Standards and Interoperability in Electric Distribution Systems

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List of Acronyms

AMI	Advanced metering infrastructure
ANSI	American National Standards Institute
ARRA	American Reinvestment and Recovery Act
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CEC	California Energy Commission
CIM	Common information model
DER	Distributed energy resources
DERMS	Distributed energy resource management system
DOE	Department of Energy
DR	Demand response
DSIP	Distribution system implementation plan
GMP	Grid modernization plan
GWAC	GridWise Architecture Council
EISA	Energy Independence and Security Act
EPRI	Electric Power Research Institute
ESPI	Energy services provider interface
EV	Electric vehicle
FERC	Federal Energy Regulatory Commission
ICT	Information and communications technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
ISO	International Organization for Standards
IPRM	Interoperability Process Reference Manual
kW	Kilowatt
kWh	Kilowatt-hour
MDMS	Meter data management system
NAESB	North America Energy Standards Board
NARUC	National Association of Regulatory Utility Commissioners
NEMA	National Electric Manufacturers Association
NIST	National Institute of Standards and Technology
NOI	Notice of Investigation
OASIS	Organization for the Advancement of Structured Information Systems
OSTP	Office of Science and Technology Policy

OpenFMB	Open Field Message Bus
PAP	Priority action plan
PII	Personally identifiable information
PNNL	Pacific Northwest National Laboratory
PUC	Public utility commission
PV	Photovoltaic
SAE	Society of Automotive Engineers
SDO	Standards Development Organization
SGAC	NIST Smart Grid Advisory Committee
SGAM	Smart Grid Architectural Model
SGDP	Smart Grid Demonstration Project
SGIP	Smart Grid Interoperability Panel
SGTC	Smart Grid Testing and Certification
SGTCC	Smart Grid Testing and Certification Committee
SSO	Standards-setting organization
USB	Universal serial bus

EXECUTIVE SUMMARY

INTEROPERABILITY

Interoperability indicates the ability of systems, or components within systems, to interact and exchange services or information with each other, and to operate effectively in an expected way without significant user intervention.[1] Interoperability can be facilitated by the development of open standards,[a] adherence to those standards by participating parties, and compliance verification through independent testing and certification. Interoperability for the electric power system can be defined as "the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the distribution & transmission systems to the power source, enhancing the coordination of energy flows with real-time flows of information and analysis."[b] [2] It is a foundational component of the modernized or "smart grid" concept,[c] which is a large, complex "system of systems" with many stakeholders who each have diverse needs that must be met.[3]

ONGOING INTEROPERABILITY EFFORTS AND STANDARDS DEVELOPMENT

Efforts to both advance interoperability and to develop open interoperable standards to enable a modernized grid have been underway at the national level—among industry organizations and supported by the Federal government—for over a decade. Industry organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), the American National Standards Institute (ANSI), and North American Energy Standards Board (NAESB), among others, lead interoperable standards development efforts.

[a] The precise definition of "open standards" varies across organizations and subject matters. However, the primary principles of what constitutes an "open standard" are consistent with Free Software Foundation Europe's (FSFE) definition, which characterizes open standards as "subject to full public assessment and use without constraints in a manner equally available to all parties… without any components or extensions that have dependencies on formats or protocols that do not meet the definition of an Open Standard themselves… free from legal or technical clauses that limit its utilization by any party or in any business model… managed and further developed independently of any single vendor in a process open to the equal participation of competitors and third parties… [and] available in multiple complete implementations by competing vendors, or as a complete implementation equally available to all parties" (FSFE, "Open Standards"). Available at https://fsfe.org/activities/os/def.en.html. OMB Circular A-119 (a memorandum from the White House Office of Management and Budget regarding Federal participation in standards development) specifies the term "voluntary consensus standards," which are "standards developed or adopted by voluntary consensus standards bodies, both domestic and international. These standards include provisions requiring that owners of relevant intellectual property have agreed to make that intellectual property available on a non-discriminatory, royalty-free or reasonable royalty basis to all interested parties." Not all voluntary consensus standards are open standards but voluntary consensus standards often promote interoperability in the absence of "open" standards. (Office of Management and Budget, "Circular A-119 Revised," February 10, 1998. Available at https://www.whitehouse.gov/omb/circulars_a119.

[b] There are various definitions of interoperability, each of which capture important nuances. This definition is provided by the Gridwise Architecture Council. See GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[c] According to the U.S. Department of Energy The "'smart grid" generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation." For additional smart grid information see http://energy.gov/oe/services/technology-development/smart-grid. For additional information on interoperability as a component of the smart grid see GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf, and NREL, "Interoperability is Key to Smart Grid Success," http://www.nrel.gov/continuum/utility_scale/smart_grid.html.

Government organizations such as the National Institute of Standards and Technology (NIST), an agency within the Department of Commerce, as well as government-supported organizations such as the GridWise Architecture Council (GWAC) and the Smart Grid Interoperability Panel (SGIP) have all supported the development of a framework for interoperability in various ways (for example, coordinating multi-stakeholder discussions around standards development).

In addition to national efforts on this topic, states have also pursued interoperability for local distribution systems and toward encouraging utilities to adopt national standards, but these efforts have been mixed and limited. Yet many emerging technologies—some involving advanced communications capabilities as well as distributed energy resources—are coming online at the distribution system level. This makes interoperability on the distribution system increasingly important. Interoperability is a critical enabler. It allows such technologies to scale and the distribution system to accommodate them.[4] Unfortunately, some state policymakers and regulatory bodies may lack the resources, time, or expertise to pursue interoperability efforts for the distribution system, participate in technical standards development where necessary, or encourage their constituents to adopt recognized interoperability standards at the state level.

PURPOSE

The Federal government could play a role in supporting states in this endeavor to advance the use of interoperability standards in the electric distribution system. This report identifies, with input from states, opportunities to facilitate the use of open standards that enhance interoperability and connectivity on distribution systems. The report provides analyses of four key topics:

1) The value of open standards and interoperability on the distribution system,

2) The mechanisms and processes that states have or could use to encourage implementation and adoption of standards among their constituents,

3) The barriers to implementing interoperability at the state level, and

4) The desirability and feasibility of direct or facilitated state participation in standards development efforts.

The analyses are informed by informal discussions with public utility commissioners and staffers in nine U.S. states as well as an extensive literature review. There was no comprehensive survey of state experiences or views, however. The insights provided by state experts (which were largely aggregated and anonymized) were anecdotal.[d] Significantly, the nine states in which experts were contacted were selected because many have a reputation for being on the leading edge of interoperability efforts (i.e., within their state) or have the most advanced knowledge of standards development efforts (i.e., at the national level).

[d] Information provided during the discussions was offered by state experts based on their own personal experiences and insights gained from working on these issues in their respective states or with relevant state groups. The authors did not conduct independent, scientific research into ongoing state proceedings, open dockets, or official state policy or other pronouncements.

FINDINGS

The following findings are a synthesis of information gathered during the literature review and discussions with states.

Benefits of Implementing Interoperability on the Distribution System are Widespread but Difficult to Quantify

- Interoperability in the electric distribution system offers a diverse range of benefits for utilities, consumers, and other stakeholders. These benefits are widely agreed upon by industry experts, however they are difficult to quantify. Benefits of interoperable distribution systems and system components include:
  - **Reduction of system integration costs and extension of asset life** – Interoperability standardization necessarily decreases costs to deploy and integrate new technologies and applications into an existing system, by definition eliminating the need to modify existing systems extensively to accept and communicate with the new technology. This can lower design, installation, and upgrade costs as well as reduce overall system integration costs for new capital investments (i.e., system expansion). In addition, interoperability including equipment monitoring and assessment of operating conditions on an ongoing basis can also reduce repair costs and extend equipment life. It can lower operations and maintenance costs as well as extend the useful life of legacy infrastructure and continued asset utilization (i.e., system operations).
  - **Generation of economic benefits** – Interoperability decreases market fragmentation, enables economies of scale, and can reduce transaction, equipment, and other costs for both suppliers and customers.
  - **Catalyst of innovation** – Interoperability standards enable a technology-neutral market; reducing investment uncertainty, incentivizing innovation where standard interfaces can be defined, and ensuring that currently deployed infrastructure can continue to provide value within newer systems.
  - **Increase in customer choice and participation** – Interoperability allows customers to choose between features instead of between technologies, prevents companies from "locking in" customers (both utilities and consumers) with proprietary systems, and facilitates customer trust of new vetted technologies.
  - **Improvement of grid performance and efficiency** – Interoperability promotes a more efficient, reliable grid. It helps ensure both demand-side and supply-side load management work cooperatively and productively. Standards ensure that today's technology can interface with future technologies.
  - **Establishment of industry-wide best practices** – Interoperability standards can collectively form a playbook, providing guidance for all utilities facing emerging industry issues; smaller utilities benefit from being able to pull technology "off the shelf."

- **Facilitation of more comprehensive grid security and cybersecurity practices** – Interoperable technologies permit the application of a single, comprehensive security framework and enable coordinated and consistent cybersecurity practices. Although common standards could mean that a larger number of systems might be affected by a given vulnerability, it also has meant that security vulnerabilities and threats can be more rapidly identified and addressed. Highly interoperable systems do require disciplined cyber security, but the resultant system can be easier to administer, police and upgrade against evolving threats. Additionally, interoperable technologies can reduce the number of systems and interfaces required for operators to monitor and manage the electric grid, thus enabling more timely and coordinated responses to emergency events.[e]

- There is a deficit of quantitative analyses on the costs and benefits of promoting interoperability, or adopting associated open interoperable standards at the distribution system level. This is a key factor contributing to the absence of state efforts to encourage interoperability in any systematic fashion, and many state commissions could benefit from such analyses.

- Estimates on the financial benefits of interoperability for the electric system are limited, and currently available analyses offer wide-ranging conclusions based on the individual study's scope, sample size, scope, location, and other factors. For example, a GridWise Architecture Council analysis on the financial benefits of interoperability notes that based on peer industry experiences, potential savings for the electric industry from interoperability could amount to as much as $10 billion annually[f] across the power system, some of which would be attributable to interoperability on the distribution system. According to the same study (and also based on peer industry experience), interoperability can provide additional benefits such as increasing service quality and decreasing mistakes, as well as driving innovation to create new markets and services. An alternative gauge of the potential benefit of interoperability is offered by a 2015 industry report,[g] which concludes that interoperability accounts for 17 percent of the potential value of Internet of Things (IoT) systems in the home environment.[h] With IoT-enabled energy management applications having the potential to produce $51–$108 billion[5] in global annual savings, interoperability then could yield $9–$18 billion per year worldwide.

[e] There is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on "security through obscurity." Highly interoperable systems do require disciplined cyber security, but the resultant system can be easier to administer, police and upgrade against evolving threats.

[f] Financial figure is in 2009 dollars. Figure is assumed to be an annual number, based on report's description of peer industry savings on an annual basis. The savings estimate in this particular study applies to the electric utility industry output value (measured as revenues), although ratepayer costs and investment in technology are also important factors in quantifying financial benefits. The analysis does not provide granular details regarding the exact system components through which the interoperability savings would be derived but notes the costs-savings are related to information coding and transmission for operations (e.g., "administrative actions and time associated with meter reading, systems monitoring and reporting, and customer interactions such as billing") and maintenance and upgrades. GridWise Architecture Council, "Financial Benefits of Interoperability: How Interoperability in the Electric Power Industry Will Benefit Stakeholders Financially," Prepared for the GridWise® Architecture Council by Harbor Research, Inc., September 2009, p. 14, 17. Available at http://www.gridwiseac.org/pdfs/financial_interoperability.pdf.

[g] For additional discussion see McKinsey Global Institute, The Internet of Things: Mapping the Value Beyond the Hype, (McKinsey & Company, June 2015), p. 53.

[h] For additional discussion see McKinsey Global Institute, The Internet of Things: Mapping the Value Beyond the Hype, (McKinsey & Company, June 2015), p. 53.

Mechanisms and Processes States are Utilizing to Encourage Interoperability and Standards Adoption Are Ad Hoc

- It does not appear that many states are pursuing a systematic process of encouraging interoperability on the distribution system or the adoption of associated standards among their regulated utilities or other constituents. However, in the context of broader initiatives, some states are undertaking piecemeal efforts to support interoperability and encourage stakeholders to use open interoperable standards.
- Many of these largely informal efforts have been spurred by utility activities that solicit a commission response, e.g., as part of a commission process of approving new technologies or via state smart grid policy initiatives. Many states lack complete information on many of the benefits/savings associated with interoperability initiatives and standards development efforts occurring at the national level. Often, those that have access to all the available information, still rank promotion of interoperability/adoption of national standards low on their state's list of competing priorities, which may include on-going rate case proceedings and broad policy questions about whether and how to pursue grid modernization and integrate distributed and renewable resources.
- Processes through which states have, or could, promote interoperability and the adoption of associated standards include but are not limited to:
  - Encouraging interoperability via state-mandated policy initiatives;
  - Pursuing interoperability via rate cases, dockets, and other proceedings;
  - Establishing State Commission-recommended practices to draw attention to interoperability;
  - Increasing baseline knowledge of the topic among state commissions to elevate it as a priority;
  - Studying other state experiences or academic resources;
  - Convening stakeholders to discuss interoperability and the state's unique needs; and
  - Encouraging commissioners and staffers who have an interest in the topic to pursue it further.
- Formal state efforts to advance interoperability—typically within the context of broader grid modernization initiatives—was much more evident from roughly 2009 to 2012 than in the years since then. This decline can be attributed to the expiration of American Recovery and Reinvestment Act funding, which supported many of these efforts.

Barriers to Implementing Interoperability at the State Level on the Electric Distribution System are Wide Spread [i]

- There are many barriers to achieving interoperability and the adoption of open standards at the distribution system level. They range from limited time and resources to pursue the topic to limited interest in doing so.
- Competing priorities and lack of expertise have kept many state commissions from focusing on what interoperability for the distribution system can mean in practice and what discussions or efforts regarding interoperability and standards development are occurring at the national level. This is a significant barrier to their encouraging adoption of national standards at the state level. The limited expertise on this topic is compounded by a lack of access to needed resources.
- One of the biggest challenges to achieving interoperability on the distribution system is the absence of quantifiable data on the benefits of doing so. This sentiment was expressed by nearly every state commissioner and staffer contacted for this report. However, it is important to recognize the non-quantifiable benefits of interoperability, which have their own unique merits, while to extent possible attempting to add more quantitative analyses to the existing body of work.
- Specific barriers to increasing interoperability on the distribution system and adopting national standards at the state level to facilitate that process include: Many state commissioners and staffers lack information about the national efforts to encourage interoperability and develop related standards (including the work undertaken by NIST and groups such as GWAC, SGIP, and industry standards development efforts such as by IEEE and IEC).
  - Even the presence of a staffer or commissioner who *is* engaged on interoperability discussions at the national level does not necessarily translate into state adoption or action, due to the other barriers discussed in this section.
  - The lack of quantifiable data on the costs and benefits for ratepayers (and other state stakeholders) of implementing interoperable systems or components and use of associated standards is a significant barrier to implementation.
  - Many state commissions lack the time and funding to pursue interoperability issues (or even to become more knowledgeable about the topic). It is difficult to justify diverting strained resources to a topic that is not yet supported by clear, tangible benefit case studies.
  - Even for commissions with resources to focus on the issue, and interest in doing so, they face a limited range of recognized academic resources or studies that demonstrate how

[i] Interoperability can be both advanced and hindered by many entities and many factors. This report focuses on the role of states, particularly regulatory authorities, in furthering interoperability on the distribution system. However, there are many other entities that contribute positively or negatively to such efforts. For example, market segmentation and proprietary interface developments by technology suppliers can hinder interoperability. Reportedly, certain venders have also been known to oppose the development of common interoperability procurement language in an effort to preserve market share.

to address or encourage interoperability at the state level and how implementation could work in real-world settings.

- While they certainly can encourage such action, some state commissions are uncertain if encouraging their utilities to adopt national-level interoperability standards is within their preview, since standards-based implementation is typically a voluntary utility decision.
- The national discussions on interoperability and standards development tend to be more detailed and complex than what is occurring at the state level. For example, NIST and other industry and government partners are engaged in conversations on “Grid 3.0” (future grid) while many state commissions are still grappling with “Grid 1.0” (legacy grid) and Grid 2.0 (smart grid). This makes it difficult for states to ascertain which subsets of the national efforts are relevant for unique state situations.
- Additional technical factors that slow interoperability at the distribution level include the fact that 1) Cyber security concerns[j] may be a barrier to interoperability as some utilities can be wary of relying on standardized services and instead prefer proprietary utility systems, and 2) Decisions to upgrade existing infrastructure to have modern capabilities (e.g., to have interoperable functionality) are often undertaken when the infrastructure is reaching the end of life, which leads to a somewhat gradual process of introducing new technologies and interoperable system components. To date, interoperability efforts have often been focused on new deployments of system components as opposed to integration and interoperability with legacy infrastructure.

IMPLICATIONS AND OPPORTUNITIES

These findings and conversations with state commission experts suggest the following implications and opportunities for the Federal government to enhance interoperability and associated connectivity at the distribution level:

- Discussions with states indicate that having a state-specific “roadmap” would help them better understand how interoperability for the distribution system works in practice and how they can encourage relevant standards adoption within their states. It could include very basic information, such as 1) what interoperability means once implemented, 2) why it is relevant, 3) what standards exist, 4) which standards may be most beneficial to encourage regulated utilities and other constituents within their states to implement, and 5) the impact of the emerging, more distributed nature of power systems in the future—and ways to ensure that decisions made today do not foreclose future options. While much of this information is already laid out in various existing documents (e.g., see the NIST Smart Grid Interoperability Framework Version 3), many states indicated they were either unaware of this information and/or that in its current format it did not provide the kind of detailed, step-by-step roadmap they were envisioning or believe they need.
- State commissioners and staffers noted that having a cadre of qualified interoperability experts and consultants on these topics available to commissions—to support their analyses

[j] Some argue that there is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on “security through obscurity.”

or provide educational opportunities related to open and pending dockets—would help commissions gain a greater understanding of the benefits and risks associated with interoperability, as well as the history of such efforts and potential future of interoperability. Making these experts easily accessible for state commissions to consult with on time-sensitive questions during open proceedings would be particularly beneficial.

- Experience suggests that convening state commissioners or staff via webinars can be a cost-effective way to increase understanding of the benefits of interoperability (and associated standards).[k] The Federal government has a history of working with states and/or collaborating and supporting other organizations or state associations (e.g., NARUC) in convening states for training opportunities NARUC webinars are a good template for such cost-effective outreach. Previous NARUC webinars have touched on interoperability but more routine trainings organized in a systematic fashion would help drive state discussions on interoperability. Trainings could start from a very basic level and gradually progress to more advanced topics. Distributing a written summary of the training would reinforce and further stimulate discussions, as would providing record submissions for state proceedings depending on the topic and expertise involved.
- States indicated the need for a list of specific questions that commissions could use during rate cases or open dockets as a tool to help verify utilities' claims that they have adopted interoperable standards or implemented interoperable capabilities within their systems. The questions would need to be dynamic in order to facilitate a useful conversation between the commissions and utilities. An example of successful collaboration along these lines is the collaborative NIST-NARUC Training: NIST Cybersecurity Framework Workshop for Regulators and the associated delivered report.[l]
- As reported by states, commissions would be more likely to read and utilize information on interoperability if they had free access to relevant members-only resources (e.g., SGIP resources). For example, a summary or "news feed" of key information may serve as a way to inform commissions with limited budgets and still fulfill the business objectives of the dues-paying organizations.
- States indicated that having access to *distilled* versions of existing information (such as lengthy and sometimes technical documents from NIST, SGIP, GWAC, IEEE, others) would be very beneficial as the commissions are primarily comprised of non-engineers. This would make it more digestible for commissions and would help them understand the value and relevance of interoperability, potentially leading to greater attention to this topic at the state level.
- As states begin to more actively pursue interoperability and adopt national standards, providing a set of detailed best practices based on other states' experiences (the few that

[k] For example a NARUC training on Smart Inverters in June 2016 helped states understand California's point of view and experiences in developing Rule 21. It was anecdotally beneficial. For additional details see: https://www.naruc.org/naruc-research-lab.

[l] For additional details on the training see "NIST/NARUC Training: NIST Cybersecurity Framework Workshop for Regulators," July 6, 2016. Available via https://www.naruc.org/naruc-research-lab/lab-past-meetings.

exist) can serve as a database of such state actions and provide clarity for states that are in the early stages of considering interoperability issues.

- States indicated that quantitative analyses and studies that capture and analyze pre and post-condition data and demonstrate the costs/benefits of implementing interoperable devices and adopting associated standards at the distribution system level would help states evaluate or ascertain the quantitative value of encouraging interoperability among their constituents. It may even lead to more urgency, attention and systematic efforts to pursue interoperability at the state level. These studies would be most beneficial if they are unbiased and reliable, and if the results are easily digestible. Additionally, modeling tools that can be used to better evaluate and gauge the quantitative value of interoperability would assist states in deciding whether to actively encourage interoperability efforts. Undertaking economic evaluation and creating tools to determine cost effectiveness would also be beneficial.
- States noted that a state-centric portal for resources on interoperability, managed by and housed within an unbiased organization, would be incredibly informative and beneficial for state commissions, utilities, and other state stakeholders looking for information on the topic. Compiling existing resources into this portal that may currently be publically available but embedded among less directly useful information within the websites of NIST, SGIP, NARUC, NAESB, IEEE, IEC, and other relevant groups would make the resources more accessible to states.
  - Creating a proactive outreach program to assure states are aware of this portal and associated resources (as opposed to simply creating the portal and waiting for states to initiate efforts to access it) would make them more likely to use and digest the material. Continuously adding to the portal as additional resources become available would help keep the information relevant.
  - States indicate that creating an “interoperability 101 series” to explain interoperability standards “in plain English” would help state policymakers and commissions understand the role it plays in more advanced conversations, such as those around grid architecture.
  - Discussions with states suggest that short (5- to 15-page) documents discussing the advantages/disadvantages of pursing interoperability and associated standards in the near, medium and long term would help them ascertain the value of doing so in their particular situations. Ensuring that the information is articulated simply and is easy for commissioners to digest would be critical for ensuring absorption of the material.
- Discussions with states suggest that creating written materials, webinars, and training programs that explicate the inter-relationships between cybersecurity risks and interoperability could help provide a basis for targeted state—utility conversations.

1. INTRODUCTION AND BACKGROUND

The electric distribution system is in the midst of a profound evolution. The last decade has seen increasing deployment of distributed energy resources (e.g., distributed generation such as rooftop solar photovoltaic, storage, and electric vehicles, among others),[m] significant growth in advanced metering infrastructure (AMI) penetration,[n] and growing demand for controllability of demand-side assets via demand response (DR) mechanisms.[o] Additionally, consumers and third parties are becoming more active participants in electricity consumption and generation choices, and a plethora of vendors now offer a range of diverse energy efficient and clean energy technologies to consumers behind the meter.

As these customer-sited technologies become more prevalent, the distribution system must accommodate them. Interoperability[p]—the capability of two or more components to exchange information and utilize information so exchanged[6]—is a critical enabler in allowing these technologies to scale and in enabling the distribution system to evolve to manage them. [7] As noted in one recent report, these distributed technologies "need to be integrated into the electric grid safely, reliably, efficiently, and cost effectively. If a holistic approach to integrating these technologies into distribution systems is not developed, these technologies will not be deployed by utilities or in the market at the scale necessary to achieve national energy, economic, environmental, and consumer benefits."[8] This sentiment similarly applies to achieving state energy, economic, environmental, and consumer benefits and goals. Interoperability provides a foundation for enabling cost-effective integration of these technologies.

Oversight and regulation of the distribution system falls under state jurisdiction. Consequently, implementing interoperability for the distribution system and encouraging or adopting associated technical standards as well as verification through independent testing and verification is a responsibility of the states, utilities, and other state-level constituents. However, many states lack the resources or time to engage in these efforts. The Federal government could play a role in supporting states in efforts to advance and adopt associated standards. Since national economic security and other broad societal goals are furthered through advancements in the distribution system, this report offers insight into how the Federal government could assist states in pursuing enhanced connectivity and interoperability on the distribution system.

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[m] Residential solar experienced over 50 percent annual growth in 2015, for the fourth consecutive year (growing 66 percent over 2014), according to the SEIA and GTM Solar Market Insight 2015 Q4, http://www.seia.org/research-resources/solar-market-insight-2015-q4.

[n] In 2013 46 million smart meters were installed nationwide, by 2015 65 million were expected, encompassing roughly one-third of the total U.S. meters (145 million), according to Department of Energy, "2014 Smart Grid System Report to Congress," p. 4, August 2014, http://www.energy.gov/sites/prod/files/2014/08/f18/SmartGrid-SystemReport2014.pdf.

[o] For example, the total revenues to DR participants from capacity payments in ISONE increased from roughly 100 million USD in the delivery period 2016–2017 to roughly 350 million USD in the delivery period 2018–2019. Rough approximations are based on figures provided by FERC State of the Markets Report 2015, data derived from ISO New England, slide 26, https://www.ferc.gov/market-oversight/reports-analyses/st-mkt-ovr/2015-som.pdf.

[p] There are various definitions of interoperability, each of which capture important nuances. This definition is provided by the European Industry Association, see EICT Interoperability White Paper, "Information Systems Communication Technologies Consumer Electronics", June 2004.

The remainder of Section 1 provides an introduction to interoperability, including its definition with respect to the electric industry, and specifically the distribution system; a brief overview of the benefits of implementing interoperability on that system at the state level; and a summary of efforts to develop and implement interoperability standards. Section 1 also provides details on the purpose of this report and methodology employed.

Section 2 outlines the key issues analyzed in this report including: the *value* of open standards and interoperability on the distribution system; the *mechanisms and processes* that states have or could use to encourage implementation and adoption of standards among their constituents; the *barriers to implementing* interoperability at the state level on the distribution system; and some suggested remedies to those barriers. The analyses are informed by informal discussions with public utility commissioners and staffers in nine U.S. states as well as an extensive literature review. Section 3 offers several examples of states or utilities that have pursued interoperability efforts and highlights the processes employed and barriers faced along the way. Sections 4 and 5 provide a list of findings and implications/opportunities, respectively.

Interoperability of Personal Electronics

Personal electronics are models of the impact of interoperability standards. Cell phones and media players with physical interoperability provided by headphone jacks, for example, allow for users to plug and play on these systems. The 3.5 mm phone jack, in particular, is considered a miniaturized version of a more classic style (the quarter-inch jack technology dates back to 1878). Known for its tip-ring-sleeve (TRS) connection, the TRS jack has been used in audio equipment from 19th century telephone switchboards to 21st century cell phones—and still remains the de facto standard to date. The announcement by Apple Inc. in September 2016 to eliminate the headphone jack may alter this status quo in the future.

Sources:
Network Centric Operations Industry Consortium, "What is Interoperability?" https://www.ncoic.org/what-is-interoperability.

British Broadcasting Corporation, "The 19th Century plug that's still being used," BBC News Magazine, January 11, 2016.

1.1. Significance of Interoperability

Definition of Interoperability

Interoperability indicates the ability of systems, or components within systems, to exchange services or information with each other, and to operate effectively in an anticipated way without significant user intervention.[9] [q] Interoperability can be facilitated by the development of open standards,[r] adherence to those standards by participating parties, and verification through

[q] There are various definitions of interoperability, each of which capture important nuances. This definition is provided by the Gridwise Architecture Council.

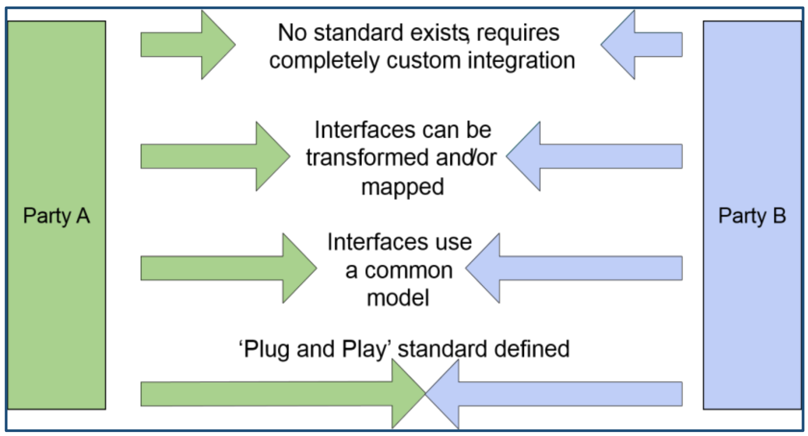
[r] The precise definition of "open standards" varies across organizations and subject matters. However, the primary principles of what constitutes an "open standard" are consistent with Free Software Foundation Europe (FSFE)'s definition, which characterizes open standards as "subject to full public assessment and use without constraints in a manner equally available to all parties… without any components or extensions that have dependencies on formats or protocols that do not meet the definition of an Open Standard themselves… free from legal or technical clauses that limit its utilization by any party or in any business model… managed and further developed independently of any single

independent testing and certification. It is important to note the standards in and of themselves do not ensuring interoperability; however, having a common understanding of standards and establishing comprehensive testing and certification protocols, (performed by trade alliances, independent organizations or others), can make achieving interoperability more feasible.

Achieving "plug-and-play" capability is a well-known example of interoperability where standards facilitate the discovery of a hardware component in a system without the need for physical device configuration or user intervention in resolving resource conflicts. In such a scenario, a user can automatically integrate a device on the system simply by plugging it in. Automated background processes assess and interpret the qualities of the connected component and configure it so it can function properly with the rest of the system. If the level of integration is considered as a length or distance, in the case of "plug-and-play" the distance to integrate a new device physically into a system is small (see Exhibit 1-1).[10]

Evidence of interoperability and enabling standards are plentiful across multiple industries and most consumers are already familiar with the plug-and-play tenet. The most common example of *physical interoperability* is found in electrical outlets. Having a standard outlet within the United States allows for the interoperable use of appliances and electronics throughout the country.[11] Similarly, the industry Universal Serial Bus (USB) standard allows for simple plug-and-play and barrier-free information exchange among a wide range of devices including memory sticks, computers, cell phones, printers, and tablets. The voluntary adoption of this standard by computer manufacturers has greatly enabled connectivity and innovation across a range of consumer devices.[12]

Exhibit 1-1 Distance to Integrate



Source: *Scott Neumann, UISol position paper*

vendor in a process open to the equal participation of competitors and third parties… [and] available in multiple complete implementations by competing vendors, or as a complete implementation equally available to all parties" (FSFE, "Open Standards." Available at https://fsfe.org/activities/os/def.en.html). Instead of "open standards," OMB Circular A-119 (a memorandum from the White House Office of Management and Budget regarding Federal participation in standards development) specifies the term "voluntary consensus standards," which are "standards developed or adopted by voluntary consensus standards bodies, both domestic and international. These standards include provisions requiring that owners of relevant intellectual property have agreed to make that intellectual property available on a non-discriminatory, royalty-free or reasonable royalty basis to all interested parties." Not all voluntary consensus standards are open standards but voluntary consensus standards often promote interoperability in the absence of "open" standards. (Office of Management and Budget, "Circular A-119 Revised," February 10, 1998. Available at https://www.whitehouse.gov/omb/circulars_a119).

In addition to physical interoperability, there are other layers of interoperability, many of which build upon the basic physical layer.[s] The USB stick and the computer (as an example) may exhibit physical interoperability via their plug-and-play capabilities, but for the computer to read the information contained within the USB device, there must be *syntactic interoperability* that enables shared understanding of the data structure in the messages exchanged. Further, for a computer application to utilize and integrate the data into an existing analysis there must be similarly defined variables and *semantic interoperability* that enables shared understanding of the concepts contained within the message data structure.[13] *Business* and *regulatory interoperability* layers are additional levels that must be considered. Ultimately, different interoperability standards may be needed to address each of these layers.

For the electric industry specifically, interoperability is defined as "the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the [distribution and transmission] systems to the power source, enhancing the coordination of energy flows with real-time flows of information and analysis."[14] [t] Interoperability of electricity system components—insofar as relates to information standards and cybersecurity—has received increasing attention in the last few decades, as the traditionally separate, disparate infrastructures and applications that historically characterized the industry have become increasingly interconnected. This has resulted in the actions of one component of the system influencing other components to a much greater extent than ever before.[15]

Furthermore, interoperability is a foundational component of the modernized or "smart grid,"[u] which is a large, complex "system of systems" with many stakeholders who each have diverse needs that must be met. [16] To realize the benefits of the modernized grid, a multitude of independently developed devices—created by a range of different manufactures or suppliers, managed by diverse utilities, and utilized by a countless number of customers—must effectively communicate and work together.[17] Additionally, these devices and systems must be compatible in terms of basic connectivity and communications capabilities as well as from a business and regulatory perspective. Interoperability for these devices on the modernized grid is often discussed within a grid architecture framework, which provides high-level context for identifying and debating the many complex interactions contained on current and future grids.[18]

At the distribution level, where many grid modernization efforts are focused, interoperability is defined by several key characteristics: [19]

[s] The concept of interoperability layers was first outlined by the GridWise Architecture Council and has since been incorporated into the NIST Smart Grid Architectural Model. See Section 2.1 of this report for additional discussion.

[t] There are various definitions of interoperability, each of which capture important nuances. This definition is provided by the Gridwise Architecture Council.

[u] According to the U.S. Department of Energy The "'Smart grid' generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation." For additional smart grid information see http://energy.gov/oe/services/technology-development/smart-grid. For additional information on interoperability as a component of the smart grid see NREL, "Interoperability is Key to Smart Grid Success," http://www.nrel.gov/continuum/utility_scale/smart_grid.html and GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

- An ability to exchange "meaningful, actionable information between two or more systems across organizational boundaries,"
- A common understanding "of the exchanged information,"
- An agreed upon "expectation for the response to the information exchange,"
- An obligatory "standard of service in information exchange: reliability, fidelity, security," availability.

Interoperability for the electric distribution system becomes increasingly important as additional distributed energy resources and advanced technologies with communications capabilities are deployed. As discussed immediately below and throughout this report, high interoperability among these devices can improve system efficiency and generate consumer and utility benefits. Low interoperability can lead to unnecessarily high system integration costs.

High-Level Benefits of Interoperability and Interoperable Standards

When the above characteristics are all present on the distribution system, enhanced capabilities extend beyond the local component of each subsystem and can provide a wide range of benefits to the system, to individual stakeholders, and to the industry more broadly.[20] Although the greatest benefits will be achieved from comprehensive grid modernization implementation, interoperability standards enable the integration of information and communications technologies (ICT), which are a critical component of the modernized grid.

Additionally, encouraging distribution system interoperability through the development and implementation of interoperability standards can generate important benefits. For example, standards can **enable future compatibility** by providing a structured interface for future developments and help ensure that technologies deployed today (such as AMI), are interoperable with more advanced technologies or future AMI deployments. Standards that advance interoperability can also **decrease system integration costs** by enabling the use of common, specified interfaces (as opposed to necessitating customized interfaces for each new system or component that is added), thereby reducing the cost of introducing new technologies and applications onto the system. Similarly, it can extend the useful life of legacy infrastructure. Additionally, interoperability and associated standards can help **encourage innovation** by increasing the likelihood that new technologies can be deployed across the grid, thereby providing a reliable market for end products. It can further reduce costs and can reduce investment uncertainty by reducing market fragmentation, decreasing transaction costs, promoting competition among vendors, helping avoid "vendor-lock," and enabling economies of scale.21

While standards do *promote* interoperability, they do not *guarantee* interoperability. Testing programs are needed to ensure that products are both compliant with standards *and* interoperable. Standards enable functional performance and testing programs provide the verification that the standards have been implemented appropriately to provide interoperability. Testing and certification is taking on increased urgency driven by the fact that while there are many smart grid standards, there remains a large gap in the availability of test programs corresponding to these standards.

From a security perspective, such well-designed standards can build in and help **improve cybersecurity** in the future grid by making sure the system is not susceptible to security threats from undiscovered vulnerabilities in today's (often proprietary) installations. From a consumer perspective, interoperability standards that are open and consensus-based decrease the likelihood that companies will lock consumers into proprietary technologies that are incompatible with other systems/devices, which **increases consumer choice**.[22] This may become even more important as smart appliances, smart thermostats, and smart building management system become more widespread.

It is important to keep in mind, however, that achieving interoperability on the modernized distribution system—and standards to support those efforts—is a complicated endeavor that will require the buy-in of many industry stakeholders. Additionally, numerous other enabling aspects of achieving a modernized grid, which are all evolving at their own rates, will have various impacts on interoperability standards decisions and need to be considered in tandem with such efforts. These factors include determining what the prevailing grid architecture(s) will be, the rate of technology advancement, policy requirements and regulatory initiatives, among others. Similarly, achieving interoperability will presumably be dependent on the voluntary adoption of industry standards as well as testing and certification, which is the prevailing method of standards adoption today among utilities and other relevant stakeholders.

Ultimately, creating a modernized grid with full interoperability will require continuous revision and deliberation as the industry progresses. However, advancing the discussion on interoperability and necessary standards now is a critical step in helping to reduce barriers to system integration tomorrow and so that decision makers have a baseline knowledge of the value that pursuing interoperability and implementing associated standards can provide.

1.2. Purpose and Methodology

Although the significance and qualitative value of interoperability for the electric grid, including distribution system components, is acknowledged (see section 2.2), state efforts to pursue interoperability for the distribution system are limited and the rate of open interoperable standards adoption at the state level is ad hoc. This fragmentation is due in part to the fact that 1) there are a vast number of distribution utilities 2) interoperability standards—like most—are not typically mandatory, and 3) the distribution system falls under individual state jurisdictions as opposed to Federal jurisdiction. Further, state governments and regulators may not have the bandwidth, financial resources, or technical expertise to encourage or ensure, the pursuit of interoperability or the adoption of open interoperable standards.

However, the Federal government could provide resources to support states in this endeavor. The purpose of this report is to identify, with input from states, opportunities to help facilitate open standards that enhance interoperability and connectivity on the distribution system. To do so, this report investigates four key topics. These focus areas include identifying:

- The value of pursuing interoperability and implementing associated standards at the state level;

- The mechanisms through which a state might pursue interoperability or encourage its constituents to adopt open interoperable standards;
- The gaps or barriers to achieving interoperability at the state level and potential remedies; and
- The feasibility and interest that states have in direct or facilitated participation in standards development or other interoperability forums.

To assess these topics adequately, a thorough review of existing literature was conducted, including a review of publications produced by independent organizations and government agencies, industry groups, academic institutions, and other reports from relevant stakeholders. Additionally, informal discussions were held with commissioners and staff members from public utility commissions in nine states as well as with an expert from the National Association of Regulatory Utility Commissioners (NARUC). In these discussions, information was gathered on the mechanisms and processes state regulatory commissions are using (or have used) in encouraging their constituents to pursue interoperability and implement associated standards, and barriers they have encountered along the way. Several of the state experts contacted were either currently or previously involved with the Smart Grid Interoperability Panel (SGIP).

The insights these experts provided were anecdotal.[v] There was not a comprehensive survey of state experiences or views. Significantly, the nine states in which experts were contacted were selected because many have a reputation for being on the leading edge of interoperability efforts (i.e., within their state) or have the most advanced knowledge of standards development efforts (i.e., at the national level). Insight gained from the discussions with state experts has largely been aggregated and anonymized to protect the integrity of ongoing commission proceedings and to accommodate other sensitivities. All statements provided reflect the opinions of the individual and were not expressed on behalf of the state commissions. See the Appendix for a list of individuals contacted for this report. Information gathered during the literature review and discussions with states has been evaluated to identify key findings and implications/opportunities.

1.3. Current Status of Interoperability Standards

The majority of efforts related to developing and marketing interoperability standards are undertaken by industry standards organizations, such as the Institute of Electrical and Electronics Engineers (IEEE), which is an international Standards Development Organization (SDO)[w] or the International Electrotechnical Commission (IEC). Additional standards developing organizations include the Society of Automotive Engineers (SAE); the American Society of Heating,

[v] Information provided during the discussions was offered by state experts based on their own personal experiences and insights gained from working on these issues in their respective states or with relevant state groups. The authors did not conduct independent, scientific research into ongoing state proceedings, open dockets, or official state policy or other pronouncements.

[w] According to the American National Standards Institute, Standards Development Organization, "SDOs are independent organizations that identify market needs and react accordingly, working directly with technical experts from around the globe to develop appropriate standards. Most SDOs welcome – or even actively encourage – participation from companies, government officials, organizations and other stakeholders from around the globe." For additional discussion and a list of national and international SDOs (not all relevant to smart grid interoperability standards) see https://www.standardsportal.org/usa_en/resources/sdo.aspx.

Refrigeration and Air-Conditioning Engineers (ASHRAE); the North American Energy Standards Board (NAESB); the International Organization for Standards (ISO) and the Internet Engineering Task Force (IETF), among others. Within the United States, the National Electric Manufacturers Association (NEMA) and ANSI are key coordinators and drivers of standards development. Once standards have been developed and tested, still other organizations support the deployment and wide-scale implementation of interoperable platforms and frameworks, including trade alliances such as the OpenADR Alliance and the Green Button Alliance, and other organizations such as the Organization for the Advancement of Structured Information Systems (OASIS).

The U.S. Federal government also supports interoperability standards development and adoption through a number of avenues, such as by convening key stakeholders, forming working groups like the GridWise Architecture Council (GWAC), sponsoring projects through the Department of Energy, or encouraging the creation of the SGIP. Implementation of standards at the state level has progressed at various rates.

National Efforts Related to Interoperability and Standards Development

Several nation-level groups have been actively involved with supporting the development of interoperability standards since 2004, when the DOE formed GWAC to identify key interoperability challenges and to promote the integration of interoperable modernized grid technologies by industry stakeholders.[23] These technologies include AMI for distributed generation, a variety of demand-side management (DSM) technologies, and other devices that facilitate network communications.

In 2007, the Energy Independence and Security Act (EISA) identified NIST as the lead agency for coordinating the development of a framework of protocols and model standards that would facilitate interoperability among smart grid devices and systems.[24] The American Reinvestment and Recovery Act of 2009 (ARRA) allocated $10 million of funding to support grid modernization interoperability efforts, to be transferred from DOE to NIST. This funding was supplemented by an additional $2 million of DOE ARRA funding for a total of $12 million provided to NIST to enable the Agency to increase its smart grid activities under EISA and to coordinate the development of an interoperability framework.[25] In May of 2009, NIST identified its initial set of interoperability standards, composed of 16 protocols that addressed a range of grid infrastructure and cybersecurity concerns.[26] Following the release of this initial framework, NIST published a report in September of 2009 that added 14 “priority action plans” and 64 additional standards—for a total of 80—that comprised a more complete strategy for ensuring smart grid interoperability.

In November of 2009, NIST convened the Smart Grid Interoperability Panel (SGIP) as a government-funded public-private stakeholder forum. The panel functions as a national forum through which electricity industry stakeholders can work together to identify and address smart grid interoperability issues and provide input and cooperation to NIST, which supports the Institute in its responsibilities under EISA and to accelerate smart grid interoperability standards development through implementation of priority action plans.[27] Initially a public-private partnership, the SGIP transitioned to a non-profit organization in 2013 and today operates as a private entity, supported by membership dues and with continuing but lower financial support from NIST, and participation by NIST, DOE and other interested Federal parties through membership.

The panel pursues a mission to accelerate grid modernization through education, coordination and the acceleration and promotion of interoperability standards, as well as through coordination with GWAC and international standards-setting organizations.[28]

In January of 2010, NIST released its first "Framework and Roadmap for Smart Grid Interoperability Standards," a report that outlines extensively the standards and protocols that promote smart grid interoperability. Since 2010, NIST has twice revised this "Framework and Roadmap," with the most recent version (Release 3.0) being published in September of 2014.[29] Part of this NIST process has been to identify existing standards that are relevant to the development of the modernized grid (see Appendix). FERC was charged by EISA with "instituting rulemaking proceedings to adopt the standards and protocols [identified by NIST] as may be necessary to ensure smart grid functionality and interoperability once, in FERC's judgment, the NIST-coordinated process has led to sufficient consensus."[30] FERC initially reviewed the first set of smart grid interoperability standards identified by NIST framework in 2011, finding the five families of standards did not achieve sufficient stakeholder approval.[31] Despite withholding formal approval, FERC encouraged stakeholders to continue working with NIST on the interoperability framework process and to use it for guidance on smart grid standards."[32] To date, FERC has not formally approved the standards and protocols of NIST's current framework, but maintains that NIST's process represents the best vehicle for developing standards for the modernized grid.[33]

NIST and SGIP support industry-led grid modernization interoperability efforts in a number of ways. This includes executing active Priority Action Plans (PAPs), identifying new areas to be addressed by future PAPs, reviewing standards for inclusion in SGIP's Catalog of Standards, and working with standards-setting organizations (SSO) and other industry stakeholders both to improve current standards and to develop new ones that will address emerging issues related to grid integration of new technologies.[34]

Industry Efforts Related to Interoperability and Standards Development

While NIST and SGIP play an important role in creating a *framework* for enabling grid modernization interoperability and associated standards, it is important to recognize that interoperability standards development is an industry-led process. These standards are typically adopted by utilities and other relevant industry stakeholders voluntarily. Government organizations can partner with industry on standards development of mutual interest. The Green Button Initiative is an example of industry-government collaboration to respond to a White House call to action (see box below).

Green Button Initiative

One example of an industry effort with government co-leadership is the response to the national call to action through the Green Button Initiative. Launched by the White House's chief technology officer, Aneesh Chopra, and the Office of Science and Technology Policy (OSTP) in 2011, the initiative encouraged the design of a "Green Button," a user-friendly tool that would enable electricity customers to access their energy usage information easily and securely.[a] NIST and DOE worked closely with OSTP to provide encouragement and technical support to enable several major utilities across the country—with several operating in California—to implement Green Button pilots in response to the Administration challenge. This work built upon prior standards efforts initiated and coordinated by NIST and SGIP, resulting in the completion of the North American Energy Standards Board's (NAESB's) Energy Services Provider Interface (ESPI) standard.[b] REQ.21 created a consistent process for the retrieval of customer energy usage information, and an interface over which a third party service provider could facilitate this query.[c] NIST and industry collaborators, including UCAIug and OpenESPI and the Green Button Alliance, further developed testing and certification for Green Button and software support tools including a developer "sandbox" to support utility and third party Green Button implementations and application development. NIST provides leadership and support that has accelerated—and will continue to accelerate—the development and ongoing evolution of the technical standards that serve as the foundation for Green Button.

As part of this activity, Green Button was developed with privacy best practices, and reviewed to ensure that certified applications met the agreed-upon specification that no personally identifiable information (PII) is contained within Green Button-accessible data.[d] Today, Green Button still uses NAESB REQ.21 to ensure that customers can view their metered data in standard format. Additional frameworks have been developed that allow users of Green Button to download their data, as well as to connect their data over secure channels to application developers who can provide third-party services. The "Connect My Data" aspect of Green Button exemplifies yet another example of advancement through collaboration; the IETF developed an updated set of Authorization Framework standards (RFC6749) and (RFC6750) to facilitate these data transfers. Future demand-side management programs, other customer-choice initiatives, and interoperable standards development processes may be able to use lessons learned from the Green Button process to support future innovations in customer service, cybersecurity, interoperability initiatives, or other aspects. For example, the SGIP contacted NAESB to use the Green Button Initiative as a template for developing an OpenFMBTM standards framework.[e]

[a] *North American Energy Standards Board, "REQ.21—Energy Service Provider Interface," site updated 2016, https://www.naesb.org/ESPI_Standards.asp, p. 1.*
[b] *North American Energy Standards Board, "REQ.21—Energy Service Provider Interface," p. 1.*
[c] *North American Energy Standards Board, "REQ.21—Energy Service Provider Interface," p. 1.*
[d] *Green Button, "An Overview of the Green Button Initiative," http://www.greenbuttondata.org/learn/, p. 1.*
[e] *OpenFMB™ is a framework and reference architecture for the interaction of distributed intelligent nodes. Smart Grid Interoperability Panel "OpenFMB™" http://www.sgip.org/openfmb/#faq.*

Additionally, the Institute of Electrical and Electronics Engineers (IEEE) defines and promotes protocols and standards that contribute to interoperable electricity infrastructure and all associated communication networks.[35] Two leading families of industry standards are the IEEE Standard 1547 series and IEEE Standard 2030 series.[36] IEEE Standard 1547, established in 2003, was the first of a group of standards to govern interconnection of distributed energy resources (DER) with grid systems. One key capability of IEEE 1547 is its technological neutrality;

the standard guides the technical specifications and testing of interconnection infrastructure, not the technology being linked.[37] Essentially, the standard provides minimum functional technical requirements to ensure sound interconnection.[38]

IEEE Standard 2030, first published in September of 2011,[39] provides a framework of approaches and best practices directed at developing an IEEE set of national and international standards to govern smart grid interoperability. The standard is multidisciplinary, including roadmaps for power applications as well as information exchange and network controls, all of which must be interoperable in order to compose a workable grid system.[40]

Other stakeholders have joined the IEEE in developing interoperability standards from the industry perspective. NEMA and ANSI have developed protocols to guide communication between meters and utility systems over an AMI network that can operate with a variety of communication media.[41]

Another leading family of standards to support smart grid interoperability is the Common Information Model (CIM), IEC standards provide an abstract information model that identifies data by its uses and associations, and can be leveraged and developed to support communications between distributed generation and utility systems.[42] While the CIM standards provide the semantic basis for standards frameworks, both utilities and third-party service providers can build off CIM categories' categorization of data relationships to develop more relevant and dynamic frameworks and structures for data collection and use. The IEC develops widely used international standards for all fields of electrotechnology, including smart grid devices.[43] A coalition of CIM developers and adapters—the CIM Users Group or CIMug—have used the CIM framework to apply IEC standards to electric utility operations. Key IEC standards include 61970 for power system modeling and both wired and wireless electric utility data exchange; 61968 for power system software that models energy asset location and performance; 61850 for substation communications; and 62325 to support modeling of both North American and European energy markets.[44] Further refinement of CIM protocols will support ongoing development of data exchange and interoperability standards as grid modernization activities deploy greater volumes of smart technology and its associated software systems.

State Efforts Related to Interoperability and Standards Adoption

A number of states have made progress toward outlining smart grid roadmaps that have an interoperability and/or interoperable standards component (often informed by the work done by NIST and SGIP). As reported by National Renewable Energy Lab (NREL), nearly 75 percent of states have used the IEEE Standard 1547 series to guide the development of interconnection rules used by their commissions, municipal utility companies, and rural electric cooperatives.[45] The standards can be further tailored to specific state needs.

For example, in California, both the state public utility commission (CPUC) and the state energy commission (CEC) have collaborated with SSOs to facilitate the development of interoperability standards for smart inverters.[46] Other states have turned to pilot projects to explore interoperability solutions for grid modernization infrastructure. Colorado created a Smart Grid Task Force to offer recommendations for the effective deployment of smart grid infrastructure.[47]

The task force published guidance that addressed open communication standards for metering protocols, open technology standards to encourage manufacturer competition, and other recommendations designed to promote grid interoperability.[48]

Ultimately, achieving interoperability at the distribution system level—and utilizing open standards along with testing/verification to further those efforts—is an ongoing and iterative process that many states are yet to fully embrace. The following section dives more deeply into the value propositions for implementing interoperability on the distribution system and adopting associated standards, the mechanisms that can be utilized, and the barriers that states currently face in encouraging their constituents to do so.

2. Discussion of Key Issues

The purpose of this report is to identify, with input from states, opportunities for the Federal government to help promote use of open standards that enhance interoperability and connectivity on the distribution system. To aid in that endeavor, an extensive review of literature was conducted and informal discussions were held with public utility commissioners or staffers in nine diverse states. The discussions below are a synthesis of insight gained from these activities.

Subsection 2.1 provides context for considering the *types* of interoperable functionality that distribution system components need. Specific technologies, individual standards and technical interoperable functionalities are referenced occasionally throughout this section but the majority of the discussion is purposely constrained to a distribution level viewpoint and to the broad *levels* of interoperability, in an effort to be widely applicable and digestible for a non-technical audience.

Subsection 2.2 notes the widely agreed upon qualitative, and thus far limited quantitative, benefits of interoperable systems/system components and of adopting standards to advance those efforts. It highlights the benefits that could be realized at the distribution system level and the state-centric value proposition for enhancing connectivity and interoperability on the distribution system.

Subsection 2.3 discusses the mechanisms and processes that states or local governments are using, or could use, to pursue interoperability for the distribution system and to encourage constituents to use open standards.

Subsection 2.4 identifies the many barriers that currently hinder states from pursuing interoperability efforts and the use of associated standards. It also highlights several potential remedies that were suggested by the state commissioners and staffers contacted.

Subsection 2.5 discusses the feasibility and desirability of state participation in developing interoperability standards.

The concluding sections list findings and implications/opportunities. They are derived from the discussions in this section.

2.1. Interoperability of Key Distribution System Components

The electric system is large and multifaceted. As it transitions toward a smarter, more modernized system, it is becoming even more complex while simultaneously necessitating greater integration and interoperability. These types of large, integrated, and multidimensional systems require various layers of interoperability.[49]

Interoperability for such a system—often referred to as the "smart grid"—is best discussed within the context of an architectural framework, which provides guidance on how interoperability can be achieved in a large-scale distributed system. Some argue that establishing interoperability requires establishing the architectural framework first.[50] Grid architecture embodies high-level principles and requirements that designs of smart grid applications and systems must satisfy (for additional discussion see box).

Grid Architecture

Definition: According to the PNNL Grid Architecture Project, "Grid Architecture is the application of system architecture,[a] network theory, and control theory to the electric power grid. A grid architecture is the highest level description of the complete grid, and is a key tool to help understand and define the many complex interactions that exist in present and future grids."[b]

Need for grid architecture and fundamental goals: The electricity grid is becoming increasingly complex and the penetration of distributed energy resources, among other factors, are changing the traditional grid structure. Historical methods of addressing grid interaction are siloed; grid architecture offers a modern way of thinking about interactions, complexities, and communication of the grid.[c] Underlying architectural goals for the smart grid, according to NIST, include having: options, interoperability, maintainability, upgradability, innovation, scalability, legacy, flexibility, governance, and affordability.[d]

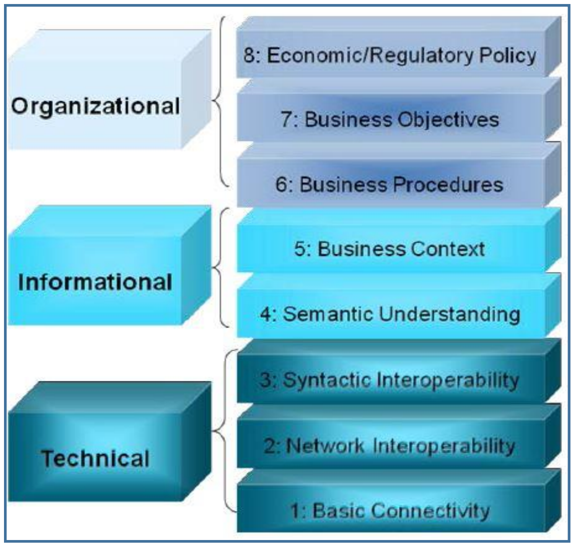
International grid architecture efforts: There are multiple smart grid architectures under development by a number of different organizations, as part of larger smart grid efforts. The U.S.-based NIST Framework and Roadmap for Smart Grid Interoperability Standards[e] and the associated Smart Grid Architecture Model (SGAM) are two key efforts. Other prominent efforts include those promoted by the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), the European Union, Korea, and China. NIST and SGIP have initiated efforts to collaborate and align activities with these groups.[f]

[a] *System Architecture is defined by the PNNL Grid Architecture Project as "A system architecture is the conceptual model that defines the structure, behavior, and essential limits of a system."*
[b] PNNL, Grid Architecture Project, *http://gridarchitecture.pnnl.gov*.
[c d] *NIST Framework and Roadmap for Smart Grid Interoperability Standards v3.0, 2014.*
[e] *NIST Framework and Roadmap for Smart Grid Interoperability Standards v3.0, 2014.*
[f] *Apel, Rolf, "Smart Grid Architecture Model Methodology and Practical Application," Siemens, EPCC, 12th International Workshop, June 4, 2013. Also NIST Framework and Roadmap for Smart Grid Interoperability Standards 3.0, 2014.*

Several different grid architecture frameworks are promoted worldwide. The prevailing framework in the United States is outlined by NIST (most recently in the NIST Framework and Roadmap for Smart Grid Interoperability Standards Version 3 in 2014), and referred to as the Smart Grid Architectural Model (SGAM). The SGAM is an evolving framework that can be used to guide the development of the smart grid. SGAM has many complex components and uses, the details of which are outside the scope of this discussion.[x] The SGAM discusses the interoperability component of the smart grid in layers. The concept of layers was originally defined by GWAC and is referred to as the GWAC Stack.[51] In the last several years, NIST and SGIP have undertaken efforts to align those layers with a broader architecture standard,[52] but for the purposes of this discussion, the original GWAC Stack provides the most useful basis for understanding the types of interoperable functionality needed by components of the distribution system. The GWAC Stack layers represent a "vertical cross-section of the degrees of interoperation necessary to enable various interactions and transactions on the Smart Grid."[53]

The GWAC Stack includes eight layers of interoperability (see Exhibit 2-1). They represent the different types of interoperation that are needed in order to allow devices and systems on the smart grid to communicate, interact, and conduct transactions effectively. At the distribution level in particular, the key technologies and components of the distribution system that most necessitate interoperable functionality include, but are not limited to AMI, integration of distributed renewable energy generation and storage, distribution grid management, DR, consumer energy efficiency, and network communications (which enables the previously listed technologies).

Exhibit 2-1. GWAC Stack



Source: GridWise® Interoperability Context-Setting Framework is a work of the GridWise Architecture Council.

The lowest layers of interoperability, such as basic connectivity and network and syntactic interoperability, include simple functionality (e.g., interoperability of physical equipment and software for encoding and transmitting data). The middle layers, such as semantic understanding and business context, include communications practices and functionality (e.g., the content, meaning, and format for informational flows). The highest layers, such as business procedures and objectives, as well as economic/regulatory policy, address relationships between individuals and/or organizations at various parts of the system, such as business (e.g., contracts), legal (e.g., intellectual property rights), and policy (e.g., regulations).[54]

The eight GWAC layers can be grouped into three categories of interoperability*: technical, informational, organizational*. To achieve full, effective interoperability all three types must be addressed.[55]

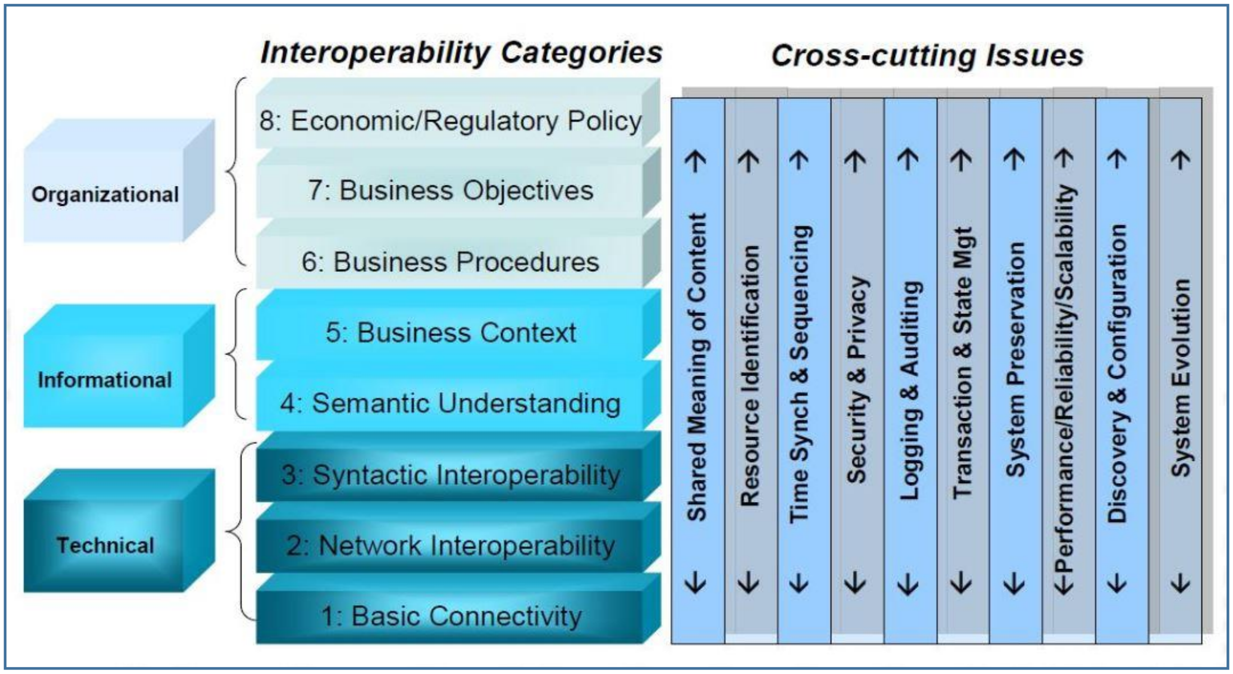
Each layer represents increasing sophistication and complexity. Additional layers are required to interoperate to attain the desired outcome as devices/systems become more sophisticated. Each

[x] For example, the SGAM framework can be used to provide stakeholders a common understanding of the elements that make up the smart grid and their relationships; provide a series of high-level and strategic views of the envisioned business and technical services, supporting systems, and procedures; and guide the various implementation architectures, systems, organizational structures and supporting standards that make up the smart grid. For additional use, information, and discussion see NIST Framework v3.0 p. 123, available via: http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

layer builds upon and is enabled by the layers below it.[56] According to NIST, "the most important feature of the GWAC Stack is that the layers define well-known interfaces which are loosely-coupled: establishing interoperability at one layer enables flexibility at other layers."[y]

In addition to the eight layers and three categories of interoperability, GWAC identified a number of issue areas that cut across all of the layers. These topics include areas such as "shared meaning of content," which highlights the importance of effective communication at all levels of interoperability. Additionally "security and privacy" are needed throughout each layer to ensure that systems and their components maintain confidentiality, integrity, availability, and accountability.[57] For a full list of crosscutting issues see Exhibit 2-2.[z]

Exhibit 2-2. GWAC Stack with Crosscutting Issues



Source: The GridWise® Interoperability Context-Setting Framework is a work of the GridWise Architecture Council.

A useful example of how each layer builds upon lower layers to collectively enable full interoperable functionality can be found in the various layers of interoperability that are needed for demand pricing signals (see Exhibit 2-3).

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[y] In the most recent version of the NIST Framework, work is being pursued by the SGAC, EU M490, and IEC62357 to align the "GAWC Stack" layers with the SGAM use of The Open Group Architecture Framework (TOGAF). For more information see National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," NIST Special Publication 1108r3, p. 39, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[z] Additional discussion on these issues can be found in various GridWise Architecture Council reports.

Exhibit 2-3. Layers of Interoperability Needed for Demand Pricing Signals

LAYER OF INTEROPERABILITY*	STANDARD	OUTCOME
Layer 8: Economic/Regulatory Policy	PUC- approved retail real-time pricing program	Customers manage consumption based on real-times prices
Layer 7: Business Objectives	Registrations and certifications for various provider functions with oversight by state and Federal regulators, while customers are subject to particular retail tariffs	Electricity retailer objectives align with building services providers to aggregate demand; building owners choose service provider with package that best meets their needs
Layer 6: Business Procedures	Data formats generally specified by energy providers or energy market operators	Hour ahead price sent by electricity retailer to building service providers, acknowledgment returned with forecast next hour demand
Layer 5: Business Context	Tailored portion of Common Information Model (CIM), e.g., model building and energy price information	Building controls and operational systems share data and understand instructions
Layer 4: Semantic Understanding	IEC 61968 and 61970 Common Information Model standards using W3C OWL (web ontology language) for defining a common vocabulary about the electric power grid	Information exchanged between electric power distribution systems and utility energy management systems
Layer 3: Syntactic Interoperability	SOAP messaging, UDDI registry and discovery, and XML for message formats and structuring of information	Applications recognize and parse messages
Layer 2: Network Interoperability	TCP/IPsec for secure packaging and addressing of data	Data transfer among networked devices
Layer 1: Basic Connectivity	IEEE 802.11 for wireless connectivity [Wi-Fi]	Networked remote devices

Source: Information Derived from GridWise Architecture Council, Presentation by Ron Melton & Ron Ambrosio.

**According to GWAC Stack concept.*

2.2. Benefits of Enhancing Connectivity and Interoperability at the Distribution System Level

Qualitative Value of Interoperability

Interoperability on the distribution system, and standards that help advance implementation, can provide a wide range of benefits to customers, utilities, third parties, and other grid stakeholders. The benefits of interoperable systems and system components are difficult to quantify,[58] however, a widely agreed upon set of qualitative benefits underscores the value of interoperability at the state level on the distribution system and serves to encourage the development of quantitative analyses in these areas.

Qualitative benefits of interoperability can be summarized as follows:

- **Reduction of system integration costs and extension of asset life** – Interoperability standardization necessarily decreases costs to deploy and integrate new technologies and applications into an existing system, by definition eliminating the need to modify existing systems extensively to accept and communicate with the new technology. It can also lower operations and maintenance costs as well as extend the useful life of legacy infrastructure and continued asset utilization.
- **Generation of economic benefits** – Interoperability decreases market fragmentation, enables economies of scale, and can reduce transaction, equipment, and other costs for both suppliers and customers.
- **Catalyst of innovation** – Interoperability standards enable a technology-neutral market; reducing investment uncertainty, incentivizing innovation where standard interfaces can be defined, and ensuring that currently deployed infrastructure can continue to provide value within newer systems.
- **Increase in customer choice and participation** – Interoperability allows customers to choose between features instead of between technologies, prevents companies from "locking in" customers (both utilities and consumers) with proprietary systems, and facilitates customer trust of new vetted technologies.
- **Improvement of grid performance and efficiency** – Interoperability promotes a more efficient, reliable grid. It helps ensure both demand-side and supply-side load management work cooperatively and productively. Standards ensure that today's technology can be interface with future technologies.
- **Establishment of industry-wide best practices** – Interoperability standards can collectively form a playbook, providing guidance for all utilities facing emerging industry issues; smaller utilities benefit from being able to pull technology "off the shelf."
- **Facilitation of more comprehensive grid security and cybersecurity practices**– Interoperable technologies permit the application of a single, comprehensive security

framework and enable coordinated and consistent cybersecurity practices. [aa] Additionally, interoperable technologies can reduce the number of systems and interfaces required for operators to monitor and manage the electric grid, thus enabling more timely and coordinated responses to emergency events.

These benefits are discussed in greater detail below.

Reduction of System Integration Costs and Extension of Asset Life

An important benefit of interoperability for the distribution system is that it allows distributed devices and applications to integrate onto the grid more quickly, easily, and cost effectively, which ultimately makes them more affordable for utilities and consumers. Standardization necessarily decreases costs to deploy and integrate new technologies and applications into an existing system, by definition eliminating the need to modify existing systems extensively in order to accept and communicate with the new technology. In addition, interoperability including equipment monitoring and assessment of operating conditions on an ongoing basis can also reduce repair costs and extend equipment life.[59] It can also lower operations and maintenance costs as well as extend the useful life of legacy infrastructure and continued asset utilization (i.e., system operations).

Further, interoperability down to the consumer level can facilitate easier integration and greater adoption of devices such as renewable energy resources or storage, and can even provide the foundation for widespread deployment of technologies such as plug-in electric vehicles. Lack of interoperable functionality and the inability to communicate effectively can hinder adoption of these, and other, technologies and can increases deployment costs.[60] It may also limit scalable energy efficiency measures, renewable technology deployment, and storage adoption; the connectivity and interoperability of buildings provides a useful example:

> *"Integrating legacy sensors and actuators in buildings with new retrofit control and automation systems requires development of customized device drivers that bind the legacy systems to the new integration architecture. This is expensive when the number of devices is large. The desired state of technology interoperability is where end-use resources (generation, storage, and loads) can seamlessly communicate and transact with a range of energy services. This exchange will occur across the meter with the utility and with other end-use loads or generation. Interoperability, in particular as embedded in software, reduces the cost (and time) of technology integration, including the cost of software installation."*[61]

Generation of Economic Benefits

Interoperability can decrease transaction costs, lead to lower equipment costs, and increase competition among suppliers.[62] By reducing the level of market fragmentation and enabling

[aa] There is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on "security through obscurity." Highly interoperable systems do require disciplined cyber security, but the resultant system can be easier to administer, police and upgrade against evolving threats.

economies of scale, interoperability can lower costs for utilities and therefore their customers.[63] By standardizing technologies, interoperability can ensure that ratepayers today are not funding utility projects that will be obsolete tomorrow. [64] In this way, standards help keep prices lower while providing greater choice for customers.[65]

Interoperability standards can also help utilties manage costs.[66] Over the long term, integration and interoperability will enable greater production and capture of information and data from advanced metering, customer data management systems, DR, and distribution automation, which can help utilities and grid operators use grid assets more effectively and efficiently. This allows owners and operators to make more precise investment decisions, ultimately lowering their grid capital costs.[67]

Standardizing interoperable communications between devices can also cut down on costly errors and reduce barriers to information sharing.[68] The overall costs of operating the grid can decrease as smart devices autonomously and easily integrate without needing to be reworked from the back end, as they are able to perform tasks more quickly and cost effectively than traditional, non-interoperable devices.[69]

Catalyst of Innovation

Interoperability standards can foster innovation among competitors by spurring the development of new technology and new applications.[70] Standards that ensure interoperability between hardware and software from diverse vendors, as well as those that allow newly developed products to work with legacy equipment,[71] serve to support the development and deployment of emerging technologies.[72] With the assurance that new, compliant technologies can be used throughout the grid, standards encourage the creation of a significant market for entrepreneurship.[73]

For instance, the telecommunications industry is interoperable—cell phones can all communicate with each other regardless of network provider.[74] This foundation of interoperability allowed for mobile technology development such as camera functions and Internet connectivity across all users, and also ensures that software and hardware can be updated or upgraded without becoming obsolete (e.g., smartphones).[75] Similarly, as the grid modernizes, interoperability standards could ensure that technological developments foster the interaction of grid infrastructure with non-grid devices, such as electric vehicles.[76]

Increase in Customer Choice and Participation

Interoperability standards are not designed to favor one type of technology over another. That is, they allow consumer choice between vendors offering similar, interoperable technologies with different features, rather than between types of different, non-interoperable technologies.[77]

Standards enhance user choices by enabling innovation and product development. They also enable additional energy use options for customers, including integration of demand-side and behind-the-meter technologies such as distributed generation and AMI.[78] Without interoperability standards, companies may attempt to “lock in” customers with proprietary technology.[79] Once implemented, standards help consumers trust and adopt new technologies and products in their homes and businesses.[80]

Improvement of Grid Performance and Efficiency

When advanced communication and information technology work interchangeably, better control of energy flows can be achieved. The result is a more efficient, resilient, and reliable grid.[81] Interoperability standards allow for more effective interaction and collaboration between power users and power suppliers to manage and meet electric load.[82] In addition, interoperability allows more information to be transferred to grid operators who can use the data to improve grid reliability and protect grid operations. Better monitoring and communication systems, as well as better control and power management devices, allow the grid to meet electricity demand more efficiently, seamlessly, and automatically.[83]

The success and full advantages of new technologies like distributed renewable generation, distributed storage, AMI, and EVs depends partially on higher levels of grid connectivity. EVs in particular present a new opportunity to meet goals around DR while serving a growing public interest in alternative vehicles; interoperability can build on both those prospects by facilitating activities such as load balancing in response to EV charging, an intermittent burden on the grid.[84] Similarly, smart meters that all adhere to the same interoperability standards will be compatible with those installed in the future, even as the technology evolves and improves.[85] The greatest benefits of interoperability standards will accrue when grid components are all interoperable and network communications are automatic, allowing for real-time load balancing at both the demand-side and supply-side.[86]

Establishment of Industry-wide Best Practices

Standards can serve as industry best practices, providing guidance for utilities facing emerging cybersecurity, grid modernization, and privacy challenges.[87] By applying data collected from the grid in more precise and efficient ways, interoperable components benefit grid participants by expanding interconnectivity and promoting increased automation.[88] In addition, standards can define exact functions and procedures relating to engineering, performance, and application of grid components.[89] Pilot programs executed by the Smart Grid Testing and Certification Committee (SGTCC) can assist in this area by identifying where certain technologies and standards have the greatest success.[90]

Facilitation of More Comprehensive Grid Security and Cybersecurity Practices

Over time, an interoperable grid could have advanced technologies that seamlessly transmit data from AMI, ADMS, DR, and other applications—information that helps system operators better manage customer loads through sophisticated meter coordination and DR triggers.[91] Standards can help ensure that investments made in today's modernizing grid will be compatible with advancing technology and be capable of oversight from a single, comprehensive security framework.[92] Although common standards could mean that a larger number of systems might be affected by a given vulnerability, it also has meant that security vulnerabilities and threats can be more rapidly identified and addressed. There is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on "security through obscurity." Highly interoperable systems do require disciplined cyber security, but the resultant system is easier to administer, police, and upgrade against evolving threats.

Standards also direct current smart grid devices to comply with measures critical to enabling and protecting the future grid.[93] Interoperability helps utilities and businesses mitigate risks by setting guidelines that enable them to navigate and adapt to new cybersecurity and privacy concerns.[94] In addition to mitigating risks as new technologies are introduced to legacy systems, interoperability standards can also serve as a playbook for utilities, reducing their costs by allowing them to leverage others' innovations. Installing a system "off the shelf" can save both time and money, without sacrificing product quality or system security.[95]

As the technologies in grid systems become more dynamic and responsive to signals, the systems themselves become more volatile. Mitigating and managing volatility, as well as the associated risk of malfunctions, is one task aided by the implementation of interoperability standards.[96] For example, the MultiSpeak standard is used by more than 725 power producers in 19 different countries and provides real-time information on outages, alerts, and alarms. Its benefits include financial savings, fewer technical personnel and training needed for monitoring purposes, improved customer service, and enhanced safety through the streamlining and automatic nature of the information reporting process.[97]

The Benefits of Interoperability from a Utility Point of View

Duke Energy has been working to advance interoperability on the distribution system through the Open Field Message Bus (OpenFMB) framework and standards development efforts (for additional information see the OpenFMB Case Study in section 3). Duke describes the benefits of interoperability for distribution level assets in the following manner:[a]

"Interoperability among devices, systems and applications is important for several reasons. First, new industry-changing activities such as distributed energy resources (DER), microgrids and advanced demand response require disparate field devices to work together remotely and with little delay. Second, it is key to the operation of a more efficient, cost-effective and secure grid. Successful interoperability allows utilities to leverage existing grid network infrastructure and underutilized assets. Furthermore, it reduces the effort in device configuration, management and commissioning. Finally, the expected and growing implementation of DER and microgrids will require distributed analytics and operations."

[a] Duke Energy, "OpenFMB Interoperability Framework with a Microgrid Implementation, 2016, p. 4. Available at http://www.duke-energy.com/pdfs/interoperability-brochure.pdf.

Quantitative Value of Interoperability

Quantitative data and analysis on the costs and benefits of interoperability are not comprehensive. However, reports such as GWAC's "Benefits of Interoperability" pull together diverse grid modernization studies and apply the results to an interoperability context. From there, it is possible to begin constructing some understanding of the quantifiable benefits gained by implementing interoperability standards. These benefits can be categorized into three areas: financial, environmental, and reliability.

Financial Benefits

The financial benefits arising from interoperability on the distribution systems could be significant, although calculating exact financial savings is challenging. For example, implementing interoperability now can help avoid costly retrofits in the future. California identified this benefit during their Rule 21 Smart Inverter process (see continued discussion in Case Study in section 3). The state's Smart Inverter Working Group noted in a report to the California Public utility Commission and California Energy Commission that lessons learned from Europe demonstrate that "waiting to implement these functions [smart DER system capabilities], and/or providing overly prescriptive requirements for low penetration scenarios and not anticipating higher [DER] penetration scenarios, may lead to costly upgrades and replacements."[98] One estimate notes that in Germany smart inverter regulations have been implemented to address power quality issues caused by significant solar penetration and that retrofitting currently installed solar installations will cost up to $300 million.[99] The SIWG[100], the Western Electric Industry Leaders[101], and others[102] have all pointed out that the U.S. could avoid these retrofit costs if preemptive regulatory and industry action is taken.

Estimates on the financial benefits of interoperability for the electric system are limited, and currently available analyses offer wide-ranging conclusions based on the individual study's scope, sample size, location, and other factors. For example, GWAC estimates that "based on peer experience, the potential savings in the electric power industry due to interoperability falls in the range of 1 percent to 3 percent. In the [United States]... this could amount to as much as $10 billion in savings."[bb] [103] The savings estimate in this particular study applies to industry output value (measured as revenues), although ratepayer costs and investment in technology are also important factors in quantifying financial benefits. The analyses does not provide granular details regarding the exact system components through which the interoperability savings would be derived but notes the costs-savings are related to information coding and transmission for operations related to the distribution system (e.g., "administrative actions and time associated with meter reading, systems monitoring and reporting, and customer interactions such as billing") and maintenance and upgrades. [104]

An alternative gauge of the potential benefit of interoperability is provided in a 2015 Industry Report.[cc] The report notes that 40%--60% of the potential value of Internet of Things (IoT) systems depends on interoperability among systems.[dd] It also estimates that the application of IoT

[bb] Financial figure is in 2009 dollars. Figure is assumed to be an annual number, based on report's description of peer industry savings on an annual basis. For additional discussion see GridWise Architecture Council, "Financial Benefits of Interoperability: How Interoperability in the Electric Power Industry Will Benefit Stakeholders Financially," Prepared for the GridWise® Architecture Council by Harbor Research, Inc., September 2009, p. 14, 17. Available at http://www.gridwiseac.org/pdfs/financial_interoperability.pdf.

[cc] See McKinsey Global Institute, "The Internet of Things: Unmapping the Value Beyond the Hype," McKinsey & Company, June 2015.

[dd] Includes various types of IoT settings and systems, not exclusively electricity related, though electricity is a cross-cutting factor of the multiple IoT setting analyzed. See McKinsey Global Institute, The Internet of Things: Unmapping

technology to home energy management—in other words, the retail end of smart grid—has the potential to produce \$51–\$108 billion of savings annually worldwide.[105] Of those savings, approximately 17 percent[106] is tied to interoperability, meaning interoperability in the home energy market alone (ignoring commercial and industrial applications) could yield roughly \$9–\$18 billion of savings per year coming about through reduced heating, air-conditioning, and overall electricity use.

Meters provide another example of potential financial benefits. Ensuring that meters installed today will work with meters installed in the future can save money by eliminating lengthy and costly reworking and produce fewer glitches and errors, thereby saving money for utilities and their customers[107]

Additionally, billions of dollars in savings can be realized in other industries that take advantage of interoperable devices, such as healthcare, security, and building construction, according to a GWAC analysis on th Finanical Benefits of Interoprability. Financial benefits may be common across industries, as the examples in Exhibit 2-4 below demonstrate.

Exhibit 2-4. Financial Benefits are Common across Industries

	BENEFITS TO OTHER INDUSTRIES	GRID MODERNIZATION BENEFITS
Lower costs of research & development, installation, and upgrades	• Interoperable computer hardware (like USB ports) reduces costs of developing new complementary technology for the market • Installation of industry-standard devices will require minimal training and will allow widespread deployment	• Standards allow designers and manufacturers to use established industry best practices • Interoperable devices can be installed to standardized systems at lower costs • Interoperability standards ensure that future technology will be able to be integrated with existing grid systems
Lower costs of system operation & maintenance	• Industries like facility management and building construction save as much as two-thirds of standard O&M costs by updating out dated support systems, a figure that as early as 2004 topped \$15 million per year (NIST)[108]	• Operating and repairing grid systems can often be done remotely, reducing personnel time and expense • Integrated device monitoring allows for timely maintenance and repairs to prevent costly malfunctions (i.e., device signaling lets utilities respond to outages before customers would report)
Savings from communication and personnel efficiencies	• Interoperable email and software systems allow businesses across sectors to communicate and engage in commerce globally • Interoperable location-based monitoring systems can optimize resource allocation of personnel and equipment in the U.S.	• Interoperable grid technology allows electric signals to communicate messages that previously required in-person monitoring (like meter-reading by utilities)

the Value Beyond the Hype, (McKinsey & Company, June 2015), p. 4, 9, 53. Available at https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

	BENEFITS TO OTHER INDUSTRIES	GRID MODERNIZATION BENEFITS
	healthcare industry, potentially saving up to $18 billion annually[109]	• Remote monitoring of the status of distributed generation infrastructure requires fewer in-person sites
Savings from reducing human and device error	• Electronic medical records allow for better patient care and reduce the risk of insufficient information causing malpractice impacts like over-medication or severe allergic reactions • Emergency rooms have especially benefited, as electronic records allow many staff members to access patient data in real-time	• Utilities will be able to monitor and respond to emerging load imbalances instantaneously by using device signals to trigger demand-response systems • Electronic meter-reading supports more timely and accurate billing of customers • Interoperable grid technology like inverters and voltage monitoring devices will be able to regulate electricity flows faster than human operators could identify and respond to potential surges or shortfalls
Improved control enables customer choice	• Interoperable components of larger systems (like vehicle tires or lightbulbs for homes and offices) allow for greater customer choice in consumption patterns • Open cell phone architecture allows consumers to customize their devices with a variety of apps and compatible programs	• With inter-device communication, customers are able to opt-in to demand-response programs, allowing them to lower electric bills and allowing utilities to forego expensive (and rate-based) peaker plants • Distributed generation enabled by interoperable generation and transmission infrastructure allows homes and businesses the choice to produce electricity
Interoperability spurs innovation and supports new business models	• Standard electrical outlets allow for many types of devices to be marketed to entire countries or continents • Without interoperability, market failure can occur—as in the case of few charging stations impeding electric vehicle adoption —or monopolies can develop, as with the construction of early railroads	• Interoperability standards ensure a market for entrepreneurs and manufacturers • Standard designs allow for new products to participate in plug-and-play systems • Near-instant device communication supports the integration of DSM programs • More accurate load signaling supports the integration of distributed generation and other intermittent resources

Source: Information for this table was largely derived from a GridWise Architecture Council report (Table 2, p. 13): "Financial Benefits of Interoperability: How Interoperability in the Electric Power Industry Will Benefit Stakeholders Financially."

Reliability Benefits

Interoperability can also enable a smart grid with improved reliability. A San Diego Smart Grid Study quantified the benefits for reliability that a smart grid with an interoperability foundation would provide; the estimated savings for the geographic area covered in the study totaled over \$100 million,[ee] which accounted for functions such as increased distributed generation installation, installation of predictive functions and self-analysis to solve grid issues, and improved management of forced outages or other power interruptions.[110] In addition, a 2008 study found that interoperable AMI communications could improve a utility's System Average Interruption Duration Index (SAIDI) during a power outage by 4 to 6 minutes.[111]

Environmental Benefits

A study released by the Electric Power Research Institute (EPRI) in 2008 included a quantitative analysis of energy savings and emissions reductions that could result from smart grid implementation (as previously noted, interoperability is a foundational component of the smart grid).[112] EPRI projected that by 2030, energy savings could total between 40 and 121 billion kilowatt-hours (kWh) and between 22 and 68 million metric tons of CO_2 emissions could be avoided.[113] Interoperability among devices and networks could not only drive down technology costs, but also allow clean energy goals to be reached through higher grid efficiency.[114] Related environmental benefits include the optimization of resource use and higher energy conservation. For example, AMI and other smart grid devices allow customers to track and modify their energy usage in real time. Reviews of multiple studies determined that interoperability of these devices could result in energy savings potentials (and associated environmental savings) of between 5 and 15 percent.[115]

2.3. Mechanisms and Processes for Encouraging Interoperability at the State Level

A major focus of the discussions with state public utility commissioners and staffers was the mechanisms and process for encouraging interoperability on the distribution system, as well as the barriers to doing so. Therefore, the information provided in subsections 2.3 and 2.4 is derived from those conversations unless otherwise noted. To respect the sensitivities of open dockets and upcoming state proceedings, the information has been aggregated and is presented without specific attribution.[ff]

Systematic Pursuit of Interoperability at the State Level

Across states, it does not appear that a uniform process exists to promote, encourage, and/or monitor the implementation of interoperability at the distribution level or the adoption of associated standards. Similarly, within individual states, discussions regarding, or efforts to pursue interoperability typically arise in an ad hoc manner. In many states, interoperability is only discussed in the context of broad, smart grid discussions or during analyses of new technologies or related topics (e.g., during a tariff proceeding or docket). None of the states contacted for this

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[ee] Value is in 2006 dollars. Study was conducted in 2006; circumstances may have changed since this study was conducted.

[ff] The insights provided by state experts were anecdotal. There was not a comprehensive survey of state experiences or views; however, of the nine states in which experts were contacted were selected because, many have a good reputation to for being on the leading edge of interoperability efforts (i.e., within their state) or have the most advanced knowledge of standards development efforts (i.e., at the national level).

report were pursuing a systematic process of encouraging interoperability among their regulated utilities or other constituents. Similarly, a robust review of existing literature did not reveal any systematic mechanisms or processes states were using to encourage interoperability as a stand-alone initiative. This can be attributed to several factors, including lack of sector expertise among public utility commissions regarding the technical details of interoperability, absence of quantitative value propositions, and more pressing priorities among other drivers (barriers to implementation are discussed in more detail in the following section).

Additionally, some state experts expressed uncertainty regarding whether it is within the commission's prerogative to encourage their utilities to pursue interoperability and adoption of associated standards (utilities are typically responsible for voluntarily adopting standards). Consequently, when states are involved in discussions on interoperability they typically center on customer-facing components of the distribution system, such as AMI, DER integration, or smart inverters.

However, in the context of broader initiatives, a few states *have* undertaken concerted efforts to support interoperability and encourage constituents to use open interoperable standards. Many of these largely informal efforts have been spurred by utility activities that solicit a commission response, e.g., as part of a commission process of approving new technologies or via state smart grid policy initiatives or are driven by the personal interest of individual utility commissioners or staffers. Examples of the processes and mechanisms that states have used to promote interoperability and the adoption of associated standards are described below. Processes and mechanisms that states *could* utilize are also noted.

Encourage Interoperability via State Grid Modernization Initiatives

Numerous states have launched grid modernization initiatives. Some of these directly address the need for open, interoperable standards as part of broader grid modernization efforts. Several recommend ensuring that state level efforts are consistent with prevailing national standards development efforts and frameworks (such as the NIST Framework and Roadmap for Smart Grid Interoperability Standards).[116]

For example, Colorado Senate Bill 10-180 created the Colorado Smart Grid Task Force to provide guidance on cost and feasibility of implementing grid modernization initiatives. As directed by the bill, the task force produced recommendations for the Governor of Colorado, the General Assembly, and the Colorado PUC. The task force recognized that "it is critical to Smart Grid development and deployment in Colorado that the technology 'platform,' or base operating system of protocols and communications, is standardized such that all new software systems, hardware devices and new products can be "plugged in" to the network and immediately recognize and be recognized on the network."[117]

Additionally, the report noted the ongoing efforts at the national level (e.g., via NIST) to create a framework and roadmap for interoperability and that given these discussions and the costs associated with replicating the efforts, the state of Colorado should attempt to work *within* the existing national structure as opposed to developing its own approach. One of the primary recommendations was that "Smart Grid technical specifications in the state of Colorado should be consistent with prevailing national standards. In order to achieve this, leaders in Colorado should coordinate with the appropriate bodies, such as NIST."[118] An accompanying recommendation for the PUC and Colorado Governor's Energy Office (GEO) suggested the possible creation of a representative stakeholder group, comprising industry members, utilities, the PUC, the GEO, and regulators, for purposes of becoming and staying informed about the Smart Grid Interoperability Panel (SGIP) process and accompanying recommendations.[119]

In Illinois, the Energy Infrastructure Modernization Act (SB 1652) and Public Acts 097-0616[120] and 097-0646[121] require the state's regulated utilities to establish a series of plans to support the modernization of the state's electricity grid, among them an Interoperability Plan "that is consistent with guidelines and standards of the National Institute of Standards and Technology (NIST), and includes open standards and Internet Protocol to the maximum extent possible."[122] Additionally, the Public Acts 097-0616 specifically calls for an AMI plan and states that "the AMI Plan shall be fully consistent with the standards of the NIST for smart grid interoperability that are in effect at the time the participating utility files its AMI Plan, shall include open standards and Internet Protocol to the maximum extent possible consistent with cybersecurity, and shall maximize, to the extent possible, a flexible smart meter platform that can accept remote device upgrades and contain sufficient internal memory capacity for additional storage capabilities, functions and services without the need for physical access to the meter."[123]

In Massachusetts, the Department of Public Utilities (DPU) opened a grid modernization proceeding (see discussion in the following subsection regarding MA DPU Order 12-76 ultimately requiring regulated utilities to file grid modernization plans). As part of that process, it solicited input from relevant stakeholders, which informed the state commission's Order. In response, the Electric Grid Modernization Stakeholder Group—comprising members from industry, utilities, regulators, and public offices—submitted recommendations to the Massachusetts DPU. Their consensus was that interoperability needs to be incorporated into any grid modernization plan filed by distribution companies.[124] Additionally, the Clean Energy Caucus (CEC), Office of the Attorney General (AG), Low Income Network (LIN), and MA Department of Energy Resources recommended that adhering to state interoperability standards consistent with industry (NIST) standards be mandatory for utilities. [125] However, the AG and LIN recommended that new interoperability standards not be used as a reason or excuse to invest in risky or emerging technologies that might have an adverse effect on cost effectiveness for consumers. CEC recommended that utilities should try to implement the same standards across the state, possibly developing a common set of standards for guidance purposes.[126]

Encourage Interoperability via State-Mandated Policy Initiatives

New York's Reforming the Energy Vision (REV) initiative—initiated by Governor Andrew Cuomo—provides an example of the way in which state legislative initiatives can encourage interoperability among regulated utilities. As part of REV, the New York Department of Public Service (DPS) issued an order requiring each regulated utility to file a Distribution System Implementation Plan (DSIP), which outlines the utility's approach to planning, managing, and operating a distribution grid that integrates higher levels of DER, among other mandates.[127] Utilities are also required to submit a joint plan. The development of these plans has encouraged discussion on the role of and need for interoperability among devices, utilities, and the system as a whole.

For example, the DPS staff order describing what the joint utility filing should address specifically notes, “there should be a uniform interface with the markets and very extensive interactions and interoperability among the utilities.”[128] In turn, the DPS Order has spurred utilities to contemplate the degree to which interoperable functionality will be needed to achieve utility and system goals. For example, Orange and Rockland (O&R) notes in its DSIP filing that it has selected its AMI vendor due in part to the fact that interoperability is a foundational concept of the vendor’s business model, and that by selecting a company that embraces interoperability standards O&R will be better positioned to grow its ecosystem of devices participating in the network.[129]

In Massachusetts, Docket 12-76 from the DPU discusses the requirements for utilities to submit grid modernization plans, including recommendations from the Grid Modernization Stakeholder Working Group (mentioned above). The “Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid” began in 2012 and was intended to explore policy options that would enable utilities to implement grid modernization efforts.[130] This Notice of Investigation (NOI) called for utilities to submit 10-year grid modernization plans (GMPs) to the DPU for review and approval. The NOI specifically called attention to the consideration of integrating distributed generation, electricity storage, electric vehicles, AMI, and communication systems into the current grid structure.[131] Interoperability specifically was listed as an “additional potential concern” that reached across all these grid modernization topics.[132] In the NOI, the DPU asked what steps it could take to “promote open, interoperable grid modernization technologies.”[133]

The GMPs submitted by Massachusetts’ utilities mention interoperability as a component of their overall activities; although it is noted in high-level summaries, the GMPs do not ultimately go into great detail on interoperability implementation, and instead present more material on rates and the financial aspects of grid modernization technology.[gg] NSTAR’s (d/b/a Eversource) GMP specifies the need for “optimizing [systems]…integration…and ensuring systems interoperability,”[134] although later the GMP goes into detail on the “significant costs” that AMI implementation, to include interoperability testing costs, would add for consumers.[135] National Grid’s GMP addressed interoperability by indicating an interest to “pilot and demonstrate” emerging technologies, with the expectation that addressing interoperability challenges in these pilot programs would provide a useful learning experience for other utilities.[136] In addition, in 2012, National Grid tested AMI data collection and communication technology in the context of interoperability protocols in a pilot project that installed around 5000 smart meters.[137] Finally, National Grid emphasized its goal of forming relationships with vendor partners who would support interoperability with other technology providers as grid modernization efforts continued to evolve.[138]

[gg] In Unitil’s GMP, interoperability was “explored” for some planning scenarios, but the GMP did not go to enough detail to discuss it further in the GMP.

Pursue Interoperability via Rate Cases, Tariff Proceedings, Dockets

Several of the public utility commissioners and staffers contacted for this report noted that technical decisions and the adoption of interoperable standards (as well as any other standards) are purposefully left to the utilities themselves. These state experts view standards adoption as falling outside the scope of their commission's responsibilities since utilities have historically been responsible for voluntarily choosing to adopt (typically national) standards-based on their own unique circumstances.[hh] However, these experts also pointed out that when discussions on interoperability arise during rate cases, tariff proceedings and dockets (or often during the conversations leading up to those proceedings) the commissions do weigh in on the topic. This can be one mechanism for encouraging utilities to adhere to interoperable standards (such as those outlined by IEEE or IEC) or ensure that the devices utilities deploy have interoperable functionality. This may be an increasing opportunity as the penetration of DER and advanced technologies continues and as attention to grid modernization advances.

For example, in Hawaii, the Kauai Island Utility Cooperative deployed AMI in 2012 during the Kauai Smart Grid Initiative.[139] At the time, there was little discussion of ensuring that the devices had advanced interoperable functionality, aside from basic issues such as connecting with customers.[ii] However, Hawaiian Electric submitted a proposal to the Hawaii PUC in March 2016 "requesting permission to install smart grid technology [i.e., smart meters] for more than 455,000 customers" across three islands.[140] The $340 million Smart Grid Foundation Project must still be reviewed and approved by the Hawaiian PUC and it would be logical that given the current state of Hawaii's electric grid and attention to DER integration and modernization, interoperable functionality will be a larger part of the discussion than it was during the 2012 proceedings.

The tendency for utility commissions to insert guidance and direction on interoperability when the topic arises during rate cases or dockets indicates that their encouragement of such functionality is more focused on distribution technologies that have a tariff component (such as AMI) as opposed to technologies that are installed directly in customer's homes (e.g., smart appliances or energy efficient devices).

Additionally, multiple commissioners and staffers noted that while they are not actively following discussions about interoperability, rate cases and dockets that involve technologies that have a potentially interoperable component is one process through which they learn about the topic.

Increase Baseline Knowledge Through NARUC

A key factor in the process of promoting interoperability and encouraging the adoption of associated standards is ensuring that state commissioners and staffers are familiar with the topic and aware of the costs, benefits, and relevance. NARUC has several processes through which states can become more knowledgeable about interoperability efforts. For example, NARUC

[hh] There are 189 investor-owned utilities across the United States (APPA, 2016); their rate of interoperability standards adoption varies greatly; however, of the utility commissioners and staffers contacted for this report, many expressed confidence that their utilities were aware of the NIST Framework and following IEEE or ANSI standards (tweaked for their needs) motivated by their own internal valuation analyses.

[ii] This is according to one expert contacted for this report.

provides some limited training for regulators on NIST and SGIP activities (for states not already involved). The purpose of these is to provide context on the subject, such as helping regulators develop an understanding of why utilities may be coming to them with more expensive equipment requests, citing the need for interoperability or a desire to be compliant with SGIP practices. The purpose is not to focus on end implementation outcomes.

States can also learn more about interoperability from the experiences of other states, via the NARUC Lab "surge calls." These conference calls convene regulators from interested states to discuss topics that have been brought to NARUC's attention as areas of interest or concern. For example, a June 2016 call focused on *Smart Inverters: The Link between Smart Grid and Solar,*[141] which has multiple interoperable implications. Although there are no calls currently scheduled to discuss interoperability as a stand-alone topic—a potential indication of the lower prioritization of this subject among regulators—it is expected that future trainings will focus on distribution system planning and that discussions on the need for interoperability will arise during those trainings.

In addition to providing direct regulator trainings, NARUC also publishes recommendations for regulators and proven industry best practices. One such recommendation—released in NARUC's July 2011 resolution on Smart Grid Principles—advised that regulator participation in SGIP deliberations would support the development of smart grid interoperability standards that are applicable across all jurisdictions.[142] Other NARUC publications have advocated similarly for development of an interoperable grid and open, non-proprietary, flexible infrastructure and standards.[143]

Utilize Existing Resources and Look to Other States for Guidance

To learn more about what processes are used to encourage interoperability, many states noted that they either have, or would, turn to other states for guidance. For example, multiple states reported looking to California (and their Rule 21 process) for guidance on implementing smart inverter requirements. Hawaii now has a similar rule for smart inverters: Rule 14. An expert from one New England state noted that if he were in the process of looking for information on the topic he would look to the other New England states for guidance or raise the question during a New England Conference of Public Utility Commissioners meeting.

A few experts noted that NIST and SGIP have information available that is primarily focused on national-level interoperability efforts but may potentially be useful for state efforts. It is important to note that some of the SGIP information is unavailable to non-dues-paying members, which would include state PUCs; however, access may be available for government entities at a lower cost.

Some state commissioners and staffers explained that they do not know what resources exist or are available to them on this topic. Nearly all of those contacted noted that there was a dearth of unbiased, substantive, quantifiable information available on this topic in general (not only in terms of processes and mechanisms).

Establish PUC Recommended Practices

Public utility commissions in many states provide recommended practices for their regulated utilities on a range of subject areas. These can be utilized to encourage the adoption of interoperability standards. For example, the Colorado Smart Grid Task Force highlighted the PUC's ability to "deliberate, through a rulemaking procedure, on adoption of the Federal[jj] standards as 'recommended practices' by the electric utilities within Colorado" for issues such as cybersecurity and with respect to smart grid interoperability.[144] In other states with recommended practices, including New York and Oregon, commissions have expectations or guidelines for standards that utilities may follow, but no mandated rules.

Convene Stakeholders to Discuss Each State's Unique Needs

Convening stakeholders to discuss the most suitable interoperability standards for individual states is one mechanism for determining and meeting the unique needs of each state, which may differ from the broad interoperability needs identified at the national level.

For example, Hawaii is approaching interoperability implementation through a collaborative stakeholder process that involves discussions with relevant groups and ultimately funneling the outcomes, input, and advice up to the PUC. An ongoing effort is looking at DER policy and working with stakeholders to make recommendations on technical interconnection standards and to understand how to take advantage of grid-supportive functions of which some devices are capable. Most stakeholders involved in the proceedings directly are utilities, consumer advocates, public interest groups, and environmental groups. In parallel, some stakeholders are working with the solar industry and inverter manufacturers to address characteristics of the Hawaii power grid and different inverter products that may suit Hawaii's unique market. Reportedly, most parties and suppliers agree that working together to establish clear standards is preferable for all those involved.

Additionally, working groups in Massachusetts and California have brought together various stakeholders who have discussed interoperability in the context of broader policy directives and commission orders, as well as the benefits and challenges of implementation. In a number of other states, however, the need was recognized for better coordination among stakeholders.

Appropriately Value Individual Commissioners' and Staffers' Interest

Informal mechanisms also play an important role in moving interoperability efforts forward at the distribution level and in bringing information from the national conversations down to the state level. For example, individual utility commissioners and/or staffers who have interest in encouraging interoperability and have knowledge of national interoperable standards efforts (e.g., those by NIST, SGIP, IEEE, others) have been described as being a key reason why certain states have been more involved in these initiatives than others.

[jj] At the time of the Colorado Smart Grid Task Force publication, FERC was deliberating on adopting interoperability standards suggested by NIST. FERC did not ultimately adopt the standards but the ability of state commissions to offer recommended practices remains relevant.

California, Minnesota, New York, Iowa, and other states all have, or recently had, commissioners or staffers who are involved with SGIP and stay abreast of the activities and discussions occurring in that national forum. Based on informal conversations with these experts, their knowledge of national-level interoperable standards development efforts, understanding of the perceived value of interoperability, and interest in encouraging it within their states is noticeably more robust than that of utility commissioners and staffers in states not involved in the national conversations. While this does not necessarily translate to quantifiable activity at the state level, it does indicate a higher likelihood of attention being paid to these issues. Other industry experts have articulated the same sentiment, noting that, traditionally, discussions on interoperability have been most prominent in the states in which an individual commissioner was interested in and engaged on the topic.

Make Use of Existing Resources

Some literature on various aspects of interoperability for the electric system is available. Few of these offer state-centric information for utility commissions or other state stakeholders. A list of relevant literature is provided in the Appendix. It includes several categories of resources: interoperability framework documents and general overview information, policy and regulatory background information, technical and engineering background information, and information on costs, benefits, and challenges.

2.4. BARRIERS TO IMPLEMENTING INTEROPERABILITY AT THE STATE LEVEL

There are many barriers to states moving forward on addressing interoperability at the distribution system level.[kk] They range from limited time and resources to pursue the topic to limited interest in doing so. The barriers listed below have been compiled from published literature and/or were articulated by the experts contacted for this report. Some of the barriers are agreed upon widely. Others are viewed as barriers by only certain facets of the industry.

Potential remedies for overcoming these barriers are also provided below, all of which were suggested by the state public utility commissioners and staffers contacted for this report. The barriers and potential remedies are discussed here without specific attribution.

Lack of Quantitative Analyses on the Costs and Benefits of Interoperability

One of the biggest challenges to achieving interoperability at the state level is the lack of quantifiable data on its benefits. This sentiment was reiterated by nearly every state utility commissioner and staffer that was contacted for this report.

While simultaneously attempting to add more quantitative analyses to the existing body of work, it is important to recognize that non-quantifiable benefits have their own unique merits, and achieving interoperability at the distribution system level is widely regarded as a beneficial goal. Many industry experts are supportive of the concept and have articulated the qualitative benefits (see subsection 2.2). However, the experts contacted for this report noted that without hard data

[kk] Interoperability can be both advanced and hindered by many entities and many factors. This report focuses on the role of states, particularly regulatory authorities. However, there are many other entities that contribute positively or negatively to such efforts (e.g., market segmentation and proprietary interface developments by technology suppliers can hinder interoperability).

demonstrating the benefits for ratepayers, it is unlikely that state commissions would pursue interoperability in a systematic way or actively encourage their regulated utilities to adopt interoperable standards. The lack of quantifiable benefits and pre-/post-condition data is not only missing at the state level but also at the national level. As one expert pointed out, intelligent devices have multiple sets of value and determining the criteria with which to evaluate them has not been fully accomplished.

There are other informational and data challenges as well, such as lack of tools and models. As one expert noted, it is difficult to model the direct impact of interoperability because it involves specifying the counterfactual: discerning the costs/benefits of implementing a system with, versus without, interoperability standards. Further, these costs and benefits may be embedded in other system costs/benefits. Efforts are underway via the DOE’s Grid Modernization Lab Consortium to develop tools to gauge interoperability maturity but the project is still in its early stages. Additionally, modeling on interoperability is still in its nascent stages and most existing models are too generic; modeling buildings connectivity is an example of this.[145]

- *Potential remedy: Undertake quantitative analyses that demonstrate the benefits of interoperability to ratepayers. Develop studies that capture and analyze pre- and post-condition data and demonstrate the costs/benefits of implementing interoperable devices and adopting associated standards. These studies would be most beneficial if they are unbiased and reliable, and if the results are easily digestible.*
- *Potential remedy: Develop modeling tools that can be used to better evaluate and gauge the quantitative value of interoperability and assist states in deciding whether to encourage interoperability efforts actively. Undertake economic evaluation and create tools to determine cost effectiveness.*

Lack of Expertise on Interoperability

Public utility commissioners and staffers play a key role in influencing activities that occur on the electric distribution system. The level of expertise regarding interoperability ranges greatly among states and may be one reason that interoperability and standards adoption is not a more common discussion at the state level. For example, according to those familiar with the activities in a multiple states, many state commissioners are unclear on the precise meaning of interoperability for the electric distribution system and have limited involvement in the conversations that are underway at the national level on interoperability (such as the efforts by NIST and SGIP). This makes it difficult to encourage interoperability at the state level. Other state commissions may be generally familiar with the concept but may not have devoted much time to delving into the topic in further detail. A few state commissions are very informed; these tend to be the states in which a commissioner or staffer is involved in NIST or SGIP efforts.

Additionally, many commissions lack the engineering expertise to understand fully the technical components of interoperable standards development and utilization, which can hinder the adoption of these standards. As one expert pointed out, even if commission staff knows in general terms what grid interoperability means and believe that in the long run it will benefit ratepayers, they often are not entirely familiar what it means in practice. Thus, when a utility requests to install a certain suite of technologies that will support an interoperable framework, state commissions cannot explore these issues adequately during rate cases or other adjudicatory proceedings. In fact, while many commissioners and staffers may agree that, for example, a third party should be able to communicate with a smart meter and the interoperability standards for doing so should not be proprietary, it is complicated to do so. If the correct questions are not asked and the details are not adequately analyzed it is possible for commissions to believe that interoperability has been achieved while it has not actually been attained.

Other experts confirmed this challenge, noting that utilities employ significantly more staff than state commissions do, leading to a mismatch in technical expertise and making it difficult for commissioners to verify the claims that utilities make regarding the technical requirements or limitations of policies (including interoperability initiatives). For example, utilities may, technically, have interoperable devices but choose to internally limit the functionality of what the devices can do, thereby decreasing their broader interoperable functionality. This may be difficult for the commission to monitor, especially for commissioners and staffers with limited education on interoperability and many other responsibilities to juggle.

- *Potential remedy: States could benefit from a roadmap that includes very basic information such as what interoperability means in practice, why it is relevant, what standards exist, and which standards may be most beneficial to encourage their utilities to adopt.*
- *Potential remedy: Have experts on these topics available to commissions, to support their analyses or provide educational opportunities related to open and pending dockets. This would help commissions 1) gain a greater understanding of what the risks associated with interoperability are, 2) the history of such efforts and 3) the potential future of interoperability. Making these experts easily accessible to commissions, to answer time-sensitive questions during open proceedings, would be particularly beneficial. Additionally, having a process in place to preemptively ensure that relevant information on interoperability is in front of commissions leading up to specific proceedings could help inform their discussions with utilities.*
- *Potential remedy: Provide training opportunities (either in person or via phone) to commissioners interested in learning more about the relevance of interoperability and how it can benefit ratepayers in their states. This would increase understanding and knowledge of the topic among commissioners and staffers. NARUC's webinars offer a useful vehicle for relaying information to commission staff.*
- *Potential remedy: Provide a list of issues that require exploration with specific questions and data requirements that commissions could use during rate cases or open dockets. This would provide them with one tool to help verify utilities' claims that they have adopted interoperable standards or are implementing interoperable capabilities within their systems. The GWAC Decision Makers Checklist offers a good starting point but it is not well known among commissions and may need to be updated.*[146]

Lack of Access to Resources

The limited expertise on this topic is compounded by the lack of access to resources. There are very few written materials that commissions can utilize to educate themselves on this topic (at least that they are aware of), especially in terms of how to address or encourage interoperability at the state level and how implementation could work in reality. The scarcity of resources includes not only a lack of quantifiable cost/benefit analyses (as discussed above), but also an absence of case studies from other states, and a lack of easily digestible explanations on what the prevailing interoperable standards are, why they are important, and which of the many competing standards are most applicable for their unique circumstances. The limited resources that do exist are often unavailable to commissions (for example SGIP has a few documents on the topic but some are only available to dues-paying members, which makes it difficult for many commissions to access them). Similarly, several experts noted that they were unsure where to access resources or who to contact for informed, unbiased advice.

- *Potential remedy: Negotiate free access to relevant members-only resources (e.g., SGIP, EPRI) so that commissioners can utilize the information.*
- *Potential remedy: Distill existing information (such as lengthy and sometimes technical documents from NIST, SGIP, GWAC, IEEE, EPRI, others) to be relevant to commissioners.*
- *Potential remedy: As states begin to more actively pursue interoperability and adopt national standards, providing a set of detailed, step-by-step best practices based on other states' experiences (the few that exist). This can serve as a framework for states that are just beginning discussions on interoperability.*

Competing Priorities and Lack of Time or Funding

Although state experts expressed a general interest in interoperability and acknowledged its high-level, qualitative importance, one barrier that was reiterated by those contacted for this report was the lack of time available to dedicate to this issue. The limited number of commissioners and small support staff in many states make it difficult to justify diverting strained resources to a topic that is not yet supported by clear, tangible analyses. Several experts noted that compared to topics such as cybersecurity and net metering or rate reform, the need to address interoperability feels less urgent. Thus, while ensuring widespread interoperability at the distribution system level may be an area that commissions would eventually like the commission to evaluate, it is currently a lower priority compared to other topics such as on-going rate case proceedings and broad policy questions about whether and how to pursue grid modernization and integrate distributed and renewable resources.

Additionally, experts noted that limited funding is available to devote to learning more about these issues, which hinders them from joining dues-paying organizations or attending in-person meetings/workshops where the topic is more widely discussed. Further, while there are some free resources available to commissions, it is not always clear which resources are relevant or where to find them, as they are often buried within industry organizations' websites.

- *Potential remedy: Create a state-centric portal for information on interoperability, which is managed by and housed within an unbiased agency/organization, and that state commissions, utilities, and other state stakeholders can access free of charge. Compile existing resources into this portal that may currently be housed within the websites of NIST, SGIP, NARUC, NAESB, IEEE, IEC, and other relevant groups. Initiate outreach efforts to* *states to make them aware of this portal and associated resources. Continuously add to the portal as additional resources become available.*

- *Potential remedy: Provide routine workshops via teleconference or remote webinar (thereby eliminating travel costs).*
- *Potential remedy: Create short documents (5 to 15 pages) discussing the advantages/disadvantages of pursing interoperability and associated standards in the near, medium, and long term. Ensure that the information is articulated simply and is accessible to commissioners/staffers and other readers without a highly technical background.*

Concerns Regarding Cybersecurity and Reliability

Interoperability and cybersecurity are intimately linked, and utilities' concerns regarding increasing cybersecurity vulnerabilities due to interoperable devices may be one reason that interoperability has not taken root in many states. Additionally, utilities have rejected what he describes as "a lot" of interoperable equipment during testing because they fail security checks.[ll] Some utilities can be wary of relying on standardized services and instead prefer proprietary utility systems.[mm]

Other concerns about system security, privacy, and safety have also not been adequately addressed. These are demonstrated in buildings connectivity and interoperability challenges.[147] For example, older standards are difficult to integrate and often are lacking in security. Policies on security and sensitive data are only just beginning to be considered. There is no standardized equipment identity management. In addition, connectivity between devices must often be manually set up and is therefore prone to error. [148]

- *Potential remedy: Increase efforts around education and awareness of cybersecurity risks, and how to avoid those risks while still advancing interoperability. This could occur through written materials, training programs, webinars, or a number of other tools.*
- *Potential remedy: Implement state/Federal policy or direct a commission mandate to require certain minimum levels of cybersecurity and reliability requirements that do not preclude interoperability efforts. These directives would include the assumption that interoperability and cybersecurity can go hand-in-hand, and that cyber technology is continuously evolving and protection measures would adapt accordingly.*

Uncertainty Regarding the Commission's Role in Encouraging Interoperability and Which Stakeholders to Convene for Discussions

Multiple commissioners/staffers have expressed uncertainty over whether it is within the commission's purview to advocate for interoperability and/or encourage their regulated utilities to adopt interoperable standards. Standards adoption has traditionally been a utility-centric activity. Additionally, several experts pointed out that technical decisions on topics such as interoperable technologies are typically left to the utility engineers and the role of the commission is to evaluate

[ll] The exact numbers of interoperable equipment rejected by utilities due to security concerns could not be verified.

[mm] There is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on "security through obscurity."

utility actions from a broader, more policy-oriented level. These roles, coupled with the limited data on quantifiable benefits of interoperability for utilities or ratepayers, leads to uncertainty over who should ultimately be responsible for pursuing interoperability at the distribution level.

Additionally, one expert noted that in Hawaii—which is convening stakeholders to discuss what kind of interoperable criteria may be needed for DER devices—there is uncertainty regarding who should participate in the discussions and if key experts from elsewhere across the country should be involved. Other states have similarly noted that it is difficult to both identify and convene all of the right people at the table to discuss this topic.

- *Potential remedy: Have an unbiased, neutral party (such as NARUC or DOE) routinely convene states to discuss interoperability and share experiences (NARUC does convene states for inter-state discussions but they are not routinely focused on interoperability, due in part to lack of request for such discussions).*

Disproportionate Emphasis on Complex Stages of Interoperability

Several state experts noted that many of the national-level conversations on interoperability and standards development tend to be more complex than those at the state level. This makes it difficult for states to ascertain which subsets of the national efforts or conversations are relevant for unique state situations. For example, whereas NIST groups may be discussing communications among and controllability of devices, even cutting-edge states are still primarily focused on the electrical interface that is related to the power system itself. Thus, as one expert who is familiar with activities in multiple states noted, much of the work that NIST is doing around smart grid and interoperability may not be relevant at the state level because it is "focusing on grid 3.0 [future grid] whereas many state commissions are still grappling to understand grid 1.0 [legacy grid] or 2.0 [smart grid]."

- *Potential remedy: Develop a set of plain-language documents to explain interoperability standards to commissions and to convey the role that interoperability plays in more advanced conversations, such as those around grid architecture.*
- *Potential remedy: Develop "roadmaps" that help commissions consider the emerging, more distributed nature of power systems in the future and ways to ensure that decisions made today do not foreclose future options.*

Investment in Interoperable Devices is tied to Infrastructure Aging

Utilities can be hesitant to invest in new technologies that have unclear rate recovery or that may result in stranding existing assets. Utility commissions can be hesitant to approve utility investments in new technologies that do not have clear, quantifiable benefits for ratepayers. Thus, one state expert predicted that as devices and equipment get outdated, they will be replaced with newer versions that may lead to a discussion between the utility and their commission on the need for the new technology to have interoperable functionality. However, as also predicted by this expert, unless there is an increase in the rate at which infrastructure is being replaced, there will not be a noticeable change in the rate at which utilities are adopting interoperable technology.

Challenges Regarding Technology, Communication, and Organization

Connectivity and interoperability in buildings provides an example of technology, communications and performance challenges associated with implementing interoperability at the state level.[149] For example, interoperable technology choices can be confusing, especially given the wide variety available. Layers of communication are not often separated clearly from information. Attempts at unified approaches, such as Internet Protocol, have experienced policy challenges and performance issues. Technical specifics on interoperability configurations and the potential for evolution are lacking. Operations and performance are generally not scalable. Performance options could be limited due to lack of clarity between communications medium and messages standards. [150]

Uncertainty Regarding the Impact on Ratepayers

According to an Energy Information Administration (EIA) report from 2011,[nn] the Maryland Public Service Commission (PSC) expressed concerns that implementing AMI devices would result in additional costs for ratepayers, as they would be locked into paying for outdated technology as the smart grid continues to evolve in the coming years. For that reason, the PSC initially declined a smart meter program proposed by the utility BGE, stating that the change would impose significant financial and technological risks to BGE's ratepayers, as associated shifts in rate design would likely cost customers more in the short run for uncertain long-term savings achieved through system communications efficiency or reductions in electricity consumption.[151] Although the PSC's primary arguments in refusing to grant BGE's first application to initiate a smart meter program were closely tied to issues of inadequate funding and insufficient customer education, secondary sticking points that were noted included awaiting technological advancements and delays caused by tardy state and local regulatory orders.[152] These secondary concerns highlight the role that development and implementation of interoperability standards can play in energy efficiency programs like that of BGE. If common standards apply both to present and future grid technologies, then there is less risk in committing to a technology in the near term. In 2012, following BGE's amendment of its initial proposal, the PSC granted approval for BGE to install digital electric meters at the distribution point for each customer in its service area.[153]

Lack of Direction and Regulatory Support

The NIST Smart Grid Architecture Committee (SGAC, a federal advisory committee) interviewed a number of "smart grid industry stakeholders" and found (as documented in a 2012 report) that one major hindrance to interoperability standards implementation is a lack of direction from FERC regarding why the standards would be meaningful to adopt. [154] The same SGAC report came to several other conclusions. For example, another issue it noted is lack of regulatory guidance and lack of participation in SGIP at the state level (as of 2012 at the time of publication). It also noted some discrepancy between utilities and state commissions in their understanding and appreciation of the development of interoperability standards. SGAC warned against state commissions undervaluing utility participation in these activities, and identified concerns by

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[nn] See Energy Information Administration, "Smart Grid Legislative and Regulatory Policies and Case Studies," Prepared for U.S. EIA by SAIC, December 2011.

utilities about the lack of commission involvement with interoperability standards. Stakeholders interviewed by SGAC expressed concern that there was no prioritization for the implementation of standards, nor a clear definition of roles and responsibilities for SGIP stakeholders. This sentiment was neither confirmed nor denied by the experts that were contacted for this report but it may be a contributing factor to lack of progress on implementation of interoperability of standards at the state level.

2.5. State Participation in Developing Interoperability Standards

Many states that were contacted for this report expressed general interest in participating in standards development or interoperability forums. However, states also noted that in reality they have limited time and financial resources available to dedicate to such activities (pointing out that online forums may be the most feasible). Lack of technical engineering expertise was also cited as a reason for hesitation. Other states expressed uncertainty over what benefit they would receive from participating in such conversations.

Some experts cautioned that states currently participating in NIST, SGIP, and IEEE activities may be the only ones that would ultimately participate in any new interoperability forums or standards development activities. Further, they recommended that any new initiative would have to be strategically focused and have a clear, unique purpose in order to draw interest/attention and provide added value.

3. Case Studies

This section of the report focuses on the value, process, barriers, and outcomes of state efforts to encourage the implementation of interoperability at the distribution system level and the adoption of associated standards by their constituents. After a thorough literature review and discussions with utility commissioners/staffers in nine states, it is clear that although some states are tackling aspects of interoperability, comprehensive and systematic efforts to advance interoperability at the state level are not being pursued.

Additionally, expertise on and attention to this topic is limited among state commissions. Instead, efforts to encourage interoperability occur on a case-by-case basis and have typically arisen in the context of a utility pilot project through discussions of approving/requiring a specific technology and ensuring it has interoperable functionality, or as part of a broader smart grid effort. Despite the absence of extensive activity by the states in this area, there is still valuable insight to be gained from these experiences, and these can serve as examples for other states. As such, the following case studies provide insight into states' and/or utilities' experiences pursuing interoperable technologies or implementing interoperability standards in several different scenarios. These include: California's process for implementing smart inverter requirements under Rule 21, Duke Energy's involvement in developing and testing the OpenFMB framework, and Consolidated Edison's experience implementing its Secure Interoperable Open Smart Grid Demonstration Project.

3.1. California's Process for Implementing Smart Inverters under Rule 21

California's Rule 21

California, well known as an early mover on electricity grid modernization efforts, was the first state to implement a ruling on smart inverters under the California Rule 21 (see box). Its experience serves as a solid example of how discussions on interoperability at the state level often arise: during efforts to implement new technologies, and recognizing that having interoperable functionality would make the technology most advantageous for the system and stakeholders. This example also highlights the important role that utilities sometimes play in initiating the process, the importance of industry-developed standards in furthering the process, and the advantages of multi-stakeholder collaboration. Additionally, it underscores the financial benefits of taking preemptive action to implement smart technologies today to avoid costly retrofits in the future.

> **California Rule 21**
>
> *"California's Electric Tariff Rule 21 is a CPUC-approved tariff based on IEEE 1547 technical requirements that describes the interconnection, operating, and metering requirements for generation facilities to be connected to a utility's distribution system, over which the CPUC has jurisdiction." Source: SIWG, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013.*

Utility Involvement in Initiating the Process

One notable aspect of the smart inverter process in California is that the conversation was in part initiated by utility engineers. Concerned about the impact that growing DER penetration would have on system reliability, utility engineers (among others) pointed out to the California PUC (CPUC) the need for devices that could help the utility communicate with and manage growing penetration of DER. This process is representative of experiences articulated by other states, in that the utilities are sometimes the first to identify the need for devices to have interoperable functionality (e.g., to ensure continued system reliability or support other business objectives).[oo]

High-level Overview of Process[155]

To further the discussion on smart inverter implementation and identify which technical functions (e.g., interoperable communication capabilities) would be feasible and beneficial for the State of California, the CPUC and the California Energy Commission (CEC) convened the Smart Inverter Working Group (SIWG) in early 2013.[156] The SIWG provided recommendations to the CPUC on Rule 21 specifically relating to the integration of smart inverters as part of the increase of DER installments across the state; the importance of these devices having interoperable functionality is noted throughout the recommendations.[157] The recommendations included three phases of technical implementation: Phase 1, which covers autonomous functionality, including interoperability; Phase 2, which addresses communications capabilities, including interoperable communications; and Phase 3 (current phase), which focuses on additional advanced functions that build on the communications standards identified in Phase 2.[158]

In December 2014, the CPUC issued Decision 14-12-035 amending Rule 21 based on the input of SIWG Phase 1 recommendations. In the Decision, the commission adopted seven functions that smart inverters must perform autonomously, and made the seven functions mandatory for all interconnecting DERs (as of 12 months following the approval of UL Standard 1741 Supplement SA).[159]

In February 2015, the SIWG released Phase 2 of its recommendations for DER communication protocols; the CPUC is currently in the process of collaborating with its regulated utilities to implement them into Rule 21. SIWG is now focusing on its Phase 3 recommendations.

Importance of Interoperable Communications of Der Systems and Smart Inverters and the Role of Open Standards (as Noted in Phase 2 of Process)

A closer look at the requirements for the Phase 2 communications capabilities reveals the importance of keeping interoperable functionality at the forefront of the discussion while updating Rule 21 and the role that standards can play in ensuring interoperability across stakeholders. As noted in the SIWG Recommendations to the CPUC and CEC:

> *"The lack of communications requirements in the current Rule 21 causes I-DER systems either to not provide any communications capability or to use whatever communications protocols are convenient for the I-DER manufacturer. This lack of interoperable communications requirements could lead to a tower of Babel situation, with the utilities needing to use many different protocols to communicate with different types of I-DER systems. If a single set of communications standards are not specified*

[oo] However, this is on a case-by-case basis. As other states pointed out, utilities may be wary of adopting interoperability standards or investing in interoperable devices if it means stranding existing assets and uncertain cost recovery.

from the beginning, I-DER systems would most likely have to be retrofitted at a later date so that DER owners and utilities could take full advantage of the smart I-DER functions.

Communications for large numbers of disparate types of I-DER systems should be based on a small set of well-designed communications standards that ensure interoperability across all stakeholders. Otherwise, there would be a proliferation of different methods, hardware, and software that would lead to a total lack of interoperability.

Therefore, it is critical to establish a basic set of communications standards that sets most of the requirements but allows flexibility where it is needed. For instance, I-DER communications could use different media, such as the cell phone network, or a utility radio-based network, or even the Internet, just as people can exchange emails via their phones, or their computers, or their iPads. However, standards would need to be imposed for the formats of data, since the content of the communications must be understandable regardless of what media are used to transmit it or what applications are used to read it. For instance, email standards have been established so that people can read emails in Outlook, Thunderbird, Eudora, or directly online in Gmail.

In utility domain, the IEC is the primary source of communications standards, particularly the IEC 61850 series of standards."[160]

Adding specified communications standards (knowing that they will need to be adapted) to Rule 21 helps ensure interoperability for DER systems across all manufacturers. To that end, SIWG suggested in its Phase 2 recommendations that existing international communications standards for DER functions be added to Rule 21, such as IEC 61850 series (and be adapted and adjusted as needed to meet California-specific requirements). The IEC 61850 is also part of the SGIP's Catalog of Standards, indicating that it has been approved by industry experts as "relevant for the development and deployment of a robust, interoperable, and secure Modern/Smart Grid."[161]

European Experiences

"Germany and Italy have observed that allowing DER systems to trip-off prematurely during voltage or frequency anomalies can actually exacerbate [grid stability] problems, possibly causing unnecessary outages."

Source: SWIG, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 12.

Role of Open Industry-Developed Standards in Furthering the Process

Amending the existing IEEE 1547 standard was a key step in obtaining support for the smart inverter requirements and demonstrates the important role that standards play in promoting or hindering the adoption of new technologies (such as smart inverters with interoperable communications functionality).

California's Rule 21 is grounded in IEEE 1547, which until recently required that distribution grid-connected systems automatically trip during even a brief system anomaly. In effect, this prevented DER systems from participating in the operations of the distribution system even though emerging

DER systems are capable of providing grid assistance.[162] Without an update to this IEEE standard, utilities and other industry stakeholders were hesitant to fully support the CPUC's smart inverter initiative.

After much discussion, the IEEE 1547 standards community members fast tracked an amendment to the standard in mid-2013. The amendment is labeled 1547a and was approved by IEEE in September 2013. The primary purpose, broadly speaking, is to allow certain DER actions (such as voltage and frequency ride-through) that were not previously allowed.[163] Additional adjustments to IEEE 1547 were also made and other actions were allowed.[pp] The IEEE amendment to the 1547 standard served as a "blessing from afar," so to speak, and according to multiple experts familiar with the process, was integral to advancing the smart inverter process and achieving stakeholder buy-in.

Thus, while IEEE 1547a is a unique physical interconnection standard for DER, it does showcase the significant role that open, industry-developed and approved standards play in advancing smart grid objectives and the weight that these standards carry in the industry, with vendors and among utilities. States that are interested in encouraging interoperability on their distribution systems may wish to keep the important role of standards in mind and work with industry standards organizations to ensure that interoperability standards are developed to fit their objectives and/or are well marketed to their constituents.

Benefits of Preemptively Implementing Smart System Capabilities to Avoid Costly Retrofits

One motivating factor for California to *preemptively* require smart inverter technology was to "adequately cope with the expected large amounts of the distributed generation" in the state to avoid costly retrofits in the future.[164] The SIWG points out that lessons learned from Europe demonstrate that "waiting to implement these functions [smart DER system capabilities], and/or providing overly prescriptive requirements for low penetration scenarios and not anticipating higher penetration scenarios, may lead to costly upgrades and replacements."[165] One estimate notes that in Germany smart inverter regulations have been implemented to address power quality issues caused by significant solar penetration and that retrofitting currently installed solar installations will cost up to $300 million.[166] The SIWG,[167] the Western Electric Industry Leaders,[168] and others[qq] have all pointed out that the United States could avoid these retrofit costs if preemptive regulatory and industry action is taken.

Benefits of Smart Inverters with Interoperable Functionality

Another driving factor for California to establish smart inverter requirements was the many anticipated benefits of implementing these devices with autonomous and advanced capabilities

[pp] For additional details see "IEEE 1547a Standard for Interconnecting Distributed Resources with Electric Power Systems --Amendment 1," IEEE Standards Association, http://grouper.ieee.org/groups/scc21/1547a/1547a_index.html and Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 15.

[qq] For example, see Bernhardt, John, Clean Coalition, "California adopts nation's first advanced inverter standards," January 2015. Available at http://www.clean-coalition.org/press-releases/california-adopts-nations-first-advanced-inverter-standards/.

(such as interoperable communications). Specifically, smart inverters are anticipated to offer a wide range of benefits for ratepayers and utilities.[rr] To provide just a few examples, enabling smart inverter functionalities can decrease the number of unnecessary DER disconnections, offset power quality issues caused by voltage fluctuations, and reduce the likelihood of system failures caused by power quality issues from steep ramping and sharp transitions. Collectively, smart inverters can improve system reliability, flexibility and efficiency.[ss]

Open communications between the utility and the device can also allow the utility to utilize some DER functions. Additionally, "using international communications and cybersecurity standards as much as possible, interoperability across California utilities can be enhanced." [169] For the DER customer, smart inverters with autonomous and advanced functionalities can decrease the likelihood of blackouts by enabling/allowing the DER system to remain in operation during a grid event, as opposed to automatically tripping (as traditional standards such as IEEE 1547 required).[170]

SIWG also anticipates that smart inverters with autonomous and advanced inverter functionalities can reduce costs of grid integration and grid reinforcement. This may be especially true as higher penetrations of DER come online. Cost savings can also be achieved as the smart inverter functionalities begin to more cost effectively replace the traditional approaches of upgrading or reinforcing the distribution system to accommodate DER.[171]

Collaboration with Stakeholders

The SIWG uses a collaborative working group approach to ensure multi-stakeholder buy-in and includes representatives from California's investor-owned utilities, DER developers, inverter manufacturers, ratepayer interest groups, and trade and advocacy groups. As of 2015, there were more than 200 participants in the SIWG.[172] The participation of, and continuous conversations among, diverse groups with varied interests has been a key component to California's success in implementing smart inverter requirements, according to experts familiar with the process.

3.2. OPENFMB AND DUKE ENERGY IMPLEMENTATION

What is OpenFMB™?

Open Field Message Bus (OpenFMB) is a framework for applying IoT principles to enable the smart grid, essentially allowing distributed energy resources and other devices at the periphery of the electric grid to communicate. Duke Energy launched OpenFMB in 2014 with a coalition of utilities, vendors, research labs, and government agencies—a group it calls the Coalition of the Willing (COW, now COW-II[173,174])—in an effort to reduce the cost and complexity of future smart grid integration projects. OpenFMB "provides a specification for power systems field devices to leverage a non-proprietary and standards-based reference architecture, which consists of Internet Protocol (IP) networking and IoT messaging protocols."[175]

[rr] For a full list see Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 3.

[ss] For a full list of benefits see Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 4.

In designing OpenFMB™, the COW sought to lead grid modernization efforts by aggregating interoperable field device systems into a consistent structure that could be adopted to reduce the costs and challenges associated with Smart Grid implementation. The framework is now included in the Smart Grid Interoperability Panel's (SGIP) Internet of Things (IoT) EnergyIoT™ initiative. [176] In March 2016, the North America Energy Standards Board (NAESB) ratified OpenFMB Business Practices to "guide the industry on how OpenFMB devices can be implemented to drive field device interoperability."[177]The standards development request was initiated by Duke Energy, among others, and resulted in a NAESB OpenFMB Task Force to deliberate on the issue between April-December 2015, resulting in ratification by NAESB membership on March 7, 2015. Numerous organizations participated in the discussions, including NARUC, NIST, SGIP, and EPRI.

Significance of OpenFMB

OpenFMB is anticipated to reduce the costs and inefficiencies present in current grid modernization techniques by providing a scalable, peer-to-peer publish/subscribe architecture[tt] off of which system and device data can be harmonized for both centralized and distributed infrastructure.[178] Similar platforms include the IEC Common Information Model (CIM), Standard 61850, and the MultiSpeak framework.[179] MultiSpeak, jointly developed beginning in 2000 by NRECA and vendors serving U.S. electric cooperatives, is perhaps the closest ancestor of OpenFMB™, given that both structures include specifications for data exchange standards and interoperable software.[180] However, as noted by both Duke and the creators of MultiSpeak, the framework was designed to address common integration problems, but is not sufficient to address all integration needs.[181]

SGIP notes that OpenFMB™ is designed to be both fast and flexible, taking advantage of information model and message format best practices identified by the IEC CIM, Standard 61850 and MultiSpeak frameworks.[182] By using existing standards included in the lower interoperability layers of the GWAC Stack (and the similar Open System Interconnection Stack) and then building a new information model that is compatible with upper interoperability layer standards, OpenFMB™ is designed to be more versatile and more easily adapted to test cases. Its single unified information model is compatible with IEC 61850 and MultiSpeak information modeling, as well as with the IEC 61968/61970 frameworks. By including data attributes and elements that are compatible with existing standards, OpenFMB™ can incorporate existing components—like DER devices—while establishing a more general interoperability standard for future grid device design.

It is important to note that there are conflicting views regarding the use and benefits of OpenFMB. Some have noted that a difficulty of the standard is that it requires common ownership of communicating devices and reconfigurations as new use cases are developed. It is also worth noting that OpenFMB is not the only approach being developed for enabling device-to-device communications.

[tt] Publish/Subscribe architecture is a messaging pattern that allows for scalability, among other advantages.

Application of OpenFMB

Duke Energy has put together an OpenFMB reference implementation at its Mount Holly microgrid test center in Mount Holly, North Carolina. There, COW-II members are demonstrating plug-and-play integration of solutions from 25 vendors.[183] These assets include: 100-kW PV solar system with smart inverter capabilities, 250-kW battery energy storage system, 10-kW PV solar carport with EV charging capabilities, 500-kW automated resistive load-bank, instrumented and automated distribution grid equipment (such as reclosers, smart meters, sensors and phasor measurement units), wireless devices (supporting Wi-Fi, 4G LTE, 900 MHz RF and AMI Mesh), an envision room with appliances and smart breaker monitoring and control capabilities, and an operations room with commercial application software to monitor and control the microgrid components.

Additionally, Duke Energy is testing a number of microgrid use cases at its Mount Holly facility. [184] These focus on:

- Microgrid optimization: using optimization algorithms and input on local conditions such as weather, time of use rates or, emission targets to forecast available microgrid resources
- Unscheduled islanding transition: automatically transitioning into microgrid mode at an unscheduled time due to a triggering event
- Island-to-grid connected transition: reconnecting and resynchronizing the operating microgrid back to the main grid

Results and Benefits of OpenFMB

According to Duke Energy, utilizing OpenFMB can lead to equipment and application interoperability that will help decrease the costs and inefficiencies of "siloed, single-function solutions." [185] Showcasing a variety of low-latency microgrid optimization use cases the Mount Holly reference implementation demonstrates that the OpenFMB publish/subscribe architecture can rapidly amalgamate information between nodes at the grid edge, and that doing so can be scalable and can be done resiliently. The microgrid use cases utilize a range of interoperable wireless and wired technologies to optimize successfully microgrid functionality, transition to island mode and reconnect to the main grid.

3.3. Consolidated Edison's Secure Interoperable Open Smart Grid Demonstration Project

Project Background and Purpose[186]

With sponsorship from a U.S. Department of Energy cooperative agreement signed on January 4, 2010,[187] the Consolidated Edison Company of New York (ConEd) undertook a Secure Interoperable Open Smart Grid Demonstration Project (SGDP). The purpose was to demonstrate that monitoring and control capabilities with a greater degree of interoperability would improve grid reliability, efficiency, and flexibility. ConEd and its team of 16 project partners[uu] pursued six

[uu] Project partners included Siemens, TIBCO, Alstom Grid, Orange & Rockland Utilities, Electrical Distribution Design, Digi International and Ambient Corporation, Viridity, Green Charge Networks, Innoventive, New York City Economic

demonstration projects and 13 sub-projects in three categories: Secure systems integration, DR and distributed energy resource (DER) connectivity, and optimization and control.

One of the projects under the category of secure systems integration, the Distributed Energy Resource Management System (DERMS), involved ConEd partnering with Siemens and TIBCO to establish a command and control center for an interoperable DR network. Siemens and TIBCO designed the system for visualization and optimization in near real-time on existing ConEd distribution system displays, as well as to interface with external customer sites. DR, distributed generation, and energy storage resources were also incorporated. Siemens developed the DERMS interoperability platform following the Smart Grid Architecture Model (SGAM), which incorporated frameworks from NIST and IEC.

The overarching goals for the DERMS project were to use optimized DER to improve system efficiency and reliability, improve ConEd's business processes and applications, and deliver cost savings for ConEd and its customers. ConEd and its partners also hoped to improve control capabilities of existing grid assets, minimize peak load growth, maximize energy efficiency savings, achieve cybersecurity for smart grid systems, and demonstrate open standards and interoperability.

Implementation

Consistent with the IEC Common Information Model (CIM) standard, DERMS applied new, secure integration technology to enable legacy and new applications to communicate using new IEC Standards-based messaging functions. The project produced software capable of optimizing resource utilization in response to various conditions, for instance in decreasing the number of sustained outages, while ensuring the authenticity and integrity of data from integrated systems.

DERMS produced an integrated decision aid tool to help users identify which resources can most effectively and efficiently respond to changing conditions. Using DERMS, ConEd successfully monitored and communicated with a range of DR and DER in near real-time, from a secure and interoperable control platform integrating legacy control and data systems alongside new smart grid systems and applications. DERMS supported the visualization of DR and DER including solar, wind, storage, backup generation, DR aggregators, and others on existing ConEd distribution system displays.

In the demonstration stage, the project was limited in scope, but DR and DER were mapped and integrated across ConEd's entire service area during the course of the program, and the DERMS platform now covers six boroughs and 64 networks. With enrollment in ConEd's commercial DR program increasing by 14 percent from 2013 to 2014, the company expects these resources to continue their rapid growth in the future. The project also included support for grouping multiple sites with multiple resources, a capability ConEd could use to support integrating microgrid operations in the future.

Development Corporation, Gehrlicher Solar, Softstuf, CALM Energy, Columbia University, Energy & Environmental Economics, and Navigant Consulting.

Outcomes and Lessons Learned

ConEd experienced a number of difficulties with the DERMS project, including communicating with project partners to achieve common objectives, finding subject matter experts, presenting data in a coherent way, and integrating legacy systems an environment with advanced cybersecurity capabilities. Nevertheless, the company found that the project produced many tangible benefits and thus it plans to continue exploring these issues as DERMS and other SGDP systems are scaled up across its service territory.

Through the SGDP, ConEd is now able to communicate with DR and distributed energy resource assets from a common platform. ConEd successfully deployed hundreds of communication nodes from project partners Digi International and Ambient Corporation to connect difficult-to-access interval meters with ConEd’s meter management system. In addition, DERMS led to the development of protocols for integrating smart grid resources and applications consistent with industry standards and cybersecurity principles.

SGDP projects efficiently shifted resources in response to real-time conditions and achieved cost savings for ConEd and its consumers. Program partners estimated that $4.8 million of capacity, arbitrage, and ancillary service revenue could be saved by deploying the project's DR resources, while a wireless metering project resulted in $2 million of annual operational savings. Other economic benefits could not yet be quantified. ConEd concluded that the DERMS project met its set goals in terms of achieving improved integration of legacy equipment, integration of data from system sensors, grid control capabilities, and grid reliability.

4. FINDINGS

An evaluation of the value of, mechanisms for, and barriers to states implementing interoperability on the electric distribution system and to adopting national-level standards reveal the following findings. These are based largely on the conversations with state utility commissions and staffers as well as a review of existing literature.

Benefits of Implementing Interoperability on the Distribution System are Widespread but Difficult to Quantify

Interoperability in the electric distribution system offers a diverse range of benefits for utilities, consumers, and other stakeholders. These benefits are widely agreed upon by industry experts, however they are difficult to quantify. Benefits of interoperable distribution systems and system components include:

- **Reduction of system integration costs and extension of asset life –** Interoperability standardization necessarily decreases costs to deploy and integrate new technologies and applications into an existing system, by definition eliminating the need to modify existing systems extensively in order to accept and communicate with the new technology. This can lower design, installation and upgrade costs as well as reduce overall system integration costs for new capital investments (i.e., system expansion). In addition, interoperability including equipment monitoring and assessment of operating conditions on an ongoing basis can lower operations and maintenance costs as well as extend the useful life of legacy infrastructure and continued asset utilization (i.e., system operations).
- **Generation of economic benefits –** Interoperability decreases market fragmentation, enables economies of scale, and can reduce transaction, equipment, and other costs for both suppliers and customers.
- **Catalyst of innovation** – Interoperability standards enable a technology-neutral market; reducing investment uncertainty, incentivizing innovation where standard interfaces can be defined, and ensuring that currently deployed infrastructure can continue to provide value within newer systems.
- **Increase in customer choice and participation –** Interoperability allows customers to choose between features instead of between technologies, prevents companies from "locking in" customers (both utilities and consumers) with proprietary systems, and facilitates customer trust of new vetted technologies.
- **Improvement of grid performance and efficiency –** Interoperability promotes a more efficient, reliable grid. It helps ensure both demand-side and supply-side load management work cooperatively and productively. Standards ensure that today's technology can be interface with future technologies.
- **Establishment of industry-wide best practices** – Interoperability standards can collectively form a playbook, providing guidance for all utilities facing emerging industry issues; smaller utilities benefit from being able to pull technology "off the shelf."

- **Facilitation of more comprehensive grid security and cybersecurity practices** – Interoperable technologies permit the application of a single, comprehensive security framework and enable coordinated and consistent cybersecurity practices.[vv] Although common standards could mean that a larger number of systems might be affected by a given vulnerability, it also has meant that security vulnerabilities and threats can be more rapidly identified and addressed. Highly interoperable systems do require disciplined cyber security, but the resultant system can be easier to administer, police and upgrade against evolving threats. Additionally, interoperable technologies can reduce the number of systems and interfaces required for operators to monitor and manage the electric grid, thus enabling more timely and coordinated responses to emergency events.

There is a deficit of quantitative analyses on the costs and benefits of promoting interoperability, or adopting associated open interoperable standards at the distribution system level. Many state commissions could benefit from such analyses.

Estimates on the financial benefits of interoperability for the electric system are limited, and currently available analyses offer wide-ranging conclusions based on the individual study's scope, sample size, scope, location, and other factors. For example, a GridWise Architecture Council analysis on the financial benefits of interoperability notes that based on peer industry experiences, potential savings for the electric industry from interoperability could amount to as much as $10 billion annually[ww] across the power system, some of which would be attributable to interoperability on the distribution system. According to the same study (and also based on peer industry experience), interoperability can provide additional benefits such as increasing service quality and decreasing mistakes, as well as driving innovation to create new markets and services. An alternative gauge of the potential benefit of interoperability is offered by a 2015 industry report,[xx] which concludes that interoperability accounts for 17 percent of the potential value of IoT systems in the home environment. With IoT-enabled energy management applications having the potential to produce $51–$108 billion[188] in global annual savings, interoperability then could yield $9–$18 billion per year worldwide.

[vv] There is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on "security through obscurity." Highly interoperable systems do require disciplined cyber security, but the resultant system can be easier to administer, police and upgrade against evolving threats.

[ww] Financial figure is in 2009 dollars. Figure is assumed to be an annual number, based on report's description of peer industry savings on an annual basis. The savings estimate in this particular study applies to the electric utility industry output value (measured as revenues), although ratepayer costs and investment in technology are also important factors in quantifying financial benefits. The analysis does not provide granular details regarding the exact system components through which the interoperability savings would be derived but notes the costs-savings are related to information coding and transmission for operations—e.g., "administrative actions and time associated with meter reading, systems monitoring and reporting, and customer interactions such as billing"—and maintenance and upgrades. GridWise Architecture Council, "Financial Benefits of Interoperability: How Interoperability in the Electric Power Industry Will Benefit Stakeholders Financially," Prepared for the GridWise® Architecture Council by Harbor Research, Inc., September 2009, p. 14, 17. Available at http://www.gridwiseac.org/pdfs/financial_interoperability.pdf.

[xx] For additional discussion see McKinsey Global Institute, The Internet of Things: Mapping the Value Beyond the Hype, (McKinsey & Company, June 2015), p. 53. Available at https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

Mechanisms and Processes States Utilize to Encourage Interoperability and Standards Adoption are Ad Hoc

It does not appear that many states are pursuing a systematic process of encouraging interoperability on the distribution system or the adoption of associated standards among their regulated utilities or other constituents. Further, no universal approach exists among or within states to promote, encourage, and/or monitor the implementation of interoperability efforts.

In the context of broader initiatives, a few states have undertaken concerted efforts to support interoperability and encourage constituents to use open interoperable standards. Many of these largely informal efforts have been spurred by utility activities that solicit a commission response, e.g., as part of a commission process of approving new technologies or via state smart grid policy initiatives. Many states lack complete information on many of the benefits/savings associated with interoperability initiatives and standards development efforts occurring at the national level. Often, those that have access to all the available information, still rank promotion of interoperability/adoption of national standards low on their state's list of competing priorities, which may include on-going rate case proceedings and broad policy questions about whether and how to pursue grid modernization and integrate distributed and renewable resources. .

Examples of the processes through which states have, or could, promote interoperability and the adoption of associated standards include but are not limited to:

- Encouraging interoperability via state-mandated policy initiatives;
- Pursuing interoperability via rate cases, dockets, and other proceedings;
- Establishing state commission-recommended practices to draw attention to interoperability;
- Increasing baseline knowledge of the topic among state commissions to elevate it as a priority;
- Studying other state experiences or academic resources;
- Convening stakeholders to discuss interoperability and the state's unique needs; and
- Encouraging commissioners and staffers who have an interest in the topic to pursue it further.

Limited resources are available to states to assist them in understanding the value of interoperability for the distribution system and systematically encouraging it within their jurisdictions. SGIP and NARUC have offered some webinars and trainings peripherally related to interoperability. Some written documents explaining the basics of interoperability, as well as the purpose and benefits are available via NIST, SGIP, GWAC IEEE, NAESB and others. Lists of relevant standards are also provided by these organizations. However, comprehensive documents—such as step-by-step information or a guidebook—that can help commissions understand how to encourage interoperability systematically at the state level, are not widely available.

Formal state efforts to advance interoperability—typically within the context of broader grid modernization initiatives—was much more evident from roughly 2009 to 2012 than in

the years since then. This decline can be attributed to the expiration of American Recovery and Reinvestment Act funding, which supported many of these efforts.

Barriers to Implementing Interoperability at the State Level on the Distribution System are Wide Spread [yy]

Competing priorities and lack of expertise have kept many state commissions from focusing on what interoperability for the distribution system can mean in practice and what discussions or efforts regarding interoperability and standards development are occurring at the national level. This includes the work undertaken by Federal agencies such as DOE and NIST, groups such as GWAC and SGIP, and standards development organizations such as IEEE and IEC. This is a significant barrier state adoption of national standards. The limited expertise on this topic is compounded by a lack of access to needed resources.

The presence of a staffer or commissioner who *is* engaged on interoperability discussions at the national level does not necessarily translate into state adoption or action, due to the other barriers discussed in this section. However, it indicates that these states may be better poised to initiate efforts to encourage interoperability at the distribution level. These staffers' and commissioners' insights are typically gained from current or previous involvement with national-level efforts to develop interoperability frameworks, concepts or standards, such as via NIST or SGIP.

One of the biggest challenges to achieving interoperability on the distribution system is the absence of quantifiable data on the benefits of doing so. This sentiment was expressed by nearly every state commissioner and staffer contacted for this report. However, it is important to recognize the non-quantifiable benefits of interoperability (which have their own unique merits), while to extent possible attempting to add more quantitative analyses to the existing body of work.

There are very few written materials that commissions can utilize to educate themselves on interoperability, especially in terms of how to address or encourage it at the state level and how implementation could work in reality. Resources that are lacking include state-centric information, cost/benefit analyses of adopting specific interoperable standards, and the impact of broader comprehensive efforts, among others. The resources that do exist in membership-based organizations may be unavailable to state commissions. While some written information is publically available, it is often housed within multiple different agencies' websites that are difficult for commissioners/staffers to navigate. Thus, even if states are interested in understanding more about how to pursue interoperability they have limited options for doing so.

Many state commissions lack the time and funding to pursue interoperability efforts. Others do not know who to convene to discuss the topic. This is compounded by a lack of perceived urgency among state commissions to do so. In comparison to issues such as cyber

[yy] Interoperability can be both advanced and hindered by many entities and many factors. This report focuses on the role of states, particularly regulatory authorities, in furthering interoperability on the distribution system. However, there are many other entities that contribute positively or negatively to such efforts. For example, market segmentation and proprietary interface developments by technology suppliers can hinder interoperability. Reportedly, certain venders have also been known to oppose the development of common interoperability procurement language in an effort to preserve market share.

security, rate reform, and even day-to-day responsibilities, pursuing interoperability is considered a lesser priority. The limited number of commissioners and small support staff in many states make it difficult to justify diverting strained resources to a topic that is not yet supported by clear, tangible benefit case studies. Some states are also unclear on which stakeholders, both from within the state and externally, should be convened to discuss this topic in a more comprehensive way.

Even for commissions with resources to focus on interoperability, and interest in doing so, they face a limited range of recognized academic resources or studies that demonstrate how to address or encourage interoperability at the state level and how implementation could work in real-world settings. This is a notable barrier to the advancement of interoperability at the distribution level and the adoption of associated standards.

Some state commissions are uncertain if encouraging their utilities to adopt national-level interoperability standards is within their preview, since standards-based implementation is typically a voluntary utility decision. Further, the technical nature of these standards can dissuade or hinder state commissions (many of whom have legal or economic backgrounds and not engineering backgrounds) from getting deeply engrossed in the details or becoming further engaged on the topic.

The national conversations on interoperability and standards development tend to be more complex than those at the state level. This makes it difficult for states to ascertain which subsets of the national efforts are relevant for unique state situations. For example, NIST and other industry and government partners are engaged in conversations on “Grid 3.0” (future grid) while many state commissions are still grappling with “Grid 1.0” (legacy grid) and Grid 2.0 (smart grid). There are a lack of processes and mechanisms to ensure that relevant information from NIST and other national organizations reaches the state level and is presented in a way that is useful for states’ needs.

Decisions to upgrade existing infrastructure to have modern capabilities (e.g., to have interoperable functionality) are often undertaken when the infrastructure is reaching the end of life, which leads to a somewhat gradual process of introducing new technologies and interoperable system components. To date, interoperability efforts have often been focused on new deployments of system components as opposed to integration and interoperability with legacy infrastructure.

Cyber security concerns may be a barrier to interoperability. Several states notes that their regulated utilities can be wary of relying on standardized services and instead prefer proprietary utility systems. One state expert reported that some utilities have rejected interoperable equipment during testing because they fail security checks.[zz] Some experts argue that there is a common misconception that proprietary non-standardized systems are safer because fewer people use them, but experts generally dismiss arguments based on “security through obscurity.”

[zz] The exact numbers of interoperable equipment rejected by utilities due to security concerns could not be verified.

Lack of direction and regulatory support was identified as a barrier to standards adoption during a 2012 study. [aaa] The NIST Smart Grid Advisory Committee (SGAC, a Federal advisory committee) interviewed a number of "Smart Grid industry stakeholders" and found (as documented in its 2012 report) that one major hindrance to interoperability standards implementation is a lack of direction from FERC regarding why the standards would be meaningful to adopt. This sentiment was neither confirmed nor denied by the experts that were contacted for this report but it may be a contributing factor to lack of progress on implementation of interoperability of standards at the state level.

[aaa] See National Institute of Standards and Technology, "Smart Grid Advisory Committee (SGAC) Report," p. 15-21, Published March 5, 2012. Available at http://www.nist.gov/smartgrid/upload/NIST_SGAC_Final_Recommendations_Report_3-05-12_with_Attachments.pdf.

5. Implications and Opportunities To Enhance Interoperability on Distribution Systems

These findings and conversations with state commission experts suggest the following implications and opportunities for the Federal government to enhance interoperability and associated connectivity at the distribution level:

Discussions with states indicate that having a state-specific "roadmap" would help them better understand how interoperability for the distribution system works in practice and how they can encourage relevant standards adoption within their states. It could include very basic information such as 1) what interoperability means once implemented, 2) why it is relevant, 3) what standards exist, 4) which standards may be most beneficial to encourage regulated utilities and other constituents within their states to implement, and 5) the impact of the emerging, more distributed nature of power systems in the future—and ways to ensure that decisions made today do not foreclose future options. While much of this information is already laid out in various existing documents (e.g., see the NIST Smart Grid Interoperability Framework Version 3), many states indicated they were either unaware of this information and/or that in its current format it did not provide the kind of detailed, state-centric, step-by-step roadmap they were envisioning or believe they need.

State commissioners and staffers noted that having a cadre of qualified interoperability experts and consultants on these topics available to commissions would help commissions gain a greater understanding of what the benefits and risks associated with interoperability are. These experts could help support their analyses or provide educational opportunities related to open and pending dockets, in addition to context on the history of such efforts and potential future of interoperability. Making these experts easily accessible to commissions, to help address time-sensitive questions during open proceedings, would be particularly beneficial.

Experience suggests that convening state commissioners or staff via webinars can be a cost-effective way to increase understanding of the benefits of interoperability (and associated standards).[bbb] The Federal government has a history of working with states and/or collaborating and supporting other organizations or state associations (e.g., NARUC) in convening states for training opportunities. NARUC webinars are a good template for such cost-effective outreach. Previous NARUC webinars have touched on interoperability but more routine trainings organized in a systematic fashion would help drive state discussions on interoperability. Trainings could start from a very basic level and gradually progress to more advanced topics. Distributing a written summary of the training would reinforce and further stimulate discussions.

States indicated the need for a list of specific questions that commissions could use during rate cases or open dockets as a tool to help verify utilities' claims that they have adopted interoperable standards or implemented interoperable capabilities within their systems. The questions would need to be dynamic in order to facilitate a useful conversation

[bbb] For example a NARUC training on Smart Inverters in June 2016 helped states understand California's point of view and experiences in developing Rule 21. It was anecdotally beneficial. For additional details see: http://naruc.org/naruc-research-lab/.

between the commissions and utilities. An example of successful collaboration along these lines is the collaborative NIST-NARUC Training: NIST Cybersecurity Framework Workshop for Regulators and the associated delivered report.[ccc]

As reported by states, commissions would be more likely to read and utilize information on interoperability if they had free access to relevant members-only resources (e.g., SGIP resources among others). For example, a summary or "news feed" of key information may serve as a way to inform commissions with limited budgets and still fulfill the business objectives of the dues-paying organizations.

States indicated that having access to *distilled* versions of existing information (such as lengthy and sometimes technical documents from NIST, SGIP, GWAC, IEEE, others) would be very beneficial as the commissions are primarily comprised of non-engineers. This would make it more digestible for commissions and would help them understand the value and relevance of interoperability, potentially leading to greater attention to this topic at the state level. As states begin to more actively pursue interoperability and adopt national standards, providing a set of detailed best practices based on other states' experiences (the few that exist) can serve as a database of such state actions and provide clarity for states that are in the early stages of considering interoperability issues.

States indicated that quantitative analyses and studies that capture and analyze pre and post-condition data and demonstrate the costs/benefits of implementing interoperable components or standards at the distribution system level would help states evaluate and ascertain the quantitative value of encouraging interoperability among their constituents. It may even lead to more urgency, attention and systematic efforts to pursue interoperability at the state level. These studies would be most beneficial if they are unbiased and reliable, and if the results are easily digestible. Additionally, modeling tools that can be used to better evaluate and gauge the quantitative value of interoperability would assist states in deciding whether to encourage interoperability efforts actively. Undertaking economic evaluation and creating tools to determine cost effectiveness would also be beneficial.

States noted that a state-centric portal for resources on interoperability, managed by and housed within an unbiased organization, would be incredibly informative and beneficial for state commissions, utilities, and other state stakeholders looking for information on the topic. Compiling existing resources into this portal that may currently be publically available but embedded among less directly useful information within the websites of NIST, SGIP, NARUC, NAESB, IEEE, IEC and other relevant groups would make the resources more accessible to states.

- **Creating a proactive outreach program to assure states are aware of this portal and associated resources would serve as encouragement for them to use and digest the material.** Tools that rely on states initiating efforts to access materials run the risk of being underutilized. Continuously adding to the portal as additional resources become available would help keep the information relevant.

[ccc] For additional details on the training see "NIST/NARUC Training: NIST Cybersecurity Framework Workshop for Regulators," July 6, 2016. Available at https://www.naruc.org/naruc-research-lab/lab-past-meetings.

- **States indicated the need for a distribution-oriented/state-specific "interoperability 101 series."** The purpose would be to explain interoperability standards "in plain English" and would help state policymakers and commissions understand the role it plays in more advanced conversations, such as those around grid architecture.
- **Discussions with states suggest that short (5- to 15-page) documents discussing the advantages/disadvantages of pursing interoperability and associated standards in the near, medium and long term would help them ascertain the value of doing so in their particular situations.** Ensuring that the information is articulated simply and is accessible to commissioners/staffers and other readers without a highly technical background would be critical for ensuring absorption of the material.

Discussions with states suggest that creating written materials, webinars, and training programs that explicate the inter-relationships between cybersecurity risks and interoperability would be beneficial. Specifically, they could help provide a basis for targeted state—utility conversations.

6. APPENDIX

6.1. CONTRIBUTING STATE UTILITY COMMISSIONERS AND STAFFERS

Informal discussions were held with commissioners and staff members from public utility commissions in nine states (one of which wished to remain anonymous) as well as an expert from NARUC, to gather information on the level of activity, interest, and knowledge that state regulatory commissions have in encouraging their constituents to pursue interoperability and implement associated standards. Several of the state experts contacted were either currently or previously involved with the Smart Grid Interoperability Panel (SGIP).

The insights these experts provided were anecdotal[ddd] and outreach to states was not a fully comprehensive survey of experiences. However, the nine states in which experts were contacted were selected because many have a reputation for being on the leading edge of interoperability efforts (i.e., within their state) or have the most advanced knowledge of standards development efforts (i.e., at the national level). Insight gained from the discussions with state experts has largely been aggregated and anonymized to protect the integrity of ongoing commission proceedings and to accommodate other sensitivities. All statements provided reflect the opinions of the individual and were not expressed on behalf of the state commissions. Information gathered during the literature review and discussions with states has been evaluated to identify key findings and implications/opportunities.

Exhibit 6-1: State Utility Commissioners, Staffers and Other State Experts Providing Insight for this Report

STATE	NAME	TITLE
Massachusetts	Matthew Nelson	Director of Electric Power Division, MA DPU
California	Jamie Ormond	Legal and Water Advisor, CA PUC
Minnesota	Chris Villarreal	Director of Policy, MN PUC
New York	Mike Worden	Deputy Director of Utility Rates and Services—Electric, NY DPS
Oregon	John Savage, Jason Klotz	Commissioner, OR PUC Climate Change Lead, OR PUC
Iowa	Nick Wagner	Commissioner, IA Utilities Board; Board of Directors, NARUC; Board of Directors, SGIP
Hawaii	David Parsons	Chief of Policy and Research, HI PUC
Rhode Island	Todd Bianco	Principal Policy Associate, RI PUC

[ddd] Information provided during the discussions was offered by state experts based on their own personal experiences and insights gained from working on these issues in their respective states or with relevant state groups. The authors did not conduct independent, scientific research into ongoing state proceedings, open dockets, or official state policy or other pronouncements.

STATE	NAME	TITLE
National Association of Regulatory Utility Commissioners	Miles Keogh	Director, Research Lab NARUC

6.2. The Smart Grid Interoperability Panel Catalog of Standards

The Smart Grid Interoperability Panel (SGIP) Catalog of Standards (CoS) is a compilation of standards and practices determined by the SGIP to be relevant for the creation of a "robust, interoperable, and secure Modern/Smart Grid." In order to be added to the Catalog, the standards must first go through a multi-stage review by industry experts. The intention of the Catalog is to provide a source of important, non-exclusive, input that informs the NIST process for "coordinating the development of a framework of protocols and model standards for an interoperable smart grid." Many of them are relevant to the distribution system.

The current CoS full list of entries is publically available and can be found on the SGIP website: www.sgip.org/wp-content/uploads/SGIPs_Catalog_of_Standards.pdf.

6.3. Interoperability Resources List

The following list provides a *selection* of resources that may be relevant to states pursuing interoperability for the distribution system or encouraging constituents to adopt relevant standards.

Framework Documents and General Overview

Arnold, George W., "NIST Smart Grid Activities," NIST, August 31, 2011.

GridWise Architecture Council, "Interoperability Path Forward Whitepaper 2," 2005, p. 1–2. Available at http://www.gridwiseac.org/pdfs/interoperability_path_whitepaper_v1_0.pdf.

GridWise Architecture Council, "The GridWise® Interoperability Context-Setting Framework," March 2008.

GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010. Available at http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

IEEE, "2030-2011 - IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads," IEEE Active Standard, Sponsor: IEEE-SASB Coordinating Committees, Archived at https://standards.ieee.org/findstds/standard/2030-2011.html.

Melton, Ron and Ron Ambrosio, "Interoperability 101 Introduction and Overview," GWAC. Available at http://www.gridwiseac.org/pdfs/interop101_intro_overview.pdf.

National Institute of Standards and Technology, U.S. Department of Commerce, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0, [as well as releases 2.0 and 1.0]," Available at http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

National Institute of Standards and Technology, "Smart Grid Advisory Committee (SGAC) Report," Published March 5, 2012. Available at

http://www.nist.gov/smartgrid/upload/NIST_SGAC_Final_Recommendations_Report_3-05-12_with_Attachments.pdf.

National Institute of Standards and Technology, “Smart Grid Testing and Certification,” updated December 2012, http://www.nist.gov/el/smartgrid/sgtest.cfm, accessed July 14, 2016.

Neumann, S. “Position Paper for the GridWise Interoperability Workshop,” April 2007.

Smart Grid Interoperability Panel, “Enabling and Accelerating Grid Modernization Through the Internet of Things (IoT),” EnergyIoT™: Accelerating Grid Modernization. Available at http://www.sgip.org/energyiot/.

Smart Grid Interoperability Panel, “New IPRM Standard Provides Framework for Smart Grid Testing and Certification,” June 2016.

Policy and Regulatory Background

Federal Energy Regulatory Commission, “Smart Grid,” http://www.ferc.gov/industries/electric/indus-act/smart-grid.asp, accessed July 5, 2016.

Federal Energy Regulatory Commission, “Smart Grid Interoperability Standards,” 136 FERC ¶ 61,039, Order issued July 19, 2011, Docket No. RM11-2-000. Available at http://www.ferc.gov/EventCalendar/Files/20110719143912-RM11-2-000.pdf.

Federal Energy Regulatory Commission, “Staff Presentation: Item E-22,” Open Commission Meeting, March 19, 2009. Available at http://www.ferc.gov/CalendarFiles/20090319120952-E-22-Discussion.pdf.

Federal Energy Regulatory Commission, “Testimony of Commissioner Suedeen G. Kelly Before the Committee on Energy and Natural Resources,” United States Senate, March 3, 2009. Available at http://www.ferc.gov/EventCalendar/Files/20090303121917-09-03-03-testimony.pdf.

Federal Energy Regulatory Commission, “Testimony of Mason W. Emnett Associate Director, Office of Energy Policy and Innovation, Before the Technology and Innovation Subcommittee Of the Committee on Science and Technology,” United States House of Representatives, July 1, 2010. Available at http://www.ferc.gov/EventCalendar/Files/20100701105022-Emnett-Testimony-07-01-10.pdf.

ISO New England Inc., “Overview of the Smart Grid—Policies, Initiatives, and Needs,” February 17, 2009. Available at http://www.iso-ne.com/pubs/whtpprs/smart_grid_report_021709_final.pdf.

National Association of Regulatory Utility Commissioners, “Resolution on Smart Grid,” July, 2010. Available at http://pubs.naruc.org/pub/53985C79-2354-D714-51E8-2CBC8B5F9C1A.

National Association of Regulatory Utility Commissioners, “Resolution on Smart Grid Principles,” July, 2011. Available at http://pubs.naruc.org/pub/53985C3E-2354-D714-51A8-281C62A21700.

National Science and Technology Council, “A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future,” June 2011. Available at http://www.ferc.gov/industries/electric/indus-act/smart-grid/21st-century-grid.pdf.

President’s Council of Advisors on Science and Technology, “Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology,” Report to the President and Congress, December 2010.

U.S. Department of Energy, "Locke, Chu Announce Significant Steps in Smart Grid Development," May 18, 2009, http://energy.gov/articles/locke-chu-announce-significant-steps-smart-grid-development.

U.S. Department of Energy, "Standards and Interoperability." Available at https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html, accessed July 5, 2016.

Technical and Engineering Background

Basso, Thomas. "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014. Available at http://www.nrel.gov/docs/fy15osti/63157.pdf.

Basso, Thomas. "Interconnection Standards," NREL, Net Metering and Interconnection Standards Information Seminar, Mississippi Public Service Commission: Jackson, Mississippi, July 22, 2011. Available at http://www.psc.state.ms.us/mpsc/pdfs/MS-Interconnection-20110722-Basso.pdf.

Basso, Thomas and Richard DeBlasio. "IEEE Smart Grid Series of Standards IEEE 2030 (Interoperability) and IEEE 1547 (Interconnection) Status (Preprint)," NREL, Presented at Grid-Interop 2011, Phoenix, Arizona, December 5-8, 2011. Available at http://www.nrel.gov/docs/fy12osti/53028.pdf.

Electric Power Research Institute, "Reference Implementation of Open AMI Endpoints Based on IEEE 802.15.4g and Wi-SUN," Power Delivery & Utilization - Distribution & Utilization: Technical Results Document, 21 December 2015. Available at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005587.

Golmie, Nada, with Hamid Gharavi, David Cypher and David Griffith, "Smart Grid Communication Networks," National Institute of Standards and Technology Engineering Laboratory, 1 October 2012. Available at http://www.nist.gov/el/smartgrid/sgcnet.cfm.

Metering & Smart Energy International, "ANSI Standards for AMI interoperability Adopted," 25 March 2009. Available at http://www.metering.com/ansi-standards-for-ami-interoperability-adopted/.

National Association of Regulatory Commissioners, Research Lab, "Smart Inverters: The Link between Smart Grid and Solar," July 2016. Available at http://naruc.org/naruc-research-lab/lab-past-meetings/.

Pacific Northwest National Laboratory, "Grid Architecture," http://gridarchitecture.pnnl.gov/, accessed August 1, 2016.

Sandia National Laboratories, "The Advanced Microgrid Integration and Interoperability," SANDIA REPORT SAND2014-1535 Unlimited Release Printed March 2014. Available at http://nyssmartgrid.com/wp-content/uploads/The-Advanced-Microgrid_Integration-and-Interoperability-Final.pdf.

Costs, Benefits, and Challenges

Davis, Kathleen, "How Does the Industry Create True Interoperability?," Electric Light & Power, Published January 1, 2012. Available at http://www.elp.com/articles/powergrid_international/print/volume-17/issue-1/features/how-does-the-industry--create-true-interoperability.html.

Electric Power Research Institute, "Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid," Final Report 1022519, March 2011. Available at https://www.smartgrid.gov/files/Estimating_Costs_Benefits_Smart_Grid_Preliminary_Estimate_In_201103.pdf.

Electric Power Research Institute, "Opportunities and Hesitations Associated with Open Advanced Metering Infrastructure," Power Delivery & Utilization - Distribution & Utilization: Technical Results Document, 21 December 2015. Available at http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006917.

GridWise Architecture Council, "Environmental Benefits of Interoperability: The Road to Maximizing Smart Grid's Environmental Benefit," Prepared for the GridWise® Architecture Council by Harbor Research, Inc., September 2009. Available at http://www.gridwiseac.org/pdfs/environmental_interoperability.pdf

GridWise Architecture Council, "Financial Benefits of Interoperability: How Interoperability in the Electric Power Industry Will Benefit Stakeholders Financially," Prepared for the GridWise® Architecture Council by Harbor Research, Inc., September 2009. Available at http://www.gridwiseac.org/pdfs/financial_interoperability.pdf.

GridWise Architecture Council, "Reliability Benefits of Interoperability," Prepared for the GridWise® Architecture Council by Alison Silverstein Consulting, September 2009. Available at http://www.gridwiseac.org/pdfs/reliability_interoperability.pdf.

National Institute of Standards and Technology, "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry," Authored by Michael P. Gallaher, Alan C. O'Connor, John L. Dettbarn, Jr., and Linda T. Gilday, NIST Advanced Technology Program: NIST GCR 04-867, August, 2004. Available at http://nvlpubs.nist.gov/nistpubs/gcr/2004/NIST.GCR.04-867.pdf.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, " The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings," February 2016. Available at http://energy.gov/sites/prod/files/2016/03/f30/Interoperability%20and%20National%20Benefits%20Through%20Buildings-031616.pdf.

Wakefield, Matt and Mark McGranaghan, "Achieving Smart Grid Interoperability through Collaboration," Electric Power Research Institute, Grid Interoperability Forum paper, 2008. Available at http://smartgrid.epri.com/doc/Achieving%20Smart%20Grid%20Interoperability%20through%20Collaboration.pdf.

Widergren, Steve, "Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015. Available at http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

State Experiences and Examples of Implementation

California

California Public Utilities Commission, "Annual Report to the Governor and the Legislature: California Smart Grid per Senate Bill 17," January, 2015. Available at http://www.cpuc.ca.gov/uploadedfiles/cpuc_website/content/utilities_and_industries/energy/reports_and_white_papers/smartgridannualreport2014final011215.pdf.

Fisher, Scott, "eV2g LLC: Reply Comments on Alternative Fuel Vehicles Rulemaking," NRG EV Services LLC, Princeton, NJ, May 31, 2016. Available at http://docs.cpuc.ca.gov/publisheddocs/efile/g000/m164/k010/164010939.pdf.

Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013. Available at https://view.officeapps.live.com/op/view.aspx?src=http%3A%2F%2Fwww.energy.ca.gov%2Felectricity_analysis%2Frule21%2Fdocuments%2Frecommendations_and_test_plan_documents%2FCPUC_Rule_21_Recommendations_v7.docx.

Smart Interoperability Working Group, "Rule 21 Recommendations for the CPUC," January 2013.

California Public Utility Commission, "SIWG Recommendations for Phase 2 Communication Protocols," 2016, http://www.cpuc.ca.gov/General.aspx?id=4154.

Cleveland, Francis, CA SIWG, "Recommendations for Advanced Functions for Distributed Energy Resources (DER) Systems," phase 3, March 2015.

Colorado

Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission. Available at https://www.colorado.gov/pacific/energyoffice/atom/14261.

Hawaii

Hawaii Clean Energy Initiative, "Kauai Smart Grid Initiative," December 2012. Available at http://www.hawaiicleanenergyinitiative.org/storage/media/7_12.07.12WG_MikeYamane.pdf.

Illinois

Ameren Illinois, "Ameren Illinois Advanced Metering Infrastructure Plan," June 28, 2012. Available at http://smartgridcc.org/wp-content/uploads/2012/08/Ameren-Ex.-2.1-AIC-AMI-Plan-Revised.pdf, accessed July 15, 2016.

Massachusetts

DPU 12-76 Massachusetts Electric Grid Modernization Stakeholder Working Group Process: Report to the Department of Public Utilities from the Steering Committee, Raab Associates, Ltd. & Synapse Energy Economics, Inc., July 2, 2013. Available at http://www.mass.gov/eea/docs/dpu/electric/grid-mod/ma-grid-mod-working-group-report-07-02-2013.pdf, accessed July 15, 2016.

Massachusetts Department of Public Utilities, "Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid," October 2, 2012.

National Grid, Grid Modernization Plan, August 19, 2015.

NSTAR, Grid Modernization Plan, August 19, 2015.

New York

Consolidated Edison Company of New York, Inc., with Innoventive Power and Verizon Communications. “Interoperability of Demand Response Resources Demonstration in NY,” Final Technical Report, Award Number: DE-FC26-08NT02869, Regional Demonstration Project. New York, Feb. 25, 2015. Available at https://www.smartgrid.gov/files/Con-Edison-NY-RDSI_Final-Interoperability-Project-Report-2-25-2015.pdf.

Consolidated Edison Company of New York, Inc. "Secure Interoperable Open Smart Grid Demonstration Project." December 28, 2014.

New York Department of Public Service, "Staff Proposal: Distributed System Implementation Plan Guidance," October 2015.

Orange & Rockland, Initial Distribution System Implementation Plan, Case No. 14-M-0101, June 2016.

Other

Duke Energy, “Leading Advancements in Interoperability: Open Field Message Bus (OpenFMB™) Interoperability Framework with a Microgrid Implementation.” In partnership with Coalition of the Willing (COW – II) partners, January 16, 2016.

Energy Information Administration, “Smart Grid Legislative and Regulatory Policies and Case Studies,” December 2011. Available at http://www.eia.gov/analysis/studies/electricity/pdf/smartggrid.pdf.

7. References

[1] GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[2] GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[3] NIST Special Publication 1108R2, "NIST Framework and Roadmap for Smart Grid Interoperability Standards," Release 2.0, February 2012, p. 37-39, http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf.

[4] U.S. Department of Energy – Energy Efficiency and Renewable Energy, The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings, (U.S. Department of Energy, 2016), p. 2.

[5] McKinsey Global Institute, The Internet of Things: Unmapping the Value Beyond the Hype, McKinsey & Company, June 2015, p. 53. Available at https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

[6] EICT Interoperability White Paper, European Industry Association, Information Systems Communication Technologies Consumer Electronics, June 2004.

[7] U.S. Department of Energy – Energy Efficiency and Renewable Energy, The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings, (U.S. Department of Energy, 2016), p. 2.

[8] Department of Energy – Energy Efficiency and Renewable Energy, The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings, (Department of Energy, 2016), p. 2.

[9] GridWise Architecture Council, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[10] S. Neumann, "Position Paper for the GridWise Interoperability Workshop," April 2007.

[11] World Standards, "Plug & Socket Types," last updated April 30, 2016, p. 1, http://www.worldstandards.eu/electricity/plugs-and-sockets/.

[12] FERC, "A Policy Framework For The 21st Century Grid: Enabling Our Secure Energy Future," June 2011, http://www.ferc.gov/industries/electric/indus-act/smart-grid/21st-century-grid.pdf.

[13] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," September 2014, p. 38.

[14] GWAC, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[15] GWAC, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 12, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[16] NIST Special Publication 1108R2, "NIST Framework and Roadmap for Smart Grid Interoperability Standards," Release 2.0, February 2012, p37-39, http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf.

[17] NIST Special Publication 1108R2, "NIST Framework and Roadmap for Smart Grid Interoperability Standards," Release 2.0, February 2012, p. 37–39, http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf.

[18] Pacific Northwest National Laboratory, "Grid Architecture," accessed August 1, 2016, http://gridarchitecture.pnnl.gov/.

[19] GridWise Architecture Council, "Interoperability Path Forward Whitepaper 2," 2005, p. 1–2, http://www.gridwiseac.org/pdfs/interoperability_path_whitepaper_v1_0.pdf.

[20] GridWise Architecture Council, "Interoperability Path Forward Whitepaper 2," 2005, p. 1–2, http://www.gridwiseac.org/pdfs/interoperability_path_whitepaper_v1_0.pdf.

[21] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3 p. 32, ttp://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[22] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 32, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[23] Department of Energy – Office of Electricity Delivery and Energy Reliability, "Standards & Interoperability," SmartGrid.gov, accessed July 22, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[24] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108, p. 13, http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf.

[25] Department of Energy – Office of Electricity Delivery and Energy Reliability, "Standards & Interoperability," SmartGrid.gov, Accessed July 22, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[26] Department of Energy – Office of Electricity Delivery and Energy Reliability, "Standards & Interoperability," SmartGrid.gov, Accessed July 22, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[27] Department of Energy – Office of Electricity Delivery and Energy Reliability, "Standards & Interoperability," SmartGrid.gov, Accessed July 22, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[28] Department of Energy – Office of Electricity Delivery and Energy Reliability, "Standards & Interoperability," SmartGrid.gov, Accessed July 22, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[29] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability

Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3. Available to the public at http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[30] Energy Independence and Security Act of 2007 [Public Law No: 110-140], Sec. 1305.

[31] Federal Energy Regulatory Commission, "Smart Grid Interoperability Standards," 136 FERC ¶ 61,039, Order issued July 19, 2011, Docket No. RM11-2-000, p. 1 http://www.ferc.gov/EventCalendar/Files/20110719143912-RM11-2-000.pdf.

[32] Federal Energy Regulatory Commission, "Smart Grid Interoperability Standards," 136 FERC ¶ 61,039, Order issued July 19, 2011, Docket No. RM11-2-000, p. 1 http://www.ferc.gov/EventCalendar/Files/20110719143912-RM11-2-000.pdf.

[33] Energy Independence and Security Act of 2007 [Public Law No: 110-140], Sec. 1305.; National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability.

Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 4, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[34] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 172, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[35] Thomas Basso,. "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[36] Thomas Basso,. "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, p. 4, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[37] Thomas Basso, "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, p. 4, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[38] Thomas Basso, "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, p. 4, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[39] IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads. IEEE Std 2030-2011 (IEEE), 10 September 2011. Available for purchase at http://www.techstreet.com/standards/ieee-2030-2011?product_id=1781311.

[40] IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads, IEEE Std 2030-2011 (IEEE), 10 September 2011, p. 1, http://www.techstreet.com/standards/ieee-2030-2011?product_id=1781311.

[41] Matt Wakefield and Mark McGranaghan, "Achieving Smart Grid Interoperability through Collaboration," Electric Power Research Institute, Grid Interoperability Forum paper, 2008, http://smartgrid.epri.com/doc/Achieving%20Smart%20Grid%20Interoperability%20through%20Collaboration.pdf.

[42] Matt Wakefield and Mark McGranaghan, "Achieving Smart Grid Interoperability through Collaboration," Electric Power Research Institute, Grid Interoperability Forum paper, 2008, http://smartgrid.epri.com/doc/Achieving%20Smart%20Grid%20Interoperability%20through%20Collaboration.pdf.

[43] International Electrotechnical Commission (IEC), "About Us," updated 2016, http://www.iec.ch.

[44] CIM Users Group, "Focus on Standards," updated 2014, http://cimug.ucaiug.org/default.aspx.

[45] Thomas Basso, "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, p. 2, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[46] Thomas Basso, "IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid," National Renewable Energy Lab (NREL), Technical Report NREL/TP-5D00-63157, December 2014, p. 8, http://www.nrel.gov/docs/fy15osti/63157.pdf.

[47] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 7, accessed July 8, 2016.https://www.colorado.gov/pacific/energyoffice/atom/14261.

[48] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 8–9, accessed July 8, 2016, https://www.colorado.gov/pacific/energyoffice/atom/14261.

[49] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 46, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf

[50] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 129, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[51] GridWise Architecture Council, "The GridWise® Interoperability Context-Setting Framework is a work of the GridWise Architecture Council," March 2008.

[52] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 129, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[53] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 46–47, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[54] GridWise Architecture Council, "Reliability Benefits of Interoperability" is a work of the GridWise Architecture Council, September 2009, p. 7.

55 GWAC, "Decision-Maker's Interoperability Checklist," V1.5, August 2010, p. 1, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[56] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 49, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[57] GridWise Architecture Council, "The GridWise® Interoperability Context-Setting Framework is a work of the GridWise Architecture Council," March 2008, p. 31–33.

[58] Kathleen Davis, "How Does the Industry Create True Interoperability?" *Electric Light & Power*, January 1, 2012.

[59] GridWise Architecture Council, "Reliability Benefits of Interoperability" is a work of the GridWise Architecture Council, September 2009, p. 14.

[60] Department of Energy, "The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings," February 2016, p. 4, http://energy.gov/sites/prod/files/2016/03/f30/Interoperability%20and%20National%20Benefits%20Through%20Buildings-031616.pdf.

[61] Department of Energy, "The National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized Through Buildings," February 2016, p. 1, http://energy.gov/sites/prod/files/2016/03/f30/Interoperability%20and%20National%20Benefits%20Through%20Buildings-031616.pdf.

[62] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[63] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 41, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[64] George W. Arnold, "NIST Smart Grid Activities," NIST, August 31, 2011, p. 1; Honeywell, Inc., "Initial Comments of Honeywell, Inc. on Policy and Logistical Challenges in Implementing Smart Grid Solutions," November 2010; National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011, p. 26.

[65] National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011.

[66] Kathleen Davis, "How Does the Industry Create True Interoperability?" Electric Light & Power, January 1, 2012.

[67] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[68] GridWise Architecture Council, "Reliability Benefits of Interoperability," September 2009, p. 10.

[69] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[70] GWAC, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[71] President's Council of Advisors on Science and Technology, "Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology," Report to the President and Congress, December 2010, p. 15.

[72] National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011, p. 26.

[73] NSSF, n.d., p. 3; DRSG RFI, p. 8; National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011; NIST, "Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," May 2014.

[74] GWAC, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[75] Testimony of Mason W. Emnett Associate Director, Office of Energy Policy and Innovation, Before the Technology and Innovation Subcommittee Of the Committee on Science and Technology

[76] Testimony of Mason W. Emnett Associate Director, Office of Energy Policy and Innovation, Before the Technology and Innovation Subcommittee Of the Committee on Science and Technology

[77] Testimony of Mason W. Emnett Associate Director, Office of Energy Policy and Innovation, Before the Technology and Innovation Subcommittee Of the Committee on Science and Technology

[78] Testimony of Mason W. Emnett Associate Director, Office of Energy Policy and Innovation, Before the Technology and Innovation Subcommittee Of the Committee on Science and Technology

[79] NIST, "Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," May 2014, p. 30.

[80] NSSF, n.d., p. 3.

[81] GWAC, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[82] GWAC, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[83] GWAC, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[84] Kathleen Davis, "How Does the Industry Create True Interoperability?" *Electric Light & Power*, January 1, 2012.

[85] Kathleen Davis, "How Does the Industry Create True Interoperability?" *Electric Light & Power*, January 1, 2012.

[86] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[87] National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011, p. 26.

[88] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[89] GridWise Architecture Council, "Reliability Benefits of Interoperability," September 2009, p. 5.

[90] National Institute of Standards and Technology, "Smart Grid Testing and Certification," updated December 2012, accessed July 14, 2016, http://www.nist.gov/el/smartgrid/sgtest.cfm.

[91] GridWise Architecture Council, "Decision-maker's Interoperability Checklist," Version 1.5, August 2010, p. 1–2.

[92] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems

Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 41, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[93] George W. Arnold, "NIST Smart Grid Activities," NIST, August 31, 2011; National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011.

[94] National Science and Technology Council, "A Policy Framework for the 21st Century Grid: Enabling Our Secure Energy Future," June 2011; Kathleen Davis, "How Does the Industry Create True Interoperability?" Electric Light & Power, January 1, 2012.

[95] Kathleen Davis, "How Does the Industry Create True Interoperability?" *Electric Light & Power*, January 1, 2012.

[96] Kathleen Davis, "How Does the Industry Create True Interoperability?" *Electric Light & Power*, January 1, 2012.

[97] Doug Lambert, "Considering Standardized Interoperability in your Technology Plan," MultiSpeak, http://www.techadvantage.org/wp-content/uploads/2014/03/1H_Lambert.pdf.

[98] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p14. See also European Network of Transmission System Operators for Electricity (ENTSO-E) SPD Report "Dispersed Generation Impact On CE Region Security, Dynamic Study, Final Report," 22-03-2013. See also California Energy Commission, "European Renewable Distributed Generation Infrastructure Study-Lessons Learned from Electricity Markets in Germany and Spain - Consultant Report," December 2011, CEC-400-2011-011. Available at http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-400-2011-011.

[99] St. John, Jeff. Greentech Media, "Western Utilities Call for Smart Solar Inverters," August 2013. Available at http://www.greentechmedia.com/articles/read/western-utilities-call-for-smart-solar-inverters.

[100] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 14.

[101] Western Electric Industry Leaders, Statement, August 2013. Available at https://www.sdge.com/sites/default/files/documents/1843346665/WEIL%20Smart%20Inverters%20Letter%20Final%20Aug%207%202013.pdf?nid=8436.

[102] For example, see Bernhardt, John, Clean Coalition, "California adopts nation's first advanced inverter standards," January 2015. Available at http://www.clean-coalition.org/press-releases/california-adopts-nations-first-advanced-inverter-standards/.

[103] GridWise Architecture Council , "Financial Benefits of Interoperability," September 2009, p. iv.

[104] Value is in 2009 dollars. GWAC, "Financial Benefits of Interoperability," September 2009, p. 11.

[105] McKinsey Global Institute, "The Internet of Things: Unmapping the Value Beyond the Hype," McKinsey & Company, June 2015, p.52. Available at https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

[106] McKinsey Global Institute, "The Internet of Things: Unmapping the Value Beyond the Hype," McKinsey & Company, June 2015, p24. Available at

https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.

[107] Kathleen Davis, "How Does the Industry Create True Interoperability?" Electric Light & Power, January 1, 2012.

[108] National Institute of Standards and Technology, "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry," Authored by Michael P. Gallaher, Alan C. O'Connor, John L. Dettbarn, Jr., and Linda T. Gilday, NIST Advanced Technology Program: NIST GCR 04-867, published August, 2004, http://nvlpubs.nist.gov/nistpubs/gcr/2004/NIST.GCR.04-867.pdf.

[109] David Matheson, et al., "Realizing The Promise of Disease Management," Boston Consulting Group, December 2006.

[110] GridWise Architecture Council, "Reliability Benefits of Interoperability," September 2009, p. 22.

[111] GridWise Architecture Council, "Reliability Benefits of Interoperability," September 2009, p. 23.

[112] Department of Energy, "Standards and Interoperability," accessed July 5, 2016, https://www.smartgrid.gov/recovery_act/overview/standards_interoperability.html.

[113] EPRI, "The Green Grid: Energy Savings and Carbon Emissions Reductions Enabled by a Smart Grid," EPRI 1016905, 2008.

[114] GridWise Architecture Council, "Environmental Benefits of Interoperability," September 2009, p. 3.

[115] GridWise Architecture Council, "Environmental Benefits of Interoperability," September 2009, p. 3.

[116] National Institute of Standards and Technology, "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0," Smart Grid and Cyber-Physical Systems Program Office and Energy and Environment Division, Engineering Laboratory, NIST Special Publication 1108r3, p. 32, http://www.nist.gov/smartgrid/upload/NIST-SP-1108r3.pdf.

[117] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 10, accessed July 8, 2016 https://www.colorado.gov/pacific/energyoffice/atom/14261.

[118] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 10, accessed July 8, 2016 https://www.colorado.gov/pacific/energyoffice/atom/14261.

[119] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 10, accessed July 8, 2016 https://www.colorado.gov/pacific/energyoffice/atom/14261.

[120] Illinois General Assembly, Public Act 097-0616, http://www.ilga.gov/legislation/publicacts/97/097-0616.htm.

[121] Illinois General Assembly, Public Act 097-0646, http://www.ilga.gov/legislation/publicacts/97/097-0646.htm.

122 Ameren Illinois Advanced Metering Infrastructure Plan, Ameren Illinois, June 28, 2012, p. 3, accessed July 15, 2016, http://smartgridcc.org/wp-content/uploads/2012/08/Ameren-Ex.-2.1-AIC-AMI-Plan-Revised.pdf.

123 Illinois General Assembly, Public Act 097-0616, http://www.ilga.gov/legislation/publicacts/97/097-0616.htm.

124 DPU 12-76 Massachusetts Electric Grid Modernization Stakeholder Working Group Process: Report to the Department of Public Utilities from the Steering Committee, Raab Associates, Ltd. & Synapse Energy Economics, Inc., July 2, 2013, p. 49, accessed July 15, 2016, http://www.mass.gov/eea/docs/dpu/electric/grid-mod/ma-grid-mod-working-group-report-07-02-2013.pdf.

125 DPU 12-76 Massachusetts Electric Grid Modernization Stakeholder Working Group Process: Report to the Department of Public Utilities from the Steering Committee, Raab Associates, Ltd. & Synapse Energy Economics, Inc., July 2, 2013, p. 49, accessed July 15, 2016, http://www.mass.gov/eea/docs/dpu/electric/grid-mod/ma-grid-mod-working-group-report-07-02-2013.pdf.

126 DPU 12-76 Massachusetts Electric Grid Modernization Stakeholder Working Group Process: Report to the Department of Public Utilities from the Steering Committee, Raab Associates, Ltd. & Synapse Energy Economics, Inc., July 2, 2013, p. 49, accessed July 15, 2016, http://www.mass.gov/eea/docs/dpu/electric/grid-mod/ma-grid-mod-working-group-report-07-02-2013.pdf.

127 New York Department of Public Service, "Staff Proposal: Distributed System Implementation Plan Guidance," October 2015, p. 2.

128 New York Department of Public Service, "Staff Proposal: Distributed System Implementation Plan Guidance," October 2015, p. 5.

129 Orange & Rockland, Initial Distribution System Implementation Plan, Case No. 14-M-0101, June 2016, p. 140.

130 Massachusetts Department of Public Utilities, "Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid," October 2, 2012, p. 1.

131 Massachusetts Department of Public Utilities, "Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid," October 2, 2012, p. 1.

132 Massachusetts Department of Public Utilities, "Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid," October 2, 2012, p. 16.

133 Massachusetts Department of Public Utilities, "Investigation by the Department of Public Utilities on its own Motion into Modernization of the Electric Grid," October 2, 2012, p. 16.

134 NSTAR, Grid Modernization Plan, August 19, 2015, p. 53.

135 NSTAR, Grid Modernization Plan, August 19, 2015, p. 86.

136 National Grid, Grid Modernization Plan, August 19, 2015, p. 144.

137 National Grid, Grid Modernization Plan, August 19, 2015, p. 179.

138 National Grid, Grid Modernization Plan, August 19, 2015, p. 182.

139 Hawaii Clean Energy Initiative, "Kauai Smart Grid Initiative," December 2012, http://www.hawaiicleanenergyinitiative.org/storage/media/7_12.07.12WG_MikeYamane.pdf.

[140] Hawaiian Electric, "Hawaiian Electric Companies propose plan for modernizing electric grids," March 2016,. https://www.hawaiianelectric.com/Documents/about_us/news/2016/20160331_smart_grid.pdf.

[141] National Association of Regulatory Commissioners, Research Lab, "Smart Inverters: The Link between Smart Grid and Solar," July 2016, http://naruc.org/naruc-research-lab/lab-past-meetings/.

[142] National Association of Regulatory Utility Commissioners, "Resolution on Smart Grid Principles," published July, 2011, http://pubs.naruc.org/pub/53985C3E-2354-D714-51A8-281C62A21700.

[143] National Association of Regulatory Utility Commissioners, "Resolution on Smart Grid," published July, 2010, http://pubs.naruc.org/pub/53985C79-2354-D714-51E8-2CBC8B5F9C1A.

[144] Colorado Smart Grid Task Force, "Deploying Smart Grid in Colorado: Recommendations and Options," directed by Colorado Senate Bill 10-180, Prepared for the Governor of Colorado, the General Assembly, and the Colorado Public Utilities Commission, p. 59, accessed July 8, 2016, https://www.colorado.gov/pacific/energyoffice/atom/14261.

[145] Steve Widergren, " Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015, p. 8–9, http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

[146] GridWise Architecture Council, "Decision Makers Checklist," 2010, http://www.gridwiseac.org/pdfs/gwac_decisionmakerchecklist_v1_5.pdf.

[147] Steve Widergren, " Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015, p. 8–9, http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

[148] Steve Widergren, " Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015, p. 8–9, http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

[149] Steve Widergren, " Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015, p. 8–9, http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

[150] Steve Widergren, " Buildings Equipment Connectivity Interoperability for Energy Applications," Pacific Northwest National Lab, IEA-DSM Panel Demand Flexibility: Eindhoven, The Netherlands, 29 June 2015, p. 8–9, http://www.ieadsm.org/wp/files/Steve_Widergren_BldgInteropIEA-DSMpanelEindhoven_2015.pdf.

[151] Energy Information Administration, "Smart Grid Legislative and Regulatory Policies and Case Studies," Prepared for U.S. EIA by SAIC, published December 2011, p. 53, http://www.eia.gov/analysis/studies/electricity/pdf/smartggrid.pdf.

[152] Energy Information Administration, "Smart Grid Legislative and Regulatory Policies and Case Studies," Prepared for U.S. EIA by SAIC, published December 2011, p. 53, http://www.eia.gov/analysis/studies/electricity/pdf/smartggrid.pdf.

[153] Energy Information Administration, "Smart Grid Legislative and Regulatory Policies and Case Studies," Prepared for U.S. EIA by SAIC, published December 2011, p. 58, http://www.eia.gov/analysis/studies/electricity/pdf/smartggrid.pdf.

[154] National Institute of Standards and Technology, "Smart Grid Advisory Committee (SGAC) Report," p. 15–21, published March 5, 2012, http://www.nist.gov/smartgrid/upload/NIST_SGAC_Final_Recommendations_Report_3-05-12_with_Attachments.pdf.

[155] More specific details on the process can be found at http://www.cpuc.ca.gov/General.aspx?id=3962 and http://www.energy.ca.gov/electricity_analysis/rule21/documents/phase3/SIWG_Phase_3_Advanced_DER_Functions_2015-03-12.pdf.

[156] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 2, https://view.officeapps.live.com/op/view.aspx?src=http%3A%2F%2Fwww.energy.ca.gov%2Felectricity_analysis%2Frule21%2Fdocuments%2Frecommendations_and_test_plan_documents%2FCPUC_Rule_21_Recommendations_v7.docx.

[157] Smart Interoperability Working Group, "Rule 21 Recommendations for the CPUC," January 2013, p. 13.

[158] Smart Interoperability Working Group, "Rule 21 Recommendations for the CPUC," January 2013, p. 14.

[159] California Public Utility Commission, "SIWG Recommendations for Phase 2 Communication Protocols," 2016, http://www.cpuc.ca.gov/General.aspx?id=4154.

[160] Smart Inverter Working Group, California Public Utility Commissions & California Energy Commission, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 48.

[161] Smart Grid Interoperability Panel, Catalog of Standards, http://www.sgip.org/Catalog-of-Standards.

[162] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 15.

[163] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 15.

[164] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 12.

[165] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 14. See also European Network of Transmission System Operators for Electricity (ENTSO-E) SPD Report "Dispersed Generation Impact On CE Region Security, Dynamic Study, Final Report," 22-03-2013. See also California Energy Commission, "European Renewable Distributed Generation Infrastructure Study-Lessons Learned from Electricity Markets in Germany and Spain - Consultant Report," December 2011, CEC-400-2011-011, http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-400-2011-011.

[166] St. John, Jeff. Greentech Media, "Western Utilities Call for Smart Solar Inverters," August 2013, http://www.greentechmedia.com/articles/read/western-utilities-call-for-smart-solar-inverters.

[167] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 14.

[168] Western Electric Industry Leaders, Statement, August 2013, https://www.sdge.com/sites/default/files/documents/1843346665/WEIL%20Smart%20Inverters%20Letter%20Final%20Aug%207%202013.pdf?nid=8436.

[169] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 4.

[170] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 4.

[171] Smart Inverter Working Group, CPUC & CEC, "Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources," December 2013, p. 4.

[172] Cleveland, Francis, CA SIWG, "Recommendations for Advanced Functions for Distributed Energy Resources (DER) Systems," phase 3, March 2015.

[173] Smart Grid Interoperability Panel, "FAQ," OpenFMB™. Available at http://www.sgip.org/openfmb/#faq.

[174] Duke Energy, "Leading Advancements in Interoperability: Open Field Message Bus (OpenFMB™) Interoperability Framework with a Microgrid Implementation," In partnership with Coalition of the Willing (COW – II) partners, January 16, 2016.

[175] Smart Grid Interoperability Panel, "FAQ," OpenFMB™. Available at http://www.sgip.org/openfmb/#faq.

[176] Smart Grid Interoperability Panel, "Enabling and Accelerating Grid Modernization Through the Internet of Things (IoT)," EnergyIoT™: Accelerating Grid Modernization. Available at http://www.sgip.org/energyiot/.

[177] NAESB, "NAESB Announcement Concerning The Open Field Message Busmodel Business Practices," March 2015. Available at https://www.naesb.org/pdf4/031516press_release.pdf

[178] Smart Grid Interoperability Panel, "FAQ," OpenFMB™. Available at http://www.sgip.org/openfmb/#faq.

[179] Smart Grid Interoperability Panel, "FAQ," OpenFMB™. Available at http://www.sgip.org/openfmb/#faq.

[180] MultiSpeak, "History of MultiSpeak." Available at http://www.multispeak.org/about/history/Pages/default.aspx.

[181] MultiSpeak, "About Multispeak: FAQ." Available at http://www.multispeak.org/about/FAQ/Pages/default.aspx.

[182] Smart Grid Interoperability Panel, "FAQ," OpenFMB™. Available at http://www.sgip.org/openfmb/#faq, p. 1.

[183] Duke Energy, "Leading Advancements in Interoperability: Open Field Message Bus (OpenFMB™) Interoperability Framework with a Microgrid Implementation." In partnership with Coalition of the Willing (COW – II) partners, January 16, 2016, p. 3.

[184] Duke Energy, "Leading Advancements in Interoperability: Open Field Message Bus (OpenFMB™) Interoperability Framework with a Microgrid Implementation." In partnership with Coalition of the Willing (COW – II) partners, January 16, 2016, p. 6.

[185] Duke Energy, "Leading Advancements in Interoperability: Open Field Message Bus (OpenFMB™) Interoperability Framework with a Microgrid Implementation." In partnership with Coalition of the Willing (COW – II) partners, January 16, 2016, p. 4.

[186] All references in this case study are from the following source unless otherwise noted: Consolidated Edison Company of New York, Inc. "Secure Interoperable Open Smart Grid Demonstration Project," December 28, 2014.

[187] Consolidated Edison Company of New York, Inc. "Technology Performance Report: Secure Interoperable Open Smart Grid Demonstration Project," July 5, 2012, p. 1.

[188] McKinsey Global Institute, The Internet of Things: Unmapping the Value Beyond the Hype, McKinsey & Company, June 2015, p. 53. Available at https://www.mckinsey.de/files/unlocking_the_potential_of_the_internet_of_things_full_report.pdf.