HVDC: Pathway to America's Sustainable Future

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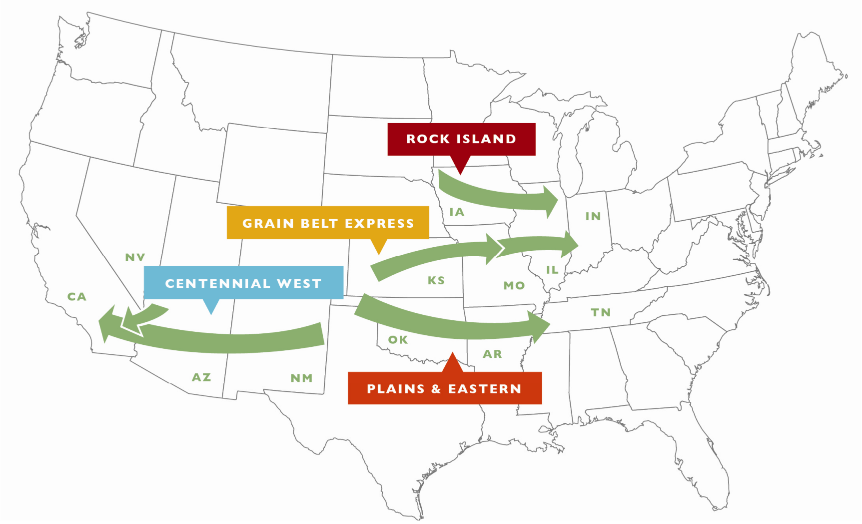
DOE Applications of High-Voltage Direct Current Transmission Technologies Workshop

CLEAN LINE
ENERGY PARTNERS

Who is Clean Line Energy Partners?

Clean Line Energy's Projects



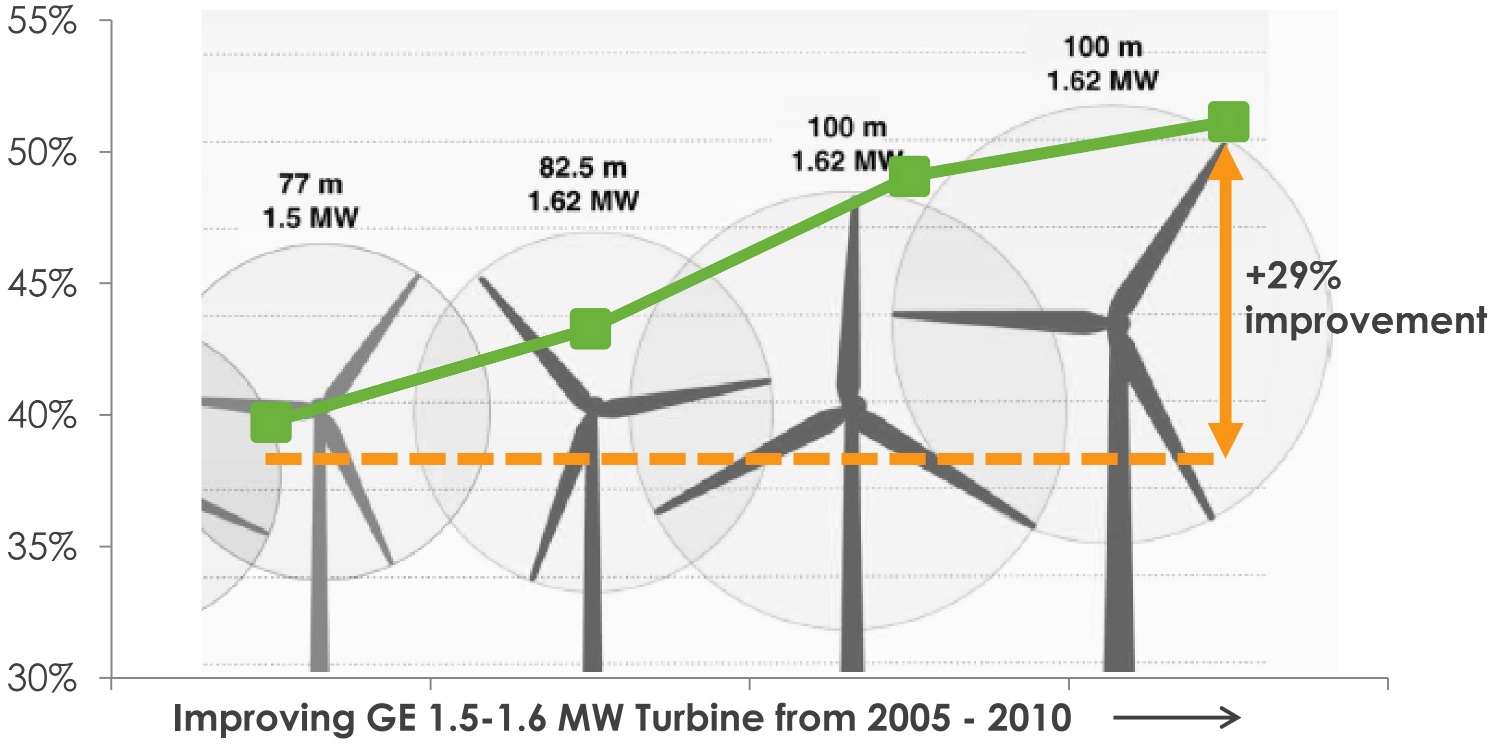
CLEAN LINE ENERGY PARTNERS

- Founded in 2009
- Headquartered in Houston
- 37 full-time employees
- Four projects under active development
- Investors have a long term vision and patient capital

- Clean Line Energy Partners ("Clean Line") develops long-haul, high-voltage direct current ("HVDC") transmission lines to connect the best wind resources in North America to load centers that lack access to low-cost renewable power
- HVDC is the lowest cost, least land intensive, most reliable transmission technology to integrate large volumes of renewable energy
- Clean Line's four projects (of lengths between 550-900 miles each) present up to $10 billion in new infrastructure investment and will supply over 17,500 MW in wind generation capacity

Improving wind turbine technology is increasing capacity factors and reducing generation costs

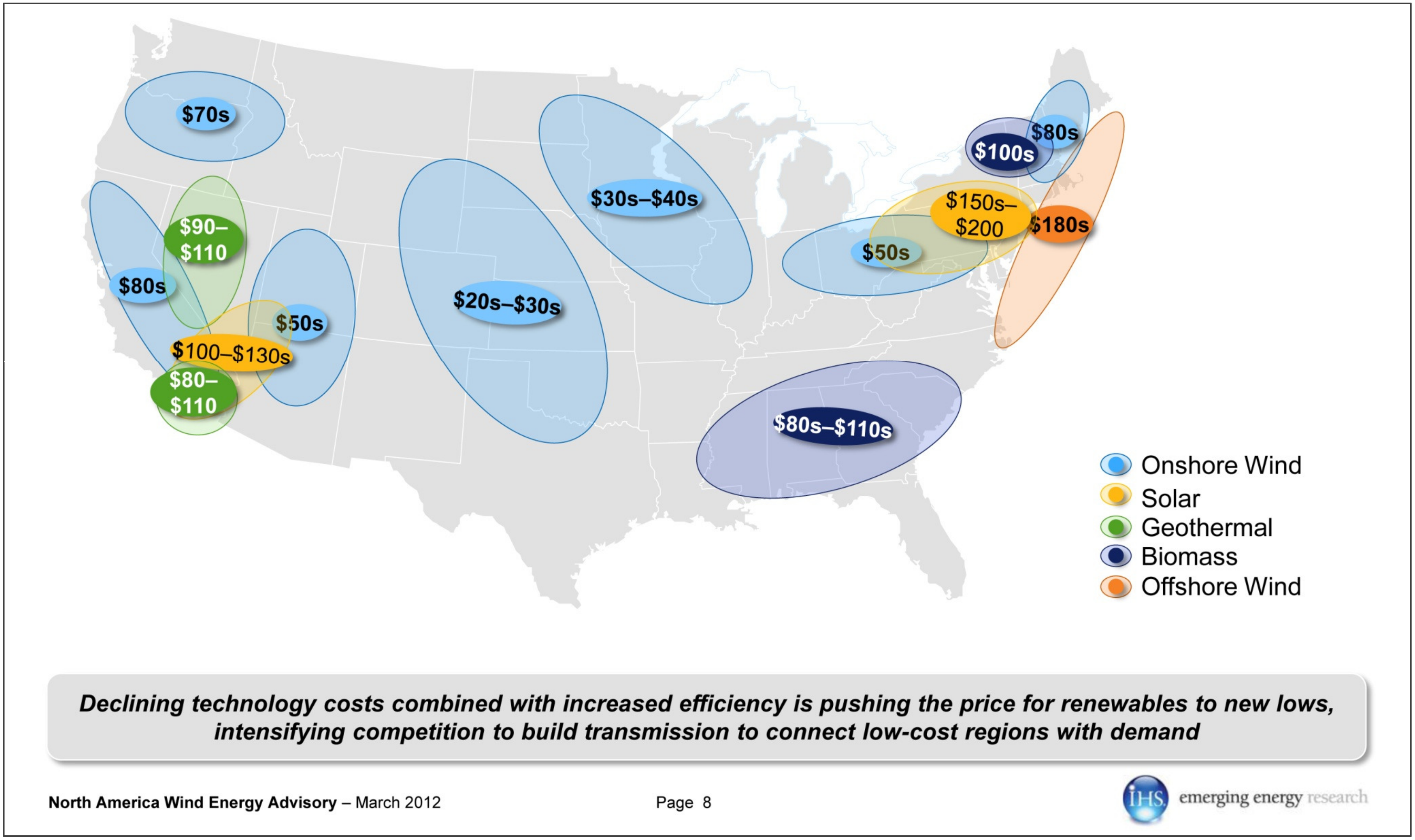
Net Capacity Factor[1]
At 8.5 meters per second wind speed



In meters				
Rotor Diameter	77	82.5	100	100
Hub Height	80	80	80	100

1. Assumptions: shear alpha = 0.2, Rayleigh distribution, 17% losses from GCF to NCF

Lowest cost energy still comes from the windiest areas



Declining technology costs combined with increased efficiency is pushing the price for renewables to new lows, intensifying competition to build transmission to connect low-cost regions with demand

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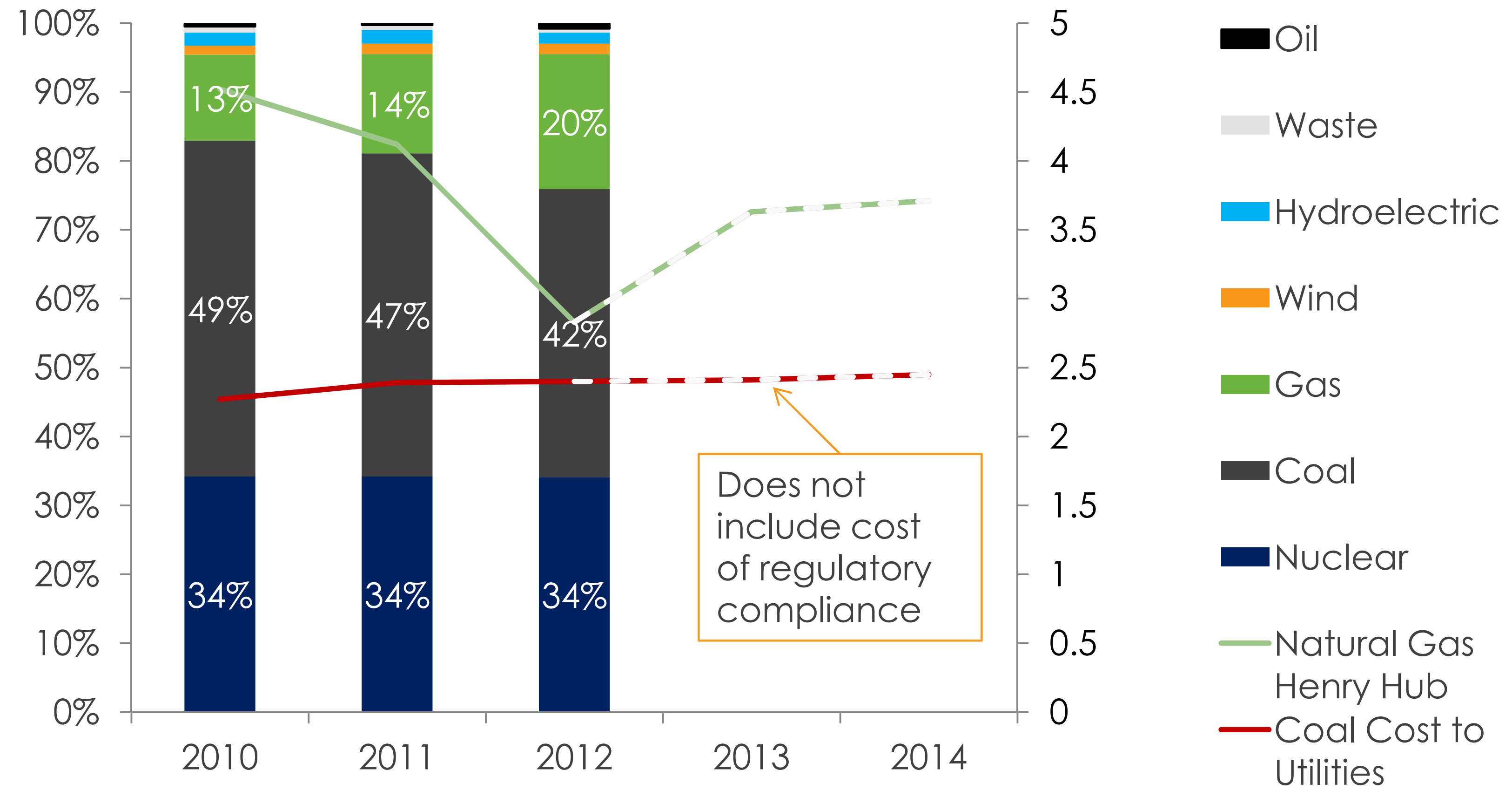
IHS emerging energy research

Wind provides fuel diversity with natural gas exposure increasing

Generation by fuel source
% of total PJM Generation

EIA fuel cost
$/MMBTU

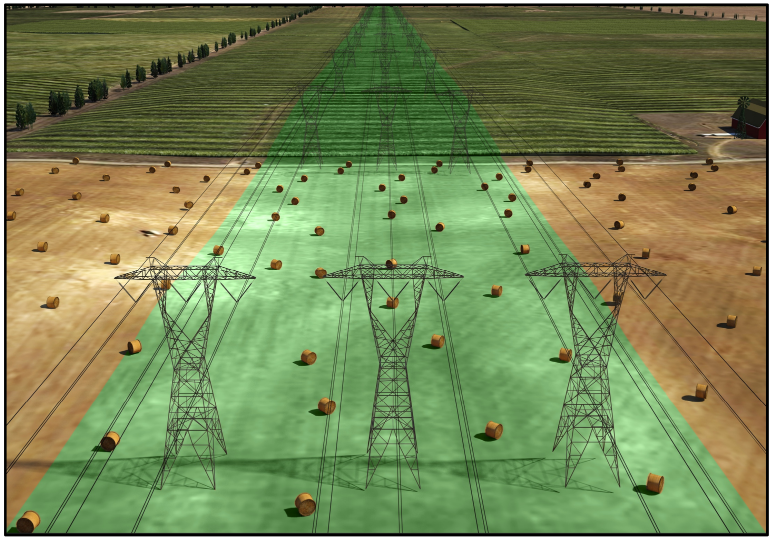


Does not include cost of regulatory compliance

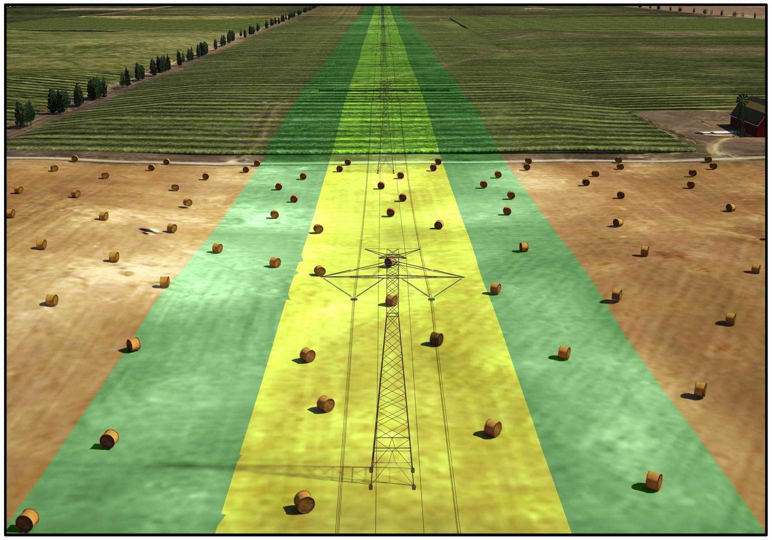
Source: PJM 2011 and 2012 State of the Market Report, EIA

HVDC is the most efficient method to transmit large amounts of electricity over long distances

- More efficient — Lower line losses
- Lower cost — Requires less infrastructure, results in lower costs and lower prices for delivered renewable energy
- Improved reliability — Control of power flow enhances system stability and lowers cost of integrating wind
- Smaller footprint — Use narrower right-of-way than equivalent Alternating Current (AC)



AC Footprint



DC Footprint

HVDC transmission brings a unique set of advantages for wind integration

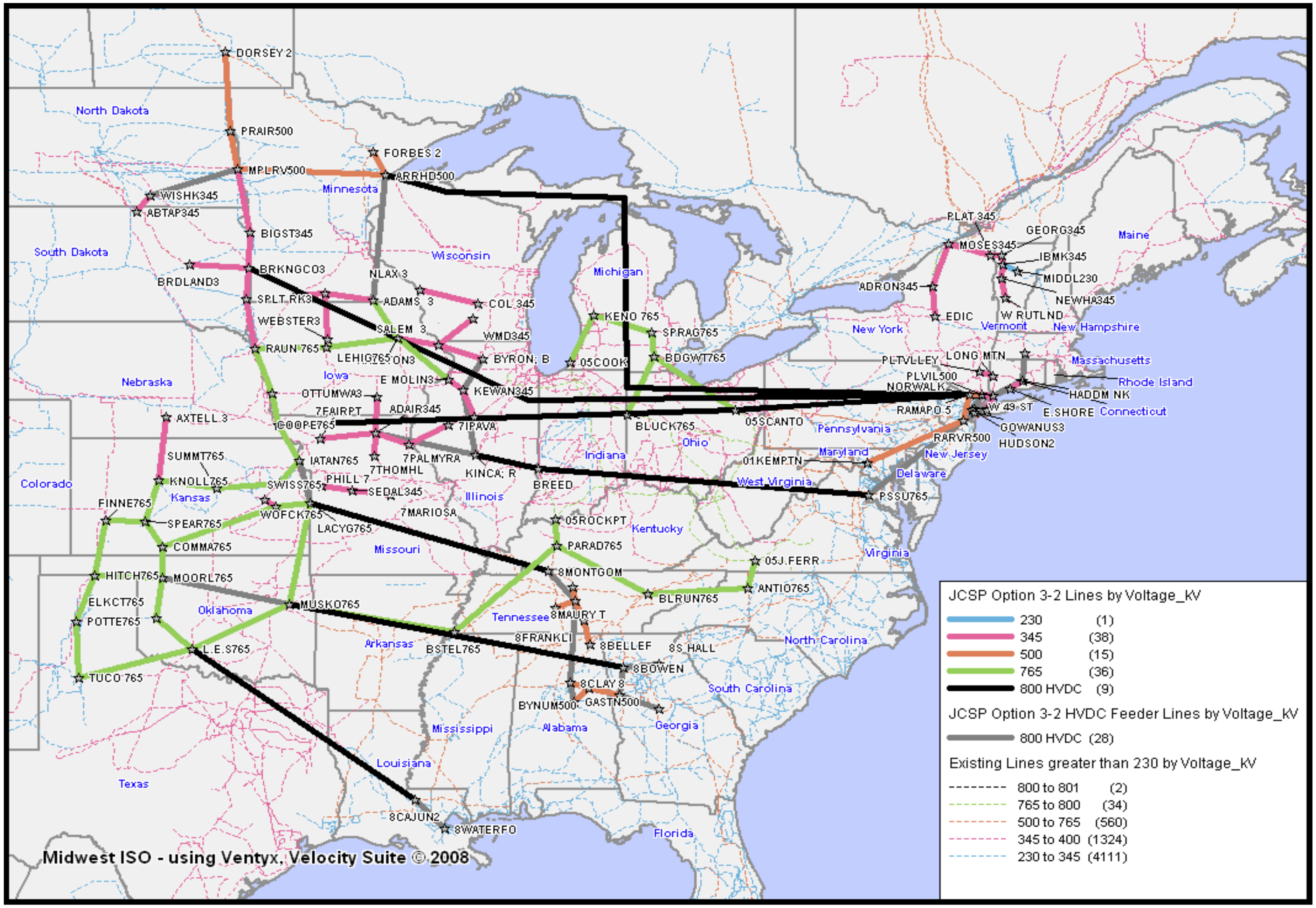
Access to high capacity factor wind resources

Appropriate technology for long-distance transmission

Move variability to larger balancing areas that are better suited to integrate large amounts of wind

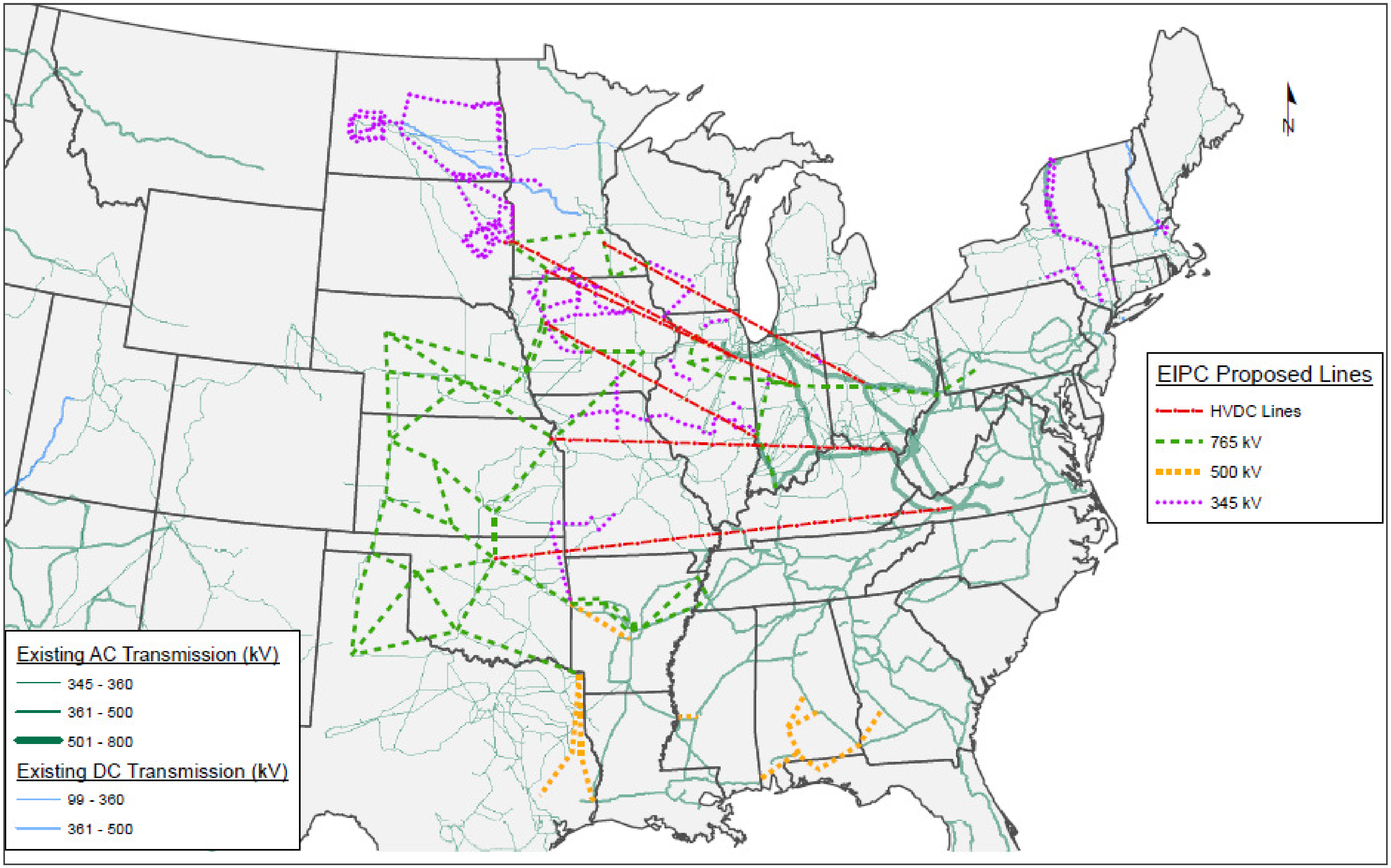
Transmit large volumes of renewables with high reliability and direct control

In the US, the Joint Coordinated System Plan (JCSP) identified 7 HVDC lines to move wind energy



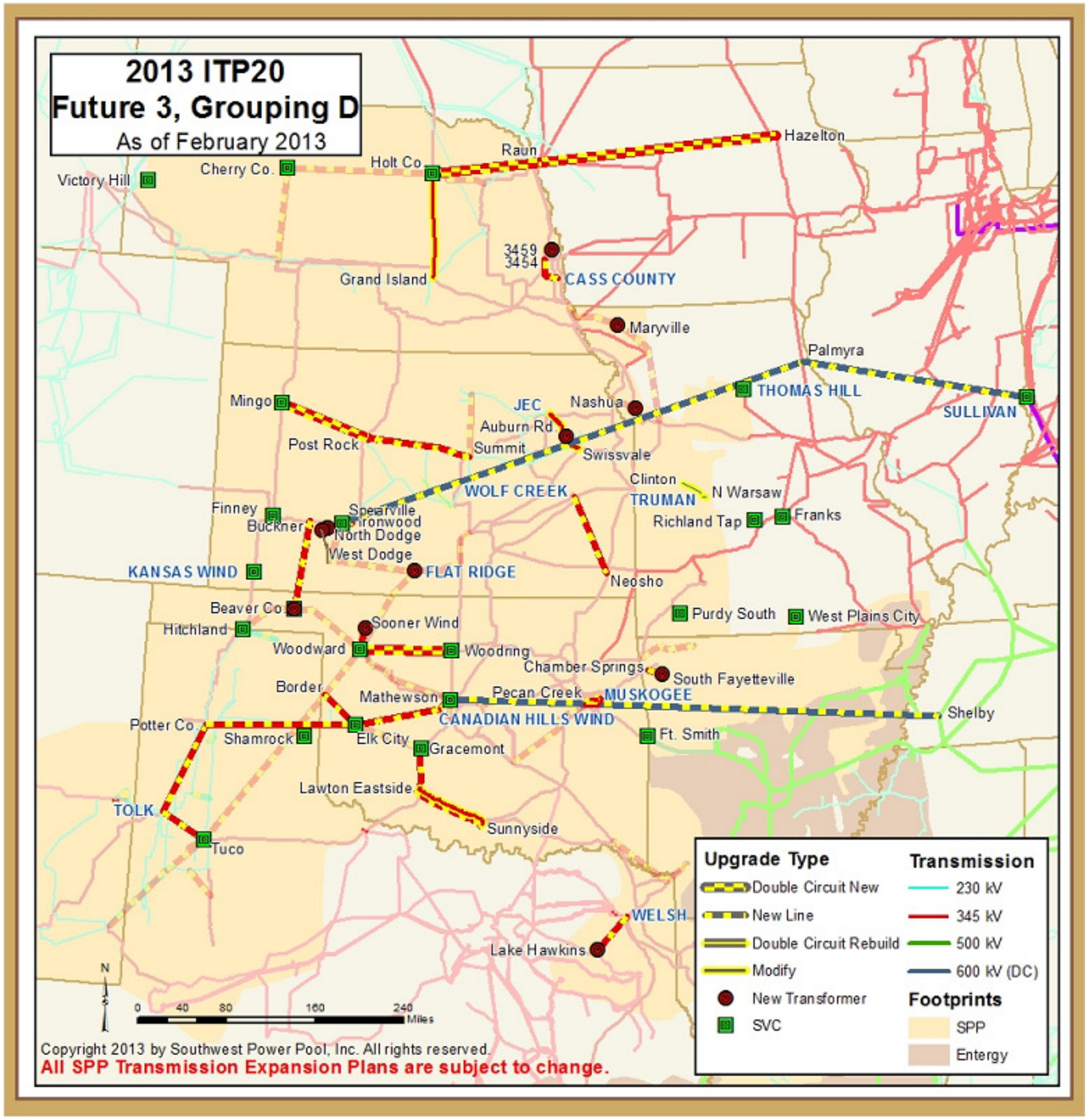
Source: JCSP 2008

Eastern Interconnection Planning Collaborative (EIPC) identified 6 HVDC lines to move wind energy



Source: EIPC TOTF 2012

SPP ITP20 Future 3 (Wind + Exports) identified HVDC as significant part of the most economical solution

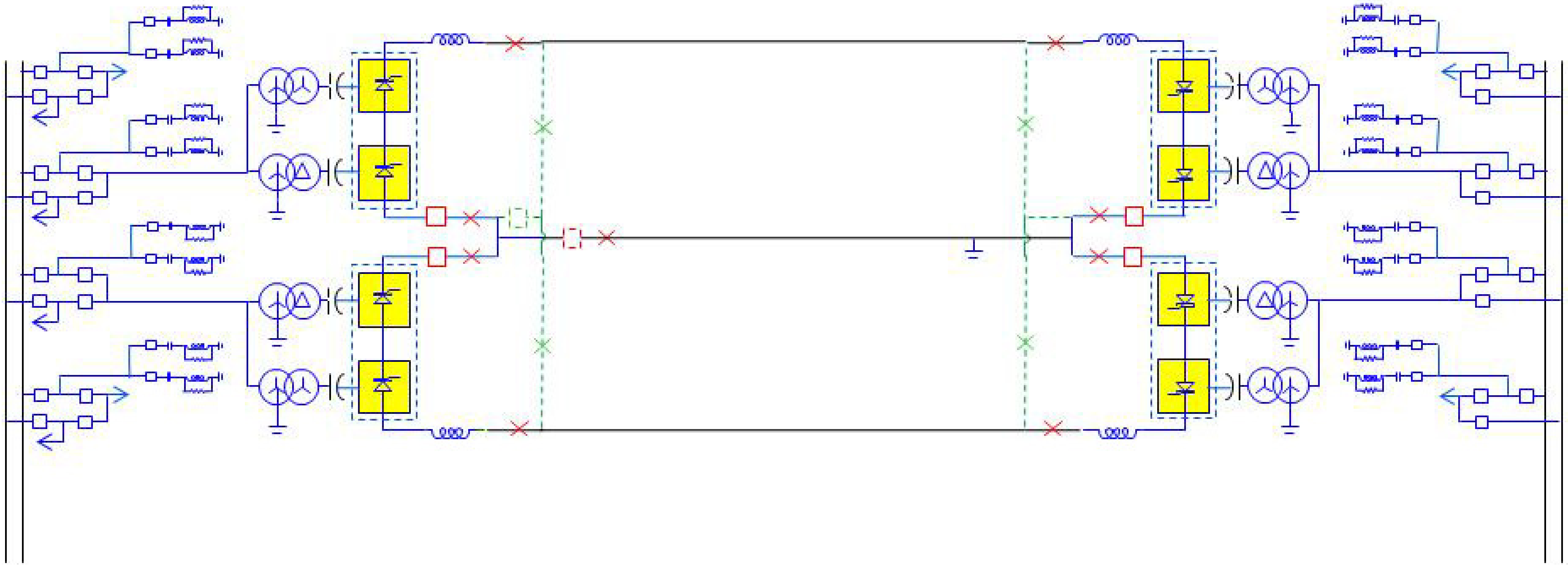


Source: April 2013 SPP MOPC Background Materials – ESWG Report

Technical Challenges of Implementation

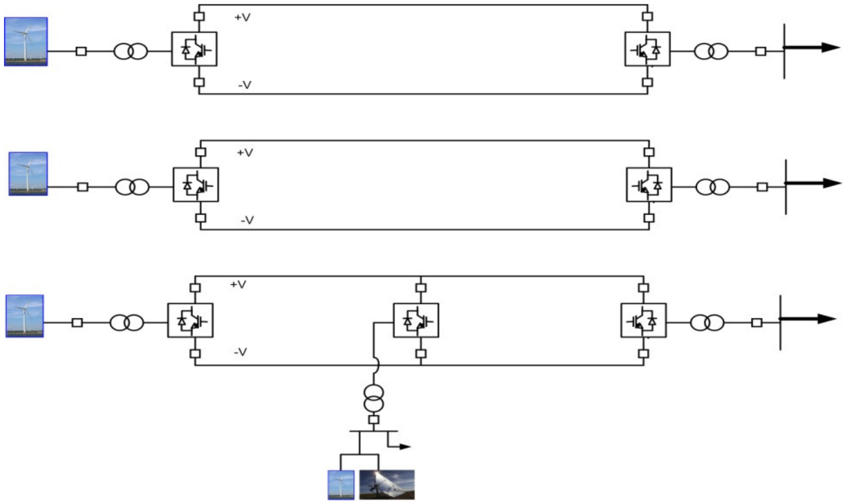
- Low short-circuit ratios mean weak system interactions on windward end
  - SCR of 3.0 or greater is best. Most Clean Line projects are less than 2.0. Dynamic reactive equipment and robust conversion concerns.
  - Who wins in voltage control? Wind farms or converter station? Possible need for wide area control and coordination with high speed communications.
- Large power injections on the load end
  - System frequency events, operating concerns
- Variability of resources
  - Wind integration concerns – lots of scientific answers, policy makers don’t always like physics

Weak grid interactions may can be addressed through use of Capacitor Commutated Converters (CCC)…

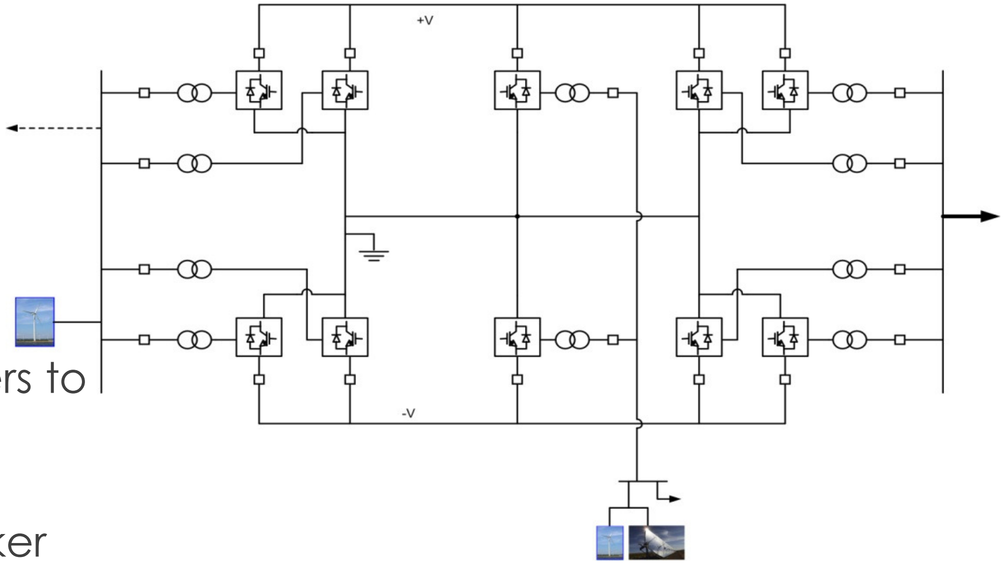


- Reduces/removes need for synchronous condensers.
- Untested on overhead lines and at such high voltages
- Only a "slight" premium over standard LCC, but huge savings over adding synchronous condensers

…or possibly by applying VSC technology in new schemes



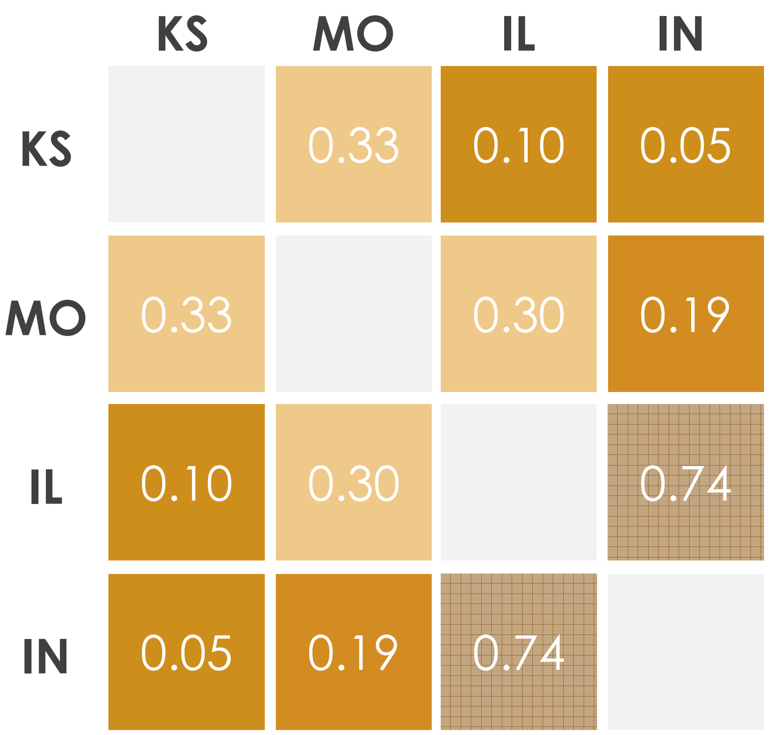
- "Tri-pole" configuration
- Three independent symmetrical monopoles
- Each pole rated ~1100 MW
- Independent placement of terminals
- Overhead still requires either full bridge converter or high speed HVDC breaker



- Bi-pole configuration with parallel converters.
- Each pole rated ~2400 MW for total power of ~4800 MW
- Same configuration as HVDC classic except the need for parallel converters to achieve more that 2200 MW.
- Overhead still requires full bridge converters or high speed HVDC breaker

HVDC addresses winds' variability challenge by enabling import of uncorrelated resources

Correlation of 10-Minute Wind Power Output



	KS	MO	IL	IN
KS		0.33	0.10	0.05
MO	0.33		0.30	0.19
IL	0.10	0.30		0.74
IN	0.05	0.19	0.74	

🟧 Low correlation

🟨 Medium correlation

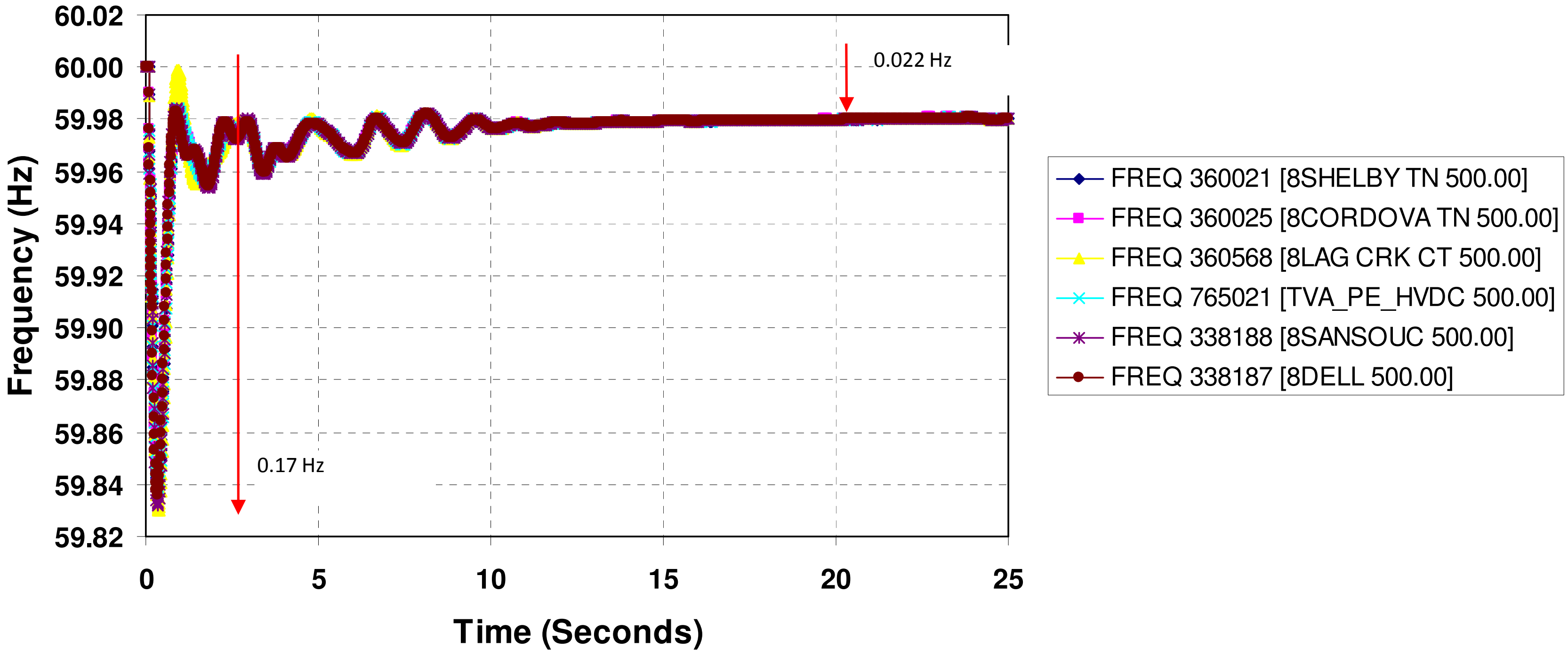
▨ High correlation

- Wind blows at different times in different places
- Geographic diversity of wind resources helps to reduce overall variability and facilitates wind integration
- Kansas and Indiana wind power output are not correlated

"Low correlation": between 0.0 and 0.25; "Medium correlation": between 0.25 and 0.5; "High correlation": between 0.5 and 1.0

Source: Eastern Wind Integration and Transmission Study, National Renewable Energy Laboratory, 2010; Clean Line analysis

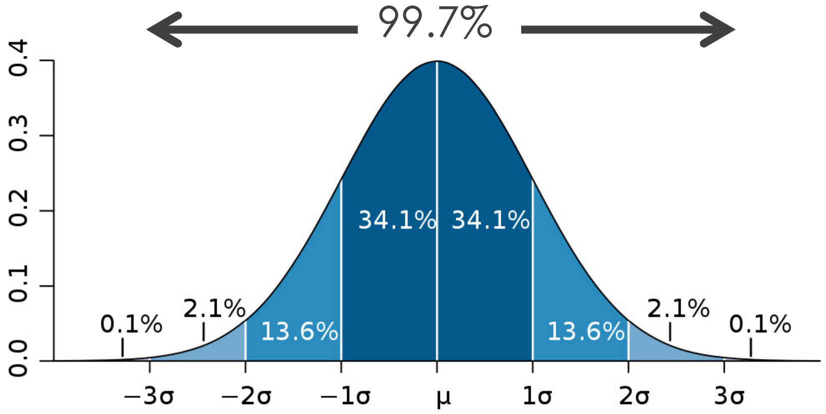
Large injections can create contingency issues that need to be addressed through planning…



- Significant coordinated planning must be involved with these projects.
- N-1, N-1-1, N-2 concerns on both load end and receiving end from a planning perspective.
- Loss of 1750 or 3500 MW of generation on the eastern interconnect.

…but integrating wind into robust systems would not require large increases in operating reserves

In a net load analysis, wind generation is treated as negative load. Using time series data for the system load and generation, a distribution of step changes is created. Comparing the distributions with and without the additional generation provides insight into the wind's impact on the system.



Three times the standard deviation (σ) contains 99.7% of a normal distribution; therefore, the difference of the load and the net load three-sigma variations is a good approximation for the additional reserve requirements for integration.

AWS Truepower performed a net load analysis to estimate the increase in operating reserves needed to integrate 3500 MW of wind energy into the TVA and surrounding systems. The table below shows the results for 1) all 3500 MW absorbed by TVA and 2) 1750 MW absorbed by TVA and the rest delivered to neighbors.

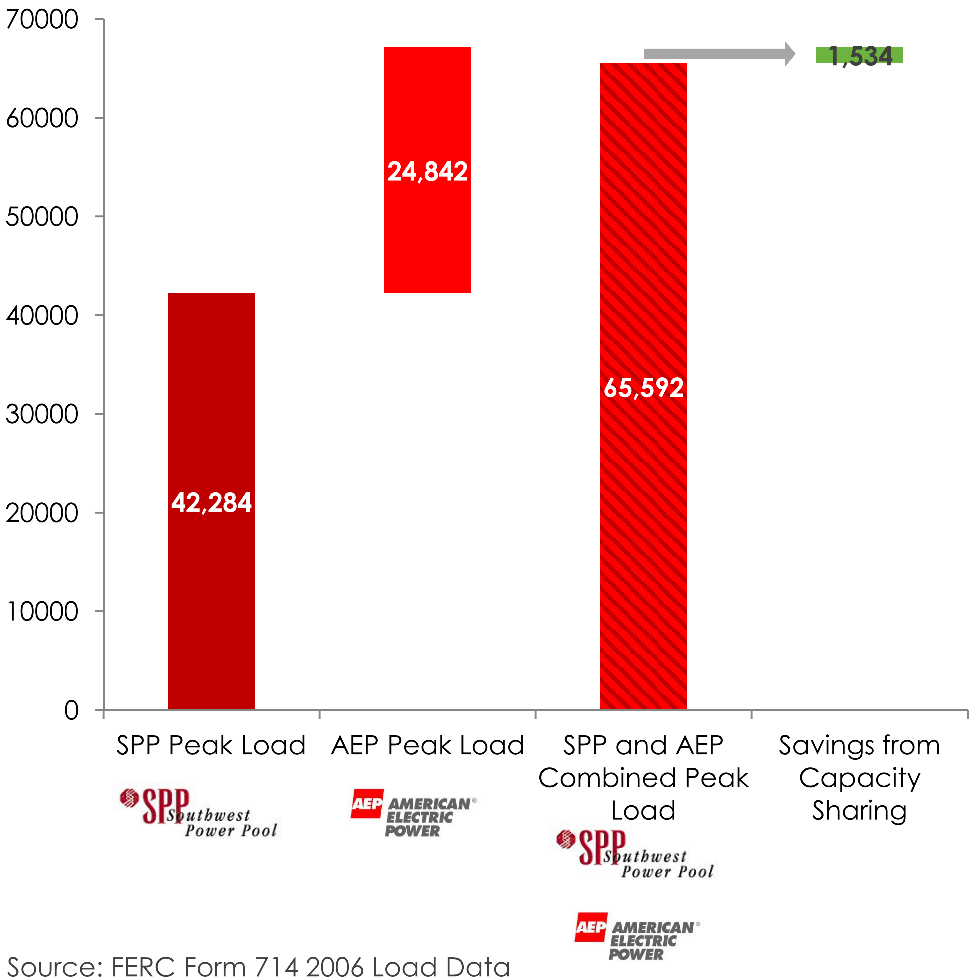
Incremental Three-Sigma Variation of Net Load Scenarios

	3500 MW All TVA	1750 – TVA, 1750 split to Neighbors
TVA	383	127
Southern		42
Duke		6
Entergy		29
Total	**383**	**204**

Clean Line projects could also aid integration by enabling interregional capacity sharing

GRAIN BELT EXPRESS CLEAN LINE

2006 Peak Load
MW



Source: FERC Form 714 2006 Load Data

- Grain Belt will interconnect to strong points on both the SPP and PJM grids
- AEP and SPP load profiles are not highly correlated (R = 0.67). AEP and SPP load peaks occur at different times
- HVDC infrastructure would enable ancillary services sharing

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