexico from oil to natural gas in electricity generation could have tremendous impacts in the manufacturing sector, reducing electricity prices, boosting manufacturing output, and increasing overall gross domestic product for Mexico.

Mexico's increasing importation of U.S. natural gas could be an economic and environmental opportunity for both sides, by offsetting expensive and high greenhouse gas-emitting diesel generation in Mexico and creating economic opportunities for U.S. exporters. The resulting reduction in electricity costs in Mexico could also boost overall North American competitiveness.

The Electric Reliability Council of Texas could benefit from greater integration with Mexico, through access to enhanced imports or as a business opportunity for power exporters.

California's ambitious clean energy policy provides an opportunity for energy exporters in Mexico, especially in the Baja California region, to supply clean energy, dispatchable power, or essential reliability services.[13]

6.1 Cross-Border Electricity Integration

6.1.1 Consensus to Enhance North American Electricity Integration

The potential for electricity integration to provide economic benefits and support the development of more modern and resilient energy infrastructure has been a long-standing theme for North American diplomacy.[14, 15] Leaders in the United States, Canada, and Mexico have publicly and repeatedly affirmed support for the concept of increasing energy integration,[16] and there is a general understanding across the continent that the benefits of cross-border electricity trade can be improved with deeper system integration. Earlier this year, at the North American Leaders' Summit, President Barack Obama, President Enrique Peña Nieto, and Prime Minister Justin Trudeau signed a statement agreeing to collaborate on cross-border transmission projects in order to achieve the mutual goal of advancing clean and secure power. In particular, the United States, Canada, and Mexico announced a goal for North America to strive to achieve 50 percent clean power generation by 2025.

A number of additional recent developments make a discussion of cross-border electricity integration[b] especially relevant:

- The completion of transformational energy reforms in Mexico in the oil, gas, and electricity sectors.
- Canada's framework on clean growth and climate change, charting an accelerated path to achieve deep greenhouse gas (GHG) emissions reductions and green infrastructure development.
- The shale gas boom in the United States, which presents new opportunities for natural gas generation, as well as raises questions about land use and emissions.
- The Paris Agreement and the steps needed to implement nationally determined contributions globally.
- All three countries' sustained interest in stimulating strategic opportunities in clean energy development and energy efficiency.[17]
- The acceleration of the deployment of renewable energy technologies, which creates opportunities for grid management through integration.

The extensive electricity integration that already exists between the United States and Canada and the potential to increase existing integration between the United States and Mexico suggest that North America has much to gain from collaborative planning, strategy, and cooperation in the power sector.

6.1.2 Regional Variation in Integration across North America

There is international consensus that electricity integration brings great value to Mexico, Canada, and the United States, but the details of planning and implementing electricity integration require the

[b] While the discussion of power sector integration has been of intense international interest, moving from aspirational objectives to actionable policy steps requires a clear, yet nuanced, definition of "integration" (or its close homologue, "harmonization"). While these terms are commonly discussed among a broad range of cross-border power sector stakeholders, there is no single definition for their use. For the purposes of this discussion, we define integration to include basic information sharing in policy making and planning, as well as the coordination of policies and decision making, often with the result of enhancing flows of cross-border trade. For the power sector, this includes any level of coordination in planning, system operations, or regulation.

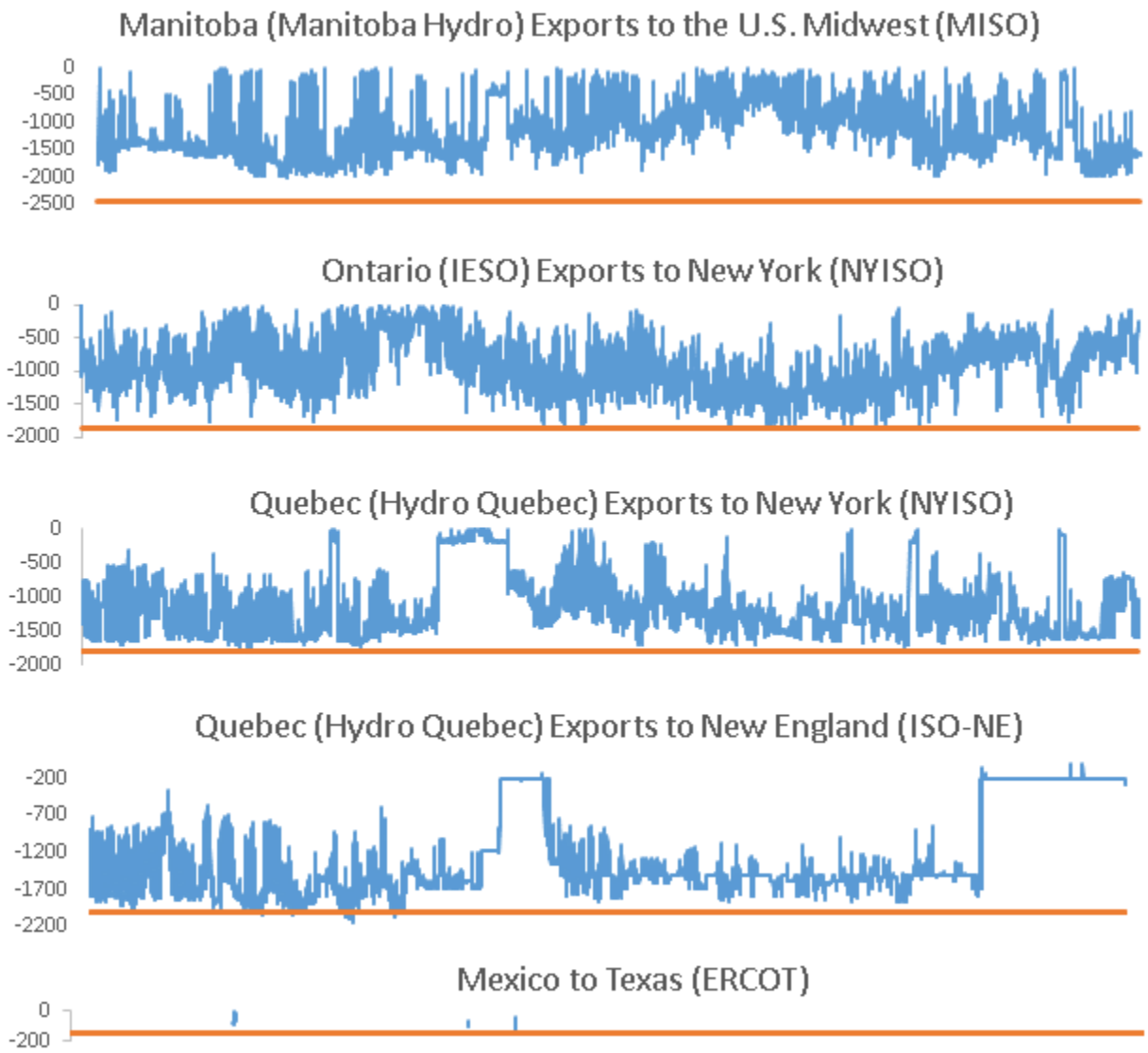
navigation of national, regional, and local interests through the engagement of a broad set of public and private stakeholders.[18] The North American electricity system is heterogeneous; operations and planning primarily take place through regional entities, and every part of the system has evolved with different characteristics and structures.[19] This leads to complex and asymmetrical jurisdictions and regulations, as well as cases in which international, cross-border coordination is sometimes greater than subregional coordination within a specific country. U.S.-Canadian integration is often greater than between Canadian provinces.[20]

A subregional lens is necessary to understand the many varying contexts of integration between Canada and the U.S. Pacific Northwest, Midwest, and Northeast Regions, as well Mexico and the southern border region with Arizona, California, New Mexico, and Texas. These contexts include different levels of integration that range from physical, asynchronous interconnections geared towards emergency trade (such as in the Electric Reliability Council of Texas (ERCOT)-Mexico cross-border interactions), to extensive, synchronous interconnections that enable Canadian cross-border participation in U.S. competitive electricity markets (such as in the Manitoba Hydro-Midcontinent Independent System Operator [ISO]). Because of this diversity, there are additional opportunities for enhanced integration that should be examined in order to bring maximum benefit for the greatest number of stakeholders at a minimum cost.

For example, additional cross-border transmission infrastructure with Canada has been projected to lead to lower overall system costs in U.S. border regions, and it could enhance reliability, backstop variable renewable energy development, and enable lower overall emissions of U.S. power consumption.[21, 22] Greater cross-border planning of transmission and operations between the United States and Mexico could maximize efficiencies for commercial opportunities for U.S. generators to sell into a higher-priced market, while lowering the electricity costs paid by industrial consumers in Mexico.[23, 24] Additional trading in electricity between Mexico and the United States could have further impacts, including possibly on long-term price stability and other market factors, which will need to be further analyzed. Coordination of the United States' and Mexico's clean energy incentives and programs, such as Clean Energy Certificates, could lead to additional opportunities for clean energy research, development, and deployment, as well as reductions in carbon emissions.[25]

The barriers to deepening integration are also regionally nuanced. Increasing cross-border integration, and especially increasing cross-border trade, raises important questions regarding the economic impacts of enhanced integration on domestic power generators and jobs; the reliability of power supply; the environment; costs for consumers; and increased reliance on international sources of power. In most border regions, increasing electricity flows would require the construction of additional transmission infrastructure (see Figure 6-1) since current lines between the United States and Canada are operating at or near capacity, and the connections between the United States and Mexico tend to have low capacity. Developers of new infrastructure will need to strategically align planning across borders in order to overcome opposition.

Figure 6-1. Transmission Capacity and Electricity Trade across Major Interconnections (June 2015–May 2016)



Blue lines show hourly export data from Canada and Mexico to the United States in negative megawatt-hours (MWh); red lines indicate maximum export capacity, recorded hourly from June 9, 2015 to May 19, 2016. As the blue lines reach the red limit of maximum capacity, transmission in that region is full and cannot be expanded on current lines. The proximity of hourly export flows to the maximum export capacity suggests that transmission lines are often fully utilized, especially in the U.S. Northeast. Flat-lined regions in Hydro Quebec figures are attributed to maintenance outages.

6.2 U.S.-Canada Integration

6.2.1 Historical Overview

The United States and Canada serve as a global model of highly functional, cross-border electricity coordination. Cross-border electricity trade and coordination of operations, policy, and regulatory

planning are extensive, mature, and efficient, and they have led to economic and reliability benefits on both sides of the border.[26] Significant levels of cross-border transmission interconnect both countries, and electricity trade has been growing overall since 2005, increasingly dominated by flows from Canada to the United States.[27, 28] Total U.S.-Canada trade (including flows in both directions) in 2015 was 77 million megawatt-hours (MWh), accounting for a total of U.S. dollars (USD) $2.6 billion in revenues (Canadian dollars $3.4 billion).[29] With the notable exception of trade in the Pacific Northwest, which continues to be bidirectional (with the United States acting as a net exporter to Canada since 1999), in all other regions, Canadian exports to the United States have significantly overtaken flows in the opposite direction (Figure 6-2).[30]

These recent trends reinforce a longer historical trajectory. Since the first electricity developments led to trade between the two countries in the early 1900s, Canadian private hydropower generators have prioritized exports to the United States over pan-Canadian trade, due to a number of factors.[31] In accordance with Section 92A of the Canadian Constitutions Act of 1867, Canadian provinces have near-complete authority over their individual electricity systems. Many hydropower-producing provinces (such as British Columbia and Quebec) have vertically integrated utilities with regulated pricing structures. Markets with more diversified generation mixes (such as Ontario and Alberta), however, have implemented varying levels of restructuring, resulting in a system in which neighboring provinces often host asymmetrical market structures that aren't conducive to trade.[32] Transmission infrastructure development is determined by Canada's spatial population distribution: 75 percent of the Canadian population lives within 100 miles of the U.S. border and is clustered along the coasts.[33] Canadian hydropower producers, who have the greatest potential to increase capacity to serve other loads, have focused on extending transmission the short distances from Canadian population centers to the U.S. border, rather than on more costly east-west transmission to other provinces.[c, 34] The high level of north-south integration between Canada and the United States, guided by jurisdictional, population, and geographic factors, means that cross-border coordination often surpasses east-west coordination among provinces, states, or ISOs within either country.[35] Primary interconnections link single Canadian provinces to markets in the United States: The Pacific Northwest to British Columbia; Manitoba to Midcontinent ISO; Ontario and Quebec to New York ISO; and Quebec to ISO New England.

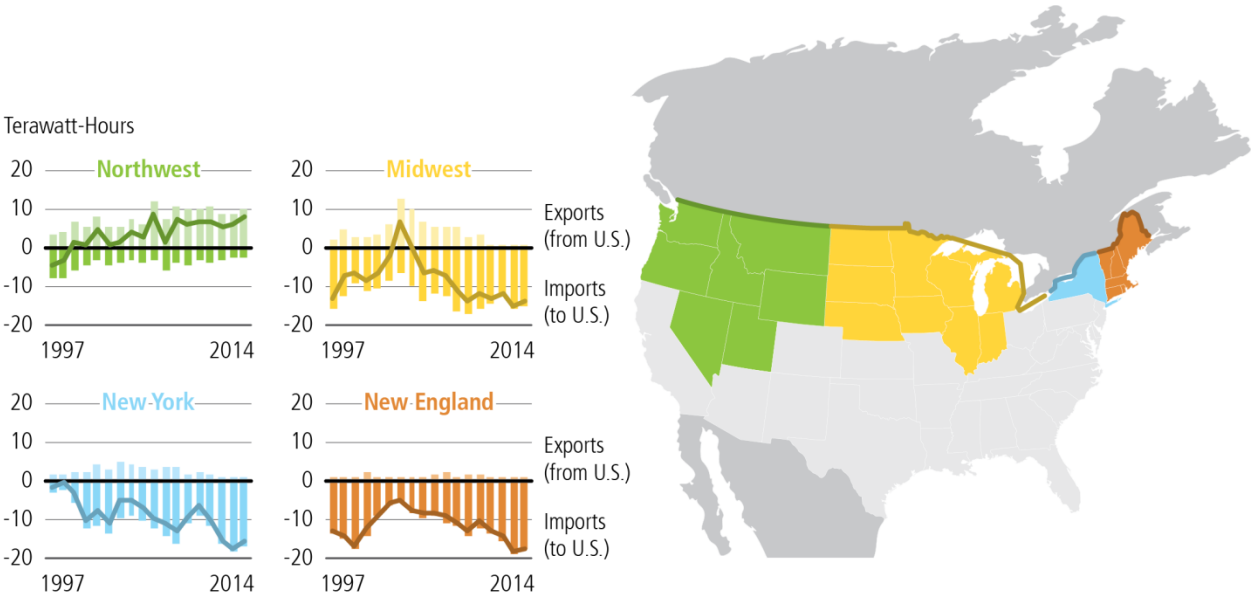
High levels of integration between the United States and Canada exist across the border and are facilitated in a variety of ways. For example, since 1964, the Columbia River Treaty has contributed substantially to the economic progress and safety of both countries through coordinated flood-risk management and clean, renewable hydropower within the Columbia River Basin in the Pacific Northwest. Ongoing negotiations on a new formal treaty with Canada to extend this arrangement beyond 2024 are critically important to the economy of the Pacific Northwest region, particularly for flood management and hydropower optimization.

The significant level of integration between the United States and Canada also has reliability implications. Two large-scale, cross-border blackouts, the Great Northeast Blackout of 1965 and the Northeast Blackout of 2003, among other factors, significantly shaped the current policies regarding reliability. Those events played a role in spurring the subsequent establishment of the North American Electric Reliability Corporation (NERC), the Energy Policy Act of 1992, and the Federal Energy Regulatory Commission (FERC)

[c] The Maritime Link Project, which links New Foundland, Labrador, and Nova Scotia, as well as discussions about exporting hydropower from British Columbia Hydro's Site C Clean Energy Project to Alberta suggest this might be changing.

orders to open transmission access.[36] See the History and Trends Appendix for additional detail on these events.

Figure 6-2. Overall U.S. Electricity Trade with Canada in Four Regions[37]



The graphs show U.S. electricity trade with Canada (1997–2014) in the Northwest, Midwest, New York, and New England. While the Pacific Northwest has been steadily increasing electricity exports to Canada, the Midwest, New York, and New England have been increasing imports over time.

6.2.2 Benefits and Barriers to Increasing Cross-Border Electricity Trade

There is high potential to increase Canadian hydropower exports to the United States. The Canadian Hydropower Association estimates that Canada has a technical hydropower-generation potential that could more than triple current levels, up to 236 gigawatts.[38] As a resource, hydropower has several advantages: it is flexible, reliable, and cost-competitive with other sources of power, and it produces nearly zero carbon emissions.[39, 40] Hydro reservoirs can provide energy storage, and hydropower generation can be adjusted relatively quickly, making it a natural complement to intermittent resources such as solar and wind power.[41] Some dams also serve additional functions, such as managing flood control or storing potable water. Already, the climate and energy security benefits of Canadian-U.S. hydropower trade may be substantial. By one estimate, trade in hydropower between Quebec and its neighbors (New England, New York, Ontario, and New Brunswick) can be credited with 20.6 megatonnes of avoided emissions from 2006–2008.[42]

Electricity imports can serve as a cost-effective supply for wholesale power markets in the United States. The External Market Monitor of ISO New England concluded that importing electricity from Quebec and New Brunswick "reduces wholesale power costs for electricity consumers in New England."[43] Similarly, a New England States Committee on Electricity study on incremental hydroelectric imports from Canada found average annual economic benefits associated with reduced electricity prices in New England to be in the range of USD $103 million to $471 million.[44]

Cross-border trade between the United States and Canada is mature and highly integrated, but enhancing integration—especially with the objective of increasing cross-border trade—faces interrelated barriers. First, there are concerns from generators within the United States that increasing cross-border trade

would have a negative impact on domestic markets and give Canadian suppliers market power.[45] In the 2000s, Canadian hydropower was viewed as one of the most cost-effective electricity sources, which presented a double-edged sword: it could lower prices for U.S. customers, but it could also outcompete U.S. generators in the natural gas and renewable energy sectors. In recent years, low U.S. natural gas prices have shifted the business case for increasing cross-border trade by reducing the extent to which imports from Canada would lower costs for electricity users.[d, 46] Continued, thorough examination of the long-term implications of integration for consumers and generators will be needed in the future.

Second, increasing electricity trade would require additional transmission capacity. While several transmission projects have already been proposed to increase capacity in the Midwest and Northeast, the complexity of these projects raises a variety of stakeholder concerns that lead to long development times and unexpected delays.[47] Concerns range from the environmental impacts of transmission infrastructure to the potential implications of greater Canadian imports on local and regional economic development.

Siting and permitting decisions are made at the state and local level, including for international transmission lines. Continued integration and transformation of the North American electricity system requires effective siting and permitting capabilities at all levels of government. Planning and permitting new cross-border transmission infrastructure, including managing ecological impacts across jurisdictions and with a wide range of domestic and international stakeholders, is uniquely challenging. State, provincial, local, and tribal governments, assisted by federal agencies, need to build capacity to minimize safety and security consequence and protect the environment, while limiting permitting-related delays.[48, 49] Government efforts at the federal and local levels should ensure that project developers have a clear understanding of expectations, best practices, and priorities during the permitting of cross-border transmission projects. The issuance of recent cross-border Presidential permits for the Great Northern Transmission Line[50] in Minnesota and the New England Clean Power Link[51] in Vermont are both examples of the application of collaborative principles of early engagement with stakeholders detailed in the new Integrated Interagency Pre-Application Process.[52] Additional study of and updated information on cross-border regulation can assist with establishing a clear understanding of requirements at the federal and state levels for the permitting of cross-border transmission facilities.

6.2.3 Clean Energy Development in the Cross-Border Context

Many states have established renewable portfolio standards (RPSs), not only to reduce GHG emissions, but also to stimulate local development of clean energy. Currently, many U.S. clean energy policies are not designed to allow existing Canadian hydropower imports as a compliance option. The additional concern about negative environmental impacts of large-scale hydropower have led a number of states to adopt RPSs that exclude large-scale hydropower, leading to a "non-counting" of Canadian hydropower, regardless of the positive impact such imports would have on the state's emissions. Currently, Minnesota, Vermont, and Wisconsin are the only U.S. northern border states that have RPSs that allow for the accounting of some forms of large-scale hydropower, including imports from Canada, as a clean energy resource.[53] Completed analysis of the economic and environmental impacts of increased levels of hydroelectric imports from Canada indicates that the potential for cumulative reductions in GHG emissions ranges from 58 million to 97 million megatonnes.

There are examples of Canadian hydropower supporting greater renewable energy development in the United States.[e] A 2013 MISO/Manitoba Hydro study explored the potential for Canadian hydropower to

[d] According to the Energy Information Administration, natural gas prices for electric power fell from USD $9.26 per thousand cubic feet in 2008 to USD $3.37 per thousand cubic feet in 2015.

[e] This association is also suggested by the preliminary ReEDS projection shown for New York ISO in Figure 6-6.

provide balancing for U.S. intermittent energy (primarily wind) and found that greater deployment of this arrangement provides economic and environmental benefits on both sides of the border, with annual modified production cost savings ranging from $228 million to $455 million for 2027, and annual load cost savings ranging from $183 million to $1,302 million for 2027.[54] Variations in planning and market design may require a different approach by region. In addition, lessons learned from examining the creation of economic and environmental benefits across international borders should be explored and disseminated when possible.

6.3 U.S.-Mexico Integration

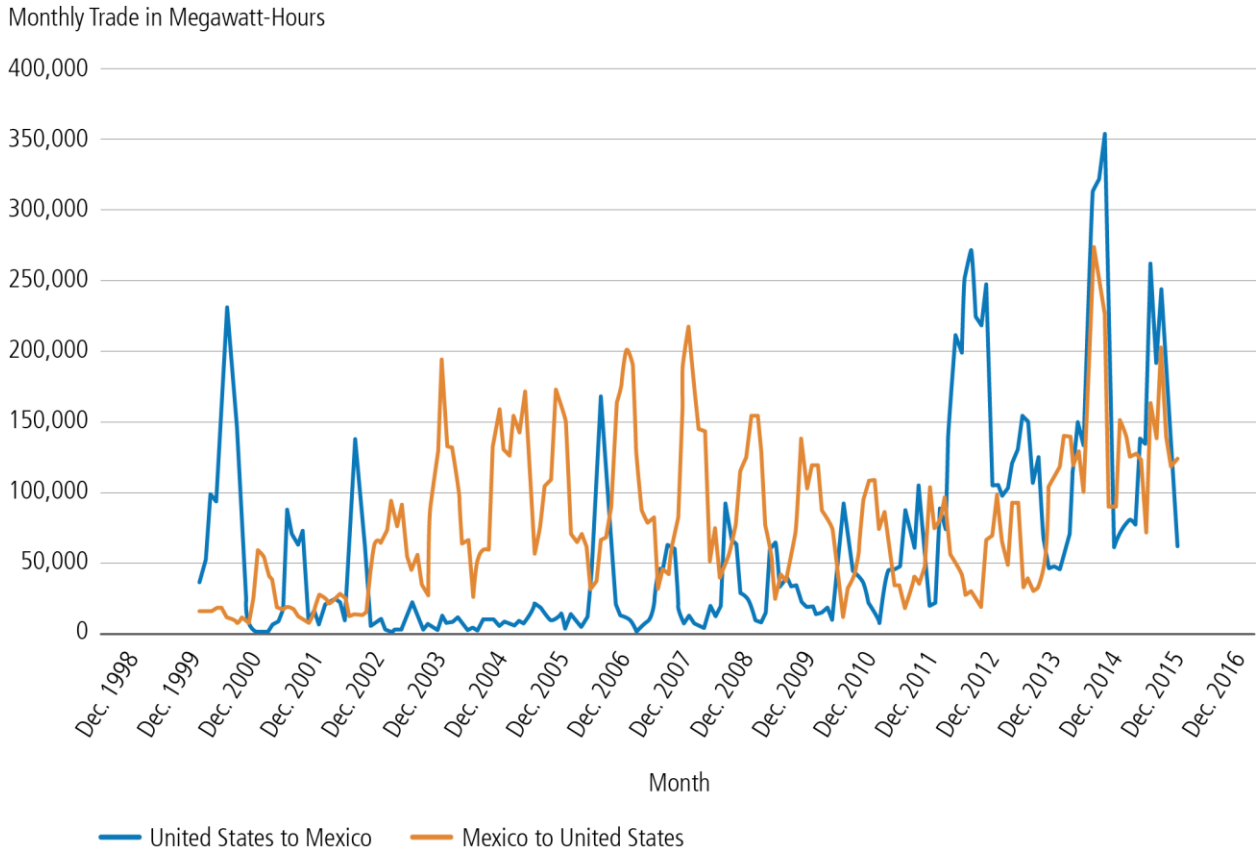
6.3.1 Mexico's Energy Industry Reforms

Due to a combination of historical, geographic, and resource factors, there is significantly less electricity integration between the United States and Mexico (Figure 6-3). According to the Energy Information Administration (EIA), in 2015, the United States and Mexico traded approximately 7.69 million MWh total (compared to 77.2 million MWh traded between the United States and Canada), with the United States exporting 0.39 million MWh and importing 7.3 million MWh.[f]

A number of factors explain the differences: both countries' border regions have experienced electricity shortages and lack reliable excess-generation resources[55] to export to the other; Mexico's states along the U.S. border have some of the lowest population densities in the country;[56, 57] and the border regions include areas with low (or insufficient) levels of existing transmission capacity. Two U.S. states, Texas and California, dominate the cross-border interactions with very different visions for integration. ERCOT shares the longest border with Mexico of any U.S. state, but all transmission connections between the Mexican grid and ERCOT are asynchronous, and trades are primarily for emergency backup, as illustrated in Figure 6-1. Baja California is not connected to the rest of the Mexican federal grid, and therefore, robust California-Baja California cross-border integration may not lead to more integration opportunities in the absence of more domestic, long-distance transmission in Mexico.

[f] U.S. and Mexican estimates of U.S.-Mexico electricity trade vary significantly—a disparity that is being addressed by energy information institutions in both countries under the North American Energy Information Cooperation. Mexico's regulatory agency (Comisión Reguladora de Energía) and wholesale market operator (El Centro Nacional de Control de Energía) estimate total trade to be 4 million MWh in 2014, nearly double the EIA estimate.

Figure 6-3. Electricity Flows Between the United States and Mexico[58]



Monthly cross-border electricity trade between the United States and Mexico shows a number of differences with U.S.-Canada trade; it occurs at lower volumes and is more sporadic/seasonal and bidirectional. Like U.S.-Canadian trade, however, it has been increasing overall since 2011.

Mexico's 2013 energy industry reforms, which included transformational structural reforms across the oil, gas, and power sectors, are highly relevant to cross-border electricity integration (Figure 6-3).[g] Until 2013, the Mexican Federal Electricity Commission (CFE), the vertically integrated, state-owned utility, served as the sole producer, provider, and distributor of electricity in Mexico,[59] and private participation in the sector was reserved for the state except in limited situations (small power production, cogeneration, and independent power production). The existing framework, however, faced significant stress in the 1990s and early 2000s, caused by a mixture of external and structural factors, including high energy prices, low industrial competitiveness, government subsidization of electricity, lagging domestic fossil fuel production, and under-investment in the power sector. Projected growth of power demand over the next decade led the government to pass extensive energy reforms in 2013, followed by a series of implementing laws that unbundled CFE and established a new wholesale electricity market to foster competition with private-sector participation (Figure 6-4). Under the new framework, the private sector is now free to participate in all aspects of the generation and sale of electricity, while CFE maintains physical control of transmission and distribution infrastructure and remains the sole provider to residential users with regulated tariffs, and the National Energy Control Center is now the ISO in charge of the operational control and administration of the new wholesale electricity market.[60] Many power

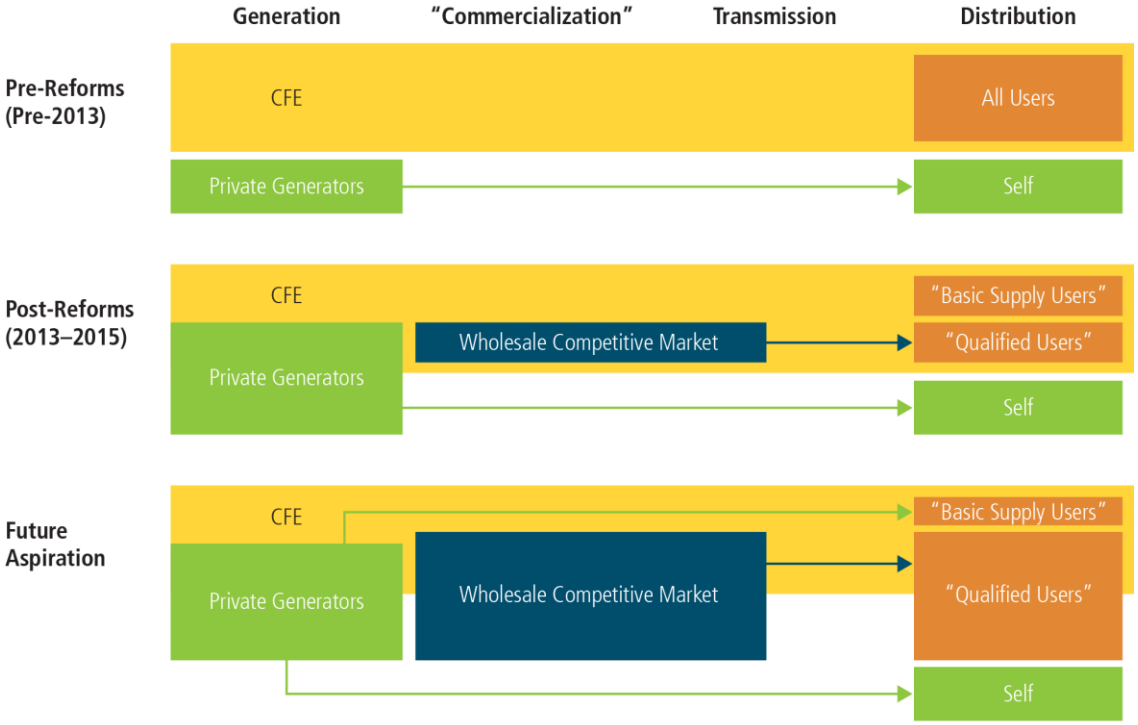
[g] Unlike U.S. and Canadian power sector governance, which defers a number of authorities to state and provincial governments, Mexico's federal government is more centralized and also has near-complete authority in the power sector.

sector stakeholders have called the reforms groundbreaking and admirable, including for reducing the strain of electricity consumption costs on industry in Mexico (Figure 6-5).[61]

The reforms are focused on the overall goal of competitiveness, with twin objectives of helping consumers pay less for electricity and have cleaner electricity.[62] Currently, the industrial sector in Mexico faces costs per MWh of electricity that are almost double electricity costs in the United States, making production and goods more expensive for all of North America. In seeking lower energy prices for its consumers, Mexico is focusing on switching from fuel oil and diesel-fired generation in the power sector to natural gas (in part through greater imports from the United States[63]); reducing transmission and distribution losses (estimated at 16 percent of total generation in 2010); and increasing renewable energy deployment.[64] The impacts for Mexico's northern border region, specifically, could be significant as the region includes a number of industrial centers in Ciudad Juárez, Matamoros, Mexicali, Nogales, Nuevo Laredo, Reynosa, Tecate, and Tijuana.[65] One economic analysis estimates that transitioning from oil to natural gas for electricity production could have tremendous impacts in the manufacturing sector, where it could reduce electricity prices by 13 percent, boost manufacturing output by up to 3.9 percent, and increase overall gross domestic product by up to 0.6 percent.[66, 67]

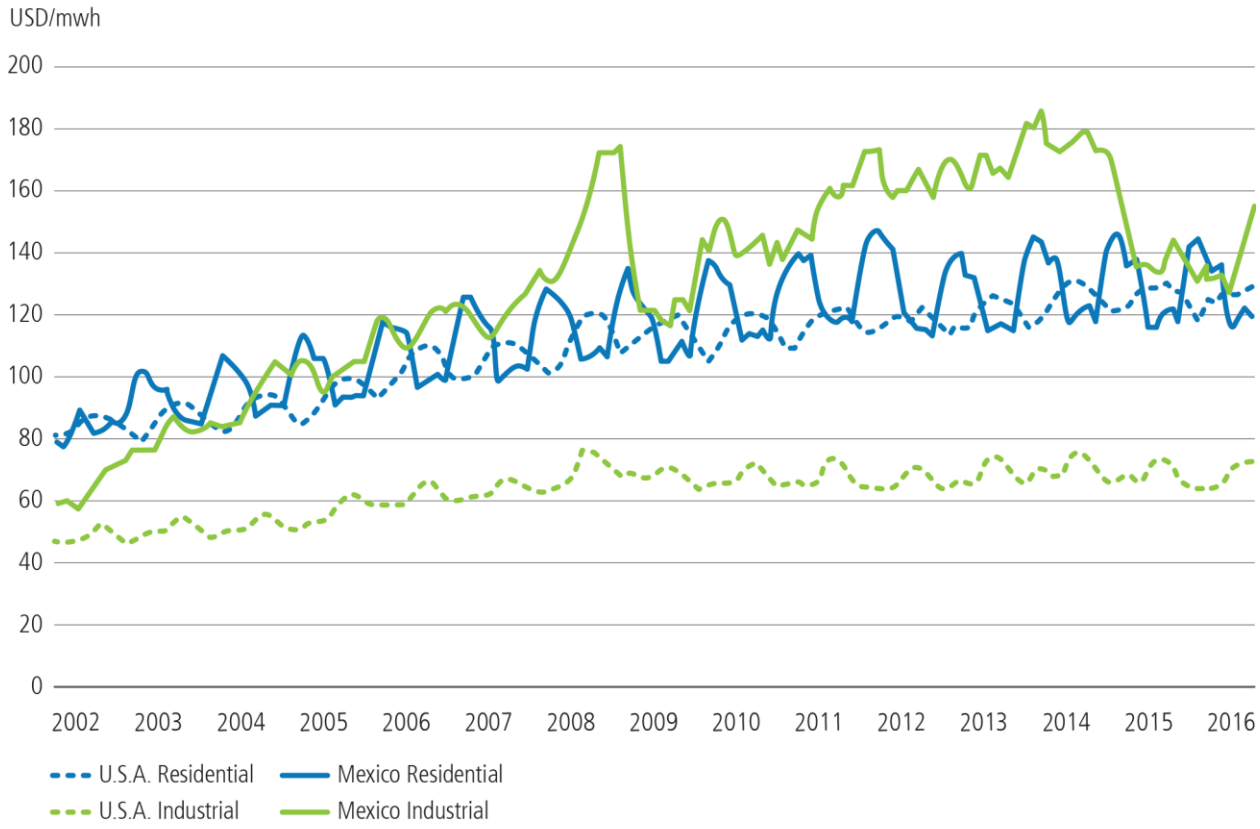
As is natural for such a transformational change to the sector, the full implementation of the reforms is still in development, and uncertainties about the final form of the new framework exist.

Figure 6-4. Structural Changes Following Mexico's Energy Industry Reforms



A simplified schematic showing the adjustments in the Mexican power sector, pre-reforms, post-reforms, and future aspirations. Pre-reforms, CFE was vertically integrated and responsible for the generation, commercialization, transmission, and distribution of electricity to nearly all users, with exceptions for some forms of self-generation. The reforms created a wholesale competitive electricity market in which private generators can participate, and divided users into "basic supply" users (those who consume under a given threshold and continue to receive direct service from CFE) and "qualified users" (those who consume over that threshold and are serviced by the wholesale competitive market). Over time, the wholesale market is intended to supply the majority of consumers. CFE continues to maintain control over transmission and distribution post-reforms.

Figure 6-5. Industrial and Residential Electricity Rates in the United States and Mexico, 1993–2013[68]



Different policies regarding industrial electricity and residential tariffs in the United States and Mexico, as well as different electricity generation sources (over the given period, Mexico used greater diesel/heavy fuel oil-fired generation, while the United States was more reliant on coal and natural gas) have led to a significant differential between U.S. and Mexican electricity rates. Of particular note, industrial rates in Mexico were slightly less than double U.S. rates in 2013, which impacts Mexican industrial competitiveness. Rates include government subsidies to Mexican residential consumers.

Mexico is already seeing reductions in electricity prices; though the recent low oil and natural gas prices are likely a contributing factor, this trend is also likely to be stimulated by the reforms. From December 2014 to December 2015, electricity rates fell between 30 to 42 percent for industry. The wholesale electricity market also began to operate in January of 2016 and renewable electricity-generation capacity increased by 8.5 percent from 2013–2014 alone.[69] However, a differential in prices still exists: in the first six months of 2016, average wholesale prices in most locations of Mexico have ranged from $48/MWh to $60/MWh;[70] while in Texas, the ERCOT North 345-kilovolt peak wholesale prices over the same period were $22/MWh.[71]

6.3.2 Projected Actions and Potential Opportunities

Mexico's energy industry reforms may shift the cost-benefit analysis of enhanced integration in meaningful ways: these reforms were intended to increase generation in Northern Mexico (including a number of industrial centers); stimulate private-sector investment in the power industry; lower energy costs; increase flows of natural gas from the United States; and increase renewable energy and energy

efficiency deployment. All of these objectives could have implications for the attractiveness of increasing cross-border coordination and electricity trade.

According to analysis done by EIA, Mexico plans to build an additional 57 gigawatts of generation capacity from 2016 to 2030 and double natural gas imports from the United States from 2013 to 2018,[72] which will lead to a decline in electricity subsidies. The Program for Development of the National Electricity System, an annual report known by its Spanish acronym "PRODESEN," also demonstrates the intent to increase transmission capacity within Mexico, with some developments that could have impacts on cross-border trade, including connection of the Baja California Peninsula to the Mexican federal system by 2021 and construction of a new 150-MW asynchronous connection between Nogales, Sonora, and Arizona.[73, 74] The government of Mexico is also studying the possibility of a larger east-west transmission line along the U.S. border, with the objective of enhancing transmission capacity in Northern Mexico and facilitating cross-border trade.[75] Policy, regulatory, infrastructure, and economic changes in Mexico may lead to a number of other new opportunities. The smart grid is a key area of focus; the PRODESEN report supports a smart grid program every three years to evaluate projects for the integration of new technologies into transmission; new wide-area monitoring systems; diagnostics and protections coordination using phasor measurements; and automation and modernization of substations. These investments will likely stimulate interest among U.S. generators to export electricity to Mexico; increase potential for flows from Mexico to the United States to supply U.S. demand for clean energy and essential reliability services; expand trade flows in both directions to enhance reliability; and/or improve cooperation to stimulate clean energy development; and reduce GHG emissions. Mexico's increasing importation of U.S. natural gas has been and will remain an economic and environmental opportunity for both sides, by offsetting expensive and high-GHG-emitting diesel generation in Mexico and creating economic opportunities for U.S. exporters. The resulting reduction in electricity costs in Mexico could boost overall North American competitiveness and opportunities to integrate supply chains.[76]

As for clean energy development, Mexico has established a program of clean energy certificates, which bears a resemblance to California's renewable energy credit system. Mexico's Transition Strategy has a significant focus on promoting clean technologies and fuels, with goals of reaching 35 percent clean energy generation by 2024.[77] A variety of tools, such as the Clean Energy Zone Atlas, will help Mexico plan for the development of clean energy power plants and the expansion of the grid, similar to the Competitive Renewable Energy Zones in Texas. Two long-term clean energy auctions in 2016 produced record-low prices for energy, capacity, and clean energy certificates, and in the first auction, contracts were awarded with an average certificate price of USD $47.76; these projects will start operations in 2018. In the second auction, renewable projects including solar, wind, geothermal, hydro, and combined-cycle natural gas (only for capacity) produced three record-low prices for Latin America: a wind price of $32/MWh and a solar price of $27/MWh. These recent auction results indicate the opportunities in Mexico for renewable energy development. There are even instances where projects in Mexico qualify for California's RPS—the Energia Sierra Juarez project, a wind farm constructed miles from the California border, is one example of a Mexican project that has received certification to qualify. The Mexican government is fully committed to capitalizing on these opportunities, and its federal authority is sufficient to implement widespread changes.

Enhanced cross-border electricity integration with Mexico does present challenges. Mexico's sector continues to experience high levels of technical and non-technical losses,[78] and it will need significant investments to improve system functionality to achieve greater efficiencies, especially in a scenario that includes significant increases in power trading with the United States' bulk power system. Mexico has different protections for open access to transmission from the United States and Canada. Though rules exist for access to government-owned transmission in Mexico, these are dissimilar to FERC Order Nos.

888 and 890.[79, 80] Additionally, both sides of the border have experienced power shortages in the past decade, suggesting that at this time, neither border region has developed significant and reliable excess power to sell to the other on a firm basis. The limitations of trade between Texas and the rest of the United States, vis-à-vis the Federal Power Act, do not apply to, and therefore are not a limitation on, ERCOT's electricity trade with Mexico.

Though ERCOT has maintained a more isolated domestic trade strategy for electricity, the same Federal Power Act issues that drive these policies should not impact ERCOT-Mexico trade in electricity. But the combination of challenges to trade, even though ERCOT shares the longest border with Mexico of any U.S. state, suggests that it will take a very compelling business case to enhance cross-border flows.

6.4 Emerging Integration Opportunities across North America

6.4.1 Carbon Trading and Pricing to Address Emissions in Mexico and Canada

In recent months, the federal governments of both Canada and Mexico have announced plans for new policies to address carbon dioxide emissions. For several years, provinces and the private sector have pursued various forms of carbon accounting, charging, and trading. The electricity sector has and will play an important leading role in reducing economy-wide emissions of carbon dioxide. Given the highly integrated nature of the U.S.-Canada electricity system and the increasingly integrated state of the U.S.-Mexico electricity system, it will be important to explore the effects of implementation of new federal carbon reduction policies across North America.

Subregional carbon markets are present all around the United States, including in states that border Mexico and Canada. The Regional Greenhouse Gas Initiative was the first mandatory carbon market in the United States, and it includes a cap-and-trade program for carbon-dioxide emissions from power generators in the Northeast, Delaware, and Maryland (see Chapter III, *Building a Clean Electricity Future* for additional detail). California and Quebec have had linked carbon markets since 2014, and Ontario will join those markets in 2018. Mexico and the province of Manitoba are also considering joining. As these arrangements evolve, the implications of these new markets for carbon trading should be examined further.

Table 6-1. New Carbon Trading and Pricing Policies in Canada and Mexico Are a First for North American Federal Governments

Canada	Mexico
	
Most of Canada's provinces have implemented initiatives to reduce carbon-dioxide emissions from the power sector,[h] and 80 percent of Canadians live in a province where there is pollution pricing.[81] In September 2016, the federal government announced a "floor" carbon tax that will be introduced in 2018 at $10/ton of carbon. Under the federal program, the carbon price will rise $10/ton per year until 2022, when the price will freeze at $50/ton. Provinces have considerable implementation flexibility. The price can be in the form of a specific tax or levy or as a cap-and-trade program, provided provinces set emissions caps that correspond to the expected reductions from the carbon price. The carbon tax will be revenue-neutral for the federal government, which will return funds to provinces from federally imposed carbon taxes. Any province can also levy the carbon tax and collect revenue itself, without involving the federal government, to meet the carbon pricing requirement.[82, 83] A number of provinces, including British Columbia,[i] Alberta,[j] Ottawa, and Quebec,[k] are already in compliance with a carbon price for 2018, though the rising federal price of carbon will necessitate additional action from all provinces by 2022.	A carbon tax on the use of fossil fuels was introduced in Mexico in 2014. The initial price on carbon was set at USD $3.5/ton of carbon.[84] In November 2016, Mexico launched its first federal initiative to deal with carbon, a pilot project with voluntary participation for study purposes of Mexico's new cap-and-trade program. The information will inform implementation of the 2018 launch of Mexico's new cap-and-trade program. The program is being guided by the Secretariat of Environment, the Mexican Stock Exchange, and the Mexican Carbon Platform, a private trading platform established in 2003. The platform involves voluntary participation of approximately 60 companies from various industries, including steel, cement, and chemicals, which combine to annually generate 70 million tons of carbon dioxide. Historically, the state of Baja California has been involved in California's carbon trading and clean energy policies for several years. To formally launch cap-and-trade in 2 years, Mexico will need to establish a cap on GHG emissions and create a program for monitoring and verification.[85, 86]

The electricity sector has and will continue to play an important leading role in reducing economy-wide emissions of carbon dioxide across North America. Table 6-1 briefly describes recent announcements and actions by the federal governments of Canada and Mexico to address carbon dioxide emissions from the electricity system.

[h] Prince Edward Island has no current targets or initiatives in place; the territory of Nunavut is implementing climate adaptation strategies that do not address power generation. All other provinces and territories either have some form of emissions-reduction target and/or carbon pricing in place, including but not limited to mass-based targets, cap-and-trading, and RPS. Two territories, Northwest Territories and Yukon Territory, have voluntary energy efficiency targets in place for households and businesses that will reduce emissions from the power sector.

[i] British Columbia currently has a carbon tax of $30/tonne.

[j] Alberta will levy a carbon tax on fuels at a rate of $20/tonne beginning in January 2017. One year later, the levy will increase to $30/tonne.

[k] Carbon was trading at $17 Canadian/tonne in May 2016 for the cap-and-trade market that includes Quebec and will include Ottawa (according to the International Carbon Action Partnership).

6.4.2 Improving Grid Security and Reliability

Protecting the grid against vulnerabilities is a shared responsibility across North America. Most recently, the United States and Canada have agreed upon goals to: (1) protect today's electricity grid and enhance preparedness; (2) manage contingencies and enhance response and recovery efforts; and (3) build a more secure and resilient future electric grid.[87] The joint U.S.-Canada Grid Security Strategy promotes improvements to information sharing, vulnerability assessment, emergency response and continuity, and management of new and evolving risks from grid technologies and design.[88]

The United States and Canada have developed respective national action plans to address and improve grid security. Going forward, there are key areas of mutual interest where joint cooperation can continue to grow between the United States and Canada. These include the Department of Energy and Natural Resources Canada working, in coordination with the Department of Homeland Security and Public Safety Canada, to

- Inform and support the private energy sector in response to a significant cyber incident
- Improve tools, frameworks, protocols, and methods for information sharing, risk assessment, and situational awareness
- Coordinate with existing table-top exercise formats
- Develop standardized curricula and training materials for utilities to educate their workforces on protection against threats, including cybersecurity.

Coordination of grid security efforts can lead to a more proactive approach to addressing emerging threats across North America. As Mexico's interconnections with the United States grow in number and capacity, it will be important for ongoing discussions of grid security goals and objectives to be informed by Mexico's experiences and perspective.

Mexico is working closely with NERC to achieve well-interconnected, secure, and stable electricity grids. Currently an inter-ministerial body (The Ministry of Energy, the System Operator, and the Regulatory Commission) has been set to produce a first version of Mexico's proposal of a Memorandum of Understanding with NERC. Along with this proposal, the group is working very closely with the staff of the Department of Energy, FERC, and the Western Electricity Coordinating Council to ensure consistency with other specific agreements.

As more interconnections are planned and built between the United States, Canada, and Mexico, the North America bulk power system must not only remain secure but reliable. High-level cooperation between all three countries on energy issues should maintain a focus on the shared goal of a reliable electricity system for the continent. From coordination on high-level principles for reliability, to modeling and analysis to inform operations of the future bulk power system, cooperation across North America on reliability will complement efforts to improve security and ensure economic competitiveness.

6.5 Policy Options for North America

There are a variety of policy options that all three countries, and the United States individually, can take to support targeted action to enhance integration: (1) engagement—often high-level and internationally through bilateral and trilateral dialogues and other cooperation mechanisms; (2) analysis—both cooperative and independent carried out through working groups and projects); and (3) policy-level actions—primarily executed by domestic federal and state entities. Specific recommendations are described more thoroughly in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

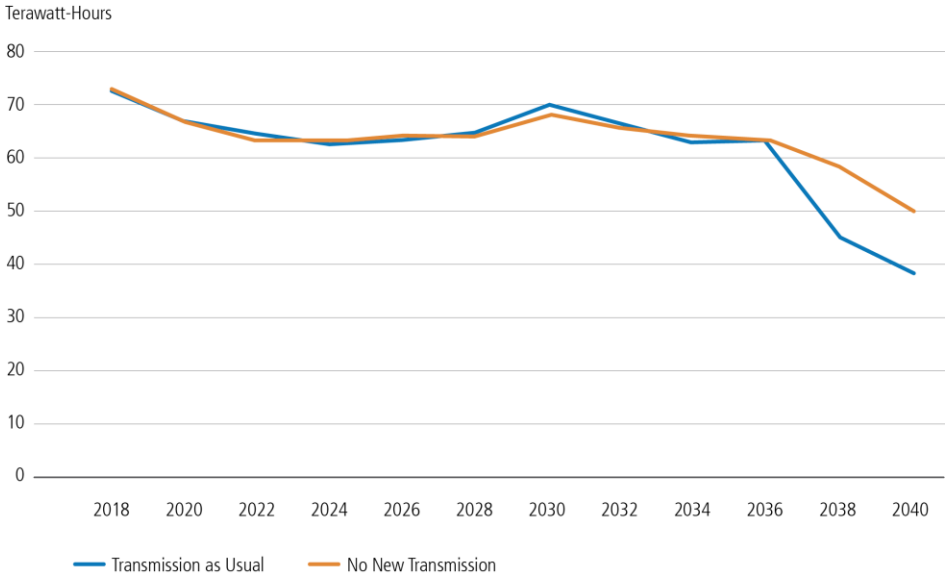
6.5.1 Key Existing Efforts to Analyze Cross-Border Electricity Policy

While many detailed electricity sector modeling tools exist for the United States (and in some cases, the United States and Canada), modeling tools capable of analyzing the economic, environmental, social, or reliability impacts of electricity integration throughout North America are relatively coarse. Improved models would lead to more informative and useful results to enable better stakeholder decisions.

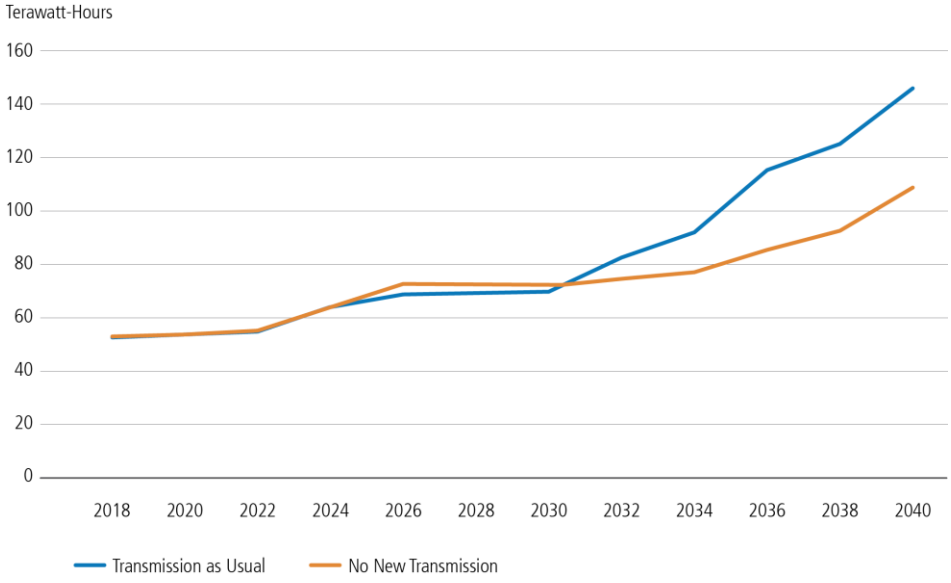
While there is a diversity of power sector modeling tools to analyze U.S. grid or market operations at varying levels of detail and accuracy, such tools do not yet exist at a robust level for the combined power system of Canada, Mexico, and the United States, limiting the ability of modeling to estimate costs and benefits of increasing cross-border trade.[89] One exception is the Regional Energy Deployment System (ReEDS), which does represent both the United States' and Canada's power systems.[90] Sample, preliminary analysis from this model is highlighted in Figure 6-6. The Department of Energy's Office of Energy Efficiency and Renewable Energy is working with the National Renewable Energy Laboratory to expand this model to Mexico in cooperation with the Mexican Secretariat of Energy and the Mexican National Energy Control Center. Final results will be used to understand the implications of a variety of U.S.-Mexican energy scenarios; inform decision-making about renewable energy integration and cross-border energy markets; and establish the analytical framework for long-term strategic thinking about a shared North American energy future. The U.S. Department of Energy, Natural Resources Canada, and Mexico's Secretariat for Energy are also supporting a 3-year effort through the North American Renewable Integration Study (NARIS) to share data and enable modeling and analysis of coordinated planning and operations across North America under high-market-penetration renewable energy scenarios. The ReEDS United States, Canada, and Mexico models will be used to inform the NARIS study scenarios. The NARIS study will be completed in 2018.

Figure 6-6. Possible Long-Term Impacts of Cross-Border Transmission on Regional Generation Mix in the United States, 2018–2040 in the Regional Energy Deployment System Model





Under a low-carbon future scenario, results from ReEDS show that transmission with Canada becomes increasingly important for sustaining emissions reductions and has a significant impact on the generation mix in border regions. In ISO New England, greater cross-border transmission capacity reduces domestic natural gas generation. In New York ISO, additional transmission capacity with Canada is associated with an increase in domestic renewable generation.



Though not scenario-based, complementary qualitative analyses (Table 0-2) can allow policymakers to understand the current status of integration and the relevance of specific factors to impact cross-border trade opportunities.

Table 6-2. Analysis of Variables That Have Led to Current Levels of Cross-Border Trade in Cross-Border Trade Relationships

Criteria	Pacific Northwest	Midwest	NYISO/Can	ISO-NE/ Quebec	California-Baja	ERCOT-Mexico
Integration enhances electric reliability						
Coordination in cross-border operations and planning						
Economic opportunities stimulate greater cross-border trade flows						
Regulatory certainty: transmission access agreements						
Sufficient transmission capacity						
Clean Energy/Climate incentives stimulate cross-border trade						

Color Legend:	Sufficient for needs in an expanded trade scenario	Sufficient for current needs	Moderately available; expansion/adjustment already in process	Present but insufficient for current needs	Not present, N/A

The analysis, done by the Office of Energy Policy and Systems Analysis, demonstrates the variables that have contributed to differences in the level of cross-border integration observed in each cross-border interaction, with robust cross-border integration between the United States and Canadian counterparts, and less developed integration between the United States and Mexico. Cross-border ties with Arizona and New Mexico were not included, due to their small capacity.

Table 0-2 assesses the degree to which cross-border electricity trade in each region has met the criteria that must be present in order to increase international trade in electricity. Cross-border trade in electricity must: provide for customer demand across the border; enhance reliability; provide sufficient transmission capacity; coordinate cross-border operations and planning; and provide regulatory certainty. Additionally, incentives for clean energy can also influence cross-border trade and have been included in this table. Looking at the assessment, it is clear that some key factors required for enhanced integration are still emerging on the U.S.-Mexico border, while supporting factors for cross-border trade in regions shared by the United States and Canada are already in place. This table points also to areas for further work and cooperation among regional stakeholders and governments, including for transmission capacity development.

6.5.2 Explanation of Policy Option Types

6.5.2.1 Engagement

Engagement between Canada, Mexico, and the United States will serve to align national objectives. For example, trilateral and bilateral dialogues or mechanisms for cooperation, including the North American Leaders' Summit, North America Energy Ministers' Meetings, and the Working Group on Climate Change and Energy; trilateral and bilateral memoranda of understanding; the U.S.-Canada Regulatory

Cooperation Council; and bilateral dialogues with Canada (U.S.-Canada Clean Energy Dialogue, U.S.-Canada Energy Consultative Mechanism) and Mexico (U.S.-Mexico High Level Economic Dialogue, U.S.-Mexico Task Force on Clean Energy and Climate Policy, U.S.-Mexico Bilateral Framework on Clean Energy and Climate Change) provide a comprehensive set of diplomatic and working group opportunities for leaders to provide a high-level commitment to action, establish national priorities, establish working groups and task forces to explore specific topics in greater detail, and coordinate developments internationally. Additionally, meetings of leaders at which commitments are made, including the recent goal of 50 percent clean power generation by 2025 for North America, can provide an important forum for engagement. All of these efforts can help to align development and technical assistance efforts; expand networks beyond governments to include key stakeholders from the private sector and other relevant power sector institutions or multilateral development institutions; and stimulate new interest in analysis of other policy options.

Descriptions of recommended engagements to enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.5.2.2 Analysis

The extraordinary complexity of the North America bulk power system means that policymakers and other stakeholders will require robust and extensive analysis to understand the implications of any specific action. Three main elements comprise what is necessary for analysis:

- Access to consistent energy information and data from all three countries (including information regarding generation, transmission, and distribution functions and expansion plans, electricity flows, and pricing).
- Access to information on existing policy, regulatory, and operational features of the power system at the national, state/provincial, ISO, and local levels.
- Rigorous power-sector modeling capabilities that can provide estimates of economic, environmental, social, and operational benefits and costs at varying levels of detail.

Descriptions of analyses that will enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.5.2.3 Specific Policy-Level Actions

Finally, at the most granular level, specific policies can be implemented, strengthened, or adjusted to support enhanced integration. These policy actions range from domestic financial incentives that affect cross-border trade (e.g., tax policy, export tariffs, clean energy incentives), to regulatory frameworks that could be improved to ensure more coordinated yet robust functioning of existing governance (e.g., permitting processes).

Descriptions of policy actions that will enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.6 Endnotes

[1] EPSA Analysis: DOE (Department of Energy), "Brief Historical Background," in *Electricity in North America* (Washington, DC: DOE, 2016), 70–71.

[2] Alan J. Krupnick, Daniel Shawhan, and Kristin Hayes, *Harmonizing the Electricity Sectors Across North America: Recommendations and Action Items from Two RFF/US Department of Energy Workshops* (Washington, DC: Resources for the Future, 2016), http://www.rff.org/files/document/file/RFF-DP-16-07.pdf.

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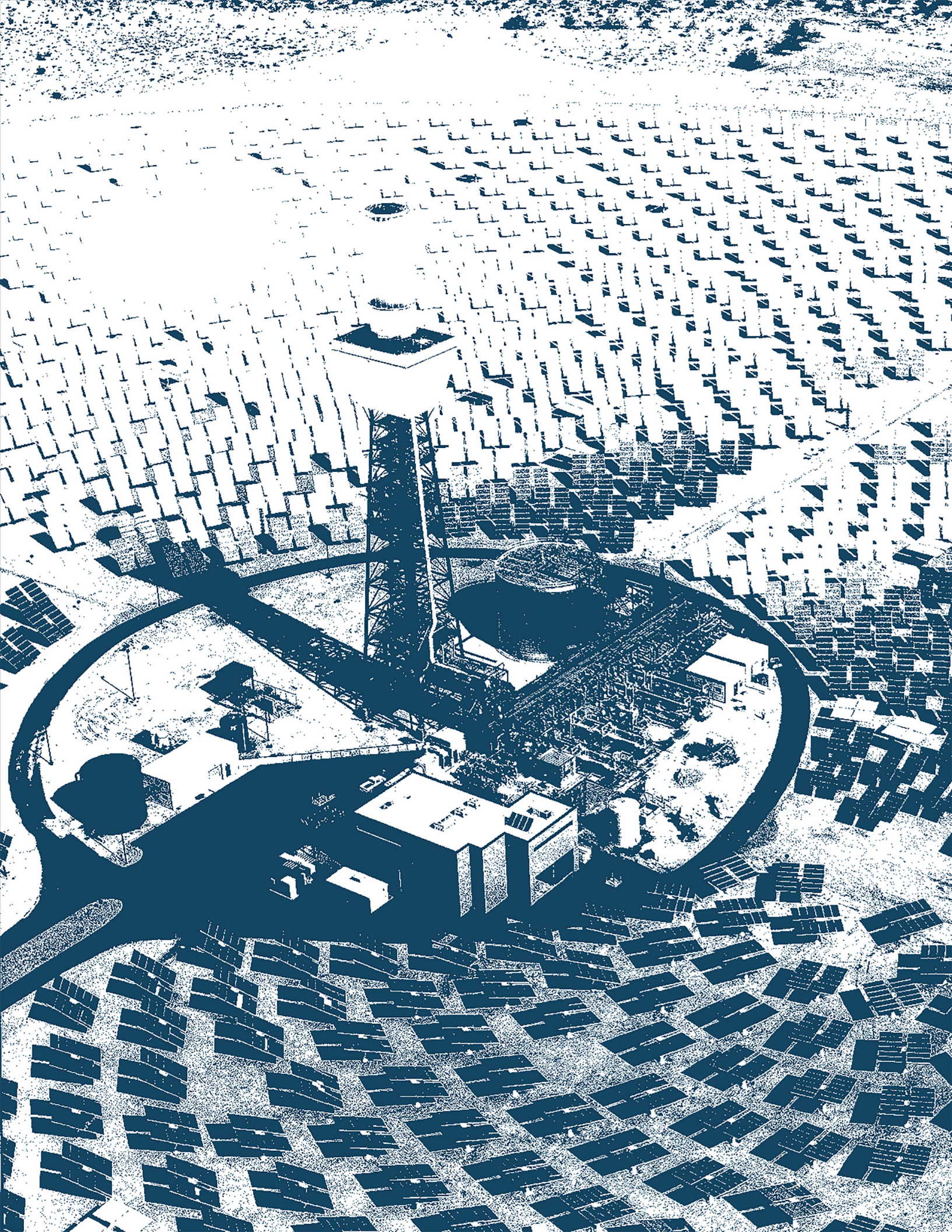


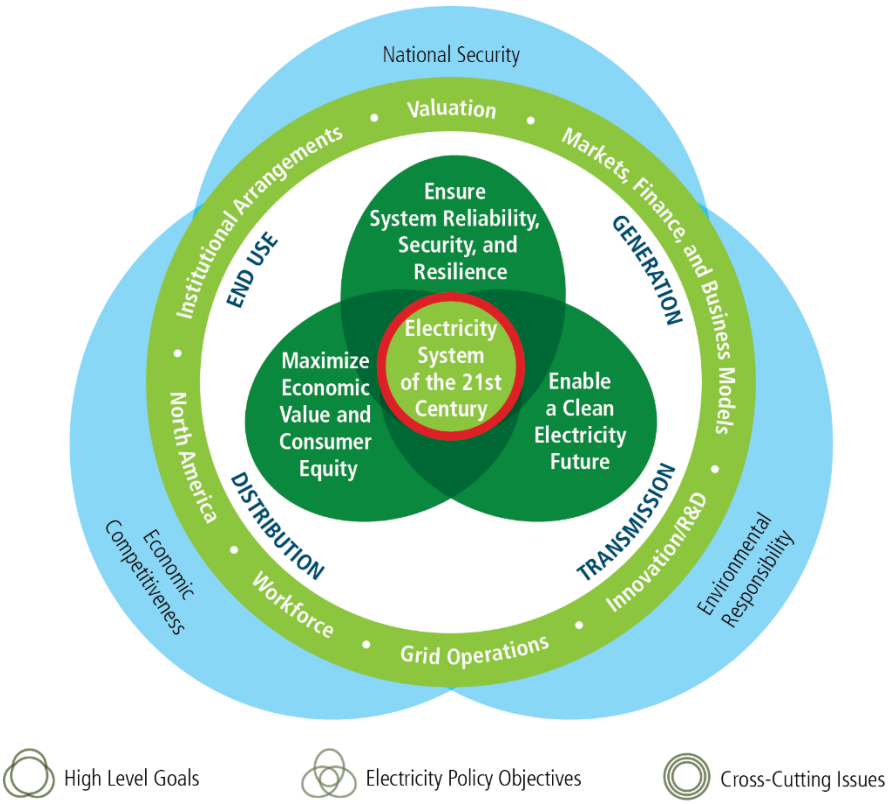
VII A 21st-Century Electricity System: Conclusions and Recommendations

This chapter highlights many recommendations that are enablers of the modernization and transformation necessary. The recommendations build on the analysis and findings in earlier QER 1.2 chapters. Many of the recommendations will provide the incremental building blocks for longer-term, planned changes and activities, undertaken in conjunction with state and local governments, policymakers, industry, and other stakeholders. The policy, research, and investment choices made today will establish critical pathways for decades.

A 21st-Century Electricity System

The central finding in the second installment of the Quadrennial Energy Review (QER 1.2) is as follows: "As a critical and essential national asset, it is a strategic imperative to protect and enhance the value of the electricity system through modernization and transformation."

Figure 7-1. Goals, Objectives, and Organization of QER 1.2



7.1 Key National Security and Reliability Priorities for a 21st-Century Electricity Sector

The electricity sector is a complex system of overlapping interests, investments, and impacts that affect industry, businesses, consumers, and communities served by electricity providers. Accordingly, migration from the present state to a desired outcome for the 21st-century electricity sector requires recognition of critical crosscutting factors that should be addressed as superordinate to the perspectives discussed in preceding chapters. These high-level, crosscutting issues and recommendations address national security, reliability, jurisdictional adjustments, technology investments, streamlined regulatory processes, better gathering and use of data and analysis, and realistic assistance solutions to enable key elements of a 21st-century electricity system.

The Electricity System as a National Security Concern

A set of actions and recommendations in the second installment of the Quadrennial Energy Review (QER 1.2) address the fundamental role of the Federal Government: promoting national security and ensuring the national defense. To this end, it is worth restating a key conclusion from Chapter I (*Transforming the*

Nation's Electricity System: The Second Installment of the QER) to illustrate the essential and growing role electricity now plays in this fundamental function of the Federal Government. The conclusion of a 2015 report from the Center for Naval Analyses notes,

> "Assuring that we have reliable, accessible, sustainable, and affordable electric power is a national security imperative. Our increased reliance on electric power in every sector of our lives, including communications, commerce, transportation, health and emergency services, in addition to homeland and national defense, means that large-scale disruptions of electrical power will have immediate costs to our economy and can place our security at risk. Whether it is the ability of first responders to answer the call to emergencies here in the United States, or the readiness and capability of our military service members to operate effectively in the U.S. or deployed in theater, these missions are directly linked to assured domestic electric power."[1]

The analysis in QER 1.2 reaches a similar conclusion: The reliability of the electric system underpins virtually every sector of the modern U.S. economy, which depends on electricity—including sectors from food production to banking to health care. Electricity is at the center of key infrastructure systems that support these activities—transportation, oil and gas production, water, finance, and information and communications technology. Electricity-dependent critical infrastructures represent the core underlying lifeline framework that supports the American economy and society.

The range of goods and services that involve grid communications and two-way electricity flows, including the Internet of Things (IoT), represents significant value creation and greatly supports and enhances our economy and global competitiveness. At the same time, these goods and services place new demands on the electric grid for high levels of reliability, smarter components, visibility, analytics, and system-wide planning. These features and services also introduce new vulnerabilities to our electricity system (e.g., accelerated time scales sufficient to require significant automation and cybersecurity) that rise to the level of national security concerns.

These vulnerabilities are underscored by the October 21, 2016, hacking incident of simple home devices. Figure 7-2 shows the location of key data centers that support the Internet (discussed in detail in Chapter I, *Transforming the Nation's Electricity System: The Second Installment of the QER*), as well as the global impacts of this event. In this incident, the "Mirai" botnet used the IoT devices, including baby monitors, to create the largest denial-of-service attack in history. The impact of this event was amplified by the U.S. Domain Name System company (called Dyn), infecting 100,000 IoT devices deployed throughout the world (Figure 7-3).[2] The IoT devices in foreign countries worked together to attack a U.S. company. This attack underscores the national security and economic vulnerabilities associated with the growing proliferation of unhardened consumer devices on the distribution network that have the potential to infect bulk power systems.

Figure 7-2. Primary Data Centers for Major Service Providers[3]

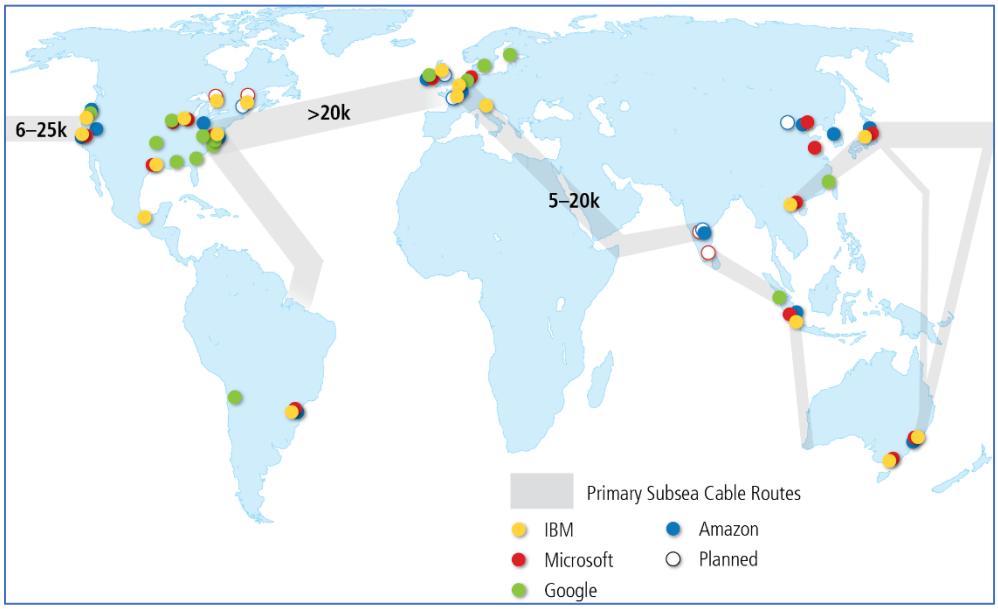
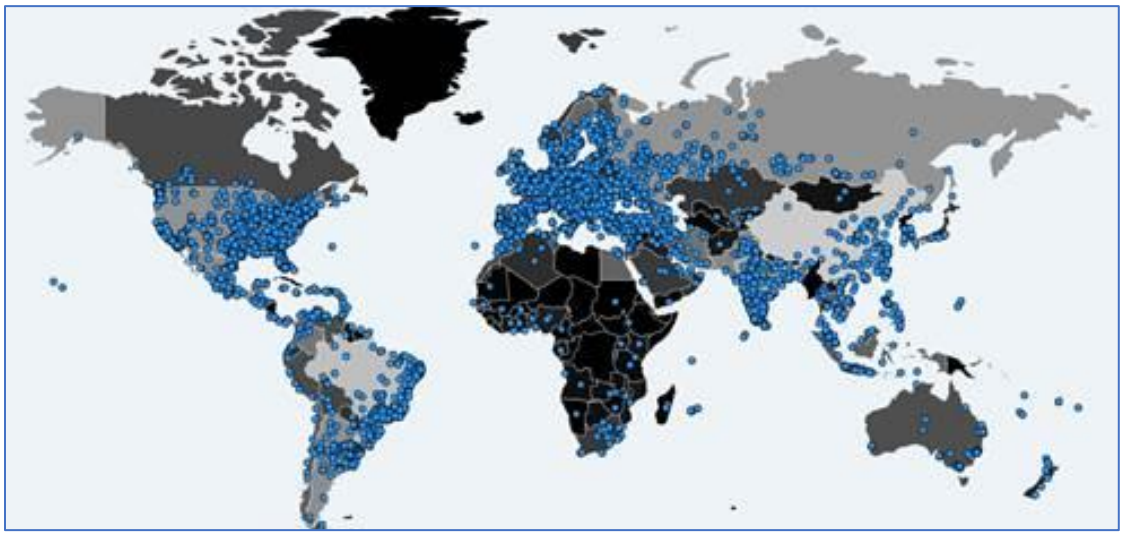


Figure 7-3. October 21, 2016, Hack Had Global Reach[4]



The global Internet is supported by a worldwide network of subsea cables and large-scale data centers operated by firms such as Amazon, Google, IBM, and Microsoft (Figure 7-2). This global reach and interconnectedness, however, also introduces vulnerabilities for U.S. assets and systems that can be affected by connected devices worldwide, as was seen in the October 21, 2016, "Mirai" botnet attack (Figure 7-3, with blue depicting the global impacts of the attack). The global exposure of the "internet of things" merits deliberate risk management activities as the electric power sector becomes increasingly interconnected with global communications networks.

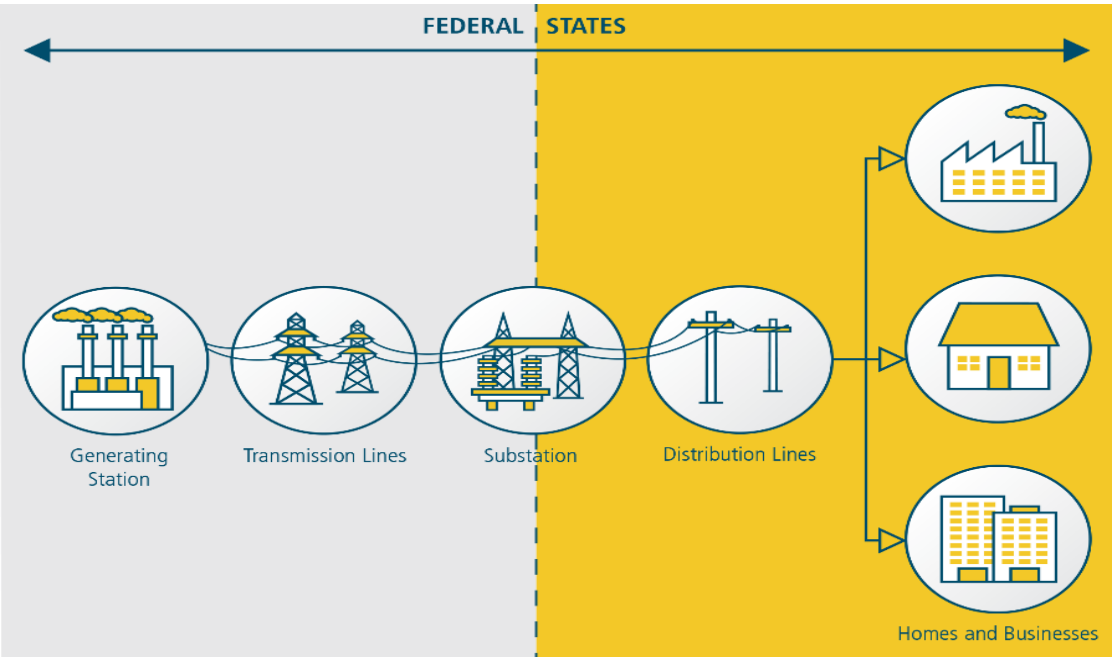
As noted in Chapter I (*Transforming the Nation's Electricity System: The Second Installment of the QER*) and worth repeating here, Congress has recognized the national security implications of the electricity system in the Fixing America's Surface Transportation Act (FAST Act), passed in December 2015. To place the recommendations in QER 1.2 in context, it is important to repeat key language in the Act. The FAST Act gives the Secretary of Energy new emergency authorities for "critical electric infrastructure," where, upon a directive from the President, the Secretary may "with or without notice, hearing or report, issue

such orders for emergency measures as are necessary…to protect or restore the reliability of critical electric infrastructure or of defense critical infrastructure during an emergency." These authorities apply to "the occurrence or *imminent danger of* [italics added]…electronic communication or an electromagnetic pulse, or a geomagnetic storm event that could disrupt the operation of those electronic devices or communications networks, including hardware, software, and data, that are essential to the reliability of critical electric infrastructure or of defense crucial electric infrastructure…the disruption of the operation of such devices or networks, with significant adverse effects on the reliability of critical electric infrastructure or of defense critical electric infrastructure…a direct physical attack on critical electric infrastructure or on defense critical infrastructure; and significant adverse effects on the reliability of critical electric infrastructure or of defense critical electric infrastructure as a result of such physical attack."[5]

Four essential observations about these provisions should be noted. First, there are, in effect, anticipatory authorities in the law, described in the FAST Act as events that present "imminent danger." Second, the provisions of the law are all tied to the *reliability* of critical electric infrastructure, directly linking reliability to security: the new security authorities of the President and Secretary of Energy cover security events that affect reliability; to inform imminent threats, they must also encompass cyber, electromagnetic pulses (EMPs), or geomagnetic disturbance events that threaten security. Third, the increasing reliance of the electricity system on natural gas—it is now the number one primary fuel source for power generation for the first time in the Nation's history—makes security information about related gas infrastructures a critical component for decision making under the FAST Act. Finally, cyber threats do not respect jurisdictional boundaries.

Figure 7-4 clearly illustrates the interconnectedness of the electricity system; the national security responsibilities included in the FAST Act must be addressed without regard to jurisdictional boundaries.

Figure 7-4. Current Jurisdictional Boundaries and the Security of the Electricity System[6]



The U.S. electricity sector regulatory authorities are generally split between the Federal Government for generation and transmission assets and states for distribution networks. The recently passed FAST Act specifies federal authorities to address critical electric infrastructure emergencies.

In addition, the interconnectedness of our modern grid was underscored by the Supreme Court's decision on Federal Energy Regulatory Commission (FERC) Order No. 745. While the Court's majority opinion on Order No. 745 acknowledged that FERC, in this order, only addressed wholesale markets, it also noted, "It is a fact of economic life that the wholesale and retail markets in electricity, as in every other known product, are not hermetically sealed from each other…To the contrary, transactions that occur on the wholesale market have natural consequences at the retail level. And so too, of necessity, will FERC's regulation of those wholesale matters…When FERC regulates what takes place on the wholesale market, as part of carrying out its charge to improve how that market runs, then no matter the effect on retail rates, [the Federal Power Act] imposes no bar."[7]

Recent FERC actions are designed to address and clarify key security issues, as well as issues raised by two-way flows and a modern electricity system. FERC has issued an order pursuant to the FAST Act to control the availability of sensitive critical energy infrastructure information on "production, generation, transmission and distribution of energy," noting that a single critical energy infrastructure information process is "…the most efficient way to fulfill the statutory mandate of the FAST Act and to avoid any confusion that could result from different processes for different types of critical infrastructure information."[8] FERC has also taken steps to enable the aggregation of storage, including at customer facilities, examining the need to develop participation models consisting of market rules.[9]

Integrated Planning Needed to Address National Security Imperatives of the Electricity System

National security investments, regardless of scale, are costs that should be born, in part, by the Federal Government acting on behalf of all Americans. Sorting out how costs should be allocated will be a critical success factor in achieving and sustaining a secure grid throughout this century. New authorities must come with appropriate budgets for Federal responsibilities, and costs to be carried by ratepayers must be made explicit as well. Managing investment requirements while keeping affordability in mind must be a key concern of the Federal Government. While most analysts do not think that these costs will cause rate shocks, having mechanisms for clearly articulating the associated Federal and ratepayer costs will be important for security and public acceptance.

QER 1.2 discusses the limits of existing reliability and resilience planning methodologies and processes in Chapter IV (*Ensuring Electricity System Reliability, Security, and Resilience*). There are many planning methods currently used by utilities, ranging from integrated resource planning to more-focused procurement planning. Despite the breadth and depth of current and emerging planning methods, there are gaps in standards, operational definitions, and geographic scope. There are also several levels of planning as well, such as state-level regulatory planning; state energy office planning; independent system operator/regional transmission organization regional planning; North American Electric Reliability Corporation (NERC) region planning; and FERC planning requirements, which affect all entities regulated by FERC. Still, when aligned with a map of the Nation, there are no adopted common demarcations that enable consistent and seamless planning related to grid security that can serve the need for a national security overlay.

7.1.1 Key Crosscutting Recommendations to Support the Security and Reliability of the Electricity System

Protect the Electricity System as a National Security Asset

The Federal Power Act provides a statutory foundation for an electricity reliability organization to develop reliability standards for the bulk power system. Pursuant to this authority, FERC has certified NERC as the Electric Reliability Organization. Under this arrangement, NERC and FERC have put into place a

comprehensive set of binding reliability standards for the bulk power system over the past decade, including standards on cybersecurity and physical security. However, the Federal oversight authority is limited: FERC can approve or reject NERC-proposed reliability standards, but it cannot author or modify reliability standards.

The nature of a national security threat, however, as articulated in the FAST Act, stands in stark contrast to other major reliability events that have caused regional blackouts and reliability failures in the past. In the current environment, the U.S. grid faces imminent danger from cyber attacks. Widespread disruption of electric service because of a transmission failure initiated by a cyber attack at various points of entry could undermine U.S. lifeline networks, critical defense infrastructure, and much of the economy; it could also endanger the health and safety of millions of citizens. Also, natural gas plays an increasingly important role as fuel for the Nation's electricity system; a gas pipeline outage or malfunction due to a cyber attack could affect not only pipeline and related infrastructures, but also the reliability of the Nation's electricity system.

1. **Amend Federal Power Act authorities to reflect the national security importance of the Nation's electric grid**. Grid security is a national security concern—the clear and exclusive purview of the Federal Government. The Federal Power Act, as amended by the FAST Act, should be further amended by Congress to clarify and affirm the Department of Energy's (DOE's) authority to develop preparation and response capabilities that will ensure it is able to issue a grid-security emergency order to protect critical electric infrastructure from cyber attacks, physical incidents, EMPs, or geomagnetic storms. In this regard, Federal authorities should include the ability to address two-way flows that create vulnerabilities across the entire system. DOE should be supported in its development of exercises and its facilitation of the penetration testing necessary to fulfill FAST Act emergency authorities. In the area of cybersecurity, Congress should provide FERC with authority to modify NERC-proposed reliability standards—or to promulgate new standards directly—if it finds that expeditious action is needed to protect national security in the face of fast-developing new threats to the grid. This narrow expansion of FERC's authority would complement DOE's national security authorities related to grid-security emergencies affecting critical electric infrastructure and defense-critical electricity infrastructure. This approach would maintain the productive NERC-FERC structure for developing and enforcing reliability standards, but would ensure that the Federal Government could act directly if necessary to address national security issues.

2. **Collect information on security events to inform the President about emergency actions as well as imminent dangers**. DOE should collect targeted data on critical cyber, physical, EMP, and geomagnetic disturbance events and threats to the electric grid to inform decision making in the event of an emergency or to inform the anticipatory authorities in the FAST Act. DOE should concurrently develop appropriate criteria, processes, and definitions for collecting these targeted data using a dedicated information protection program to safeguard utility data consistent with FERC rules. Reporting will be done on a confidential basis. Updating will be required to address evolving threats. DOE will coordinate the development of analytical data-surveillance and data-protection tools with the National Labs, states, universities, industry, Federal agencies, and other organizations as appropriate.

3. **Adopt integrated electricity security planning and standards**. FERC should, by rule, adopt standards requiring integrated electricity security planning on a regional basis to the extent consistent with its statutory authority. Such requirements would enhance DOE's effectiveness in carrying out its responsibilities and authorities to address national security imperatives and new vulnerabilities created by (1) two-way flows of information and electricity and (2) the transactive

role of customers and key suppliers (such as those providing stored fuel for strategic generators). Important national security considerations warrant careful consideration of how generation, transmission, distribution, and end-user assets are protected from cybersecurity risks. Vulnerabilities of distribution and behind-the-meter assets, which may provide an increasing number of potential entry points for access to utility control systems, are threats that can adversely affect the operation of the transmission system; for these vulnerabilities, a careful review of protections is required. To adequately address and support the security requirements of the FAST Act and DOE's implementation of the FAST Act, this review should be performed on an integrated basis, rather than separating the review into bulk power system and other assets.

To ensure that there are no unnecessary vulnerabilities associated with state-to-state or utility-to-utility variations in protections, integrated electricity security planning should be undertaken to cover the entire United States, including Alaska, Hawaii, and U.S. territories. FERC should consider having existing regional organizations undertake such planning, as it deems appropriate. FERC should evaluate whether the costs of implementing security measures identified in the integrated electricity security plan are appropriate for regional cost allocation, where such measures are found to enhance the security of the regional transmission electric system.

To the extent necessary, appropriate statutes should be amended to clearly authorize FERC to adopt such integrated electricity security planning requirements. However, FERC should immediately begin to advance this initiative to the maximum extent possible under its current authority by initiating a dialogue, including discussions with DOE and state authorities, and driving consensus on Integrated Electricity Security Plans.

4. **Assess natural gas/electricity system infrastructure interdependencies for cybersecurity protections**. DOE, pursuant to FAST Act authorities and in coordination with FERC, should assess current cybersecurity protections for U.S. natural gas pipelines and associated infrastructure to determine whether additional or mandatory measures are needed to protect the electricity system. If the assessment concludes that additional cybersecurity protections—including mandatory cybersecurity protocols—for natural gas pipelines and associated infrastructure are necessary to protect the electricity system, such measures and protocols should be developed and implemented. This work should build on existing assessments, including those underway at the Transportation Security Administration.

Increase Financing Options for Grid Modernization

Estimates of total investment requirements necessary for grid modernization range from a low of about $350 billion to a high of about $500 billion.[1011] Grid modernization is the platform for the 21st-century electricity system, bringing significant value associated with lower electricity bills due to fuel and efficiency savings, more electricity choices, and fewer and shorter outages. The Federal Government currently plays a role in providing tax incentives for deployment of clean energy technologies (discussed further in Chapter III, *Building a Clean Electricity Future*), as well as Federal credit assistance to facilitate early deployment of innovative technologies.

5. **Expand DOE's loan guarantee program and make it more flexible to assist in the initial deployment of innovative grid technologies and systems**. The design of the current DOE loan guarantee program is focused primarily on financing deployment of innovative generation technologies. Most DOE loan guarantee recipients, for example, are structured as special project entities that can raise equity outside of regulated business structures and can provide credit security in the form of power purchase agreements. This financing model is not amenable to grid

modernization financing by regulated entities, especially in cases of some technological uncertainty associated with initial commercial deployments. In addition, there will an ongoing need for innovation in grid technologies beyond the likely availability of current DOE loan guarantee authority. Also, the limitations of the loan program restrict the program to a very small and ever-changing portion of new transmission capacity; more projects and innovation are necessary to transform the grid.

Modifications to the current DOE Title XVII loan guarantee program are needed to (1) reduce restrictions on numbers/types of projects and timeframes, e.g. in order to adequately address innovative transmission capacity needs, and (2) provide clear statutory authority for lending to other public or public/private entities that support transmission and other grid modernization projects (e.g., state agencies, regional power pools) through on-lending or equity investing. By their nature, transmission projects, especially big projects, involve many entities and jurisdictions. Statutory clarification is needed on indirect lending authorities to such entities for multi-jurisdictional projects.

Some of the benefits of grid modernization are realized over time, as the electricity system itself is changed by technology and market innovations. Additional funding resources would bridge the gap between investment costs and realization of benefits and would enable utilities to invest in grid modernization. A relatively low-cost permanent Federal financing system could be established by setting up a revolving loan fund with one-time seed capital.

Increase Technology Demonstrations and Utility/Investor Confidence

The future electric grid will require that utilities deploy a wide range of new, capital-intensive technologies. Primary technologies are needed to support increased reliability, security, value creation, consumer preferences, and system optimization and integration at the distribution level. Demonstrating the technical readiness and economic viability of advanced technologies is needed to inspire the confidence of utilities and investors.

6. **Significantly expand existing programs to demonstrate the integration and optimization of distribution-system technologies**. The complexity of the issues facing distribution systems—including new technologies, the need for systems approaches, and geographical differences in markets and regulatory structures—points to a significant need for multiple "solution sets" to enable two-way electricity flows on distribution systems, enhance value, maximize clean energy opportunities, optimize grid operations, and provide secure communications. Building on existing demonstration programs and reflecting the Administration's commitment to the doubling of Federal clean energy innovation over 5 years as part of its Mission Innovation initiative, DOE should develop a focused, cost-shared program for qualifying utilities to demonstrate advanced distribution system technologies at the community scale, including advanced voltage control/optimization systems; dynamic protection schemes to manage reverse power flows, communications, sensors, storage, switching and smart-inverter networks; and advanced distribution management systems, including automated substations.

   Demonstrations supported by the cost-shared, cooperative agreement program would be specifically designed to inform standards and regulations and increase regulatory and utility confidence in key technologies or technology systems. Under this program, utilities would have to make a positive business case for projects and obtain regulatory approvals for their proposed demonstrations. Preference would be given to multi-utility partnerships with diverse customer profiles and to projects that promote education and training in key academic disciplines that are

essential for distribution system transformation. Cybersecurity plans for all projects would be required and supported by programmatic review of plans and deployments.

Existing DOE programs, including advanced distribution management systems, microgrids, communications and sensors, storage, and cybersecurity, should be leveraged to provide technical assistance regarding technological issues, planning and performance evaluation, and institutional needs. A percentage of funding could be dedicated to small, publicly-owned utilities. The program should be of sufficient size to have a material impact; it should start in fiscal year (FY) 2018 and be ramped up over the time period identified in the Mission Innovation initiative.

Build Capacity at the Federal, State, and Local Levels

The 21st-century electricity system is becoming increasingly transactive, and properly valuing attributes is key to an efficient system. Application of lessons learned that pair economic and system analysis will lead to a power system that cost-effectively serves customers while providing nationally valued public goods, e.g., reliability, resilience, and acceptable environmental performance.

Advances in electricity technologies (i.e., smart grid processes and solutions) require enhanced capabilities in human resources to ensure the cost-effective selection, deployment, and operations of key technologies.

7. **Provide funding assistance to enhance analytical capabilities in state public utility commissions and improve access to training and expertise for small rural electric cooperative and public power utilities**. Federal support should be provided to states and small utilities to enable them to better manage the increasing complexities in the electricity system, such as integrating variable energy resources; incorporating energy efficiency, demand response (DR), and storage into planning; developing competencies in various technologies; and making investment and security decisions within uncertain parameters. These issues are highly technical and require a new knowledge base and skillset often within the domain of computer sciences, economics, and cybernetics. At the same time, these entities are dealing with the workforce issues of outside recruitment or retirement across the electricity industry, which are referenced in the QER. DOE should build and cultivate much-needed analytical capacity at the state level over a limited period of time by allocating funding to state public utility commissions to allow them to hire new or train existing analysts with more sophisticated and advanced skills and build institutional knowledge. Eligibility for state and local funding should be contingent upon demonstration of consideration for Integrated System Planning, which is outlined in this chapter. DOE should support these analysts through an online interactive education and training platform with access to nationally recognized experts. This platform would also be available and tailored to the needs of small utilities. On a national scale, these actions will serve to sustain system reliability and security and bolster resilience.

8. **Create a Center for Advanced Electric Power System Economics**. DOE should provide 2 years of seed funding for the formation of a center designed to provide social science advice and economic analysis on an increasingly transactive and dynamic 21st-century electricity system. The center should be modeled after the National Bureau of Economic Research and be managed by a university consortium. The consortium will establish and maintain a network of experts in economics, the social sciences, and the electricity system; these experts should be from academia, industry, nonprofit institutions, and the National Laboratories. The center will develop new methods where appropriate, serve as advisor and consultant to stakeholders preparing germane analyses, and foster the advancement of students and professionals who are developing expertise

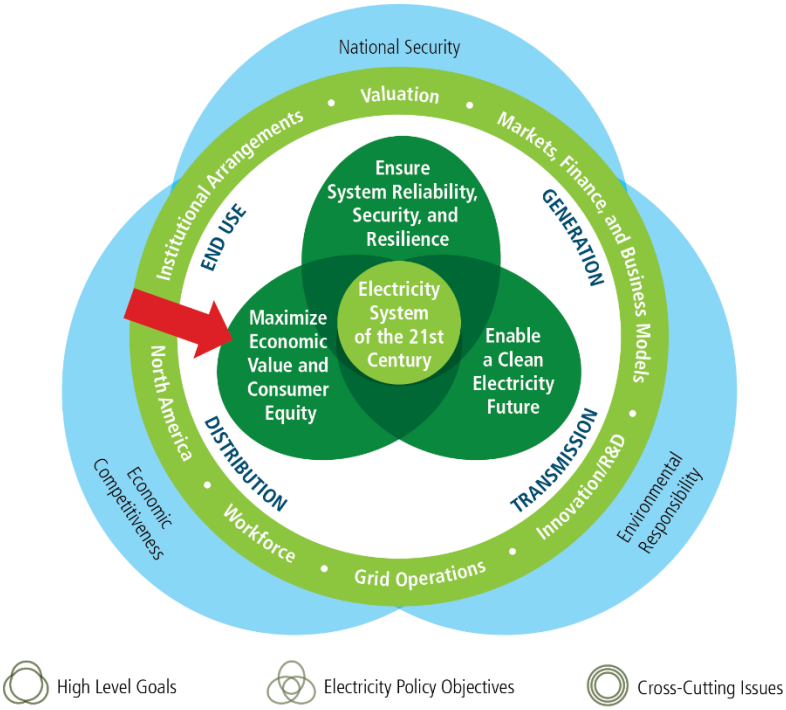
in these disciplines. The focus of the center will include power systems evaluation (e.g., valuation, benefit-cost, and competition analysis).

Inform Electricity System Governance in a Rapidly Changing Environment

The rapid rate of change in the electricity sector today often exceeds the ability of institutions and governance structures to respond in a manner sufficient to meet critical national goals and objectives. This is particularly true in the resolution of jurisdictional disputes over responsible price formation and valuation. Clarification and harmonization of roles and responsibilities for developing pricing can reduce market uncertainty, facilitate the achievement of policy goals, and reduce costs to ratepayers.

9. **Establish a Federal advisory committee on alignment of responsibilities for rates and resource adequacy**. DOE, in collaboration with the National Association of Regulatory Utility Commissioners, should convene a Federal advisory committee that reports to the Secretary or the Secretary's designee to examine potential jurisdictional concerns and issues associated with harmonizing wholesale and retail rates and tariffs. This advisory committee will evaluate and make recommendations (where appropriate) on the way in which the organized markets reflect state policy; pricing mechanisms for maintaining resource adequacy; state and Federal roles in pricing and operation of distributed energy resources (DERs), storage, and microgrids; the role of aggregators; and mechanisms for implementing consumer protection across the various markets and jurisdictions. The advisory committee will represent a broad cross-section of industry and stakeholders. An annual report will be prepared by this advisory committee for the Secretary that identifies the impact of governance issues and recommends solutions.

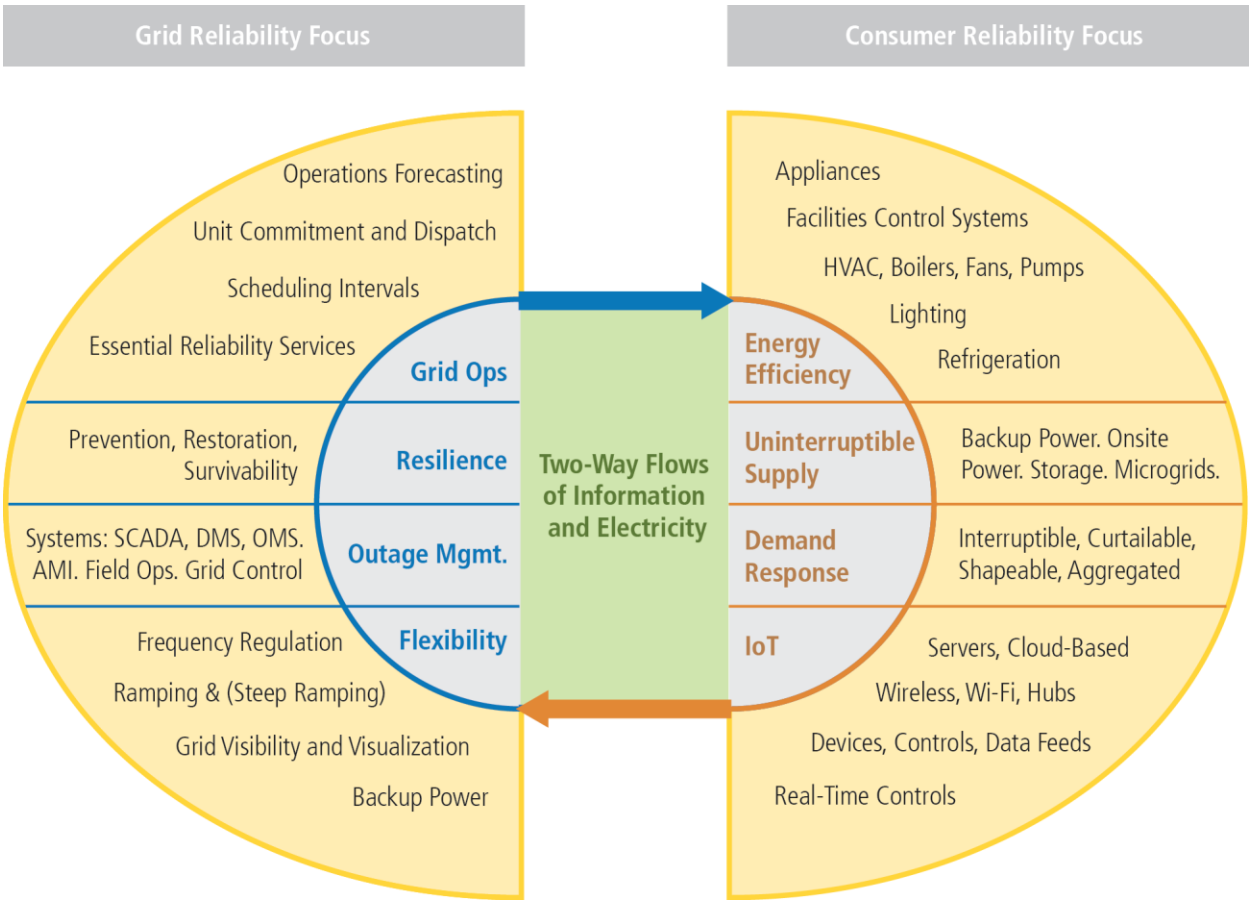
7.2 Maximizing Economic Value and Consumer Equity



Consumer options for electricity services have grown dramatically, enabled in part by the smart grid and the IoT, and supported by significant consumer demand. New consumer options range from building efficiency technologies that reduce consumer costs for high-quality electricity services, to distributed generation (DG) technologies, to technologies for dynamic energy management. In addition to technology options, different utility business models also have a significant impact on consumer value and compensation. Utilities still provide a majority (84 percent) of the electricity supplied nationwide;[12] however, in the 16 states and the District of Columbia where retail competition is allowed, 58 percent of industrial load, 44 percent of commercial load, and 7 percent of residential load have switched to

competitive energy suppliers.[13] These technologies can create value for both grid operators and consumers; adequate and accurate valuation of these new services is essential for maximizing their value. As noted in Chapter IV (*Ensuring Electricity System Reliability, Security, and Resilience*), these two-way flows are affecting both consumer demands for reliability as well as reliability requirements for grid operations. The key components of both consumer and grid reliability are highlighted in Figure 7-6.

Figure 7-5. Electric Service Reliability Increasingly Interactive between Grid and Consumer



The development and adoption of new consumer technologies and services have dramatically outpaced those of the grid. The electricity sector is adapting to the demands placed on the grid by the two-way flows with new market structures, technological solutions, interconnection and reliability standards, and complex grid controls enabled by wide-spread operational data. The evolution of technologies and services on both sides of the grid will likely continue at the same or an accelerated pace. Maintaining—or increasing—grid reliability in the midst of these changes will require new approaches in both the public and private sectors. Acronyms: supervisory control and data acquisition (SCADA); distribution management system (DMS); outage management system (OMS); advanced metering infrastructure (AMI); heating, ventilation, and air conditioning (HVAC).

The two-way flows and different expectations about reliability between consumers and grid operators can benefit both grid operators and consumers if flows are transactional and collaborative. In the alternative, two-way flows can significantly complicate grid operations. Grid operators must adapt to increased consumer options that can both positively and negatively affect grid reliability by changing their systems, processes and technologies. Only when the depth of grid and consumer interdependencies are understood equally by each group can the 21st-century electricity sector be fully realized.

Tailor and Increase Tools and Resources for States and Utilities to Effectively Address Transitions Underway in the Electricity System

States and electric utilities are responsible for making critical decisions regarding how to improve the reliability, affordability, and sustainability of the electric grid, and officials from state agencies and utilities provided comments as part of the QER stakeholder process on the Federal role in informing these decisions. Technical assistance, improved regional consideration in program offerings, and new analysis for decision making will allow the Federal Government to respond to the needs of states and utilities in ensuring consumer value and equity in the electricity system of the 21st century.

10. **Improve energy management and DR in buildings and industry**. Communication-capable and programmable energy management systems that monitor and control energy using appliances and equipment have demonstrated substantial potential to reduce both volumetric (kilowatt-hours) and peak (kilowatt) electricity demand, delivering significant economic value and service benefits to both consumers and utilities. This joint DOE–Environmental Protection Agency (EPA) initiative could further accelerate the deployment of communications-capable control systems that can deliver improved energy management and DR for residential buildings, small to medium commercial buildings, and comparable industrial facilities.

11. **Create a multi-sector initiative to improve efficiency of miscellaneous electric loads through research and development (R&D), testing, labeling, targeted incentives, and minimum standards**. Miscellaneous electric loads are a broad, rapidly growing, and poorly understood group of end users, which can be addressed by building on existing DOE and EPA efforts. Working with utilities, states, manufacturers, and other key stakeholders, this DOE, Energy Information Administration (EIA), and EPA initiative could gather data, set priorities and take action to increase R&D, improve testing and labeling, and implement targeted incentives and minimum standards to improve the efficiency and management of miscellaneous electric loads in the residential, commercial, and industrial sectors.

12. **Increase Federal support for state efforts to quantitatively value and incorporate energy efficiency, DR, distributed storage, and DG into resource planning**. DOE and EPA should leverage existing programs to provide targeted capacity building and related analytical support to states on the merits of incorporating the value of energy efficiency, DR, distributed storage, and DG in resource planning, meeting environmental goals, and to extract additional value from advanced metering infrastructure networks and resulting data and digital services.

13. **Conduct an analysis of the potential for deployment of demand side (energy efficiency, DR, DG, storage) technologies**. While numerous studies have indicated significant cost-effective potential from energy efficiency investments, there is an incomplete patchwork of different energy efficiency potential studies and other distributed resources at the utility or state level that use a variety of different methodologies. These studies, which typically consider only energy efficiency, do not take into account the potential to integrate energy efficiency investments with other consumer options, such as DR, DG, and onsite storage—technologies to which consumers have growing access. DOE, with input from EPA, should conduct a national demand-side resources potential study with sufficient geographic resolution to more effectively value and integrate DERs into state and national electricity policy, while meeting environmental goals.

14. **Increase state-level clean energy financing**. DOE and the Department of the Treasury, in coordination with other Federal agencies, will identify promising practices in the types of state-level policies, mechanisms, and incentives that support system evolution to a cleaner grid, e.g., Property Assessed Clean Energy (PACE) financing. These efforts will provide states with the tools

and potential solutions to better leverage state resources and deploy clean energy. As part of sharing promising practices, DOE and the Department of the Treasury would help standardize contracts/financing structures for nontraditional project structures.

15. **Evaluate the potential to further increase energy savings and reduce costs to consumers and manufacturers through appliance efficiency standards**. DOE's minimum appliance efficiency standards have resulted in significant energy savings for consumers and businesses across a wide range of products. DOE, working with the Department of the Treasury and EPA, will evaluate approaches for further increasing or optimizing energy savings to consumers, while reducing costs for manufacturers and consumers.

Expand Federal and State Financial Assistance to Ensure Electricity Access for Low-Income and Under-Served Americans

Analysis indicates that electricity costs represent a disproportionate share of total income for low-income Americans. Increased funding for proven, state-administered programs and enhanced data and tools for targeting assistance can reduce this "electricity burden." Ensuring that the costs of the rapid transition of the electricity system are not disproportionately borne by low-income Americans is a top priority; low-income Americans should also be able to share in the benefits from an electricity system transition.

16. **Increase Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP) funding**. Low-income Americans in areas across the country face disproportionate burdens from electricity costs. Congress should increase Federal support for low-income home weatherization, through DOE's WAP, over the next 5 years to weatherize 100,000 homes per year, including support for training and improving auditing tools. Congress should also create a mandatory contingency funding mechanism for LIHEAP, as described in the President's FY 2017 budget.

17. **Evaluate incentives to cut electricity bills for low- and moderate-income households**. The Federal Government should improve the coordination between WAP and LIHEAP to ensure optimal use of resources and increased benefits to households served. The Federal Government should encourage state and local governments to (1) take full advantage of the use of LIHEAP funds for weatherization, (2) use the National Renewable Energy Laboratory's solar savings-to-investment ratio calculator to identify cost-effective areas for solar projects, and (3) find other ways to make it easier for low-income households to access the long-term savings possible from energy efficiency and renewable energy. In particular, DOE should evaluate the impacts of utilizing WAP and LIHEAP to decrease energy bills (i.e., from energy efficiency retrofits and installing renewable energy projects). In addition, state and local governments should ensure human services providers educate low-income clients receiving bill assistance about opportunities to save on their electricity bills through energy efficiency and renewable energy programs and should actively encourage participation in those programs.

18. **Strengthen incentives for public housing authorities to invest in renewable energy and energy efficiency**. Small- and medium-sized housing authorities are often unable to participate in existing energy performance contracting (EPC) options because of a lack of capital or interest from energy services companies. This project would incentivize such public housing authorities to use existing resources to make energy upgrades by allowing them to retain energy cost savings outside of an EPC contract. Congress should authorize a pilot program to allow public housing authorities to retain a greater portion of the savings realized from investments in energy efficiency and renewable energy. The Office of Public and Indian Housing at the Department of Housing and Urban Development (HUD) would focus the pilot on strengthening incentives for housing

authorities, especially smaller and medium-sized housing authorities, to invest their Capital Fund dollars in energy efficiency or renewable energy. The pilot would provide an alternative to the long-standing EPC program, which has primarily served larger housing authorities.

19. **Improve HUD data and utility benchmarking**. In order to reduce taxpayer costs on tenant utility bill allowances, Congress should enact legislation allowing HUD and property owners to access whole-building, aggregated energy consumption and expenditure data for HUD-assisted properties (i.e., whole-building utility data) and appropriate funding for HUD to implement its utility benchmarking strategy, including building out the information technology (IT) systems needed to link current systems with benchmarking software.

20. **Encourage public-private partnerships to underwrite and support clean energy access for low- and moderate-income households**. The Federal Government should align public funding programs and encourage private-sector investment to help make energy efficiency and renewable energy accessible to households that do not qualify or are unlikely to be served by WAP. The bank regulatory agencies are encouraged to publicize recently-issued Community Reinvestment Act guidance concerning loans financing renewable energy or energy efficiency improvements, which help reduce operational costs and maintain the affordability of single-family or multifamily housing.

21. **Provide assistance to address rural, islanded, and tribal community electricity needs**. The Tribal Indian Energy Loan Guarantee Program provides loan guarantees for renewable energy on Indian land and is authorized under the Energy Policy Act of 2005. Indian lands have over 9,000,000 megawatts (MW) of renewable energy potential. Because of the lack of capital, only 125–130 MW have been built. Most tribes do not meet eligibility requirements for existing loan guarantee programs. Existing rural and islanded electricity systems generally rely on imported (nonlocal) diesel fuel oil and, consequently, are high cost and produce significant emissions. Renewable electricity generation and other electricity technologies have the potential to lower cost and reduce emissions on such systems, yet may require new technology capabilities or significant technical expertise to successfully integrate into such systems. The Federal Government should increase support for grants and technical assistance to allow isolated communities that rely on expensive diesel-generated electricity to install more renewable energy, such as wind, small-scale hydro, or solar energy.

Increase Electricity Access and Improve Electricity-Related Economic Development for Tribal Lands

The interdependencies of electricity access, health, economic wellbeing, and quality of life underscore the importance of universal access to electricity. While recent data on electricity access on tribal lands are limited, there are still areas that lack adequate access to electricity despite the Nation's commitment to full electrification, which dates back to the Rural Electrification Act of 1936. More recent anecdotal evidence suggests that the problem broadly persists. It is a moral imperative that the Federal Government support tribal leadership and utility authorities to provide basic electricity service for the tens of thousands of Native Americans who currently lack access to electricity and to foster the associated economic development on tribal lands. Federal agencies should also support renewable energy acceleration and economic development opportunities through renewable energy incentives, workforce development, financing program improvements, and improved consultation with tribes.

22. **Support the achievement of full tribal land electrification**. Over 10 years and building on existing programs, DOE, the Department of the Interior (DOI), and the Department of Agriculture (USDA) will provide technical assistance for distribution infrastructure with the goal of supporting tribal

communities' efforts to achieve complete electrification (Indian tribes, including Alaskan Natives, on Indian lands), while respecting the sovereignty and culture of tribal and Alaska Native communities. DOE, DOI, and USDA should support development of distribution infrastructure to provide access to household electricity and electricity distribution that enables productive economic activity and public services.

23. **Support advanced technology acceleration and economic development opportunities for tribal lands**. While wind energy and solar energy have grown exponentially in recent years, tribes have not been able to fully take advantage of their wind or solar resources. DOE and DOI could accelerate renewable energy development on tribal lands and economic development in tribal communities through new incentives and financing support, workforce development resources, and enhanced consultation with tribes.

Strengthen Rural Electricity and Broadband Infrastructure

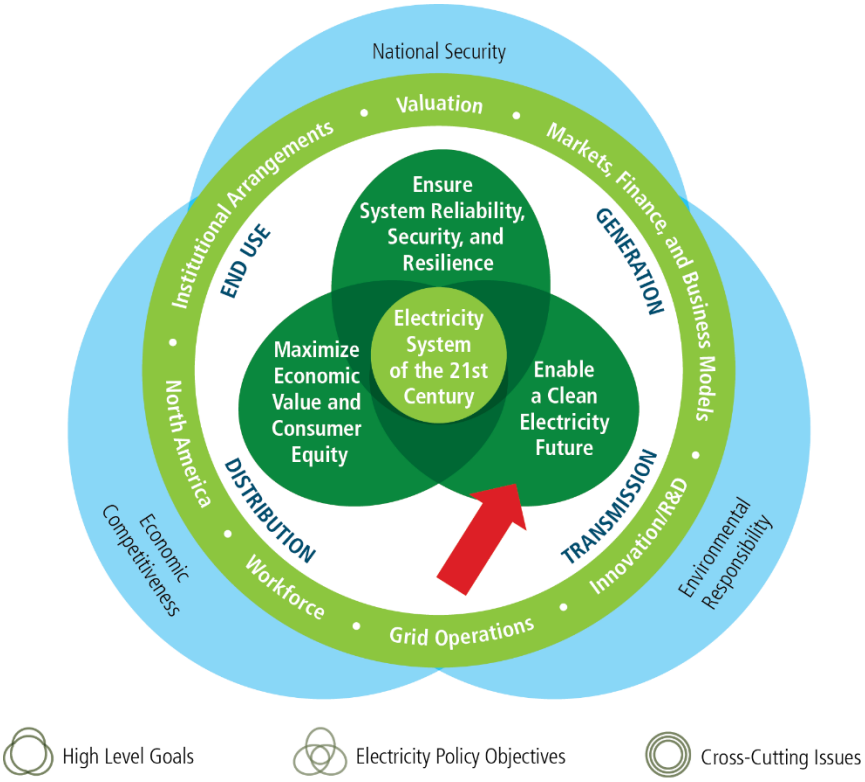
The Federal Government has historically supported the expansion of access to affordable electricity and communications service in rural America, with major initiatives continuing today mainly through USDA. The lack of access to broadband in rural areas means that these consumers lack access to DR technologies, such as smart meters, smart thermostats, and other technologies, which can reduce pollution, help consumers save electricity, improve overall grid resilience and reliability, and enhance economic development. Broadband expansion into these regions would significantly advance grid modernization goals, while providing significant communications, connectivity, and educational benefits to numerous regions of the country. Supporting broadband access in sparsely-populated rural areas, many of which are low-income areas, is not, however, profitable for the private sector. Federal support would help enhance security, environmental, and economic development goals.

24. **Leverage utility broadband build-out to expand public broadband access in rural areas**. Many rural areas presently lack access to public broadband service required to take advantage of these consumer smart grid technologies. The Federal Government should continue to modernize Federal programs to expand support for rural broadband, smart grid, and smart home technologies. USDA should update guidance for the Rural Development Community Facility Program to make broadband projects eligible, revise regulations to expand eligibility for the Rural Utilities Service (RUS) Telecommunications Program, and expand financing for smart grid and communications improvements for energy management in the RUS Electric Program.

25. **Increase opportunities for small and rural utilities to utilize USDA's electricity financing programs**. USDA should develop and implement a strategy to remove barriers to participation in its RUS financing program for energy efficiency and renewable energy investments, which would support Congress' intent to provide Federal financial support for ratepayers served by small and rural utilities. DOE and USDA should strengthen collaboration on strategic priorities, including developing a strategy to increase the use of USDA's financing programs by borrowers and supporting the technical needs of small and rural utilities, in part through their industry stakeholders.

26. **Improve the competitiveness of USDA's financing for small and rural utilities**. Congress should give USDA's RUS the authority to refinance its loans to small and rural utilities to keep their competitiveness and reflect economic changes in the broader economy. Congress should undertake legislative action to unlock USDA's renewable energy financing under Section 317(c) of the Rural Electrification Act.

7.3 Enable a Clean Electricity Future



Achieving a clean, affordable, and reliable electricity sector for the 21st century is a key national objective. The transition for accomplishing this objective is complicated and will require major changes in the generation resource mix; in the valuation of key services; and in the way the grid is operated. Managing this complex set of changes while ensuring affordability, reliability, and security for electricity consumers, will require focused investments, incentives and policies in key areas, including the following: optimizing the management of many different types of generation; enhancing the visibility, integration, and valuation of load-shaping and consumer technologies; enabling the development and diffusion of distributed and utility-scale storage technologies; managing the large-scale integration of variable energy resources and DERs into grid operations; and supporting the ongoing need for dispatchable baseload generation. This transition will also require a core investment in operational and predictive analytics, including control algorithms and granular grid visualization tools. Clean electricity options from generation to end use need to be advanced through a combination of additional research, development, and demonstration (RD&D) across the portfolio of solutions and additional policy that encourages the most cost-effective options.

Transform the Electricity System through Leadership in National Clean Electricity Technology Innovation

Private-sector investment in clean energy technology faces many barriers; for example, prices do not reflect the costs and benefits of clean energy, investments are made in a highly regulated environment, and there are high capital costs and lengthy time horizons for R&D and capital stock turnover in comparison to many other sectors (e.g., IT). Increased investments in electricity technology innovation are essential for the transformation of the electricity system. Federal investments have a history of success and have been leveraged by the private sector to create significant economic value; case studies on nuclear energy, shale gas, and solar photovoltaic power, among many other electricity-related technologies, demonstrate the instrumental role of Federal investment in early-stage R&D.

27. **Significantly Increase Federal investment in clean electricity RD&D**. The current scale and speed of clean electricity innovation is well short of what is needed for meeting the Nation's clean energy and climate goals, yet there are a series of barriers to the private sector investing adequate

amounts on its own. The American Energy Innovation Council in 2010 identified specific needs for government involvement in accelerating energy innovation and recommended that Federal clean energy funding be more than tripled, as the minimum level required to maintain America's competitive edge. Pursuant to the Mission Innovation initiative, the Federal Government should double clean energy R&D funding across all relevant Federal agencies from $6.4 billion to $12.8 billion between FY 16 and FY 21.

28. **Implement regional clean energy innovation partnerships**. Create cost-shared, technology-neutral innovation partnerships based in multi-state regions intended to accelerate clean energy R&D, including electricity, by tailoring project portfolios to the needs, opportunities, innovative capabilities, and intellectual and economic infrastructure of those regions. The FY 17 DOE Mission Innovation request includes initial funding of $110 million for regional partnerships.

29. **Expand clean electricity innovation analysis and tools**. Improve the data, metrics, analysis, and tools used to plan DOE's investments in clean energy innovation. Although there is substantial research on the value and impact of innovation for individual technologies, there are few robust measures and quantitative assessments of energy innovation. Enhanced energy innovation frameworks and models that include policy interactions are needed to characterize the relationship between inputs and outputs of energy innovation, help inform investment, and deploy scarce innovation dollars.

30. **Continue reducing barriers to deploy clean energy technologies**. Since 2008, the cost of solar, wind, storage, and electric vehicle technologies has decreased more than 50 percent. DOE should continue working to cut the costs of solar, wind, storage, and electric vehicle technologies through their world class programs, continuing to reduce the cost of solar more than 50 percent by 2030; making electric vehicles cost competitive with gasoline-powered cars by 2022; decreasing the price of energy storage; and developing the next-generation wind technologies, including offshore technologies and tall turbines, to expand the geographic reach of cost-competitive wind.

31. **By 2030, reduce the electricity intensity of newly constructed residential and commercial buildings by at least 50 percent relative to typical new building construction today**. Buildings, which last for decades, account for significant portions of electricity demand and greenhouse gas emissions in the United States. Ensuring highly efficient new construction will capture decades of energy savings for American families and businesses. DOE, in consultation with EPA, should set a goal, establish baselines, and scale up activities to deploy energy efficient technologies and DERs in newly-constructed residential and commercial buildings.

Address Challenges to Large-Scale, Centralized Clean Generation

Regardless of the energy source, there are a number of challenges to deploying large, centralized power generation facilities. Lower electricity prices, largely related to low-cost natural gas, are reducing the economic viability of other clean generation resources, especially nuclear energy. Nuclear power currently provides 60 percent of zero-carbon generation in the United States. Hydropower is one of the oldest and most established forms of electricity generation, contributing 6 percent of the electricity generated in the United States in 2015 and 19 percent of zero-carbon generation. Non-hydropower renewables—including wind, solar, geothermal, and biomass—accounted for about 7 percent of electricity generated in the United States in 2015. Each of these technologies faces a range of siting constraints, licensing and permitting processes, or environmental concerns, which can be broad and extensive; this can make new, large-scale deployments difficult. In some cases, these deployments can take a decade or more to build. A combination of Federal coordination, licensing support, analysis of financing opportunities, and RD&D can help address these barriers.

32. **Analyze financing for advanced large-scale generation**. Alternative financing and organizational structures should be explored for advanced large-scale generation, including small modular reactors, advanced reactors, enhanced geothermal, concentrated solar power, offshore wind, and advanced carbon capture and storage projects. Many of these new, larger systems require sponsors to make significant upfront capital investments, and several also contain technology risk, which creates barriers for lenders and regulators. For example, it is currently challenging for state public utility commissions to allow a regulated utility to begin construction on an advanced new nuclear or carbon capture and storage plant with guaranteed rate base recovery. DOE should analyze potential opportunities to support the financing options for advanced large-scale generation by utilities and others, building upon existing programs where applicable.

33. **Increase funding for the life-extension R&D program to ensure maximum benefits from existing nuclear generation**. The existing DOE research program to resolve technical issues with regard to subsequent license renewals for existing nuclear plants should be significantly expanded to accommodate the expected increase in renewal applications and to enable the continued operation of existing plants through technology development, as well as to improve performance and reduce costs and the use of high-performance computing to simulate reactor processes.

34. **Increase support for advanced nuclear technology licensing at the Nuclear Regulatory Commission**. Congress should provide funding to the Nuclear Regulatory Commission for the certification and licensing of advanced reactors, including the development of advanced reactor certification and licensing criteria, and processes and for general public outreach, as reflected in the President's FY 17 budget proposal. In addition, Congress should authorize and fund a program at DOE to support advanced reactor license applicants, especially in the development and submission of pre-applications.

35. **Develop environmental mitigation technologies for hydropower**. Increase funding for RD&D to better understand and mitigate the environmental impacts of new and existing hydropower projects. Continued operation of some existing facilities and deployment of new facilities depends upon demonstration and acceptance of environmental mitigation technologies and strategies for facilities of all sizes.

36. **Promote responsible operation, optimization, and development of non-Federal hydropower**. Organize a national dialogue to address potential licensing and re-licensing processes that would encourage the responsible operation, optimization, and development of non-Federal hydropower in a manner that maximizes opportunities for low-cost, low-carbon renewable energy production, economic stimulation, and environmental stewardship to provide long-term benefits for the Nation.

Address Significant Energy-Water Nexus Issues Affecting—and Affected by—the Electricity System

Electricity systems and water systems are, in many cases, interconnected. Water is a critical requirement for many electricity generation technologies. Two-thirds of total U.S. electricity generation—including many coal, natural gas, nuclear, concentrated solar power, and geothermal plants—requires water for cooling. In addition, carbon capture, utilization, and storage (CCUS) technologies have significant water demands. Electricity is also required for water and wastewater conveyance, treatment, and distribution. From a full-system perspective, the joint reliance of electricity and water systems can create vulnerabilities (e.g., drought impacts on thermoelectric generation and hydropower), but it can also create opportunities for each system to benefit from well-designed integration. Such challenges and

opportunities can be addressed through improved policy integration; data collection; modeling; analysis; research, development, demonstration, and deployment (RDD&D); and engagement with stakeholders.

37. **Launch an electricity-related energy-water nexus policy partnership with Federal, state, and local partners**. DOE should create an electricity-related energy-water nexus policy partnership with states, related organizations, local governments, and other Federal agencies, where appropriate; this policy partnership would discuss ways to improve and better integrate existing energy and water policies with respect to goals, data, metrics, and compliance dates. Many energy and water policies are designed to address only energy or water, but not both, potentially leading to conflicting incentives and unintended consequences that could be avoided through more integrated policy design. In support of the partnership, DOE should develop an Integration Analysis Framework to map out broad, system-wide benefits and potential vulnerabilities of energy-water systems integration (at multiple temporal and spatial scales) to inform relevant decision makers. This analysis framework would serve to enable valuation of costs and benefits associated with energy-water systems.

38. **Support additional RDD&D to reduce water requirements for carbon capture technologies**. Provide additional funding to complement existing efforts in technology RDD&D to reduce water requirements of carbon capture systems, including capture systems themselves (solvents, membranes, materials), as well as integration of the capture system with the generation plant or industrial facility. Reduced water use at power plants and other industrial facilities outfitted with CCUS would lower water withdrawal and consumption out of natural water bodies and could make CCUS technology more attractive in water-scarce areas.

Provide Federal Incentives for a Range of Electricity-Related Technologies and Systems

A package of tax incentives targeted at specific market segments can support an all-of-the-above energy strategy by helping to reduce the costs of deploying and using innovative, commercially available energy technologies. The economies of scale and "learning by doing" promoted by such deployments support continued technology cost reductions and greater market competition.

39. **Expand tax incentives for renewable electricity, electric vehicles, and energy efficiency**. Consistent with the current Administration's Green Book proposal, expand the list of technologies eligible for Federal tax incentives to include other sources of low-carbon generation beyond wind and solar; extend the timeframe for the Production Tax Credit (PTC) and Investment Tax Credit (ITC); and make the PTC refundable, available to otherwise eligible renewable electricity consumed directly by the producer, and also available to individuals who install solar electric or solar water heating property on a dwelling. In addition, implement the proposed reform to the electric vehicle tax credits and extension of commercial building energy efficiency tax credits included in the President's FY 17 budget.

40. **Extend the time frame and the total capacity allowed under the PTC for nuclear generation**. Current law provides a $0.018/kilowatt-hour production tax credit for new nuclear plants placed in service by 2020 and places a capacity cap of 6,000 MW. Extend the eligibility date so that reactors placed in service after 2020 could qualify and increase the capacity cap.

41. **Provide tax credits for CCUS**. Provide a tax credit, such as the proposal to create $2 billion in refundable ITCs for 30 percent of eligible CCUS equipment and infrastructure in the President's FY 17 budget; create a refundable sequestration tax credit ($10 per metric ton for carbon dioxide that is stored and reused, and $50 per metric ton for carbon dioxide that is stored and not reused);

index to inflation; or implement reforms to the existing 45Q tax credit that would achieve similar goals. Expand eligibility to include industrial-sector applications of CCUS.

42. **Assess business model inequities associated with Federal electricity financial incentives and public-private partnerships**. DOE should assess the current utilization of energy tax credits by ownership type, including the impact of proposed changes to the tax code on the ability of entities to utilize incentives. DOE should also identify options to increase the impact of tax credits on the deployment of clean energy assets. Relevant topics could include the usage of tax credits by tax-exempt entities, the exclusion of ITCs from normalization, Federal financing for public power and rural electric cooperative utilities, and the possibility for expanded use of public-private partnerships.

43. **Increase power purchasing authorities for the Federal Government from 10 to 20 years**. The Federal Government is currently subject to goals and mandates for the purchase of clean energy which, if achieved, can help to catalyze action in the private, state, and local sectors. However, widespread Federal Government clean energy purchases are constrained by generally applicable procurement rules that prohibit entering long-term contracts. Congress should authorize all Federal agencies to negotiate 20-year power purchasing authorities for clean energy.

Address a Range of Power Plant Siting Issues

The land-use requirements for different types of power generation reflect significant differences between the various types of infrastructure and their operational requirements.

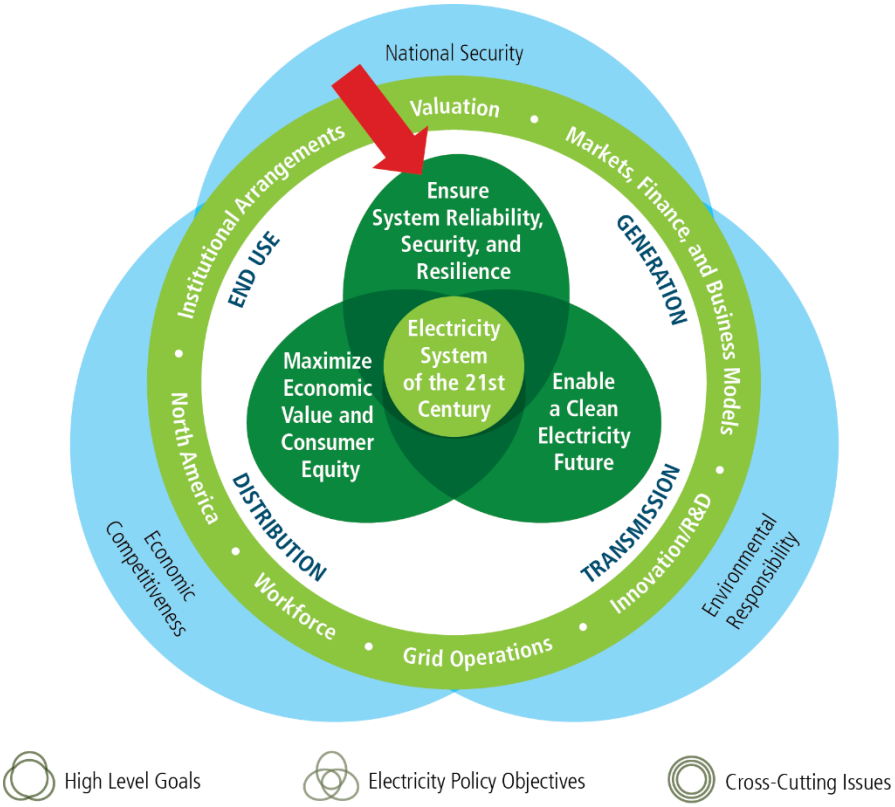
44. **Evaluate and develop generation-siting best practices**. DOE and DOI should initiate a 2-year series of technical workshops to evaluate generation-siting best practices, environmental impacts, mitigation options, and risk to inform decision making by developers and regulators. The workshops will draw upon state and local permitting expertise and experience and will issue reports to provide developers and regulators tools and best practices for streamlining and potentially standardizing underlying requirements for environmental impact studies and siting analysis. Permitting of projects should continue expeditiously during this process.

45. **Support improved regional and interregional transmission planning processes**. DOE should fund the development of a systematic monitoring program to enable valuation of new transmission facilities, measure the outcomes of FERC Order Nos. 890 and 1000, and develop methodologies to improve their effectiveness. The objective of FERC Order No. 1000 is to identify methods and approaches that enable the selection of the "best" set of transmission facilities (i.e., the more efficient or cost-effective transmission facilities selected in a regional transmission plan for purposes of cost allocation); it aims to accomplish this by (1) establishing requirements for regional transmission planning and interregional transmission coordination processes, and (2) opening transmission investment to non-incumbent owners. However, because implementation of FERC Order No. 1000 is in early stages and no systematic monitoring system is in place, it is not possible to assess whether its requirements are having their intended effects. Success would mean that transmission planning and cost allocation would be effectively supporting transmission, while also reducing costs, sustaining or improving reliability, reducing congestion, and/or meeting transmission needs driven by public policy requirements.

46. **Modernize electricity transmission permitting procedures**. DOE should expand the domestic coverage of its Regulatory and Permitting Information Desktop (RAPID) Toolkit, which contains information relating to critical state requirements to include the 36 states that currently have no transmission-related information in the Toolkit. This would provide support for the Federal Permitting Improvement Steering Council, which was tasked with modernizing Federal

infrastructure permitting to create efficient project delivery and improve outcomes. One step in reducing complexity is providing developers, government agencies, tribes, and other affected entities ready access to information relating to Federal and state policies and requirements that would expedite their involvement

7.4 Ensure Electricity System Reliability, Security, and Resilience



System reliability has been an essential expectation of electricity consumers since the development of the modern electricity system. Reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent of the outage. The utility industry is primarily responsible for ensuring system reliability through risk-management strategies to prevent disruptions from reasonably expected hazards. Risk-management practices need to keep pace with the emerging threat environment, particularly cybersecurity and severe weather associated with climate change. The grid's growing interconnectedness and incorporation of new energy resources also create new risks and vulnerabilities, even as they create significant new value to all users of the electricity system.

For these reasons, the traditional definitions of reliability alone may be insufficient to ensure future system integrity and available electricity services. U.S. policies, markets, and institutional arrangements must evolve to reflect this new reality. Actions and approaches are needed to integrate resilience concerns into system planning and reliability standards, prioritize investments in reliability and resilience, quantify the benefits of investments that address emerging or low-probability hazards, broaden the range of risk-reduction options, improve flexibility through activities both pre- and post-disruption, and ultimately, focus on maintaining and improving energy delivery outcomes for the customer under all conditions.

A focus on evolving hazards, new metrics, better analysis, finer data granularity, and strong interdependencies between grid operators and consumers frames the scale and scope of necessary sector transformation. These challenges could be mitigated through a combination of standards, risk-

management methods and processes, and collaboration across industry, state, local, and Federal stakeholders.

Support Industry, State, Local, and Federal Efforts to Enhance Grid Security and Resilience

Some types of extreme weather events are projected to increase in frequency and intensity. Cyber threats to the electricity system are increasing in sophistication, magnitude, and frequency. Physical threats remain a concern. These challenges could be addressed through a combination of cost-benefit analyses, standards, and collaboration across industry, state, local, and Federal stakeholders. The following recommendations build upon and extend current initiatives, such as DOE's Grid Modernization Initiative and Partnership for Energy Sector Climate Resilience.

47. **Develop uniform methods for cost-benefit analysis of security and resilience investments for the electricity system**. DOE should develop methods for calculating the costs and benefits of investments in resilience solutions, as well as methods for managing the risks associated with many types of high-impact, low-frequency events or emerging and rapidly evolving threats related to climate change, cyber or physical attacks, or combined threats. This could be implemented in part through the establishment of a "community of practice" for valuation of electricity-sector reliability and resilience, providing a stakeholder forum for sharing current practices and developing uniform valuation methods.

48. **Provide incentives for energy storage**. Provide a financial incentive to reduce the cost and support deployment of non-emitting energy storage. Qualified storage includes equipment that receives, stores, and delivers energy using batteries, compressed air, hydrogen storage (including hydrolysis), thermal energy storage, regenerative fuel cells, flywheels, capacitors, superconducting magnets, technologies and systems that provide the verified services and benefits or technologies and systems.

49. **Improve and upgrade existing Federal hydropower operations**. Fifty percent of U.S. hydropower is federally owned. DOE, the Army Corps of Engineers, and the Bureau of Reclamation should convene relevant stakeholders to identify and discuss opportunities to improve existing Federal hydropower. Relevant topics to address include technology upgrades; increasing generation, capacity, and essential reliability service capabilities; operations and maintenance efficiency; acquisition improvements; funding flexibility; and mitigating impacts from hydropower.

50. **Account for emerging threats in reliability planning**. Reliability standards and planning requirements should be updated to increase electricity-sector resilience to emerging and rapidly evolving hazards, like climate change and cyber and physical threats. The Federal Government should take formal steps to update reliability planning standards for the bulk power system. States, cooperatives, and public power should update or establish new requirements for resource planning and other planning processes for distribution systems. States should also update design standards for critical infrastructure and annually update Energy Assurance Plans accordingly. Similarly, standard making organizations (e.g., the American National Standards Institute and the Institute of Electrical and Electronics Engineers [IEEE]) should take steps to evaluate whether new performance standards and testing procedures are needed to ensure electrical equipment resilience to rapidly evolving hazards.

51. **Support grants for small utilities facing cyber, physical, and climate threats**. Small utilities cover over 75 percent of the Nation's landmass, including sensitive and military installations.[a] The combination of large service territories, minimal staffing, limited budgets, lack of access to tax incentives, and low customer density presents challenges to small utilities addressing such new and evolving threats. DOE and USDA's RUS should work together to develop risk-management tools, provide grants for shared staff to implement solutions (such as through joint action and/or generation and transmission programs), and host workshops to facilitate knowledge transfer to support small utilities as they address these challenges.

52. **Support mutual assistance for recovering from disruptions caused by cyber threats**. Utilities have a long history of providing mutual assistance in the event of traditional disruptions, but as the grid becomes more reliant on digital technology, cyber and cyber-physical threats present new and distinct challenges to system restoration. DOE, in coordination with interagency partners and industry, should increase support for private-sector efforts to respond to significant cyber incidents on the electric system.

53. **Support the timely development of standards for grid-connected devices**. Common interoperability standards are critical to enabling the distribution system to accommodate the growth of grid-connected technologies at large scale and to potentially improve grid cybersecurity. DOE should work with the National Institute of Standards and Technology to increase the pace of standards development so that it aligns with the rapid development and deployment of grid-connected devices.

54. **Support development of an enhanced reliability service class for commercial customers**. When there is a power failure, a new and growing class of commercial customers loses significant economic value immediately. The electricity demand of individual commercial customers is of insufficient scale, however, to support options similar to those of large industrial customers, who can pay their utilities to install additional feeders to enhance service reliability. This lack of scale and rate options has led some commercial customers to pursue third-party options (e.g., storage, back-up generators, onsite generation) to improve their electricity reliability. Associated grid defections could affect the overall customer and rate base. Analysis is needed to inform new rates for this class of customers. DOE should encourage states to consider having utilities offer enhanced reliability through commercial service packages that provide reduced outages, higher reliability, and quicker recovery for interested customers.

55. **Improve system reliability through analysis of back-up generation best practices**. Many industrial, commercial and residential customers utilize onsite back-up power generation during electricity disruptions. There have however been several high-profile failures of back-up generation had significant impacts on consumers and businesses. Also, as load management grows in importance, so too does the visibility of the level and reliability of back-up generation. Finally, key lifeline infrastructures and defense facilities depend on back-up generation. DOE should conduct a nationwide study of back-up generation; it should specifically identify related gaps and critical needs for consumers, critical infrastructure, and sensitive facilities. This analysis should further consider interconnection approaches for back-up generation to improve overall system resilience and reliability through the update and adoption of IEEE 1547 interconnection standards. This analysis should also take into account cost effectiveness and environmental performance. DOE should consider the outcomes of this analysis and provide recommendations

[a] Although such facilities frequently have back-up power capabilities, the durability of such backups is typically limited to fuel supplies on hand.

on best practices for back-up generation and how to maximize is value for grid operations, lifeline networks, and consumers.

56. **Develop guidance, best practices, and protocols for select categories of distribution equipment and consumer grid-interactive devices**. Distribution system-wide outages could be induced by disrupting interconnected DERs and their associated data feeds to the distribution grid, especially during critical peak demand or by causing lasting damage to a distribution transformer. DOE will do this in coordination with the National Institute of Standards and Technology and industry.

57. **Require states to consider the value of DERs, funding for public purpose programs, energy and efficiency resource standards, and emerging risks in integrated resource or reliability planning under the Public Utility Regulatory Policies Act (PURPA)**. PURPA section 111(d) establishes Federal standards for regulated electric utilities that State public utility commissioners "must consider." Because rates of distribution utilities are not directly regulated by the Federal Government, PURPA amendments serve to preserve the legal authority of the states to amend or establish new standards. Without statutorily dictating any final state decisions, Congress should amend PURPA to require state public utility commissions and nonregulated utilities to consider the following: (1) the costs and benefits of DERs and alternatives in rate design and integrated resource planning, (2) stable funding for public purpose programs, (3) energy efficiency resource standards, and (4) emerging risks in integrated resource or reliability planning.

Improve Data for Grid Security and Resilience

As the Nation increasingly relies on electricity to power the economy and support consumer options and choices, the consequences of electricity outages are rising. The United States currently lacks sufficient data on all-hazard events and losses. Such data would help utility regulators, planners, and communities analyze and prioritize security and resilience investments.

58. **Establish Federal standards for maintaining and sharing common data on Presidentially-declared natural disasters and physical attacks affecting the electricity system.** DOE and DHS should improve the collection, curation, and accessibility of data related to the impacts of disasters along with detailed characterizations of the nature and cause of each disaster. By improving the availability and quality of historical disaster impact data, the government and its partners can develop improved risk models, as well as gain the ability to more effectively locate and more clearly understand points of vulnerability within existing systems. Defining data standards would increase the ability of Federal agencies to manage and share disaster impact data by making it possible to merge and query disparate data sets by common feature, such as Presidential disaster declaration number. Types of data that would be more readily available as a result of this effort include detailed characterization of the nature and cause of each disaster as well as the extent and degree of associated impacts, such as power outages, fatalities, injuries, property losses, as well as other data to inform decision making that will help communities better prepare for and respond to future disasters.

59. **Enhance coordination between energy-sector information sharing and analysis centers and the intelligence communities to synthesize threat analysis and disseminate it to industry in a timely and useful manner**. The nature of cyberspace and its associated threats requires individuals, organizations, and the government to actively participate in incident response activities. Increased coordination would provide deeper analysis of threats based on both classified and unclassified data available from the operational and enterprise environments.

Encourage Cost-Effective Use of Advanced Technologies that Improve Transmission Operations

Permitting and planning are necessary but complex processes that can slow transmission development and increase costs. Other barriers restrain the use of new technologies that can increase transmission system capacity utilization and improve reliability and security, as well as other planning priorities.

60. **Promote deployment of advanced technologies for new and existing transmission**. DOE should work with stakeholders to identify, analyze, and develop recommendations for removing barriers to the valuation and deployment of advanced technologies for new and existing transmission, such as those that enhance reliability, security, and affordability through visibility and control. DOE should explore a range of legislative and regulatory options and analytically test their potential effectiveness on both a stand-alone basis and a collective basis to enable deployment of technologies that cost-effectively increase existing transmission capacity utilization (i.e., remove barriers to technology solutions that enable greater transmission utilization of existing transmission capacity). In addition, DOE should identify and mitigate barriers to technologies that can increase transmission capacity utilization and create a framework for future work based on the experiences of work in capacity utilization, synchrophasors, and storage.

Improve EIA's Electricity Data, Modeling, and Analysis Capabilities

EIA provides all levels of stakeholders—government, companies and customers—with data to inform the evaluation and development of policies that affect the electricity grid. More timely and publicly accessible data on how system operations are changing and on how efficiency and renewable energy are specifically affecting them would facilitate the development of Federal and state policies and investments needed to ensure the reliability, resilience, and security of the grid. Substantially improved electricity transmission data and related analyses by EIA would support significant improvements in the effectiveness of a broad range of government policies and programs, including market design and transmission planning.

61. **Expand economic modeling capability for electricity**. EIA should be able to more accurately reflect the role of energy efficiency, DR, electricity storage, and a variety of DG technologies in current and future energy consumption to better inform investments and modeled policy scenarios.

62. **Expand EIA data collection on energy end uses**. EIA should expand the scope and frequency of its data collection on energy end uses and services in the residential, commercial, and industrial sectors, including the use of new data collection methods and tools, in order to enable a more detailed representation by region, income, and other characteristics.

63. **Expand EIA hourly data collection on power system operations**. EIA should expand the scope of the current grid operations data collection to require (1) net generation by energy source (e.g., coal, solar, wind, natural gas, nuclear) and (2) sub-regional detail for large balancing authorities in order to inform investment decisions and provide higher-resolution and more quickly delivered data on how system operations are changing. EIA should continue to evaluate new definitions for National Energy Modeling Systems Electricity Market Module.

64. **Expand EIA data collection on electricity transmission**. EIA should improve the scope, frequency, and resolution of transmission data collection by (1) developing an regional transmission organization/independent system operator dashboard on the operation of centrally organized, wholesale power markets; (2) collecting and maintaining information on the utilization of the bulk transmission system that complements current data collection; and (3) improving reporting on transmission investment and on the functioning and outcomes of transmission planning activities,

to enable analysis on whether transmission policies and regulations are achieving their intended effects. All proposed activities should be undertaken through processes that comply with existing data-collection protections.

65. **Support EIA's collection of additional data on Electricity and water flow for water and wastewater utilities**. Electricity usage in delivering water services represents a significant portion of U.S. electricity consumption (estimated at 3 to 4 percent of total electricity consumption) and may present major opportunities for both efficiency and renewable generation; however, EIA does not currently collect this data in its surveys. EIA should expand its data collection to include annual electricity and annual water flow (millions of gallons) by water and wastewater utilities, in order to enable identification of new opportunities for electricity use and savings.

7.5 The Electricity Workforce: Changing Needs, New Opportunities

Support the Electricity-Sector Workforce

The electricity sector is undergoing a number of significant shifts in structure, energy sources, and applications as the industry modernizes and evolves. The full potential of these shifts will, however, only be realized if the electricity-sector workforce appropriately adapts and grows to meet the needs of the 21st-century electricity system. The Federal Government has an interest in the development of this workforce.

66. **Support cyber-physical systems (CPS) curriculum, training, and education for grid modernization and cybersecurity**. The December 2010 report of the President's Council of Advisors on Science and Technology, titled "Designing a Digital Future," highlighted the unique importance and challenges of CPS, such as the power grid. One of the challenges with such systems is the lack of a dedicated and trained cross-disciplinary workforce skilled at comprehending, designing, and managing CPS. This presents an acute challenge in the realm of power-sector cybersecurity, where cyber and cyber-physical threats are presenting new and distinct challenges. Prevention, mitigation, and response and recovery efforts require a workforce that understands the unique electric sector IT and operational technology systems and challenges; however, the industry currently faces a shortage of such workers. The Federal Government—through the Department of Education, DOE, National Science Foundation, and others—should sponsor development and deployment of CPS and cybersecurity educational curricula with community colleges, universities, and institutions of higher education to meet the grid-modernization needs of the 21st-century electricity system; they can do this by offering grants and supporting programs for educational institutions to develop and deploy CPS and power-sector cybersecurity educational curricula.

67. **Enhance and align skills-based training and electricity-sector workforce development**. The Federal Government has multiple resources that help address the difficulty employers are experiencing in hiring skilled workers in the electricity sector. To facilitate access to these Federal programs, the following steps should be taken:

    - DOE should, with other Federal agencies (e.g., the Department of Labor [DOL], National Science Foundation, Department of Commerce, Department of Education, and Department of Defense), coordinate Federal initiatives on electricity-sector education and training, including programs to facilitate national training credentials in new electricity technologies.
    - DOL should expand its pre-apprenticeship programs.

- DOE should expand its existing programs to increase the number of internships, fellowships, traineeships, and apprenticeships.
- DOE, DOL, and the Department of Defense should work together to create workforce opportunities for veterans, to build a more inclusive workforce, and to bring clean energy job training to low- and moderate-income communities.
- DOL and DOE should develop a single resource web portal to inform industry and potential employees about the multiple Federal agency workforce development initiatives and resources.

68. **Support Federal and regional approaches to electricity workforce development and transition assistance**. Changes in the electricity sector are increasing the need for a diverse and specialized workforce. To ensure electricity-sector workers maintain the capabilities required to provide for reliable and affordable electricity in a rapidly changing environment, DOE (in partnership with other agencies) should facilitate programs and regional approaches for workforce development. Federal funding and technical support should enhance existing programs on workforce diversity; apprenticeship and apprenticeship-readiness programs; skills-based training and education; transition assistance; and curriculum development. Workforce assessment tools should be developed to complement training programs. Federal agencies should coordinate their efforts through the interagency Energy and Advanced Manufacturing Workforce Initiative, staffed by DOE. Unemployed workers nearing but not yet eligible for retirement may have difficulty retraining after careers built on specialized skills that are no longer in demand in the modern electricity industry. Retirement transition assistance should be provided to these workers. Where possible, Federal agencies should leverage existing government, nongovernment, labor, and industry workforce consortia.

Meet Federal Commitments to Communities Affected by the Transformation of the Electricity Sector

To achieve the transition to the electricity sector of the 21st century smoothly, quickly, and fairly, the Federal Government should offer a synthesized package of incentives that address the needs of the most important stakeholders both within and outside of the electricity sector. Many of these needs are addressed through other recommendations on this list, including incentives to reduce the cost of flexible and clean assets, encourage the deployment of new and improved technologies throughout the electricity supply chain, and train workers for 21st-century electricity jobs. Recognizing that the shift to the 21st-century electricity system can impact communities dependent on 20th-century resources, the following recommendations provide transition assistance for communities affected by the multi-decadal decline in coal production.

69. **Fulfill Federal commitment to fund coal miner retiree benefits**. Over the last 50 years, coal miners have repeatedly foregone increases in wages in exchange for pension and healthcare benefits. These benefits are now imperiled by (1) the recent bankruptcy of three of the largest public coal companies in America—allowing those companies to avoid fully funding their employees' benefit funds—and (2) the declining ratio of active contributing workers relative to beneficiaries in the health and pension funds. Recognizing the commitments to support coal miner retirement benefits made by the Federal Government in the 1946 Krug-Lewis Agreement, the 1992 Coal Industry Retiree Health Benefit Act, and the 2006 amendments to that act, and also recognizing the contribution that coal miners have made to the U.S. economy, the Administration strongly supports legislation that would transfer funds to the largest multi-employer health and pension fund serving retired coal miners and their families, thereby ensuring that it can continue paying benefits.

70. **Meet the Federal commitment to appropriate sufficient funding to accomplish the mission of the Abandoned Mine Lands (AML) Fund**. DOI's Office of Surface Mining Reclamation and Enforcement estimates that there are more than $4 billion worth of high-priority, health- and safety-related abandoned coal mine lands in the United States. At the same time, the AML Fund has an unspent balance of $2.5 billion dedicated to reclaiming these sites. The AML fees should be returned to their original 1977 levels to raise additional reclamation funds, and disbursements from the AML Fund should be accelerated over the next 5 years, enhancing economic development in distressed coal communities through reclamation employment.

7.6 Targeted Opportunities to Enhance Electricity Integration in North America

Increase North American Cooperation on Electric Grid and Clean Energy Issues

Cooperation on electricity is needed to strengthen the security and resilience of an integrated, cross-border electricity grid, as well as to provide increasing amounts of clean energy and improve economic competitiveness across North America. A clear understanding of the regulatory requirements at the Federal and state levels for the permitting of cross-border transmission facilities, a sharing of best practices, and an exploration of potential future cooperation on grid management issues will limit uncertainties and improve policy coordination at the multilateral and international levels. This includes implementing the target established in the 2016 North American Leaders Summit to increase clean power to 50 percent of the electricity generated in North America by 2025.

71. **Increase U.S. and Mexican cooperation on reliability**. In 2005, the United States and Canada codified an international reliability framework based on an electricity reliability organization. As Mexico moves ahead with electricity reform and looks to expand their electricity system (including planning for international transmission), an international commitment to reliability would signal good progress towards improved electricity system management across North America. A commitment to working jointly on reliability was also included in the statement from the North American Leaders Summit in June 2016, where these leaders "committed to deepened electric reliability cooperation to strengthen the security and resilience of an increasingly integrated North American electricity grid."[14] The U.S. Government should increase cooperation on reliability between the United States and Mexico by establishing bilateral reliability principles between the United States and Mexico.

72. **Advance North American grid security**. In December 2016, the United States and Canada released a Joint United States–Canada Grid Security Strategy framing how these two countries plan to work together to strengthen the security and resilience of the electric grid, including against the growing threat from cyber attacks and climate change impacts. This recommendation aims to complete that objective through sharing of best practices and exploration of potential future cooperation on grid security issues with Mexico, in parallel with implementation of the Joint United States–Canada Grid Security Strategy and domestic Action Plans.

73. **Promote North America clean energy infrastructure development by sharing best practices for community engagement**. Lessons learned from sharing across regional entities can be a challenge, but the Federal Government can provide a forum for that engagement. This recommendation proposes that the U.S. Government initiate a series of high-level meetings with Canada and Mexico to share best practices relating to community engagement for clean energy infrastructure development throughout North America.

74. **Promote permitting of cross-border transmission facilities**. The "Regulatory Side-by-Side Governing Permitting of Cross-Border Electricity Transmission Facilities between the United States and Canada" summarizes existing regulations as of the time of publication. The document has proved incredibly useful as a resource for other analytical efforts and in informing discussion about simplifying or harmonizing regulations. Expanding this work to Mexico as the energy reforms move ahead would be very helpful to developers and governments. In addition, high-level meetings to improve community engagement for infrastructure can be supported by an effort at the U.S. Department of Energy with partners in Canada and Mexico to complete and update the Regulatory Side-by-Side and expand the Regulatory and Permitting Information Desktop (RAPID) Toolkit to the North America cross-border context. Consistent with the "North American Climate, Clean Energy, and Environment Partnership Action Plan," DOE should promote permitting of cross-border transmission facilities by expanding the Regulatory and Permitting Information Desktop (RAPID) Toolkit. Expansion of this toolkit will enable a clear understanding of the regulatory requirements at the Federal and state levels for the permitting of cross-border transmission facilities, in addition to those for bulk transmission.

75. **Modernize international cross-border transmission permitting processes**. Building upon Executive Order 13604, "Improving Performance of Federal Permitting and Review of Infrastructure Projects," a 2013 Presidential Memorandum titled "Transforming our Nation's Electric Grid through Improved Siting, Permitting, and Review" aims to modernize transmission permitting processes. The Presidential Memorandum directed Federal agencies to create the integrated interagency pre-application process (IIP) across the Federal Government (1) to help identify and address issues before the formal permitting process begins and (2) to improve coordination of permitting across Federal, state, and tribal governments. On September 21, 2016, DOE's Office of Electricity Delivery and Energy Reliability announced a final rule for the IIP. The IIP process encourages robust early coordination prior to the submission of a formal transmission permit application. That includes increased engagement with DOE as a coordinating agency, as well as relevant state, local, and tribal stakeholders. The principles of the IIP have already been successfully applied to two existing and recent Presidential permit applications for clean energy transmission. Building on these activities, DOE should modernize international cross-border transmission permitting processes by implementing a pre-application process and update the Presidential Permitting rules.

76. **Increase North American clean energy and technical coordination**. **T**echnical discussions have the potential to support better coordination on clean energy and climate goals, primarily through the creation of more robust North American modeling capabilities and wider accounting of clean energy and carbon emissions associated with cross-border trade. Technical discussions can also continue and enhance cooperation on energy information exchange across North America. In addition, technical discussions should focus on increasing North America wholesale electricity markets cooperation by sharing best practices for market development. As North America moves towards greater integration, there should be continued engagement on the cross-border impacts of climate and clean energy policies in order to limit uncertainties and improve policy coordination at the multilateral and international levels. There is a need for analytical tools and models that can estimate the value of technology deployment and summarize the impacts of policies in the clean energy and climate policy space. Specifically, models and studies are needed to examine (1) policy levers and incentives for clean energy and technologies to achieve climate goals; (2) the emissions impacts of jointly planning climate action and policies for climate and clean energy; (3) the impacts of cross-border trading on clean energy development, emissions, and the electricity system; and (4) the impacts of market policies, including cross-border trading schemes for carbon

and emissions. With new modeling capabilities and through technical discussions, DOE should explore the impact of enhanced cross-border trade on greenhouse gas emissions, economic development (in all countries, and collectively), as well as system reliability. Specific analysis could model market structures and examine the interplay between short-term operational flexibility and long-term financial certainty; examine the impact of enhanced U.S. imports of Canadian hydropower on carbon emissions and U.S. renewable energy development; examine best practices for the development of wholesale electricity markets; study Mexico's integration into the Western Climate Initiative; and explore impacts on the U.S. renewable energy industry, end-use costs for consumers, and the impacts of adjustments in sub-national policies on clean energy consumption across the continent.

7.7 Endnotes

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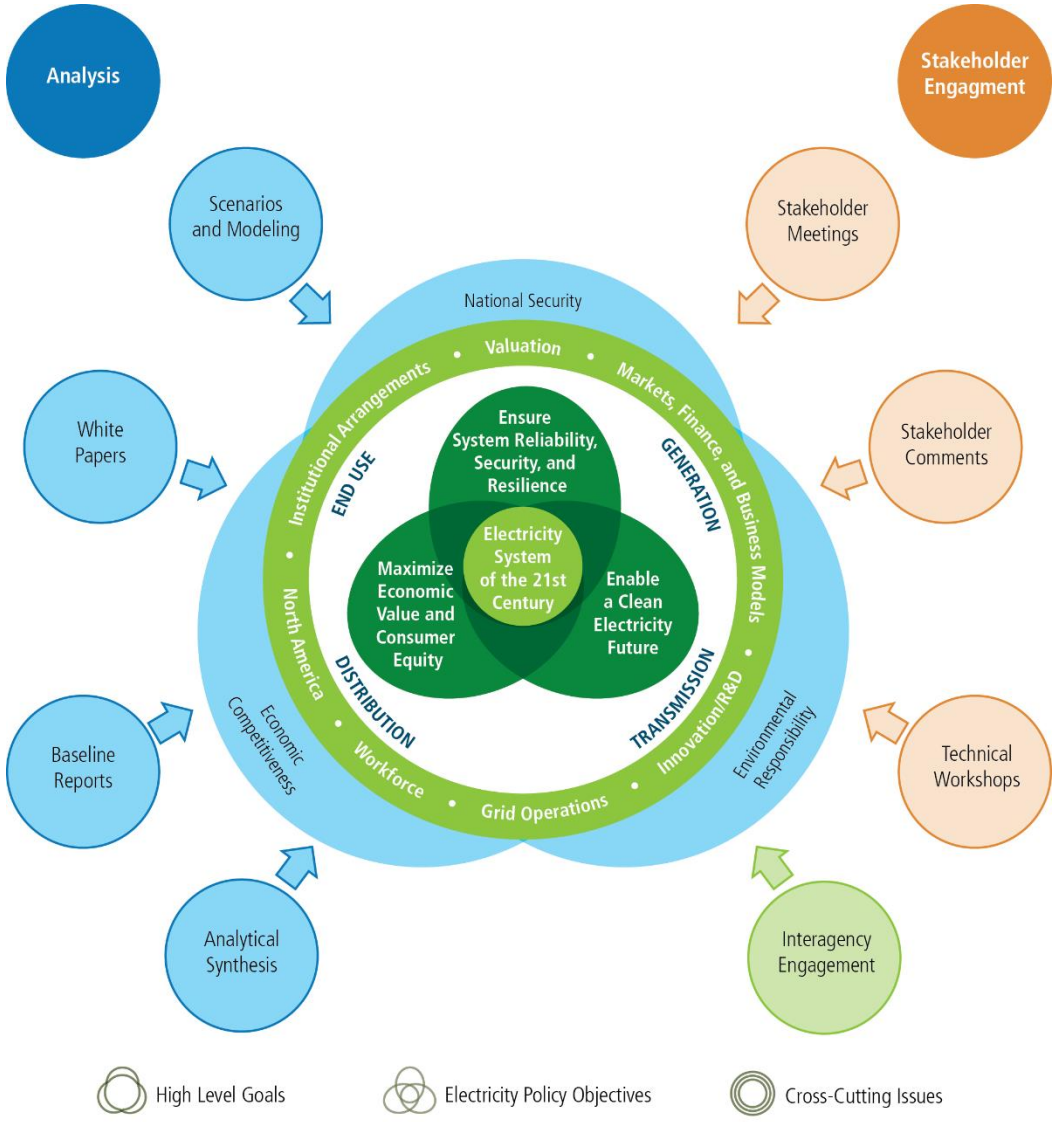
VIII Analytical and Stakeholder Process

This chapter describes the analyses and stakeholder engagement process that provided the substantive basis for this second installment of the Quadrennial Energy Review (QER 1.2). The first section describes the analytical work carried out for the QER 1.2, including baselines, models, topical reports, and white papers. The second section describes how the QER 1.2 process included engagement with a broad range of stakeholders across the Nation, through technical workshops, seven formal public stakeholder meetings, and the collection and consideration of public comments. This chapter is intended to document the process of developing the QER 1.2 and to provide transparency on the methods used to develop the material in the report.

Figure 8-1. Inputs to QER 1.2



This figure shows the analytical, stakeholder, and interagency efforts underpinning the QER 1.2.

8.1 Systems Analysis

The Administration-wide Quadrennial Energy Review (QER) is intended to enable the Federal Government to translate policy goals into a set of analytically based, integrated actions over a 4-year planning horizon. The White House Domestic Policy Council and Office of Science and Technology Policy jointly chair the interagency QER Task Force, while the Secretary of Energy provides an Executive Secretariat in the Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA). The QER involves a multi-agency review process, and more than 20 executive departments and agencies[a] play key roles in

[a] The members of the Task Force include: (1) the Department of State; (2) the Department of the Treasury; (3) the Department of Defense; (4) the Department of the Interior; (5) the Department of Agriculture; (6) the Department of Commerce; (7) the Department of Labor; (8) the Department of Health and Human Services; (9) the Department of Housing and Urban Development; (10) the Department of Transportation; (11) the Department of Energy; (12) the Department of Veterans Affairs; (13) the Department of Homeland Security; (14) the Office of Management and Budget; (15) the National Economic Council; (16) the

developing and implementing policies proposed in the QER. Unlike other Federal quadrennial review processes where analysis is done every 4 years, the QER is conducted through installments to allow for granular analysis of key energy subsectors. Serving as Secretariat, EPSA is responsible for coordinating activities related to the preparation of the report, including commissioning an extensive suite of policy analysis focused on the electricity system (see Figure 8-1).

QER 1.2's analysis was completed over many months through the following methods:

- Commissioning five baseline reports to provide an overview of the current state of the electricity system
- Commissioning analyses, modeling, synthesis, and white papers from U.S. National Laboratories, energy consultants, and analytics firms
- Convening technical workshops with relevant stakeholders and producing write-ups of findings and stakeholder viewpoints
- Performing analysis and modeling within EPSA, in collaboration with partners across DOE and other Federal agencies, to generate analysis, policy working papers, and reports
- Meeting with EPSA and staff-level agency representatives and experts on the findings and recommendations proposed in QER 1.2.

8.2 Crosscutting Analysis

This section provides examples of major external analyses commissioned by EPSA that support the findings and recommendations within QER 1.2. The descriptions below categorize the analyses (with the caveat that most QER 1.2 analyses are crosscutting in nature and apply to more than one energy objective or sector).

8.2.1 Baselines

A series of EPSA baselines were developed to provide an overview of elements of the electricity system. These baselines helped inform QER 1.2 and focused on the following issue areas: generation, distribution, end use, markets, and climate and environment.[b] These baseline analyses identify major historical trends in the electricity sector and reflect the workings, characteristics, and issues of the current electricity system. These baselines provide a foundation for the analysis of systems and policy recommendations that form QER 1.2.

8.2.2 Key Reports and Studies

QER 1.2 drew from multiple studies of the electricity system, including but not limited to the following:

National Security Staff; (17) the Council on Environmental Quality; (18) the Council of Economic Advisers; (19) the Environmental Protection Agency; (20) the Small Business Administration; (21) the Army Corps of Engineers; (22) the National Science Foundation; and (23) such agencies and offices as the President may designate.

[b] The environmental baseline was divided into four volumes in the following categories: Greenhouse Gas Emissions, Solid Waste and Decommissioning, Energy-Water Nexus, and Environmental Quality.

Table 8-1.[c] List of Chapter Specific Analyses for QER 1.2

Title	Performer
Transforming the Nation's Electricity Sector: The Second Installment of the QER	
Accelerate Energy Productivity 2030	NREL
Principles for Creating and Evaluating Electric System Reliability Plans in the 21st Century	NREL, PNNL, ORNL
Cyber Threat and Vulnerability Analysis of the U.S. Electric Sector	INL
Energy Supply Chain Vulnerabilities: Framework and Case Study	ANL, ORNL, INL
Modernizing the Electric Distribution Utility to Support the Clean Energy Economy	EPSA
Harmonizing the Electricity Sectors across North America	RFF
Electricity Distribution System Baseline Report	PNNL
Electricity Generation Baseline Report	NREL, INL, NETL
Residential Electricity Bill Savings Opportunities from Distributed Electric Storage	EPSA
Establishing the Playing Field: Surveying Clean Energy-Related Economic Development Policy across the States	NREL
Ensuring Electricity System Reliability, Security, and Resilience	
Assessing Cost and Benefits of Investments in Climate Resilience	ORNL
Utility Risk-Mitigation Strategies	Deloitte
Scoping Analytical Tools and Methods for Vulnerability Analysis of Linked Electricity Generation and River Basin Systems	ORNL
Guide to Cybersecurity, Resilience, and Reliability for Small and Under-Resourced Utilities	NREL
Resilience of the U.S. Electricity System: A Multi-Hazard Perspective	ORNL, LANL, ANL, SNL, PNNL, BNL
Front-Line Resilience Perspectives: The Electric Grid	ANL
State Energy Resilience Framework	ANL
Building a Clean Electricity Future	
Energy Efficiency under Alternative Carbon Policies: Incentives, Measurement, and Interregional Effects	NREL
Evaluating the CO_2 Emissions-Reduction Potential and Cost of Power Sector Re-Dispatch	NREL
Literature Review of Studies That Includes an 80% Reduction in GHGs by 2050	Energetics
Characterizing Energy Efficiency in Low-Income Communities	LBNL
Environment Baseline Vol. 4: Energy-Water Nexus	EPSA
Advanced Water Metering Infrastructure	NREL, INL, NETL
The Electricity Sector: Maximizing Economic Value and Consumer Equity	
Energy Efficiency Financing Programs	LBNL
Characterization of Regional Electric Markets	Pace Global
Review of the Economics Literature on U.S. Electricity Restructuring	University of California, Davis
Distributed Energy Resources and Rate Financial Analysis	EPSA
Recovery of Utility Fixed Costs: Utility, Consumer, Environmental and Economist Perspectives	LBNL
Fixed Cost Allocations and Rate-Making Instruments to Address Distributed Energy Resources	EPSA

The QER commissioned multiple studies across the electricity system, including but not limited to these reports for specific chapters.

[c] NREL – National Renewable Energy Laboratory; PNNL – Pacific Northwest National Laboratory; ORNL – Oak Ridge National Laboratory; INL – Idaho National Laboratory; ANL – Argonne National Laboratory; RFF – Resources for the Future; NETL – National Energy Technology Laboratory; LANL – Los Alamos National Laboratory; SNL – Sandia National Laboratories; BNL – Brookhaven National Laboratory; GHGs – greenhouse gases; LBNL – Lawrence Berkeley National Laboratory.

8.2.3 Technical Workshops

As part of the crosscutting analysis conducted for QER 1.2, the QER Task Force flagged some topics deemed particularly complex for technical workshops to discuss further with stakeholders and industry experts. Technical workshops convened subject matter experts and relevant stakeholders to provide expert insights on various elements of the electricity system through the intensive analytical approach of these 1-day and 2-day symposia. Each technical workshop featured a roster of subject matter experts from industry, academia, the National Laboratories, and other relevant organizations.

Below are details about the topics, dates, and locations of the technical workshops that DOE held to inform QER 1.2:

Technical Workshop on Electricity and Information and Communication Technologies Convergence
June 15, 2015 – Washington, D.C.
DOE hosted a technical workshop to understand stakeholder issues on electricity and information and communications technology (ICT). The workshop sought to inform the completion of the Pacific Northwest National Laboratory white paper commissioned by DOE: *The Emerging Interdependence of the Electric Power Grid and Information and Communication Technology*. The second focus of the workshop was to elicit additional electricity and ICT research and policy-analysis topics for potential examination within DOE. The workshop included participants from utilities, industry stakeholders, energy associations, and regulators.

The goal of this meeting was to leverage the inherent synergies between DOE's research and policy functions and gather expert input. Specifically, this workshop concerned the current status of deployment of electricity and ICT infrastructure, as well as trends and developments in market places, technologies, and regulations.

Electric Power in the United States and Canada: Opportunities for Regulatory Harmonization
October 20, 2015 – Boise, Idaho
October 27, 2015 – Albuquerque, New Mexico
DOE sponsored a workshop hosted by Resources for the Future—in concert with the International Institute for Sustainable Development and Boise State University—looking at the electricity sectors in the United States and Canada. The workshop had several purposes: (1) to identify gaps, best practices, and inconsistencies with regulations and electricity-system planning across the United States, Canada, and Mexico; (2) to inform the creation of legal, regulatory, and policy roadmaps for harmonizing regulations and planning; and (3) to bring together individuals who can help implement greater harmonization. The two workshops examined policies, regulations, and planning associated with the electricity sector, and within that sector, environmental regulations (for air pollution, greenhouse gases [GHGs], and renewables). They also examined the regulations and processes associated with the operation and planning of the electricity system—including generation and transmission. DOE and Resources for the Future published a final paper summarizing the recommendations and observations of workshop participants in early 2016.

Low-Carbon Futures of the U.S. Energy System
January 14, 2016 – Washington, D.C.
In 2009, and subsequently in 2014, the Administration set GHG-emissions reduction targets in the range of 17 percent below 2005 levels by 2020 and 26 to 28 percent below 2005 levels by 2025. Both of these goals are intended to put the United States on a path toward 80 percent decarbonization by 2050. DOE hosted a 1-day workshop to better understand possible pathways to achieving substantial economy-wide GHG-emissions reductions by 2050.

Participants from academia, DOE, the National Laboratories, and other interested stakeholder groups met to discuss two main topics: (1) potential pathways for substantial GHG reductions in electricity generation and (2) how future end-use demand for electricity might shape the scale of required GHG-emissions reductions in the electric-power sector. There were two primary goals for the workshop. The first goal was to identify a set of representative pathways (and elements of such pathways) toward substantial economy-wide reductions in GHG emissions by 2050. The second goal was to identify the key characteristics, challenges, opportunities, and requirements of different pathways. The workshop informed analysis of the transition to a cleaner, low-carbon electricity system for QER 1.2.

Electricity Use in Rural and Islanded Communities

February 8–9, 2016, *Washington, D.C.*

The objective of this workshop was to help EPSA's public outreach efforts by focusing on communities with unique electricity challenges. The workshop explored challenges and opportunities for reducing electricity use and associated GHG emissions while improving electricity system reliability and resilience in rural and islanded communities. Although the statement of task mentioned design of microgrids for hospitals, universities, military bases, and other unified load centers, presenters covering microgrids were encouraged to describe potential applications serving isolated communities and towns in keeping with the theme of the workshop. The workshop assembled speakers from diverse locations that have rural or islanded energy issues, including Hawaii, Alaska, North Carolina, and Vermont, and they held expertise in many facets of electricity-system design and operation. Speakers were encouraged to do the following: (1) identify and share best practices between rural and islanded electricity-system users and operators and (2) provide suggestions for Federal policies and research and development investments that could be implemented in both the near and long term.

The Future of Energy Efficiency

February 10, 2016 – Washington, D.C.

This session, held at a meeting of the National Association of State Energy Offices, provided a discussion of the role of energy efficiency in response to the emerging electric-system challenges and opportunities that DOE intends to address in QER 1.2. The purposes of this workshop were to focus on issues related to electricity end use and to explore the potential for energy efficiency moving forward; barriers and opportunities to overcome; system benefits and the costs of increased energy efficiency deployment; and what policies or methods can be deployed to meet evolving consumer needs, and how these needs can be met while creating a more efficient system. Key themes and areas of interest from the discussion included evolving trends in electricity demand; in benefits and costs for energy efficiency in a more integrated grid; options for increasing consumer value/equity/access to services; the potential for greater electrification and decarbonization of the economy; data access and security issues; improving methods for valuing energy efficiency; and opportunities for new services and business models.

The Future of U.S. Bulk Power Markets

March 4, 2016 – Washington, D.C.

DOE, in coordination with Boston University's Institute for Sustainable Energy, hosted a technical workshop to gather input from current industry stakeholders on the future of the Nation's bulk power markets. The workshop also included distinct discussions on the state of transmission-planning efforts, essential reliability services (also known as ancillary services), and the potential for markets at the distribution-system level.

Participants from academia, industry associations, individual companies, public power, and state/Federal regulatory agencies were encouraged to discuss these topics and outline the major issues in their respective areas of expertise. The participants provided recommendations and feedback for ways in which DOE and the QER process could help alleviate those issues. The workshop ultimately informed the

direction of subsequent analyses in support of QER 1.2, specifically with regard to transmission systems and resource adequacy constructs.

Workshop on Siting and Regulating Carbon Capture, Utilization, and Storage Infrastructure
April 8, 2016 – Washington, D.C.
DOE sponsored a workshop to identify and promote best practices for siting and regulating carbon dioxide (CO_2) infrastructure—including pipelines, enhanced oil recovery, and saline CO_2 storage sites. The purposes of this workshop were to foster communication and coordination, as well as to share lessons learned and best practices among states that are already involved in siting and regulating CO_2 infrastructure or that may have proposed future CO_2 infrastructure projects.

The workshop convened subject matter experts, industry representatives, Federal officials, and state agencies with jurisdiction over energy-infrastructure planning, siting, and economic development. The aim of the workshop was to facilitate a knowledge exchange regarding CO_2 pipeline and storage-site infrastructure needs. The workshop also informed issues being addressed in QER 1.2, including discussions around CO_2-enhanced oil recovery and other storage sites, which serve as infrastructure for entities capturing CO_2.

Technical Workshop on Electricity Valuation
May 2–3, 2016 – Washington, D.C.
DOE hosted a technical workshop to understand stakeholder issues relevant to the valuation of electricity system technologies, products, and services. The workshop sought to examine four major topics: (1) valuing electricity system components and attributes; (2) valuing technologies for contributions to power quality and reliability; (3) managing electricity risks; and (4) valuation within the distribution system.

The workshop included stakeholders from state and Federal regulatory agencies, electric utilities, technology developers and manufacturers, universities, the National Laboratories, industry associations for consumers, and electricity-system operators. The opening session began with a presentation on a proposed valuation methodology. During the workshop, participants provided their views on issues that must be adequately resolved to support higher penetration levels for advanced or distributed energy technologies. Participants also discussed the challenges associated with methods to value and plan for their integration. The workshop informed and improved analysis commissioned on valuation for QER 1.2.

QER 1.2 Finance Workshop
June 1, 2016 – New York, New York
As input to the QER 1.2, EPSA hosted a technical workshop to gather stakeholder views on power-sector finance in the context of national energy objectives, a changing resource mix, and new technologies and business models. The discussion focused on financing required to deploy proven or advanced clean electricity technologies. Workshop participants included senior leaders from industry and investor communities, who were encouraged to provide examples of existing barriers and ideas on effective public policies and programs for U.S. electricity-system modernization.

Participants emphasized that there is sufficient capital available for proven clean electricity projects with an identified revenue stream, but there is a revenue model problem for many projects and technologies. Some of the topics discussed included the potential role of grid-scale storage; challenges with large-scale nuclear; and the need for policy stability. Participants also encouraged a systems approach to modernization. They emphasized the need to provide assets with revenue streams (via price signals) for all services they provide to the grid so that asset valuations reflect their overall value to the system. The discussion included near-term, incremental changes to facilitate asset financing and deployment such as changes to the tax code, as well as longer-term policy and market changes such as incentive-based

regulation, a clean capacity incentive, or pricing local reliability to provide an economic signal for customers to behave in ways that benefit the grid.

Technical Workshop on the Implications of Increasing Electric-Sector Natural Gas Demand
June 7, 2016 – Washington, D.C.
This workshop explored how medium- and long-term planning is evolving given the trend of increased use of natural gas in the electric-power sector. While there are favorable economic and environmental benefits to increased use of natural gas in electricity, potential challenges in infrastructure compatibility and reliability arise, as well. Stakeholders from both the natural gas and electric sectors from different regions of the country convened at this workshop. Participants then shared the practices, tools, and metrics that they employ in order to understand the interdependency between the electric and natural gas industries, as well as the approaches that stakeholders have implemented to resolve challenges and leverage opportunities.

Accelerate Energy Productivity 2030 Executive Review and Dialogue Session
June 28, 2016 – Washington, D.C.
The purpose of this session was not only to provide input to DOE from key industry representatives but also to build upon the work done under the Accelerate Energy Productivity 2030 partnership between DOE, the Alliance to Save Energy, and the Council on Competitiveness. Through the partnership, energy productivity has become an increasingly influential way to drive meaningful policy deployment in the United States and abroad. This session followed the 2014 announcement of the initiative at the 2014 American Energy and Manufacturing Competitiveness (AEMC) Summit by Secretary of Energy Ernest Moniz and the release of *Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth* at the 2015 AEMC. Representatives at the session provided input on several issues relevant to the QER 1.2, including increased deployment of electric vehicles; electric utility rate design that supports deployment of new technologies; regulatory consistency and certainty; improving electric consumer equity; ensuring a strong electric-sector workforce; the role of states in driving energy productivity; the role of incentives and consumer awareness in promoting clean energy technology; the importance of public-private partnerships; and improving access to financing for energy efficiency.

8.3 QER Stakeholder Engagement

In the Presidential Memorandum establishing the QER, President Obama directed the QER Task Force to "gather ideas and advice from state and local governments, tribes, large and small businesses, universities, National Laboratories, nongovernmental and labor organizations, consumers, and other stakeholders and interested parties." The President also ordered the QER Task Force to "develop an integrated outreach strategy that relies on both traditional meetings and the use of information technology."

In its role as Secretariat for the QER Task Force, EPSA undertook an open, transparent process for informing stakeholders of the purposes and scope of the QER 1.2.

This outreach process included the following:

- Informal meetings at DOE headquarters involving EPSA staff members and dozens of stakeholder groups from the electricity sector, such as academic researchers; local, state and Federal governments; and regulatory agencies
- Briefings on the QER process at meetings with industry associations; groups of state officials; the offices of environmental groups; and with Members of Congress, their staffs, and the staffs of multiple relevant congressional committees

- A series of seven formal public stakeholder meetings, beginning in Washington, D.C. and extending to Boston, Massachusetts; Salt Lake City, Utah; Des Moines, Iowa; Austin, Texas; Los Angeles, California; and Atlanta, Georgia
- Special dialogues with officials in Canada and Mexico to discuss cross-border integration and international collaboration, given the extensive electricity integration that exists between the United States and Canada and opportunities present to increase integration between the United States and Mexico
- Speeches and briefings to interested groups in Washington, D.C., and across the country by the Secretary of Energy, the Director of the President's Office of Science and Technology Policy, other White House officials, and various members of DOE leadership
- The creation of a public comments portal to allow interested stakeholders and the general public to provide comments on individual stakeholder meetings, as well as outside experts to submit studies, reports, and data sets related to topics within the scope of the QER 1.2.

8.3.1 Formal Public Stakeholder Meetings

Some of the most visible effort to engage stakeholders during the QER 1.2 process was the series of seven public meetings held around the country from February 2016 to May 2016. These meetings provided opportunities for the Administration to fully consider the unique challenges and opportunities facing each of the many geographically diverse segments of our Nation's electricity system. The regions selected for QER 1.2 stakeholder meetings were based on wholesale market footprints as a convenient approach to capturing the Nation's regional electricity diversity, which is also characterized by differing resource mixes, state policies, and a host of other factors.

The mixture of panel discussions and a public comment period framed multi-stakeholder discourse around deliberative analytical questions in QER 1.2 relating to the intersection of electricity and its role in promoting economic competitiveness, energy security, and environmental responsibility. The Administration sought public input on key questions relating to possible Federal actions that would address the challenges and take full advantage of the opportunities of this changing system to meet the Nation's objectives of reliable, affordable, and clean electricity.

Each meeting began with opening statements by the hosting Administration representatives, along with local, state, and national political leaders who participated at events in their parts of the country. Each meeting, with the exception of the kickoff meeting in Washington, D.C., had three panel discussions. The first two topics were the same for all regions (*Bulk Power Generation and Transmission Opportunities: How Can We Plan, Build, and Operate the Appropriate Amount for Future Needs?* and *Electricity Distribution and End-Use: How Do We Manage Challenges and Opportunities?*)—although content varied as there are significant regional differences. The third panel's topics were different for each session to highlight issues of regional importance, and these discussions are described in more detail below. Each meeting concluded with an "open microphone" segment, during which members of the general public could make statements for the QER 1.2 record and had the opportunity to offer prepared presentations, studies, reports, and more for review by EPSA analysts and inclusion in the QER Library.

Federal Register notices announcing each formal public stakeholder meeting were published; these notices also were made available via the DOE QER website (http://energy.gov/epsa/quadrennial-energy-review-qer). DOE publicized the meetings by sending advisories to local media; using social media; and emailing state, local, and tribal governments, as well as representatives of energy stakeholders—both in the region of each meeting and in Washington, D.C.

In the interests of transparency and open government, court reporters produced a transcript for each meeting, and EPSA produced a summary of each meeting's presentations and discussions. The transcripts and summaries, along with links to the live-streamed recordings and panelists' prepared remarks and presentations, are available on the QER website.

Following are details about the dates, topics, locations, and focus areas of the formal public stakeholder meetings organized by EPSA to inform QER 1.2 (Table 8-2).

Table 8-2. List of QER 1.2 Formal Public Stakeholder Meetings (with Topic, Location, Date, and Administration Officials)

Location	Topic (Third Panel)	Date	Administration Chair(s) and Local/State/Congressional Officials
Washington, D.C.	Not Applicable	2/4/16	Secretary of Energy Ernest Moniz; Assistant to the President for Science and Technology Dr. John Holdren; Deputy Assistant to the President for Energy and Climate Change Dan Utech; and Representative Earl Blumenauer (D-OR)
Boston, Massachusetts	Resource adequacy	4/15/16	Secretary of Energy Ernest Moniz; Assistant to the President for Science and Technology Dr. John Holdren; and Governor Charlie Baker
Salt Lake City, Utah	Cyber- and physical security and resilience	4/25/16	Deputy Assistant to the President for Energy and Climate Change Dan Utech; and Department of Agriculture Rural Utilities Service Deputy Administrator Joshua Cohen
Des Moines, Iowa	Transmission development	5/6/16	Secretary of Energy Ernest Moniz; Governor Terry Branstad; Lieutenant Governor Kim Reynolds; Mayor T.M. Franklin Cownie; and Department of Agriculture, Rural Development Rural Business-Cooperative Service Administrator Sam Rikkers
Austin, Texas	New technologies and actors in the grid edge space	5/9/16	Secretary of Energy Ernest Moniz; Department of Agriculture Deputy Under Secretary for Rural Development Lillian Salerno; and Mayor Steve Adler (Austin)
Los Angeles, California	Generating and delivering electricity to meet GHG targets	5/10/16	Deputy Secretary of Energy Elizabeth Sherwood-Randall; Department of Agriculture, Rural Development Rural Business-Cooperative Service Administrator Sam Rikkers; and Deputy Mayor for City Services Barbara Romero (Los Angeles)
Atlanta, Georgia	Financing new electricity infrastructure	5/24/16	Secretary of Energy Ernest Moniz; and Department of Agriculture, Rural Utilities Service Deputy Administrator Joshua Cohen

Dates, topics, locations, and focus areas for the formal QER 1.2 Stakeholder Meetings.

1. **Washington, D.C., Kickoff Meeting**
   February 4, 2016

   The Washington, D.C., public stakeholder meeting served as the formal kickoff meeting for QER 1.2, an integrated study of the U.S. electricity system from generation through end use. The meeting included two main panel discussions and a public comment period focused on the challenges and opportunities facing the electricity sector and its key role in promoting economic competitiveness, energy security, and environmental responsibility.

2. **Boston, Massachusetts**
   April 15, 2016

   The QER 1.2 public stakeholder meeting in Boston covered the footprint of the 21 states and the District of Columbia which are, all or in part, in the Regional Transmission Operator (RTO) PJM Interconnection, Independent System Operator (ISO)-New England, or New York ISO. The third

panel for the Boston public stakeholder meeting covered "*Ensuring Resource Adequacy*," highlighting the proper design and operation of the eastern RTO/ISO markets, with Federal and state policies and consumer demand creating momentum for low-carbon options, as crucial.

3. **Salt Lake City, Utah**
   April 25, 2016

   The Salt Lake City meeting covered the footprint of 13 of the 14 states (excluding California) which are, all or in part, in the Western Interconnection, and are represented by the Western Electricity Coordinating Council. The third panel in the Salt Lake City public stakeholder meeting covered "*Cyber/Physical Security and Resilience.*"

4. **Des Moines, Iowa**
   May 6, 2016

   The Des Moines meeting covered the footprint of the 20 states which are, all or in part, in the Southwest Power Pool and the Midcontinent ISO. The third panel in the Des Moines public stakeholder meeting covered "*Transmission Development with an Evolving Generation Mix.*"

5. **Austin, Texas**
   May 9, 2016

   The Austin meeting covered the footprint of the state of Texas, grid operations, and the flow of energy—most of which is managed by the Electric Reliability Council of Texas. The third panel in the Austin public stakeholder meeting covered "*New Technologies and Actors in the Grid Edge Space.*"

6. **Los Angeles, California**
   May 10, 2016

   The Los Angeles meeting covered the footprint of the State of California, grid operations, and the flow of energy—most of which is managed by the California ISO. The third panel for the Los Angeles public stakeholder meeting covered "*Generating and Delivering Electricity in a High GHG-Reduction Environment.*"

7. **Atlanta, Georgia**
   May 24, 2016

   The Atlanta meeting covered the footprint of the 10 southeastern states that, all or in part, have bilateral wholesale electricity markets. The third panel for the Atlanta public stakeholder meeting covered "*Financing New Electricity Infrastructure*."

8.3.2 Comments Portal and QER Library

From the beginning of the QER 1.2 process, stakeholders and the general public were encouraged to offer suggestions, comments, insights, and criticisms on issues surrounding the electricity system. Public comments were collected through a web-based portal, which allowed stakeholders to share comments as well as studies, reports, data sets, and any additional materials from stakeholder organizations to help inform QER 1.2. All comments submitted to the portal will be made publically available at http://energy.gov/epsa/quadrennial-energy-review-stakeholder-engagement.

EPSA received 295 total comments—including 215 total attachments comprising detailed reports and studies on behalf of trade associations, utilities, and energy companies; state and local governments; nonprofit organizations; and other stakeholders (totaling over 2,600 pages). EPSA reviewed each of the

comments received. Insights and recommendations extracted from these comments and materials have been included in QER 1.2. Stakeholder comments were grouped into multiple themes, namely issues with evolving generation mix; increased attention to cyber and physical security; reliability needs during transformation; problems with organized wholesale markets; evolving transmission planning and investment; activity at distribution and end-use sector; valuation and rate reform; business models; evolving state and Federal regulations; and the Federal role.

8.4 QER Interagency Engagement

As outlined by the QER Presidential Memorandum, the President identified more than 20 executive departments and agencies that play key roles in developing and implementing policies governing energy resources and consumption, as well as associated environmental impacts. The President directed the QER Secretariat (1) to develop a comprehensive and integrated review of energy policy, based on interagency dialogue and active engagement of external stakeholders, and (2) to make recommendations on what additional actions it believes would be appropriate. The findings and recommendations in QER 1.2 are based on Task Force deliberations, meetings with staff-level agency representatives and experts, and information provided to the Secretariat and the Task Force by external stakeholders.

Throughout the development of QER 1.2, the White House has convened regular interagency meetings and worked closely with the agencies' leadership and staff. Member agencies have collaborated to develop QER 1.2 by providing information on topics within their statutory and regulatory jurisdiction or areas of particular expertise related to energy infrastructure transmission, storage, and distribution. Agencies have delivered studies, data, and other information to be considered in policy analysis and modeling; reviewed analysis and findings; leveraged the work of other relevant Administration initiatives and led by the Office of Science and Technology Policy and the Domestic Policy Council, collaboratively developed policy recommendations. A series of roundtable discussions was held with representatives from key departments and agencies to ensure a transparent and inclusive process in the development of policy recommendations.

Interagency members also partnered with the Secretariat on the seven formal public stakeholder meetings and opened the events and set the focus for the expert panels that followed.

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A QER 1.2 Appendix A: Electricity System Overview

A.1. Elements of the Electricity System

The U.S. electric power system is an immensely complex system-of-systems, comprising generation, transmission, and distribution subsystems and myriad institutions involved in its planning, operation, and oversight (Figure A-1). End use and distributed energy resources (DERs) are also important parts of the electric power system.

A.1.1 Generation

Electricity generation accounts for the largest portion of U.S. primary energy use, using 80 percent of the Nation's domestically produced coal,[1] one-third of its natural gas, and nearly all of its nuclear and non-biomass renewable resource production. In 2014, 39 percent of the Nation's primary energy use was devoted to electricity generation, and electricity accounted for 18 percent of U.S. delivered energy.[2]

In 2014, there were over 6,500 operational power plants of at least 1 megawatt in the U.S. electric power system.[a, 3, 4] These power plants delivered nearly 3,764 billion kilowatt-hours (kWh) of power in 2014, supplying electricity to over 147 million residential, commercial, and industrial customers at an average price of $0.104/kWh for a total revenue from electricity sales of more than $393 billion.[5, 6, 7, 8]

The U.S. electricity generation portfolio is diverse and changes over time through the commercial market growth of specific generation technologies—often due to a confluence of policies, historic events, fuel cost, and technology advancement. Today, coal and natural gas each provide roughly one-third of total U.S. generation; nuclear provides 20 percent; hydroelectric and wind provide roughly 5 percent each; and other resources, including solar and biomass, contribute less than 2 percent each.[9] However, there are major generation mix differences between regions (Figure A-2**Error! Reference source not found.**).[10]

The availability of primary energy resources, like coal and natural gas, and renewable energy resources, like wind and solar, differs widely across the country (Figure A-3). This dispersed resource availability influences the regional generation mixes.

[a] A megawatt is a thousand kilowatts. A kilowatt is a unit of power output commonly used in the electricity industry. A kilowatt-hour (kWh) is a related unit of energy (the amount of power provided times the number of hours that it is provided). Electricity is usually billed by the kWh. An average American home uses roughly 11,000 kWh per year. Source: "How Much Electricity Does an American Home Use?" Energy Information Administration, Frequently Asked Questions, last updated October 18, 2016, https://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3.

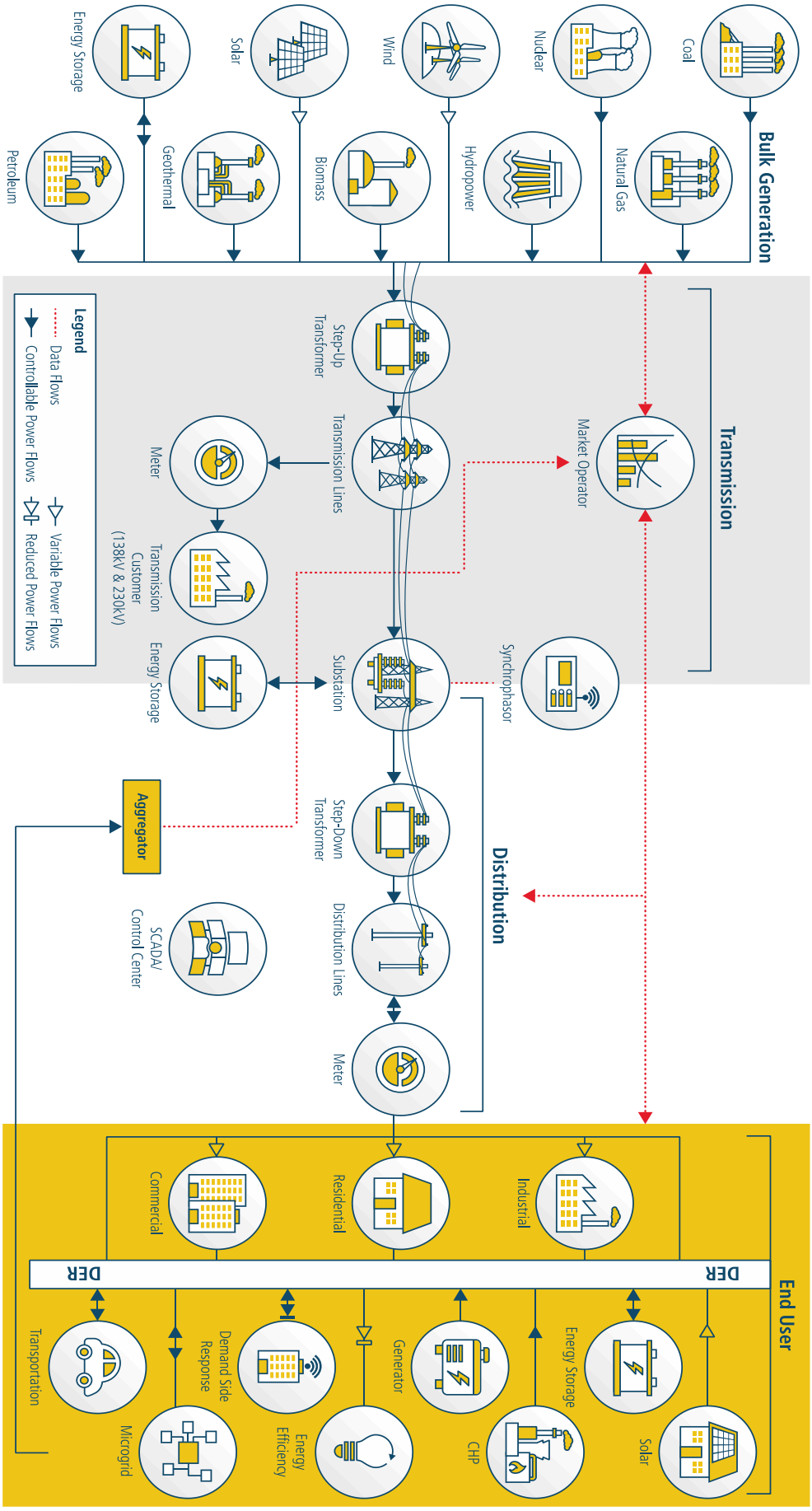
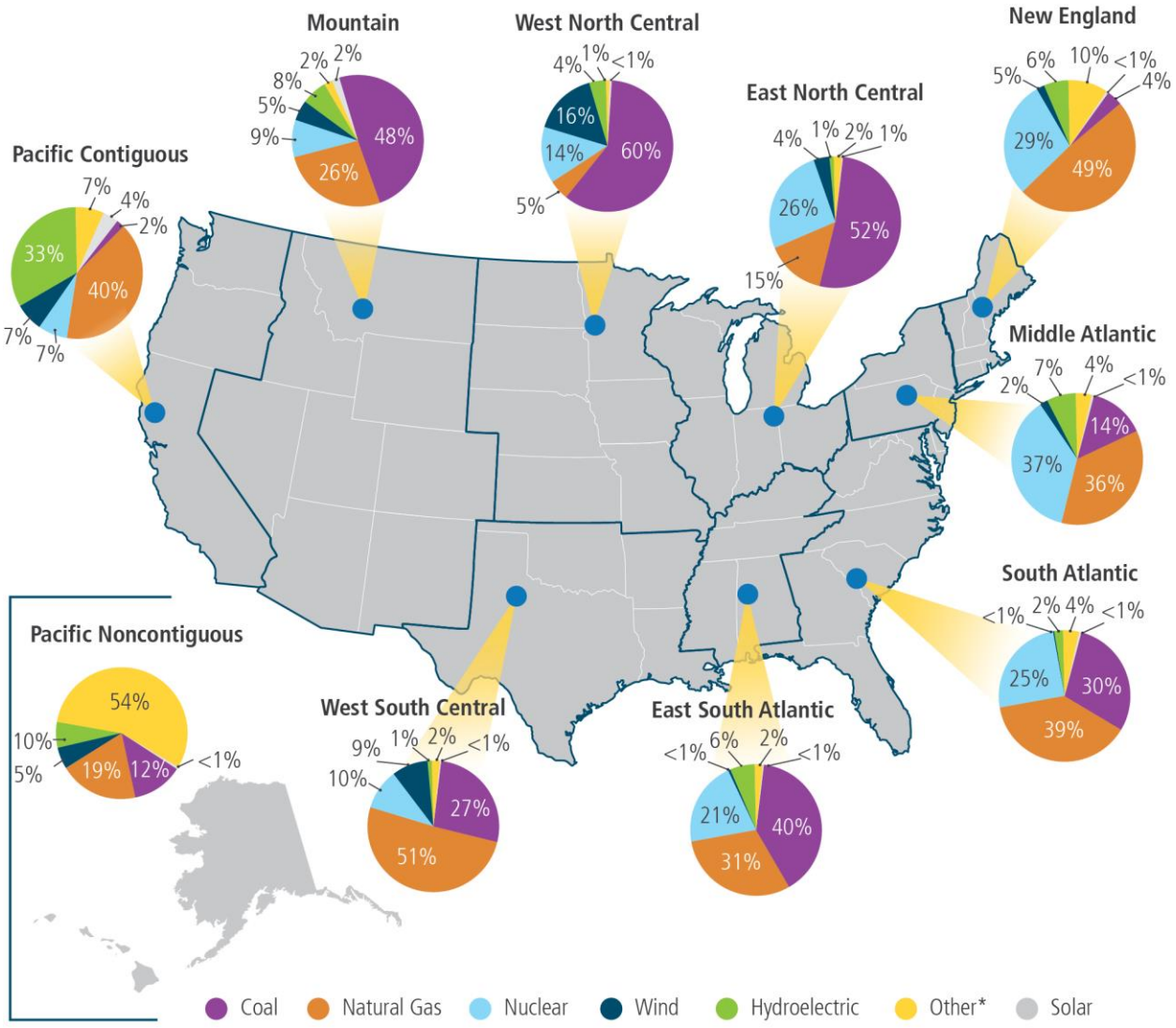


Figure A-1. Schematic Representation of the U.S. Electric Power System

The electric power system comprises the following broad sets of systems: bulk generation, transmission, distribution, and end use (including DERs).

Figure A-2. Electric Power Regional Fuel Mixes, 2015[11, 12]

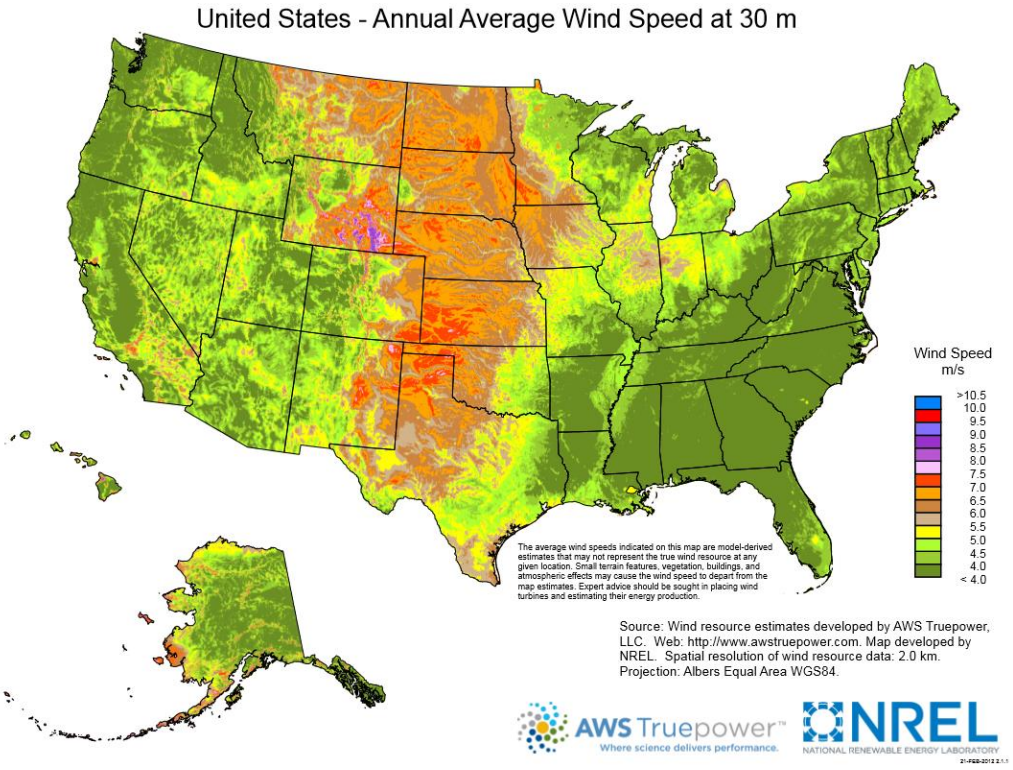


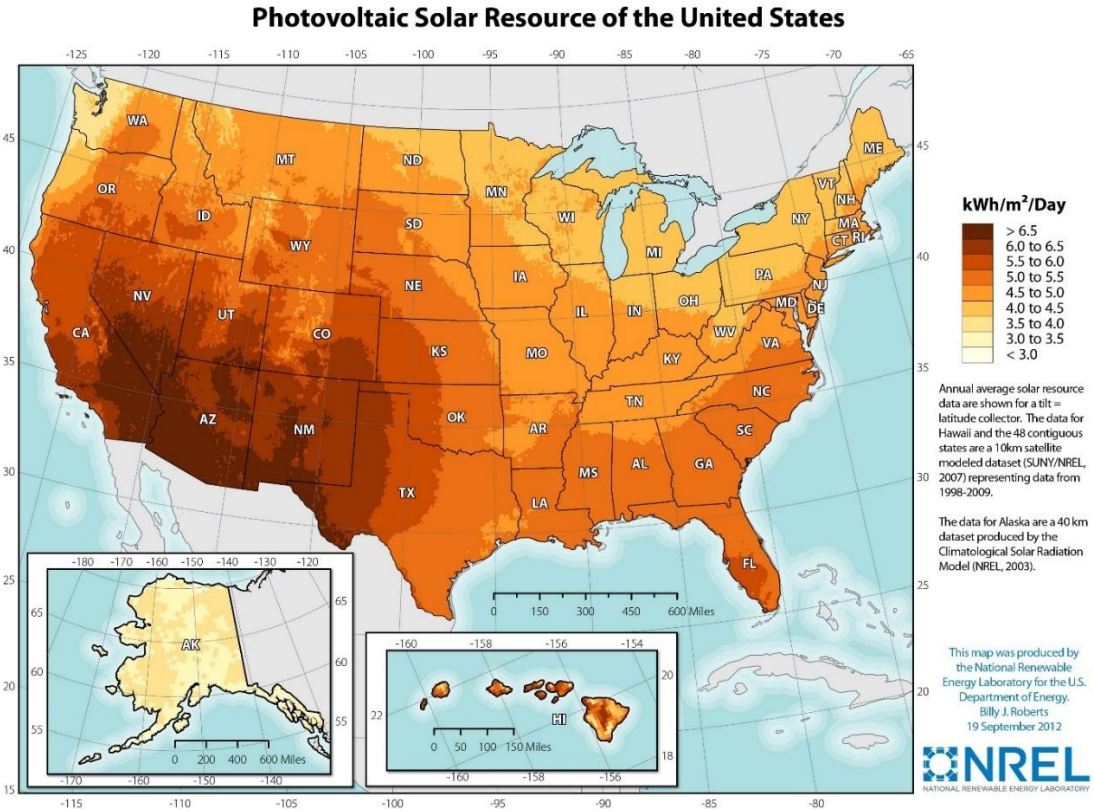
*Includes the following EIA fuel type designations: Distillate Petroleum, Geothermal, Biogenic Municipal Solid Waste and Landfill Gas, Other Gases, Other Renewables, Other (including nonbiogenic MSW), Petroleum Coke, Residual Petroleum, Waste Coal, Waste Oil, and Wood and Wood Waste.

Note: Sum of components may not add to 100% due to independent rounding.

The U.S. electricity industry relies on a diverse set of generation resources with strong regional variations. As of 2015, coal fuels the majority of electricity generation in the Mountain, West North Central, East North Central, and East South Central regions. Coal is also a significant resource for the South Atlantic and West South Central regions, though both have sizable natural gas generation as well, and the South Atlantic region includes substantial shares of nuclear. The Pacific Contiguous and New England regions are predominately natural gas, with significant contributions of hydroelectric and nuclear, respectively. The Middle Atlantic is the only region that is predominately nuclear, and the Pacific Noncontiguous region is the only region in which fuel oil represents more than a few percentage points of total generation, where it constitutes nearly half of all generation.

Figure A-3. Wind and Solar Energy Resource Maps for the United States[13, 14]





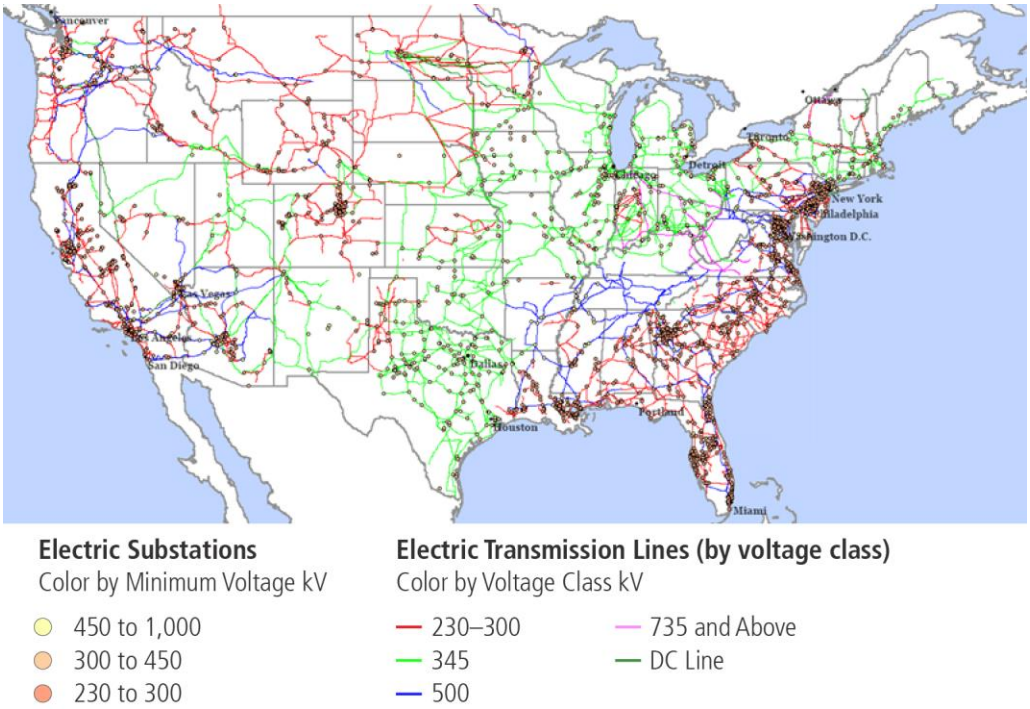
Energy resource availability varies widely across the United States. Wind and solar energy resources are concentrated in the Midwest and Southwest regions of the United States.

A.1.2 Transmission

The U.S. transmission network includes the power lines that link electric power generators to each other and to local electric companies. The transmission network in the 48 contiguous states is composed of approximately 697,000 circuit-miles[b] of power lines and 21,500 substations operating at voltages of 100 kilovolts (kV)[c] and above.[15] Of this, 240,000 circuit-miles are considered high voltage, operating at or above 230 kV (Figure A-4**Error! Reference source not found.**).[16] A substation is a critical node within the electric power system and is composed of transformers, circuit breakers, and other control equipment. Distribution substations are located at the intersection of the bulk electric system and local distribution systems.

The vast majority of transmission lines operate with alternating current (AC). With commonly used technology, system operators cannot specifically control the flow of electricity over the AC grid; electricity flows from generation to demand through many paths simultaneously, following the path of least electrical resistance. A limited number of transmission lines are operated using direct current (DC). Unlike AC transmission lines, the power flows on DC lines are controllable. However, their physical characteristics make them cost effective only for special purposes, such as moving large amounts of power over very long distances.[17]

Figure A-4. High-Voltage Transmission Network and Substations of the 48 Contiguous States, 2015[18]



The transmission network comprises approximately 697,000 circuit-miles—of which roughly 240,000 miles operate at or above 230 kV—and 21,500 substations operating at voltages of 100 kV and above. [19, 20, 21]

[b] A circuit-mile is 1 mile of one circuit of transmission line. Two individual 20-mile lines would be equivalent to 40 circuit-miles. One 20-mile double-circuit section would also be equivalent to 40 circuit-miles.

[c] A kilovolt (kV) is a commonly used unit of electrical "force" in the electricity industry. Electricity at higher voltages moves with less loss; however, system components able to manage high voltage are costly, and high voltages can be dangerous. Lower voltage is used in distribution systems to manage costs on system equipment and for safety.

Electricity moved through transmission and distribution systems faces electrical resistance and other conversion losses. Losses from resistance and conversion amount to 5 to 6 percent of the total electricity that enters the system at the power plant.[22]

Each transmission line has a physical limit to the amount of power that can be moved at any time, which depends on the conditions of the power system. Within one market or utility control area, physical limits of system assets are the primary drivers of power price differences in different parts of the system.

A.1.3 Distribution System

The role of the large generators and transmission lines that comprise the bulk electric system is to reliably provide sufficient power to distribution substations. In turn, the distribution system is responsible for delivering power when and where customers need it while meeting minimum standards for reliability and power quality.[23] Power quality refers to the absence of perturbations in the voltage and flow of electricity that could damage end-use equipment or reduce the quality of end-use services.[24]

Before delivery to a customer, electric power travels over the high-voltage transmission network (at hundreds of kilovolts) to a distribution substation where a transformer reduces the voltage before the electricity moves along the distribution system (at tens of kilovolts). Several primary distribution feeder circuits, connected by an array of switches at the distribution bus, emanate from the substation and pass through one or more additional transformers before reaching the secondary circuit that ultimately serves the customer. One or more additional transformers reduce the voltage further to an appropriate level before arriving at the end-use customer's meter.[d, 25]

An emerging role of the distribution system is to host a wide array of distributed energy generation, storage, and demand-management technologies. Though some distributed energy technologies—like campus-sized combined heat and power—have existed for decades, rapid cost declines in solar, energy storage, and power electronic technologies, coupled with supportive policies, have led to a rapid proliferation of new devices and, at times, new challenges and opportunities for the planning and operation of distribution systems.

A.1.4 Distributed Energy Resources (DERs)

DERs constitute a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid. Though definitions of DERs vary widely, the term is used in the Quadrennial Energy Review (QER) to refer to technologies including distributed generation, distributed storage, and demand-side management resources, including energy efficiency. Given the multiple definitions and understandings of the term DER, the QER will use DER to refer to the full range of these technologies and will delineate specific technologies where only some are relevant. Current and projected market penetration of distributed generation is shown in Table A-1.

DER technologies can be located on a utility's distribution system or at the premises of an end-use customer. They differ with respect to several attributes, though a key differentiator is their level of controllability from a grid management perspective. Certain DERs, such as energy efficiency or rooftop solar photovoltaic, impact total load but may not be directly controlled by grid operators. Other DERs, such as demand response or controllable distributed energy storage, can be more directly managed and called upon by grid operators when needed.

[d] Most residential and commercial customers in the United States receive two 120-volt (V) connections. Most household plugs provide 120 V, while large appliances like dryers and ovens often combine the two 120-V connections into a single 240-V supply.

Table A-1. Current and Projected Distributed Generation Market Penetration, 2015 and 2040[26]

Resource	Total Generation (GWh)		% of Total Utility Generation	
	2015	2040	2015	2040
Combined Heat and Power (CHP)	166,946	246,896	4.2%	5.2%
Rooftop Solar PV	13,453	64,485	0.3%	1.4%
Distributed Wind	637	1,643	0.0%	0.0%
Other DG	4,298	4,298	0.1%	0.1%
Total Distributed Generation	185,334	317,323	4.7%	6.7%
Total Utility-Scale Generation	**3,947,520**	**4,745,441**		

Other distributed generation includes small-scale hydropower; biomass combustion or co-firing in combustion systems; solid waste incineration or waste-to-energy; and fuel cells fired by natural gas, biogas, or biomass. Backup generators (for emergency power) are not included here because generation data are limited, and these generators are not used in normal grid operation. Acronyms: distributed generation (DG); gigawatt-hours (GWh); photovoltaic (PV).

A.1.5 End Use

Electricity end-use infrastructure includes physical components that use, require, or convert electricity to provide products or services to consumers. Since the first time the electric light bulb lit up New York City, nearly all parts of the United States have gained access to electricity.[e] In that time, the proliferation of novel and unanticipated uses of electricity has placed electricity at the center of everyday life and established it as the engine for the modern economy.

Today, the residential and commercial sectors each consume about the same share of total electricity—38 percent and 36 percent, respectively—with the industrial sector accounting for an additional 26 percent of electricity demand.[27, 28] Cumulatively, electricity sales to end-use customers in the United States generated approximately $393 billion in 2014.[29, 30] Moving forward, new technologies, from automated thermostats to electric vehicles, are changing the way consumers use electricity.

Electricity is a high-quality energy source available at a relatively low price. However, many low-income Americans struggle to afford their monthly electricity bills.[31] Nationally, average monthly residential bills in 2015 were $114.[32]

A.2. Brief History of the U.S. Electricity Industry

The U.S. electricity system represents one of the greatest technological achievements in the modern era. The complexity of the modern electricity industry is the result of a complicated history.

A.2.1 The Beginning of the Electricity Industry

The U.S. electricity industry began in 1882 when Thomas Edison developed the first electricity distribution system. Edison designed Pearl Street Station to produce and distribute electricity to multiple customers in the New York Financial District and to sell lighting services provided by his newly invented light bulbs.[33]

[e] There are thousands of households in Indian lands that still do not have access to electricity.

Early utilities distributed power over low-voltage DC lines. These lines could not move electricity far from where it was produced, which limited utility service to areas only about a mile from the generator. Multiple generators and dedicated distribution lines were required to serve a larger area. The limited reach of distribution lines and the lack of regulation of utilities resulted in the co-location of multiple independent utilities and competition for customers where multiple distribution lines overlapped.[34, 35]

In 1896, AC generation emerged as a competitor to DC when Westinghouse Electric developed a hydropower generation station at Niagara Falls, New York, and transmitted power 20 miles to Buffalo, New York.[36] At the voltage levels used at that time, AC has better electrical characteristics for moving power over long distances. This technological development—and related business models—allowed a single utility to broaden the geographic extent of its customers and sources of revenue. A wave of consolidation followed, where small, isolated DC systems were converted to AC and interconnected with larger systems. Interconnecting with other systems and serving more customers allowed operators to take advantage of the diversity of customer demand, deliver better economies of scale, and provide lower prices than competitors.[37]

A move toward today's system of regulatory oversight occurred around the turn of the century. With the industry consolidation of the late 1890s came public concern over lack of competition and the potential for large utilities to exert a monopoly power over prices.[38] In 1898, a prominent electricity industry leader and Thomas Edison's former chief financial strategist, Samuel Insull, called for utility regulation that granted exclusive franchises in exchange for regulated rates and profits in order to create a stable financial environment that would foster increased investments and electricity access.[39] Insull claimed that such regulation was needed because utilities are natural monopolies, meaning that a single firm can deliver a service at a lower total cost than multiple firms through economies of scale and avoidance of wasteful duplication (e.g., multiple distribution substations and circuits belonging to different companies serving a single area).

In 1907, Wisconsin became the first state to regulate electric utilities, and by 1914, 43 states had followed.[40, 41] The general form of utility regulation that was established by the Wisconsin legislature in 1907 endures today and is called the "state regulatory compact."

This compact allowed electric utilities to operate as distribution monopolies with the sole right to provide retail service to all customers within a given franchise area—as well as an obligation to do so. Those monopolies were allowed an opportunity to earn a fair rate of return on their investments. Some municipal governments across the country created their own utilities, owned and governed by the local government, as an alternative to investor-owned, regulated utilities.[42, f]

[f] Since municipal utilities were first formed, they have been owned by several types of political subdivisions. These include states, public utility districts, and irrigation districts. The term "public power" is often used to refer to electricity utilities operated by any of these political subdivisions.

The State Regulatory Compact

The "state regulatory compact" evolved as a concept "to characterize the set of mutual rights, obligations, and benefits that exist between the utility and society."[43] It is not a binding agreement. Under this "compact," a utility typically is given exclusive access to a designated—or franchised—service territory and is allowed to recover its prudent costs (as determined by the regulator) plus a reasonable rate of return on its investments. In return, the utility must fulfill its service obligation of providing universal access within its territory. The "regulatory compact" applies to for-profit, monopoly investor-owned utilities that are regulated by the government. The compact is less relevant to public power and cooperative utilities, which are nonprofit entities governed by a locally elected or appointed governing body and are assumed to inherently have their customers' best interests in mind. Regulators strive to set rates such that the utility has the opportunity to be fully compensated for fulfilling its service obligation. While not technically part of the "compact," customers also have a role to play in this arrangement: they give up their freedom of choice over service providers and agree to pay a rate that, at times, may be higher than the market rate in exchange for government protection from monopoly pricing. In effect, utilities have the opportunity to recover their costs, and, if successful, their investors are provided a level of earnings; customers are provided non-discriminatory, affordable service; and the regulator ensures that rates are adequately set such that the aforementioned benefits materialize.

In the early 1900s, states regulated nearly all of the activities of electric utilities—generation, transmission, and distribution.[44] However, a 1927 Supreme Court case[45] held that state regulation of wholesale power sales by a utility in one state to a utility in a neighboring state was precluded by the commerce clause of the U.S. Constitution.[46] These transactions were left unregulated as Congress had the authority to regulate, but no Federal agency existed to do so.[47]

The 1935 Federal Power Act (FPA) addressed the regulatory gap by providing the Federal Power Commission (FPC, eventually renamed the Federal Energy Regulatory Commission, or FERC)[g] with authority to regulate "the transmission of electric energy in interstate commerce" and "the sale of electric energy at wholesale in interstate commerce."[48, 49] The FPA left regulation of generation, distribution, and intrastate commerce to states and localities.[50] Federal regulation was to extend "only to those matters which are not subject to regulation by the States."[51] FERC was given jurisdiction over all facilities used for the transmission or wholesale trade of electricity in interstate commerce and was charged with ensuring that corresponding rates are "just and reasonable, and not unduly discriminatory or preferential."[52, 53]

A.2.2 Federal Investments in Rural Electrification

Urban areas were the first areas to attract utility investment. The higher density of potential customers in urban areas made these areas more cost effective to serve. By the 1930s, most urban areas were electrified, while sparsely populated rural areas generally lagged far behind. The Great Depression and widespread floods and drought in the Great Plains during the 1930s led to a wave of significant Federal initiatives to develop the power potential of the Nation's water resources.

One example of Federal efforts to capture the benefits of the Nation's water resources is the Tennessee Valley Authority (TVA). TVA was created in 1933 as a Federally owned corporation to provide economic development through provision of electricity, flood control, and other programs to the rural Tennessee Valley area. To this day, TVA maintains a portfolio of generation and transmission assets to sell wholesale electricity to public power and cooperatives within its territory. Federal law grants first preference for this electricity to public power and cooperative utilities.

Congress passed the Rural Electrification Act in 1936, which encouraged electrification of areas unserved by investor-owned utilities (IOUs) and public power utilities. The act authorized rural electric cooperatives

[g] The Federal Power Commission was created in 1920 by the Federal Water Power Act to encourage the development of hydroelectric generation facilities.

to receive Federal financing support and preferential sales from Federally owned generation. The Bonneville Power Administration was created in 1937 to deliver and sell electric power from Federally owned dams in the Pacific Northwest.[54] Increased Federal investment in hydropower followed through the 1940s, and by the 1960s, rural electrification was largely complete.[55]

Federally Owned Utilities

There are five Federal electric utilities: Tennessee Valley Authority (TVA), Bonneville Power Administration (BPA), Southeastern Power Administration (SEPA), Southwestern Power Administration (SWPA), and Western Area Power Administration (WAPA). TVA is an independent government corporation, while BPA, SEPA, SWPA, and WAPA are separate and distinct entities within the Department of Energy. Starting with BPA in 1937, followed by SEPA, SWPA, and WAPA, Congress established the Power Marketing Administrations (PMAs) to distribute and sell electricity from a network of more than 130 Federally built hydroelectric dams.

The PMAs don't own or manage the power they sell but, in many cases, maintain the transmission infrastructure to distribute the low-cost electricity to public power and rural cooperative utilities, in addition to some direct sales to large industrial customers. The electricity-generating facilities are primarily owned and operated by the Department of the Interior's Bureau of Reclamation, the Army Corps of Engineers, and the International Boundary and Water Commission.

BPA, WAPA, and SWPA collectively own and operate 33,700 miles of transmission lines, which are integrally linked with the transmission and distribution systems of utilities in 20 states. Millions of consumers get electricity from the PMAs (usually indirectly, via their local utility), but a much larger number of consumers benefit from—and have a stake in—the continued efficient, effective operation of the PMAs and the transmission infrastructure they are building and maintaining.

TVA is a corporate agency of the United States that provides electricity for business customers and local power distributors, serving 9 million people in parts of seven southeastern states. TVA receives no taxpayer funding, deriving virtually all of its revenues from sales of electricity. In addition to operating and investing its revenues in its electric system, TVA provides flood control, navigation, and land management for the Tennessee River system and assists local power companies and state and local governments with economic development and job creation.

A.2.3 Electricity Industry Restructuring and Markets

As early as the 1920s, utilities sought operational efficiencies by coordinating generation dispatch and transmission planning across multiple utility territories. Coordination through cooperative power pools provided economies of scale and scope that ultimately lowered costs for all participant utilities. The principles of coordination pioneered in power pools later became the basis for the centrally organized electricity markets that exist today.[56]

Over time, economists and industry observers came to believe that the natural monopoly status that was the basis of so much of electricity industry regulation no longer applied to generation and instead only applied to the "wires" part of the system. While it would be economically wasteful for multiple companies to install overlapping and competing distribution and transmission lines, the generation and sale of electricity to retail customers could be organized as competitive activities.[57] To encourage fair and open competition, several states eventually restructured individual IOUs into separate companies that invested in either regulated or competitive parts of the industry.

Restructuring actions vary by region and by state, but they are typically characterized by the "unbundling" of ownership and regulation of electricity generation, transmission, distribution, and sales, with large variations in how restructuring is implemented across regions and states.

Congress took an early step toward reintroducing market competition in the generation sector in 1978 when it enacted the Public Utilities Regulatory Policies Act (PURPA).[58] PURPA required utilities to purchase

power from qualifying non-utility generators at the utility's avoided cost. This led to a wave of investment in generation by non-utility companies.

A major step toward creating electric markets was Congress' enactment of the Energy Policy Act of 1992 (EPAct 1992), which provided FERC with limited authority to order transmission access for wholesale buyers in procuring wholesale electric supplies.[59, 60, 61] Subsequent FERC actions, including Order No. 888 and Order No. 889, created greater transmission access and facilitated the creation of competitive wholesale electricity markets. These FERC orders increased access to electricity supplies from other utilities for wholesale buyers, including public power and rural cooperative utilities.

Also in the 1990s, several states made regulatory changes introducing retail electric choice programs to allow some customers to choose an electricity provider other than their local utility, and to have electricity delivered over the wires of their local utility.[62] States that allow customer choice are sometimes called "deregulated states," a misnomer, as retail electricity providers and other parts of the industry remain highly regulated. By 1996, at least 41 states, including California, New York, and Texas, had or were considering ending utility monopolies and providing electricity service through retail competition.[63] Some states, notably in the Southeast and in western states besides California, did not embrace this wave of restructuring. In 2000 and 2001, California and the Pacific Northwest experienced severe electricity shortages and price spikes. This California electricity crisis left many states that had not yet implemented restructuring wary of pursuing such reforms. Today, 15 states allow retail electric choice for some or all customers, while eight states have suspended it, including California, which suspended retail choice for residential customers after the energy crisis.[64]

The net result of these changes to jurisdictions, industry structure, and competitive markets is that the United States today has a patchwork of mechanisms governing the electricity industry and a diverse set of industry participants. Regulation of the industry continues to evolve as new technologies, policies, and business realities emerge.

A.3. Laws and Jurisdictions

Government oversight and regulation of the electricity industry centers on the concurrent needs to

- Ensure that safe and adequate electricity service is provided at just and reasonable rates
- Protect the public interest
- Enable the financial health of the system, such as ensuring that service providers can attract the investments needed to continue providing this essential public service
- Play a beneficial role in diminishing the impact of negative externalities, such as ensuring that industry activities are not inadvertently causing hardship to neighboring communities or the environment.

A.3.1 Governmental Actors

The responsibility for regulating and overseeing the numerous actors that encompass the electricity industry and the activities they carry out is vested in multiple government officials. These authorities span Federal, state, local, and tribal governments. The jurisdictional relationship between the actors is shown in Figure A-5 and is explained further below.

Figure A-5. Broad Overview of Jurisdictional Roles in the Electricity Industry[65]



Jurisdictional responsibility of the electricity industry is divided between Federal, state, local, and tribal jurisdictions. Several issues, such as generation siting, transmission siting, and environmental planning, span all of the four jurisdictions. Federal and state jurisdictions overlap in planning, resource adequacy, and mergers and acquisitions for regulated utilities. Other areas, such as interstate transmission commerce and retail sale to end users, are regulated by the Federal Government (FERC) or the states (public utility

commissions), respectively. Acronyms: Department of Agriculture (USDA); Department of Energy (DOE); Department of the Interior (DOI); Department of Justice (DOJ); Environmental Protection Agency (EPA); Federal Trade Commission (FTC); independent system operator (ISO); North American Electric Reliability Corporation (NERC); Nuclear Regulatory Commission (NRC); Occupational Safety and Health Administration (OSHA); public utility commission (PUC); regional transmission organization (RTO); Securities and Exchange Commission (SEC).

A.3.2 Federal Actors

At the Federal level, FERC carries out the vast majority of the economic Federal regulatory responsibilities pertaining to the electricity industry, primarily regulating transmission and wholesale sales in interstate commerce. In addition, other Federal authorities are involved with various aspects of regulation or oversight; their responsibilities are wide ranging and relate to environmental protection, land use, anti-trust protection, and transmission siting.

Federal Ratemaking

The Federal Energy Regulatory Commission (FERC) is the Federal Government agency responsible for overseeing rates for wholesale sales of electricity and transmission in interstate commerce. Sections 205 and 206 of the Federal Power Act (FPA) require FERC to assure that the rates charged for transmission and wholesale sales are "just and reasonable" and do not unduly discriminate against any customers or provide preferential treatment. Initially, all FERC rate regulation was based on the cost of service, but that policy has evolved. FERC continues to employ the cost-of-service approach for transmission service. For wholesale power sales, the primary means for setting "just and reasonable" wholesale electricity rates are through competitive mechanisms, subject to market rules to address market power.

A.3.3 State, Local, and Tribal Actors

At the state level, the electricity industry is regulated by state public utility commissions (PUCs), state environmental agencies, and other parts of state government, such as governors, legislatures, and state energy offices.

State governors and legislatures establish laws or standards that impact the electricity industry, such as Renewable Portfolio Standards, and state environmental agencies implement state and some Federal environmental laws and regulations and thus have jurisdiction on electricity.

PUCs in the states, territories, and the District of Columbia regulate IOUs. State laws in a handful of states also give PUCs jurisdiction over public power and cooperatives.[66] PUCs regulate all matters of IOU distribution (rates, capital expenditures, cyber security, reliability, demand-side resources, and the wholesale purchase process) and usually site transmission and generation projects; they also oversee generation choices in non–regional transmission organization (RTO)/independent system operator (ISO) states and oversee retail competition in those states that allow it.

State Retail Rate Setting

State public utility commissions (PUCs) review and set retail rates for investor-owned utilities (IOUs). In states with retail competition, rates only include the costs of the distribution of electricity, while prices for electricity generation are determined competitively. In states that have not restructured their utility industry, retail rates set by PUCs include the recovery of generation, transmission, and distribution costs that utilities incurred to serve their ratepayers.

The underlying mandate of the PUC rate-setting process is to provide affordable and reliable electricity to consumers while ensuring that IOUs are given the opportunity to recoup their costs and earn a reasonable return on their investment. Under cost-of-service regulation, PUCs calculate utility revenue requirements as the sum of (1) rate base times allowed rate of return plus (2) utility operating expenses. The rate base consists of the depreciated cost of a utility's assets. Based on the revenue requirement, rates for each consumer class are determined.[h]

A few states also grant PUCs the authority to regulate rates for public power utilities, but in most cases rates for public power utilities are set by the utility's governing body, for example, a city council or other local authority. Rates for members of rural cooperatives are set by the cooperative's governing board.[67]

A.3.4 Federal and State Jurisdictional Responsibilities

The current jurisdictional division of regulatory authority in the electricity sector between the Federal Government and the states, codified in the FPA and interpreted by subsequent Supreme Court and lower court decisions, is the result of the evolution of a regulatory scheme that was originally governed predominantly by state and local agencies. The FPA established an affirmative grant of authority to the Federal Government to regulate wholesale sales and transmissions of electricity in interstate commerce, but the FPA also attempts to draw a "bright line" where that exclusive authority ends and the state's authority to regulate other matters (principally facilities used in the generation and distribution of electric power, as well as retail sales of electricity) begins.

The "bright line" in the FPA uses factors such as transaction and customer type (wholesale v. retail), facility type (generation v. transmission v. distribution), geography (interstate commerce v. intrastate commerce), and regulatory action (e.g., rate regulation v. facility permitting) to divide exclusive regulatory responsibilities between Federal and state regulators. Congress has chosen different approaches for defining Federal regulatory responsibilities and the role of the states in other energy and energy-related statutes, however. The principal differences in approach include the following: (1) while the FPA contemplates exclusive authority for each regulator, with implicit opportunities for cooperative federalism, other Federal statutes explicitly provide for shared authority (sometimes called "cooperative federalism"); and (2) while the FPA provides the Federal Government with limited authority over energy facility siting or generation facilities in general (FERC has jurisdiction over siting hydro), leaving such matters mostly to the states, other Federal statutes, such as the Natural Gas Act, provide for Federal authority over facility siting.[68]

However, new and emerging technologies that are gaining an increasing presence throughout the electricity system today have significantly different operational characteristics and attributes than those that existed when the FPA and its jurisdictional "bright line" were written, and different characteristics than those that existed as that jurisdictional line developed over the ensuing decades. For distributed generation, no clear delineation exists between wholesale and retail jurisdiction as power flows from generation through delivery to ultimate consumption. Instead, new DERs (including energy storage) can be interconnected to either the FERC-jurisdictional, high-voltage transmission grid or the state-

[h] A more detailed discussion on different charges for consumers is included in Chapter II (The Electricity Sector: Maximizing Economic Value and Consumer Equity).

jurisdictional, low-voltage local distribution system (or behind the customer's meter). In addition, these resources, along with the other new and advanced technologies noted above, can provide (or enable demand response that can provide) several kinds of wholesale and retail grid services, with benefits that extend across the traditional generation, transmission, and distribution classifications.

Tensions between Federal and state regulatory jurisdiction over the electricity system have played out in the courts recently. From the October Term of 2014 to the October Term of 2015, the Supreme Court heard three cases involving FERC jurisdictional issues, an atypical number for a single year. The Court's decisions to hear these cases reflect, in part, the growing complexity of regulating the electricity industry, but also point to uncertainty about statutes that regulate services that are increasingly converging with the electricity industry, like natural gas and telecommunications. Two of these cases, the recent *FERC v. Electric Power Supply Association*[69] and *Hughes v. Talen Energy Marketing*[70] decisions, provide examples of the courts applying the FPA's jurisdictional division to new sets of technology and market challenges. In both of those cases, the Court decided generally in favor of the broader view of the Federal role. *FERC v. Electric Power Supply Association*—relating to FERC's Order No. 745—confirmed FERC's authority under the FPA to determine compensation for demand response that is bid into the organized wholesale market.

A.3.5 Major Federal Laws Pertaining to the Electricity Industry

While the FPA is the enabling legislation providing the FPC (and now FERC) its authority over portions of the electricity industry, additional laws and rules have further defined the legal landscape governing the electricity system. Overall, these laws and regulations can be broken into two separate categories: electricity industry–related and environmental.

The Federal Water Power Act, enacted in 1920, created the FPC (now FERC) to encourage the development of hydroelectric generation facilities by non-Federal entities. The 1935 FPA expanded the Commission's regulatory jurisdiction to include rates, terms, and conditions of service for interstate electricity transmission and wholesale electricity sales, but left regulation of generation, distribution, and intrastate commerce to state and local governments.[71] This set up the "bright line"[i] between Federal authority over wholesale rates and state and local authority over retail rates.

The utility industry of the early 1900s often relied on holding companies—a financial structure where a parent company would hold the financial stocks and bonds of subsidiary utilities—to improve financial performance and seek economies of scale. Though these companies provided cost savings that contributed to the growth of the utility industry, their complex financial structures enabled companies to subsidize their unregulated business activities with earnings from regulated activities. In response, Congress passed the Public Utility Holding Company Act in 1935, which reduced the role of holding companies in the industry and allowed closer regulatory scrutiny of utilities.[72]

PURPA (1978), passed as part of the National Energy Act, was one of the major reformations of the governance of the electricity industry. Utilities were required to purchase power from qualifying facilities at the utilities' incremental cost of producing or purchasing alternative electricity, which is now known as "avoided cost."[73] The right to sell the power at avoided cost, combined with the exemption from several state and Federal regulations, "created a new and rapidly expanding nonutility generation sector of the electric power industry."[74] Qualifying facilities fall into two categories: (1) cogeneration facilities without any size limitations and (2) small power production facilities, which use biomass, waste, or renewable resources and which have a generating capacity of no more than 80 megawatts. PURPA also required states (and utilities not regulated by states, such as public power and rural cooperative utilities) to conduct proceedings to consider charging cost-of-service rates for different customer classes; eliminating declining

[i] The term "bright line" was coined by the Supreme Court in *Federal Power Commission v. Southern California Edison Co*. in 1964.

block pricing;[j] using time-of-day, seasonal, or interruptible rates; and implementing other retail utility policies.

The Energy Policy Act of 1992 (EPAct 1992) implements many of the provisions of the National Energy Strategy proposed by DOE in February 1991.[75] EPAct 1992 authorized FERC to order transmission-owning utilities to provide transmission services to third parties on a case-by-case basis and adopted reforms to the Public Utility Holding Company Act of 1935, both of which supported increased competition in wholesale electricity markets. EPAct 1992 also included a wide variety of energy efficiency measures, such as requiring states to establish minimum commercial building energy codes and consider voluntary minimum residential codes and equipment standards for commercial heating and air-conditioning equipment, electric motors, and lamps. As a result of the incentives offered through EPAct 1992, several Native Nations developed alternative energy projects on their lands. The Renewable Electricity Production Tax Credit for wind, biomass, landfill gas, and other renewable sources was also first passed in EPAct 1992, and has been renewed several times since then.[76] As of May 2016, the Production Tax Credit provided an inflation-adjusted tax credit worth $0.023/kWh to qualifying electricity production from wind, closed-loop biomass, and geothermal, as well as a $0.012/kWh credit for open-loop biomass, landfill gas, municipal solid waste, qualified hydro, and marine and hydrokinetic.[77]

The Energy Policy Act of 2005 (EPAct 2005) addressed several major areas of the electricity industry.[78] EPAct 2005 pared back the must-purchase clause contained in PURPA by giving FERC the authority to allow utilities in regions with competition not to use the avoided-cost principle. The legislation also gave FERC responsibility for mandatory reliability standards and allowed the agency to certify an electric reliability organization to develop and enforce those standards. The North American Electric Reliability Corporation (NERC) is the designated electric reliability organization for North America and oversees eight regional reliability entities in the United States, Canada, and Baja California (Mexico). NERC is a not-for-profit corporation that, through a stakeholder process, develops and enforces mandatory electric reliability standards under FERC oversight in the United States.

EPAct 2005 also tasked DOE with issuing periodic studies of transmission congestion, and following the appropriate evaluation of transmission congestion and alternatives, authorizes DOE to designate National Interest Electric Transmission Corridors where there are electricity transmission capacity constraints or congestion. For projects located in these corridors, FERC has "backstop authority" to authorize transmission siting.[79] FERC was also given responsibility to provide rate incentives to promote transmission investment.

EPAct 2005 also increased the Investment Tax Credit, which has been renewed several times, including in the Omnibus Appropriations Act of 2015.[80] Currently, the Investment Tax Credit is 30 percent for solar, fuel cells, and small wind and 10 percent for geothermal, microturbines, and combined heat and power.[81] Additionally, EPAct 2005 provided grants for nuclear energy research and development and also implemented a $0.018/kWh production credit for modern nuclear energy plants (1) whose design was approved by the Nuclear Regulatory Commission after December 1, 1993, (2) that started construction by January 2014, and (3) that are placed in commercial operation by 2021. EPAct 2005 also created the Title XVII Loan Program, which allows DOE to provide "guarantee loans that support early commercial use of advanced technologies, if there is reasonable prospect of repayment by the borrower."[82]

Other key laws and orders in the electricity industry are included in Table A-2, and key electricity industry-related environmental laws and regulations are included in Table A-3.

[j] Effectively a bulk-purchase discount for large electricity consumers, making marginal increments of electricity cheaper as consumption rises.

Table A-2. Additional Key Electricity Industry Laws and Orders

Name	Year	Major Provisions
Atomic Energy Act	1954	• Established Federal regulatory authority over civilian uses of nuclear materials and facilities exercised through the Nuclear Regulatory Commission. • Delineated Federal/state jurisdiction for nuclear material and facilities: licensing of nuclear plant construction and operation as well as waste disposal are exclusively in the Federal domain. States retain oversight of generation planning by vertically integrated utilities (e.g., questions of whether or not to construct nuclear facilities in the first place).
Price-Anderson Act	1957	• Facilitated the development of nuclear-powered generating capacity by establishing a program for covering claims of members of the public if a major accident occurred at a nuclear power plant and providing a ceiling on the total amount of liability for nuclear accidents.
National Energy Act	1978	• Passed in response to oil shortages in the 1970s and the increased reliance on imported oil, which was seen as a threat to national security.[83] • Included the Natural Gas Policy Act of 1978, Public Utilities Regulatory Policies Act, the Energy Tax Act, the Powerplant and Industrial Fuel Use Act, and the National Energy Conservation Policy Act.[84]
Energy Independence and Security Act	2007	• Strengthened lighting energy-efficiency standards. • Added Section 1705 to the loan guarantee program, allowing subsidized loans to commercial facilities. • Called for coordination to develop a framework for smart grid interoperability standards (National Institute of Standards and Technology).
American Recovery and Reinvestment Act	2009	• Funded $31 billion in energy efficiency, renewable energy, and energy infrastructure and made other major investments in energy research and development programs administered by the Department of Energy.[85]
FERC Order 1000	2011	• Requires regional transmission planning and interregional coordination; mandates that the planning process consider transmission needs driven by public policy requirements. • Requires regional and interregional cost allocation methods that satisfy six allocation principles. • Eliminated the Federal right of first refusal in Federal Energy Regulatory Commission (FERC) jurisdictional tariffs and agreements.[86]

In addition to the FPA, the Federal Water Power Act, the Public Utility Holding Company Act of 1935, PURPA, EPAct 1992, and EPAct 2005, which are discussed in the above section, these laws and orders have played key roles in shaping the electricity industry.

Table A-3. Key Electricity Industry-Related Environmental Laws and Regulations

Name	Year	Major Provisions
Clean Air Act	1970	• Authorized comprehensive Federal and state regulation of stationary pollution sources, including power plants.[87] • Provided for National Ambient Air Quality Standards, State Implementation Plans, New Source Performance Standards, and National Emission Standards for Hazardous Air Pollutants.[88] • Requires states to decide what pollution reductions will be required from particular sources to address National Ambient Air Quality Standards, and requires states to submit State Implementation Plans.[89]
National Environmental Policy Act	1970	• Requires Federal agencies to review the environmental consequences of a proposed project before granting approval.[90] Agencies prepare statements on the environmental impact of a proposed project (Environmental Impact Statement or Environmental Assessment), considering the views of the public and of other Federal, state, and local agencies, and make the report publicly available.[91]
Clean Water Act	1972	• Established regulations for discharging pollutants into water,[92] which includes wastewater discharges from the power sector (such as cooling water, wastewater from coal ash handling, and wastewater from pollution control equipment). • The Steam Electric Effluent Limitations Guidelines—promulgated under the Clean Water Act—were updated in 2015.
Resource Conservation and Recovery Act	1976	• Provides EPA with the authority to regulate hazardous waste,[93] including management of power sector waste, such as coal ash. • The Coal Combustion Residuals rule—promulgated under the Resource Conservation and Recovery Act—was finalized in 2015.
New Source Performance Standards	1979	• EPA rule governing sulfur dioxide emissions from coal power plants.[94] • Effectively required flue gas desulfurization on all new coal plants.
Clean Air Act Amendments	1990	• Encouraged market-based principles to pollution control, such as emissions trading.[95] • Requires EPA to regulate more than 180 specified hazardous air pollutants[96] and set up specific procedures to determine whether the air pollution regulations would apply to power plants that run on fossil fuels.[97] • Established the U.S. Acid Rain Program, the world's first large-scale emissions cap-and-trade system to reduce air pollution. The program set a permanent cap on annual sulfur dioxide emissions from the power sector.
Cross-State Air Pollution Rule	2011	• Replaced the Clean Air Interstate Rule starting on January 1, 2015 • Requires states to reduce power plant emissions that contribute to ozone and fine particle pollution in downwind states.[98]
Mercury and Air Toxics Standard	2011	• EPA rule limiting mercury and other toxic pollution from power plants.[99]
Carbon Pollution Standards and Clean Power Plan	2015	• In 2015, EPA finalized the Carbon Pollution Standards rule establishing carbon dioxide emission standards for new fossil fuel-fired generators under Clean Air Act section 111(b). • Also in 2015, EPA finalized the Clean Power Plan, a rule to reduce carbon dioxide emissions from existing fossil fuel-fired generators under Clean Air Act section 111(d).[100] The rule establishes final emission

Name	Year	Major Provisions
		guidelines for states to follow in developing plans to reduce greenhouse gas emissions from existing fossil fuel–fired electric generating units, leaving states with considerable discretion to choose the approach.[101] • As of January 2016, implementation of the Clean Power Plan has been stayed by the Supreme Court pending the outcome of litigation.[102] • EPA regulation of greenhouse gas emissions followed from the 2007 Supreme Court decision in Massachusetts v. EPA that greenhouse gases are air pollutants under the Clean Air Act, and the 2009 EPA finding that the current and projected concentrations of six key greenhouse gases in the atmosphere endanger the public health and welfare, a prerequisite for implementing greenhouse gas emissions standards.[103]

Beginning with the Clean Air Act in 1970, major environmental laws and regulations have impacted the electric industry in key ways.

A.4. Federal Authorities, Policies, and Frameworks for Electric Grid Resilience and Security

The Federal Government plays a key role in enhancing the resilience and security of the grid through diverse efforts, including research and development, information sharing, the establishment and enforcement of utility performance standards, and the coordination of response resources. Presidential policy directives and congressional legislation have outlined specific authorities for the Federal Government in recognition of the importance of the electricity sector—and supporting energy sectors—for national and economic security. This section describes select Federal policies and frameworks guiding national resilience and security efforts, as well as selected challenges in fulfilling Federal roles to protect critical electricity infrastructure.

Selected Authorities for the Energy Sector

Defense Production Act: Ensures timely availability of resources for national defense and civil emergency preparedness and response, including energy-related assets. (1950)

Energy Policy and Conservation Act: Directs the Secretary of Energy to establish, operate, and maintain the Strategic Petroleum Reserve (1975), which includes the Northeast Gasoline Supply Reserve, and provides for the Presidentially-directed drawdown of those reserves. Also authorizes the Secretary to establish and manage the Northeast Home Heating Oil Reserve. (2000 as amended)

Federal Energy Administration Act: Grants the Department of Energy (DOE) the authority to collect, evaluate, and analyze energy information from facilities or businesses operating in any phase of energy supply or major energy consumption. (1974)

Federal Power Act: Provides the Secretary of Energy authority in time of emergency to order temporary interconnections of facilities and the generation, delivery, interchange, or transmission of electric energy necessary to meet an emergency. (1935, 2015 as amended by FAST Act, as defined below) The Federal Power Act also gives FERC the authority to order compliance with reliability standards. (1935, 2005 as amended by EPAct) In addition, the **Fixing America's Surface Transportation Act (FAST) Act** amended the Federal Power Act empowering the President to declare a grid security emergency in the face of an electromagnetic pulse, cyber or geomagnetic disturbances, and physical threats and, in doing so, enabling the Secretary of Energy to (1) direct users and operators of electricity assets to undertake such actions as are necessary to ensure the reliability of critical electric infrastructure, and (2) share classified information as necessary to mitigate effects of the grid security emergency. It also allows the

Federal Energy Regulatory Commission to provide a mechanism for any affected entities to recover related costs. (2015)

Natural Gas Policy Act: Authorizes DOE to allocate supplies of natural gas to help alleviate an existing or imminent, Presidentially-declared, severe natural gas shortage that would endanger the supply of gas for high-priority uses. (1978)

Stafford Disaster Relief and Emergency Assistance Act: The Stafford Act[104] gives the Federal Government its authority to provide response and recovery assistance in a major disaster. (1988). The Stafford Act identifies and defines the types of occurrences and conditions under which disaster assistance may be provided. Under the law, the declaration process[k] remains a flexible tool for providing relief where it is needed. Designates the Federal Emergency Management Agency (FEMA) as the lead for Federal emergency response; FEMA may require other Federal agencies to provide resources and personnel to support emergency and disaster assistance efforts. DOE is the sector-specific agency for energy under this framework.

Executive Order 12656—Assignment of Emergency Preparedness Responsibilities: Assigns preparedness responsibilities to Federal agencies and requires agencies to be prepared to respond adequately to all national security emergencies, including developing emergency plans. (1988)

Homeland Security Presidential Directive 5 (HSPD-5): Establishes a single, comprehensive National Incident Management System under the purview of the Department of Homeland Security, under which all other Federal agencies provide their cooperation, resources, and support. The directive also provides direction for Federal assistance to state and local authorities. (2003)

Presidential Policy Directive 8 (PPD-8)—National Preparedness: Replaces prior national planning directives and takes an "all-of-Nation" approach to prepare for a wide range of threats and emergencies. National Planning Frameworks—coordinating structures of key Federal agencies and other stakeholders—have been established around five mission areas: prevention, protection, mitigation, response, and recovery. (2011)

Presidential Policy Directive 21 (PPD-21)—Critical Infrastructure Security and Resilience: Establishes shared responsibility for strengthening critical infrastructure security across the Federal Government. PPD-21 highlights the role of the national physical and cyber coordinating centers in enabling successful critical infrastructure security and resilience outcomes.[105] Designates critical infrastructure sectors and sector-specific agencies, notably DOE as the sector-specific agency for the energy sector. (2013)

A.4.1 Planning and Coordination Frameworks

Federal policy directives and legislation address the evolving threats and institutional vulnerabilities of the Nation's critical infrastructure by defining roles and responsibilities for national grid *resilience* and security. Homeland Security Presidential Directive (HSPD)-7, Presidential Policy Directive (PPD)-8, and PPD-21 laid the groundwork for the key coordinating bodies and a national approach to plan for events.

[k] "The Robert T. Stafford Disaster Relief and Emergency Assistance Act, 42 U.S.C. §§ 5121-5207 (the Stafford Act) §401 states in part that: 'All requests for a declaration by the President that a major disaster exists shall be made by the Governor of the affected State.' A State also includes the District of Columbia, Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. The Republic of Marshall Islands and the Federated States of Micronesia are also eligible to request a declaration and receive assistance through the Compacts of Free Association." See "The Disaster Declaration Process," Federal Emergency Management Agency, accessed September 23, 2016, https://www.fema.gov/disaster-declaration-process.

Joint United States–Canada Electric Grid Security and Resilience Strategy

In December 2016, the Federal Governments of the United States and Canada released the "Joint United States-Canada Electric Grid Security and Resilience Strategy," a collaborative effort between the two nations intended to strengthen the security and resilience of the U.S. and Canadian electric grids from all adversarial, technological, and natural hazards and threats. The Strategy addresses the vulnerabilities of the two countries' respective and shared electric grid infrastructure, not only as an energy security concern, but for reasons of national security. Because the electric grid is complex, vital to the functioning of modern society, and dependent on other infrastructure for its function, the United States and Canada developed the Strategy under the shared principle that security and resilience require increasingly collaborative efforts and shared approaches to risk management.

The Strategy organizes joint approaches to protect today's grid, manage contingencies by enhancing response and recovery capabilities, and cultivate a more secure and resilient future grid. As an expression of shared intent and approach, the Strategy organizes joint efforts to manage current and future security challenges. Three strategic goals underpin the effort to strengthen the security and resilience of the electric grid:

Protect Today's Electric Grid and Enhance Preparedness: A secure and resilient electric grid that protects system assets and critical functions and is able to withstand and recover rapidly from disruptions is a priority for the governments of both the United States and Canada.

Manage Contingencies and Enhance Response and Recovery Efforts: The Strategy sets out a shared approach for enhancing continuity and response capabilities, supporting mutual aid arrangements, such as cyber mutual assistance across a diverse set of stakeholders, understanding interdependencies, and expanding available tools for recovery and rebuilding.

Build a More Secure and Resilient Future Electric Grid: The United States and Canada are working to build a more secure and resilient electric grid that is responsive to a variety of threats, hazards, and vulnerabilities. To achieve this, the electric grid will need to be more flexible and agile, with an architecture into which new technologies may be readily incorporated.[106]

The Strategy will be implemented through the U.S. and Canadian Action Plans, which detail specific steps and milestones for achieving the Strategy's goals within their respective countries.[107] These documents are intended to guide future activity within areas of Federal jurisdiction, with full respect for the different jurisdictional authorities in both countries.

Under HSPD-7 and then PPD-21, the National Infrastructure Protection Plan set out a number of partnership structures for coordination and information sharing within and across sectors, including electricity. Some of the formal coordination and information-sharing councils available to the electricity subsector include the following:

- **Electricity Subsector Coordinating Council**: Represents the interests of the industry and is composed of electric utility industry executives. It is the principal mechanism for private-sector owners and operators to work collaboratively with the government under a structured and protected framework that allows open dialogue. There is a counterpart subsector coordinating council for the oil and natural gas subsector. Numerous task forces and subcommittees have worked on supply-chain concerns, interdependencies, and coordination with other sectors. The Electricity Subsector Coordinating Council is also a critical coordination mechanism for information sharing during and after incidents.
- **Energy Government Coordinating Council**: This government counterpart to the Electricity Subsector Coordinating Council is jointly led by DOE and the Department of Homeland Security (DHS), with membership from all levels of government and international partners.

These structures collectively serve as a means of sharing information, best practices, research needs, and other critical infrastructure security information, such as information about interdependencies, across sectors.

Additionally, PPD-8 calls for the development of a National Planning System to integrate planning across all levels of government and the private sector. The intent is to provide a flexible approach to prevent, protect, mitigate, respond, and recover from an event. The National Planning System includes the following:[108, 109]

- National planning frameworks describing the key roles and responsibilities to deliver the core capabilities required for the key mission areas: prevent, protect, mitigate, respond, and recover.
- Federal Interagency Operational Plans for each mission area to provide further details regarding roles and responsibilities, specify critical tasks, and identify requirements for delivering core capabilities.
- Federal department and agency operational plans to implement the Federal Interagency Operational Plans.
- Comprehensive planning guidance to support planning by local, state, tribal, and territorial governments; the private sector; and others.

PPD-8 also outlines five frameworks to maintain proper support from the Federal Government by working through states to assist affected local jurisdictions or organizations. The five frameworks divide efforts into rational disciplines of competence—prevention, protection, mitigation, response, and recovery. The combined frameworks shape efforts to prepare our Nation for emergencies stemming from all hazards.

The National Response Framework and its Emergency Support Function (ESF)-12 Annex outline much of the joint Federal, state, and private-sector responsibility for response and recovery to energy service disruptions. The ESF-12 Annex characterizes the Federal response as the facilitation of restoration of damaged energy systems and components. For example, DOE may exercise its emergency powers depending on the conditions of certain respective declarations and findings to facilitate restoration and to meet the needs of industry. After an incident, the National Disaster Recovery Framework[110] provides guidance for an expeditious return to a normal way of life. Like the National Response Framework's ESFs, the National Disaster Recovery Framework has Recovery Support Functions. DOE is named as a primary agency in the Recovery Support Function–Infrastructure Systems.

A.4.2 Tools and Technical Assistance

The Federal Government also provides numerous tools and technical assistance to enhance states' and the electric industry's capabilities to operate electricity systems in a secure and resilient manner. Many of these resources help stakeholders understand risks, assess their systems, analyze vulnerabilities, and prioritize mitigation strategies. Below are a few examples:

- DOE's Electricity Subsector Cybersecurity Capability Maturity Model helps entities evaluate, prioritize, and improve their cybersecurity capabilities and allows for a better overall assessment of the cybersecurity posture of the energy sector.[111]
- DHS's Cyber Security Evaluation Tool[112] and the Cyber Resilience Review are complementary and voluntary tools for evaluating industrial control system (ICS) and information technology network practices, and operational resilience and cybersecurity capabilities, respectively.[113]
- DHS's ICS Cyber Emergency Response Team provides resources to critical infrastructure sectors to prevent and recover from cyber attacks. This includes working onsite to help resolve spear phishing campaigns that seem to target ICS/supervisory control and data acquisition (or SCADA) data, including data that could facilitate remote access and control of systems.[114]

- DHS's Regional Resiliency Assessment Program conducts regional assessments of the Nation's critical infrastructure, addressing a range of hazards that could have regionally and nationally significant consequences. Argonne National Laboratory has completed 56 Regional Resiliency Assessment Program projects during 2009–2014, which addressed a variety of postulated hazards, including tornadoes, ice storms, earthquakes, hurricanes, solar storms, and other threats to the electric sector.
- The National Oceanic and Atmospheric Administration supports Regional Climate Centers, which are able to provide technical assistance and climate data to support risk assessment and decision making by utilities and governments.[115]
- DOE's Office of Energy Policy and Systems Analysis convenes the Partnership for Energy Sector Climate Resilience, through which DOE provides technical assistance for 18 electric utilities that are demonstrating leadership in developing vulnerability assessments and pursuing strategies for investing in climate resilience.

Continued support for tools development and expanding technical assistance resources is increasingly important as changing risks from human-induced actions and natural hazards make risk-based planning more challenging. For example, to credibly account for projected changes in climate, utility planners and regulators need technical assistance in accessing and correctly interpreting climate data at the appropriate time and geographic scales.

A.4.3 Standards and Guidance

As previously discussed, FERC has regulatory authority over the reliability of the bulk power system, overseeing the development and approval of standards set by NERC. FERC can also proactively direct NERC to develop a new or modified reliability standard to address reliability issues identified by FERC. While these standards cover the reliability and security of bulk power assets, NERC has typically designed them with the benefit of the system as a whole in mind, balancing the interests of its stakeholders. In addition to standards, the Federal Government works with stakeholders to develop additional guidance to support risk mitigation strategies across the electric sector.

It is worth noting that NERC's planning standards for electric reliability (e.g., TPL-001-4) and facility ratings standards (e.g., FAC-008-3) require consideration of a broad range of risks to the system. However, assumptions within these standards regarding the frequency and intensity of extreme weather events, for example, do not account for projected changes in climate. Furthermore, transmission planning efforts routinely consider system-wide costs associated with average weather-related loads, rather than accounting for extreme conditions.[116] The practice of using historical data and average conditions undercuts efforts to plan and prepare for threats, such as extreme weather, cyber attacks, or hostile actions, that may have different characteristics in the future.

Within the Commerce Department, the National Institute of Standards and Technology (NIST) develops frameworks, voluntary standards, and other guidance documents to assist electric sector efforts in reliability, resiliency, and security.[117] NIST conveys unique technical requirements for authorizing, monitoring, and managing all methods of remote access to the smart grid information system.[118, 119] The NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0, is one example of these resources.[120, 121] In addition, in 2014, the NIST released the Framework for Improving Critical Infrastructure Cybersecurity, which includes a set of standards, methodologies, procedures, and processes that align policy, business, and technological approaches to address cyber risks, and incorporates voluntary consensus standards and industry best practices.[122] In 2015, DOE released guidance to help the energy sector establish or align existing cybersecurity risk management programs to meet the objectives of the Framework released by NIST.

Several organizations are also actively revising interconnection standards—the rules that prescribe capabilities that technologies like distributed generation must possesses as a precondition to connecting to the electricity system—to better support the reliability, safety, and cost effectiveness of the grid. As technologies subject to interconnection standards increase in number and potential impact on the grid, enhanced Federal support is critical to the timely and robust completion of these standards.

A.4.4 Information Sharing and Threat Analysis

Federal agencies have institutions and programs in place to enhance information sharing and the dissemination of threat analysis to government and industry partners. DHS is responsible for several key infrastructure security programs. The National Infrastructure Coordinating Center and the National Cybersecurity and Communications Integration Center are the national focal points for industry partners to obtain 24/7 situational awareness and integrated actionable information to secure the Nation's physical and cyber critical infrastructure, respectively.[123] During major incidents, the National Infrastructure Coordinating Center and the National Cybersecurity and Communications Integration Center closely coordinate with the Federal Emergency Management Agency (FEMA) to ensure that overall critical infrastructure status and impacts on life and safety are understood throughout the Federal incident response community.[124]

Below are additional examples of government programs available to electric sector participants:

- *DHS Fusion Centers* are information-sharing hubs for Federal, state, local, tribal and territorial agencies and industry to maintain situational awareness at the state and local levels. Fusion centers receive, analyze, and disseminate threat information, providing local perspectives to their partners.[125]
- *DHS Automated Indicator Sharing* is a free program that facilitates the exchange of cyber threat indicators between the Federal Government and parties that opt in to the program through machine-to-machine sharing.[126]
- *DOE's Cybersecurity Risk Information Sharing Program* facilitates the exchange of detailed cybersecurity threat information among electric utilities, the Electricity Information Sharing and Analysis Center, DOE, and several National Laboratories. The program was designed to facilitate the timely bidirectional sharing of unclassified and classified threat information, and to develop situational awareness tools to enhance the sector's ability to identify, prioritize, and coordinate the protection of their critical infrastructure and key resources.
- *Information Sharing and Analysis Organizations* encourage exchange of information to protect critical infrastructure and are supported by sector-specific agencies and DHS in accordance with EO-13691 and PPD-63.

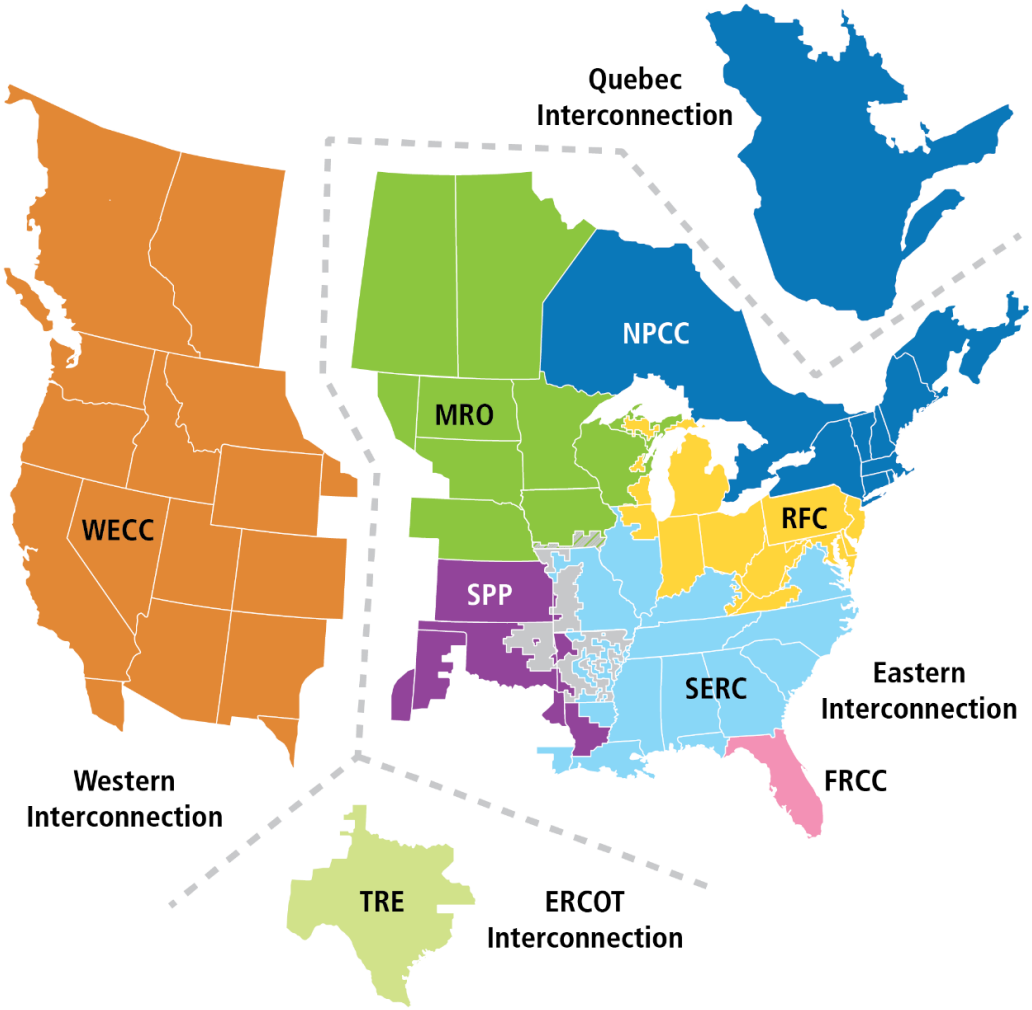
A.5. Electricity System Operations, Business Models, and Markets

A.5.1 System Operation

The electricity system of the continental United States does not function as a single, unified grid, but rather is split into three interconnections that each function as independent power systems with limited power flows between them, enabled by DC interconnections between the regional systems. Hawaii and parts of Alaska also operate as independent systems. The goal in operating each of these power systems is to deliver low-cost and reliable electricity. A complex set of institutions, defined by geographic boundaries, accomplishes this goal.

One of the broadest geographic divisions is the regional reliability entity,[l] which develops and enforces standards on behalf of NERC.[m, 127] Figure A-6 shows the three interconnections of the continental United States and the NERC reliability regions.

Figure A-6. North American Interconnections and Reliability Regions[128, n]



This map shows four North American interconnections, three of which include the United States, and eight NERC reliability regions. The four interconnections include Eastern, Western, Quebec, and the Electric Reliability Council of Texas (ERCOT). The NERC regions include: Florida Reliability Coordinating Council (FRCC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), ReliabilityFirst (RF), SERC Reliability Corporation (SERC), Southwest Power Pool Regional Entity (SPP RE), Texas Reliability Entity (TRE), and Western Electricity Coordinating Council (WECC).

[l] Instead of *entity*, the terms *council* and *organization* are sometimes used to refer to these entities as a group. Individually, their names include entities (e.g., Texas Reliability Entity), councils (e.g., Florida Reliability Coordinating Council), organizations (e.g., Midwest Reliability Organization), corporations (e.g., SERC Reliability Corporation), and pools (e.g., Southwest Power Pool, Inc.).

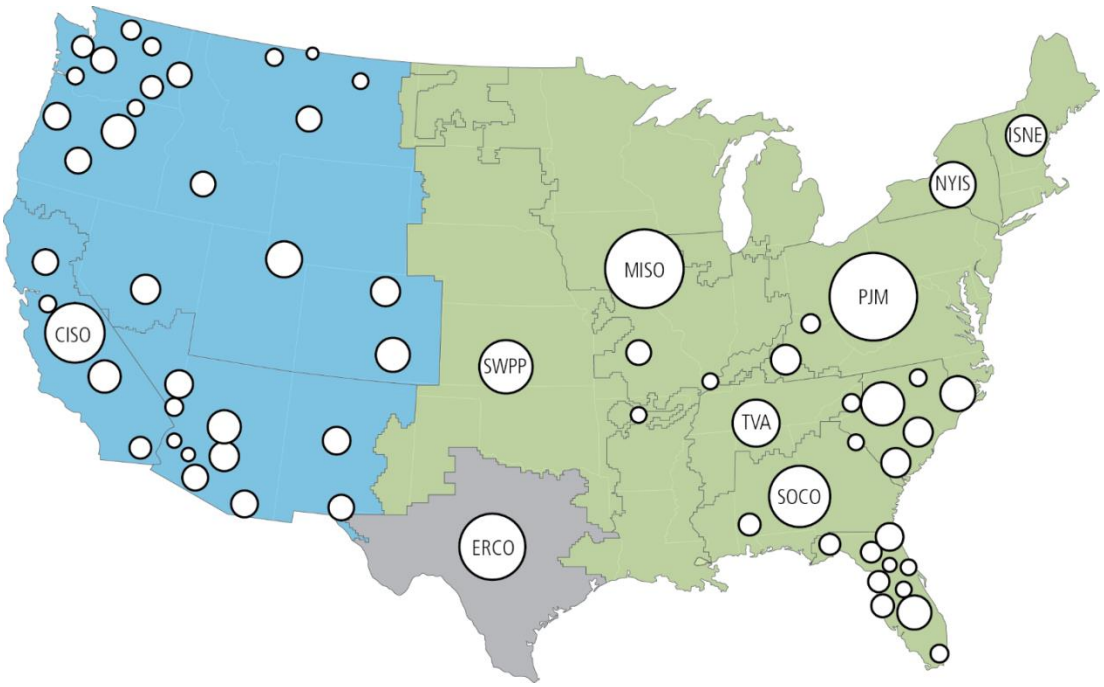
[m] NERC sets standards for the reliability of the bulk power system. The jurisdiction and authority of NERC is discussed in greater detail in Section A.3.2: Federal Actors.

[n] This figure is based on information from the North American Electric Reliability Corporation's website, which is the property of the North American Electric Reliability Corporation and is available at http://www.nerc.com/AboutNERC/keyplayers/PublishingImages/NERC_Interconnections_Color_072512.jpg. This content may not be reproduced in whole or any part without the prior express written permission of the North American Electric Reliability Corporation.

Providing electricity when and where it is needed is an incredibly complicated engineering process. Unlike most other consumer goods and energy sources, electricity is not stored in large quantities and must be produced at the instant it is needed. It is the job of power system planners and operators to ensure that electricity is produced when and delivered to where it is needed at every moment of every day.

The Nation is regionally subdivided into balancing areas, shown in Figure A-7, where balancing authorities operate regions of the grid on a day-to-day basis. Some of these regions overlap precisely with NERC reliability regions, while many others are smaller in geographic extent. On a daily basis, balancing authorities forecast demand, schedule generation supply, and schedule exchanges with neighboring regions. These decisions are generally guided by software optimization systems that minimize the total cost of meeting demand, subject to operating constraints and reliability criteria. Scheduling generation supply occurs on multiple time horizons, the most important of which include unit commitment (scheduling the availability of a generator days or hours ahead of time) and economic dispatch (providing operating instructions in near real time).

Figure A-7. Electricity System Interconnections and Balancing Areas[129]



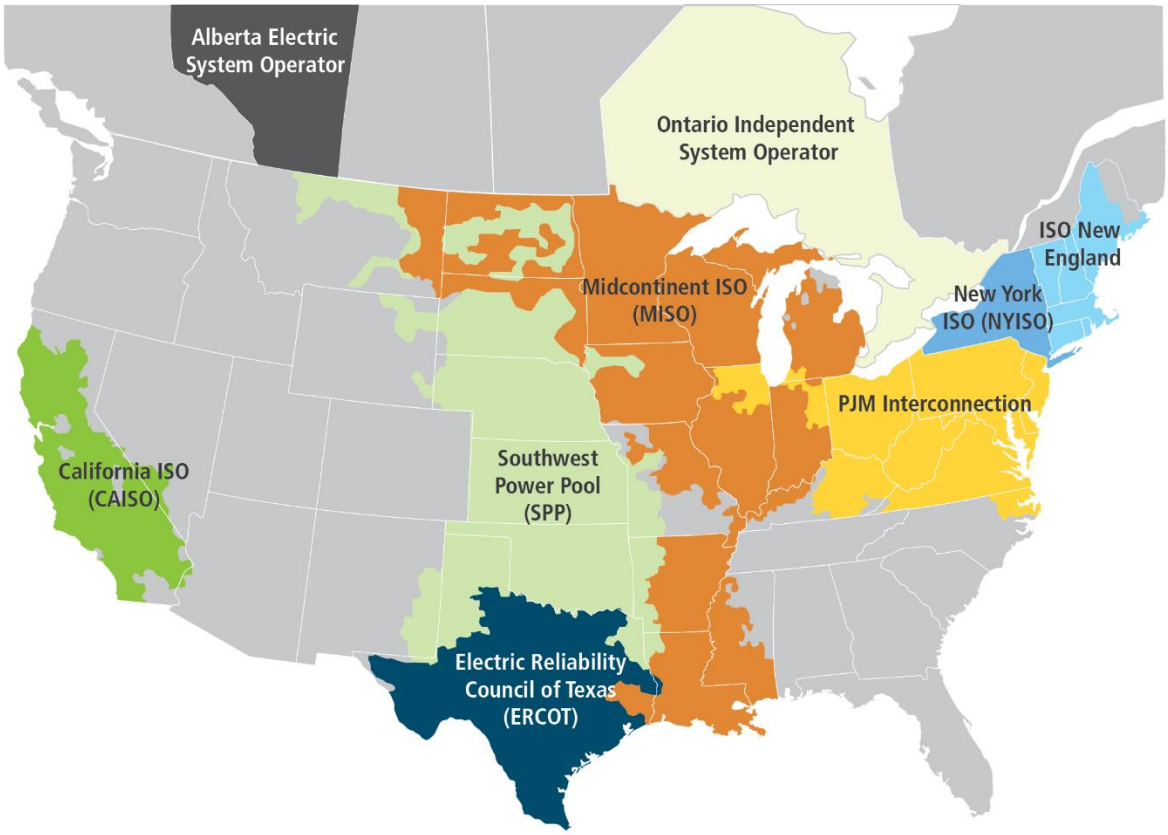
The electricity industry includes the three continental United States electricity system interconnections (Eastern, Western, and the Electric Reliability Council of Texas [ERCOT]), and the 66 balancing authorities that are responsible for maintaining a balance between supply and demand within their areas. The location of the balancing area bubbles is approximate, and the size represents a rough indication of the size of the system managed in each area.

Different operating approaches are used throughout the country, though all focus on minimizing costs and maintaining reliability. In some areas, utilities operate their own systems based on their costs for resource options and operating decisions. Other regions operate based on organized markets, where market participants place supply and demand bids into a centralized market, and a market operator determines the least-cost mix of bids.[o] Market participants then pay and earn money based on market

[o] The operations of markets are discussed in greater detail in Section A.5.3: Electric Power Markets.

prices for electricity and ancillary services. System operators in these areas are called ISOs or RTOs,[p] and their markets—except for Electric Reliability Council of Texas (ERCOT), which covers most of Texas—are overseen by FERC.[q]

Figure A-8. Regional Transmission Organizations (RTOs), 2015[130]



The Federal Energy Regulatory Commission encouraged voluntary formation of ISOs and RTOs through a series of landmark orders that paved the way for open access to transmission and created large organized power markets in the United States. There are currently seven ISO/RTOs in the United States, and their geographic extents change periodically.

FERC encouraged voluntary formation of ISOs and RTOs through a series of landmark orders that paved the way for open access to transmission and created large, centrally organized power markets in the United States. There are currently seven ISO/RTOs in the United States, and their geographic extent changes periodically.

Maintaining operational reliability of the power system requires focusing on a set of essential reliability services, called ancillary services, provided by generation and load that aid in maintaining frequency and voltage of the system within acceptable bounds during normal operations and immediately after minor system disturbances.[r] Examples of these services include frequency response (automatic generator

[p] There are small distinctions between ISOs and RTOs, though they are insignificant for the level of discussion in the QER. Throughout, the terms will be used synonymously.

[q] The jurisdiction and authority of FERC is discussed in greater detail in Section A.3.2: Federal Actors.

[r] The term Essential Reliability Services is used by NERC to describe a set of necessary operating characteristics of resources on the bulk power system required to reliably operate the bulk power system in North America. For voltage support, it includes reactive power/power factor control, voltage control, and voltage disturbance performance. For frequency management, it includes inertia, frequency disturbance performance, operating reserves, and active power control (which includes frequency control and ramping capability). Ancillary services are a subset of Essential Reliability Services. Source: North American Electric Reliability Corporation (NERC), *Essential Reliability Services Task Force: A Concept Paper on Essential Reliability Services that*

response to grid frequency deviations) and spinning reserves (generators that remain running and able to increase or decrease their output when instructed). Some ISO/RTO market regions procure ancillary services through markets that mirror their energy markets. Additional services are procured in these regions through cost-of-service payments. In non-ISO/RTO regions, many ancillary services are provided under a cost-of-service basis. The evolving composition of the electricity generation fleet has implications for long-term availability of these system-essential reliability services.[131]

Reliability and the Role of the North American Electric Reliability Corporation (NERC)

Over the past 50 years, Federal oversight of the reliability of the bulk power system has increased. The 1965 Northeast power blackout precipitated the formation of NERC, but bulk power system reliability standards were voluntary and subject only to industry oversight.[132] A 2003 blackout that affected more than 50 million customers led to the inclusion in the Energy Policy Act of 2005 of requirements for mandatory bulk power reliability standards and enforcement, including designation of an electric reliability organization.[133] The Federal Energy Regulatory Commission oversees NERC in its development and enforcement of mandatory reliability standards for the bulk power system. States retain oversight of local reliability, which includes lower voltage transmission lines and distribution systems. NERC mandatory reliability standards address weaknesses in the prior voluntary system that were identified in the 2003 blackout investigation.

A.5.2 Business Models

Electricity in the United States is produced and delivered by a diverse set of actors using a range of business models. Depending on the operating model in question, these actors can be subject to regulation and oversight by different combinations of local, state, and Federal agencies. A key factor for differentiating between actors is ownership: companies can be investor-owned, publicly owned, or cooperatively owned. Within each of these three ownership models there are significant variations in purpose, regulatory oversight, prevalence, and size. Table A-4 provides overview statistics for the most common types of utility ownership . In addition to these primary ownership models, there are a number of businesses that provide distributed resources like demand response aggregation and distributed solar. Figure A-5. Broad Overview of Jurisdictional Roles in the Electricity Industry provides a taxonomy of utility business models by ownership and asset types.

Table A-4. Characteristics of Major Utility Types[134, 135]

Utility Type	Number of Utilities	Number of Customers	Miles of Power Lines	
			Transmission	Distribution
Investor-Owned Utilities	169	107,566,949	3,467,216	459,480
Municipal Utilities	1,834	15,151,058	320,953	27,585
Rural Electric Cooperative Utilities	814	19,232,195	2,397,111	116,635
Federal and Publicly-Owned Utilities	124	5,280,112	333,720	95,962
Total	**2,941**	**147,230,314**	**6,408,000**	**699,662**

Municipal utilities are the most numerous of the various utility types, though IOUs serve far more customers. Rural electric cooperatives have a higher proportion of distribution miles per customer served than investor-owned or municipal utilities.

Characterizes Bulk Power System Reliability (Atlanta, GA: NERC, October 2014), http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Concept%20Paper.pdf.

IOUs are privately owned, for-profit utilities whose retail service is regulated by state PUCs that may be either vertically integrated or restructured to only own transmission and distribution. IOUs earn a regulated rate of return based on investments made to serve their ratepayers.

Rural electric cooperatives include nonprofit, member-owned distribution utilities and generation and transmission utilities. The cooperative business model is predicated on providing its customers with reliable, affordable energy that is locally owned and operated. The model is unique in that customers are "members" of the cooperative and, as such, hold ownership and voting stakes. Management is democratically elected by the membership, and the prevailing methodology is one meter, one vote.[136] Cooperatives receive a significant portion of their financing both directly and indirectly from the Federal Government, through both the Department of Agriculture's Rural Utility Service and cooperative banks like the National Rural Utilities Cooperative Finance Corporation. Electric cooperatives are not subject to Federal income tax, and thus must collaborate with a third party to monetize tax credits available for utility and generation investments.

Public power utilities are owned by a governmental entity, such as municipalities, states, public utility districts, or irrigation districts, and vary in size and scope from small distribution utilities to large, vertically integrated utilities. Public power also includes joint-action agencies that may own generation, transmission, and power purchasing services for their member utilities, such as the Lower Colorado River Authority and Missouri River Energy Services. Joint action agencies allow small distribution-only public power utilities to aggregate their demand and contract for and/or build generation, transmission, and other common services.

Federally owned utilities operate in the generation and transmission segments of the power system in several parts of the country. Four Power Marketing Administrations market hydropower generation at dams operated by the Bureau of Reclamation or the Army Corps of Engineers. TVA has a portfolio of generation and transmission to sell wholesale electricity to public power and cooperatives in its footprint. Federal law grants preference for electricity marketed by Federal utilities to public power and cooperative utilities.[s] Federally owned generation resources produce approximately 7 percent of all power in the United States, and they own approximately 14 percent of all transmission lines.[137, 138]

Merchant/independent power producers (IPPs) sell power through markets and bilateral contracts with utilities and other customers. IPPs typically have market-based—rather than cost-based—rates and do not have captive customers. They may or may not be affiliated with an IOU through a holding company. In 2014, IPPs produced approximately 40 percent of the Nation's electricity.[139] IPPs are often subject to hard-to-predict market conditions and can experience volatile cash flows and returns.

Competitive retail energy suppliers are companies that sell power to end users in states with competitive retail markets. As such, they do not earn a regulated rate of return. Although distribution utilities are the only entities that can *deliver* power directly to retail customers, in certain states customers can choose the *suppliers* of that power. In practice, this "retail choice" means that a consumer can sign a contract with a qualified third-party electric service provider who could, in turn, contract with a generator (on a bilateral basis), self-generate, or purchase power in the wholesale market, and pay the necessary tariffs to the transmission owner and distribution utility.

Energy service companies (ESCOs) were traditionally providers of turnkey energy efficiency retrofits, but ESCOs are now offering biomass, geothermal, wind, and solar generation, bill management, energy

[s] Preference clauses for Federal power sales originate from a series of congressional acts regarding Federal land reclamation and hydropower development, beginning with the Reclamation Act of 1906. See GAO-01-373 for further details.

monitoring, and energy procurement.[140] ESCOs explicitly guarantee energy savings for the consumer and charge a fee below that savings, known as an energy savings performance contract.[141]

Demand-response aggregators contract with large groups of end users to curtail their load if called upon to do so by the local utility or balancing authority. This flexibility is useful for reliability and economic reasons. There are many different providers of demand-response aggregation, including existing utilities and third-party providers.[142] The terms and conditions of third-party access to wholesale markets differ between ISOs and RTOs, but, generally, aggregators can participate in both energy and capacity markets to provide energy and ancillary services (including synchronized reserves).[143] Of 9.3 million participants registered in demand response in 2014, by count, over 90 percent are residential customers. However, over 75 percent of actual peak-demand savings came from commercial and industrial customers in 2014.[144]

Table A-5. Taxonomy (Ownership/Scope) of Utility Business Models with Representative Firms[145]

	State-Regulated IOU	Rural Electric Cooperative	Publicly Owned	Federally Owned	Merchant	Competitive Retail Energy Supplier*
Vertically Integrated**	Oklahoma Gas & Electric	–	Los Angeles Department of Water & Power	–	–	–
Transmission and Distribution	Pepco	Southern Maryland Electric Cooperative	Clallam County Public Utility District	–	–	–
Generation and Transmission	–	Basin Electric G&T	New York Power Authority	Tennessee Valley Authority	LS Power	–
Generation and Distribution	DTE Energy; Consumers Energy	Fox Island Electric	Lansing Board of Water & Light	–	NRG	–
Transmission Only	–	Upper Missouri Power Cooperative	Transmission Agency of Northern California	Western Area and Southwestern Power Administrations	ITC; Hudson Transmission; Transource Energy; Clean Lines Energy Partners	–
Distribution Only	Mt. Carmel Public Utility Co.	Kenergy	Nashville Electric Service	–	–	–
Generation Only	–	–	Wyoming Municipal Power Agency	Bureau of Reclamation	Calpine; BP Energy; Tenaska	–
Retail Sales Only***	–	–	–	–	–	Direct Energy; Veteran Energy

* Competitive retail energy suppliers are a special category of market participants that buy and sell electricity, but do not own any generation or infrastructure. Some ESCOs are retailers.

** Vertically integrated entities integrate generation, transmission, and distribution.

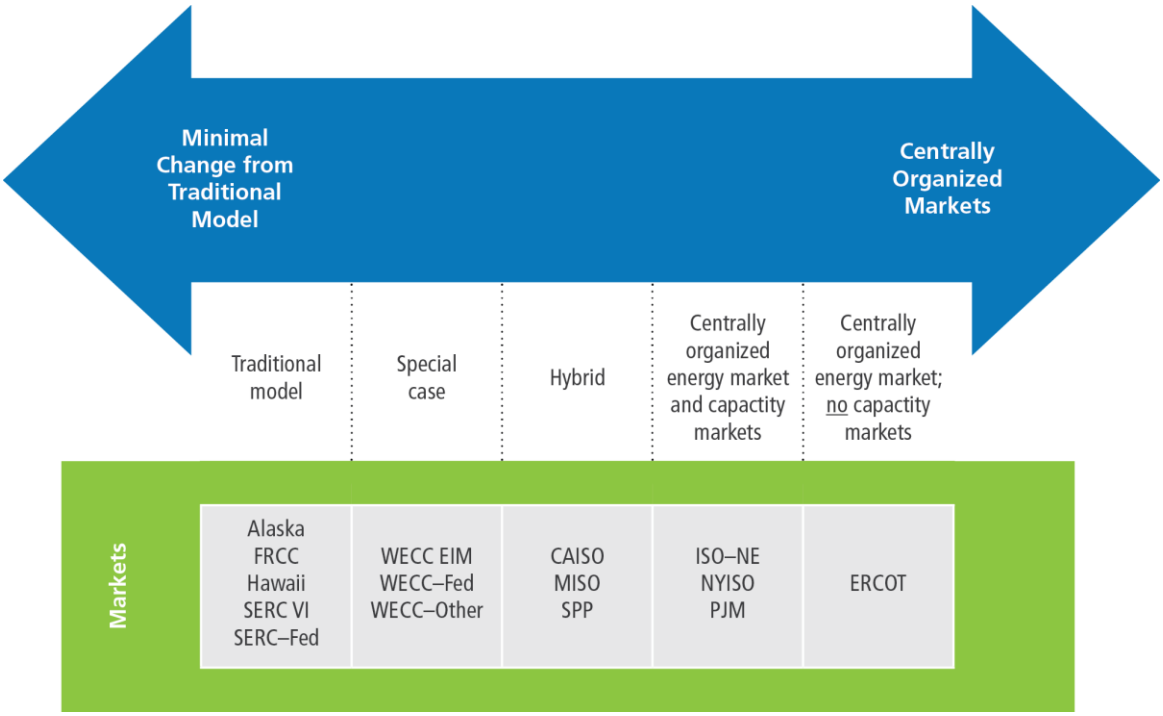
*** All business model categories in this table may include retail sales in addition to other services.

Utilities in the U.S. electricity sector have a variety of ownership and asset structures.

A.5.3 Electric Power Markets

Rather than consisting of a single overarching market, the U.S. electricity industry can instead be considered something of a patchwork, with different regional markets pursuing different mechanisms to provide electricity service to end users. The simplest characteristic differentiating these markets is whether resources are scheduled, dispatched, and compensated by a centrally organized RTO/ISO, or if they operate under the more traditional model wherein vertically integrated utilities operate within their franchise areas and receive revenues based on the cost of service. From this bifurcation, the organized markets can be further classified according to the types of resource adequacy constructs they use. These two attributes form a useful framework for analyzing the degrees to which the various markets differ from one another, and also underscore the diversity of approaches to electricity policy amongst the states.

Figure A-9. Spectrum of Electricity Markets[146]



This graphic illustrates the degree to which various U.S. regions have changed from the traditional market model. The two primary characteristics measured here are resource adequacy constructs and whether the market is centrally organized. Markets include: ERCOT, ISO New England (ISO-NE), New York ISO (NYISO), the PJM Interconnection (PJM), California ISO (CAISO), Midcontinent ISO (MISO), the Southwest Power Pool (SPP), and the Energy Imbalance Market (EIM) in the Western Electricity Coordinating Council (WECC) region. The markets listed under “special case” and “traditional model” are classified by NERC region and are not standardized designations.

Regions Address Resource Adequacy with a Variety of Mechanisms

Resource adequacy is "the ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements."[147] Planning for adequate investment in generation and transmission capacity to ensure resource adequacy is a critical component of ensuring a reliable electricity system.

Traditional, vertically integrated regions and some utilities in hybrid markets conduct an integrated resource planning process to plan for necessary capacity investments. Some centrally organized markets have implemented capacity markets as a mechanism for ensuring future resource adequacy. In these markets, the system operator conducts an auction process, and retail service providers procure resources to meet the electricity demands of their customers. These markets can be mandatory (PJM Interconnection and Independent System Operator [ISO]–New England); voluntary, where utilities can choose to operate under an integrated resource planning process (Midcontinent ISO); or voluntary backstopped by a mandatory process (New York ISO).[148] Other regions (California ISO and the Southwest Power Pool) have capacity obligations where market operators require utilities to procure necessary generation reserves, either through ownership or through contracts with third-party providers. Another market-based approach, used in the Electric Reliability Council of Texas, relies on energy prices alone and does not have formal requirements or markets for capacity. In this approach, market scarcity pricing, or relatively high energy prices during high-demand periods reflecting the lack of ample additional resources, provides necessary financial incentives for investment in generation capacity.

"**Traditional" markets** (the Southeast of the United States, for example) are dominated by vertically integrated IOUs that operate under a regulated cost-of-service model, serving customers in a defined franchise area. Public power and rural cooperative utilities also have a significant presence in some regions, and their utility asset ownership models can vary from vertically integrated to distribution-only. IPPs can also operate within these regions to some degree. However, the majority of power is produced and delivered by the integrated utilities.

Power purchases between these various entities are generally limited to bilateral trades. These can be made to take advantage of price discrepancies or cover shortfalls in supply. These bilateral transactions represent a small portion of the total generation in traditional markets and are typically in the form of long-term power purchase agreements instead of short-term trades. For example, in 2015 FERC estimated that short-term trades, called spot transactions, in the Southeast region accounted for less than 1 percent of overall supply.[149]

Centrally organized markets (ERCOT and New York ISO, for example) are markets where utilities were required to sell their power generation assets and keep only the "wires" component of the business. Generation assets were sold to IPPs who now operate these assets and build new generation based on expected market earnings. These assets work in a competitive fashion, with the IPP owners either (1) looking to sell power under bilateral contracts to utilities or other off-takers, such as industrial users, or (2) dispatching their power into wholesale energy markets.

In wholesale "energy-only" markets, units bid in on a day-ahead basis what price they are willing to produce power at, based on an assessment of their operating costs, fuel costs, and return expectations. The system operator (RTO/ISO) then pools these bids in a centralized fashion and determines a clearing price that matches supply, demand, and congestion forecasts for a given period. Notably, all units receive that marginal clearing price for that period, even if their bid prices are significantly lower than the clearing price determined by the ISO. In addition, the typical markets maintain price caps that limit what can be charged in any particular hour in order to limit the potential for market manipulation.

"**Hybrid" centrally organized markets** (for example, California ISO and the Southwest Power Pool) combine elements of centrally organized energy markets and traditional resource adequacy mechanisms.

In fact, several of these markets had moved toward more of a pure restructured model before moving back to elements of the more traditional regulated approach.

A.5.4 Transmission Access, Competition, and Planning

While Congress has found that generation can be provided through competitive mechanisms and therefore encouraged restructuring in that segment of the industry in the 1990s, increasing competition among transmission owners and reducing barriers to using transmission have been more incremental processes.

Originally, incumbent transmission owners largely controlled third-party access to transmission lines, effectively precluding competition at the wholesale level. Buyers and sellers of wholesale power that did not own the transmission connecting them had difficulty reaching each other over another's transmission lines at reasonable cost. EPAct 1992 resolves this issue by providing FERC with greater authority to provide transmission access for wholesale buyers in procuring wholesale electric supplies. Since 1992, FERC has taken multiple actions to increase operational and economic efficiency and equity of transmission operations and pricing.

FERC adopted Order No. 888 and Order No. 889, which require electricity utilities that own transmission lines used in interstate commerce to offer transmission service on a nondiscriminatory basis to all eligible customers, including non-jurisdictional entities such as public power, rural cooperatives, and Federal utilities. Order No. 2000 further encouraged utilities to join RTOs to improve the efficiency and equity of the transmission systems. FERC Order No. 890 built upon Order No. 888 to encourage more transparent planning and use of the transmission system and to reduce opportunities for undue discrimination.

FERC Order No. 1000 covers concepts such as (1) precluding, in most circumstances, incumbent transmission owners from having Federal rights of first refusal to build transmission within their service territories, (2) the opportunity for entities not previously recognized as transmission owners in the region (non-incumbents) to compete to develop transmission facilities and allocate the costs of those facilities, and (3) the requirement that project costs be allocated in a manner that is at least roughly commensurate with expected benefits from the projects.

Transmission owners, operators, and regional coordinators implement structured transmission planning processes to identify solutions that can more efficiently or cost-effectively maintain system reliability and accommodate changes in generation capacity and demand. Meeting the transmission planning goal requires both technical (engineering) analysis of different power systems configurations and economic analysis of projects proposed to meet the identified needs. In the United States, the transmission planning process generally falls into three geographic categories: local, regional, and interregional coordination.

Local transmission planning activities are carried out by incumbent transmission owners. These transmission owners assess their system and implement local solutions within their own service territory. Regional transmission planning includes assessment of solutions within a given planning region that spans several transmission owner service territories. Regional transmission planning relies on extensive stakeholder engagement, power system simulation modeling, and long-term economic impact analysis of alternative transmission projects. Interregional coordination is implemented for solutions that involve more than one ISO/RTO or planning entity. Interregional coordination activities are mostly guided by the principles outlined in FERC Order No. 1000.

A.6. Endnotes

[1] "U.S. Coal Flow, 2015," Energy Information Administration, *Monthly Energy Review*, April 2016, http://www.eia.gov/totalenergy/data/monthly/pdf/flow/coal.pdf.

[2] "Estimated U.S. Energy Use in 2014: ~98.3 Quads," Lawrence Livermore National Laboratory, 2015, https://flowcharts.llnl.gov/content/assets/docs/2014_United-States_Energy.pdf.

[3] "How Many and What Kind of Power Plants Are There in the United States?" Energy Information Administration, Frequently Asked Questions, last updated December 1, 2016, http://www.eia.gov/tools/faqs/faq.cfm?id=65&t=2.

[4] EPSA Analysis: National Renewable Energy Laboratory, "Electricity Generation Baseline Report," forthcoming.

[5] EIA (Energy Information Administration), *2014 Electric Power Annual* (Washington, DC: EIA, 2015), Tables 1.1–1.3, http://www.eia.gov/electricity/annual/.

[6] EPSA Analysis: ICF International, "Transmission Analysis: Planning, Operations and Policy," forthcoming.

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List of Acronyms and Units

AC	alternating current
AMI	advanced metering infrastructure
AML Fund	Abandoned Mine Lands Reclamation Fund
ARC	Appalachian Regional Commission
ARRA	American Recovery and Reinvestment Act of 2009
BTU	British thermal unit
CCUS	Carbon capture, utilization, and storage
CES	Clean Energy Standard
CHP	combined heat and power
DC	direct current
DER	distributed energy resources
DG	distributed generation
DOE	U.S. Department of Energy
DR	Demand response
EE	Energy efficiency
EERS	Energy Efficiency Resource Standard
ERCOT	Electric Reliability Council of Texas
ESCO	energy service company
EV	electric vehicle
FAST Act	Fixing America's Surface Transportation Act
FERC	Federal Energy Regulatory Commission
GDP	gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
HVAC	heating, ventilation, and air conditioning
ICT	information and communications technology
IEEE	Institute of Electronics and Electrical Engineers
IoT	Internet of Things
IOU	investor-owned utility
IPP	independent power producer
ISO	independent system operator
ITC	Investment Tax Credit

kWh	kilowatt-hour
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LIHEAP	Low Income Home Energy Assistance Program
MEL	miscellaneous electrical load
MISO	Midcontinent Independent System Operator
MW	Megawatt
MWh	megawatt-hours
NEMS	National Energy Modeling System
NERC	North American Electric Reliability Corporation
NGCC	Natural gas combined cycle
PMU	phasor measurement units
PPA	power purchase agreement
PTC	Production Tax Credit
PUC	public utility commission
PURPA	Public Utilities Regulatory Policies Act
PV	Photovoltaic
QER	Quadrennial Energy Review
Quads	Quadrillion British thermal units
RD&D	Research, development, and deployment (RDD&D = Research, development, demonstration, and deployment)
RPS	Renewable Portfolio Standard
RTO	regional transmission organization
SCADA	supervisory control and data acquisition
T&D	Transmission and distribution
TOU	Time of use
TWh	Terawatt-hour
VER	variable energy resource