High Voltage Direct Current

And Large Scale Wind Integration

Iowa State University
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CLEAN LINE ENERGY PARTNERS

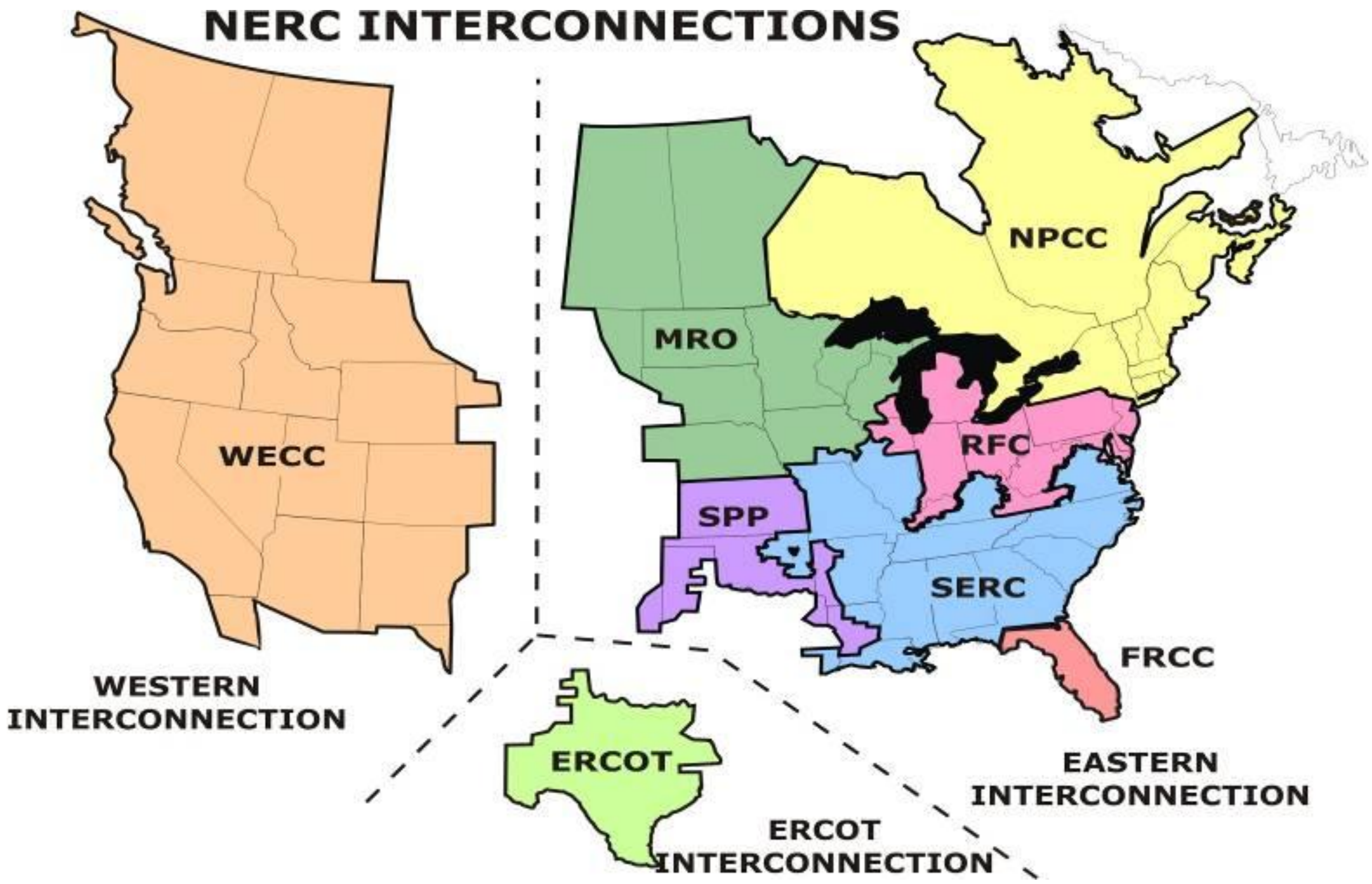
Clean Line Energy Partners

Focus, team and capital to connect renewable energy to demand

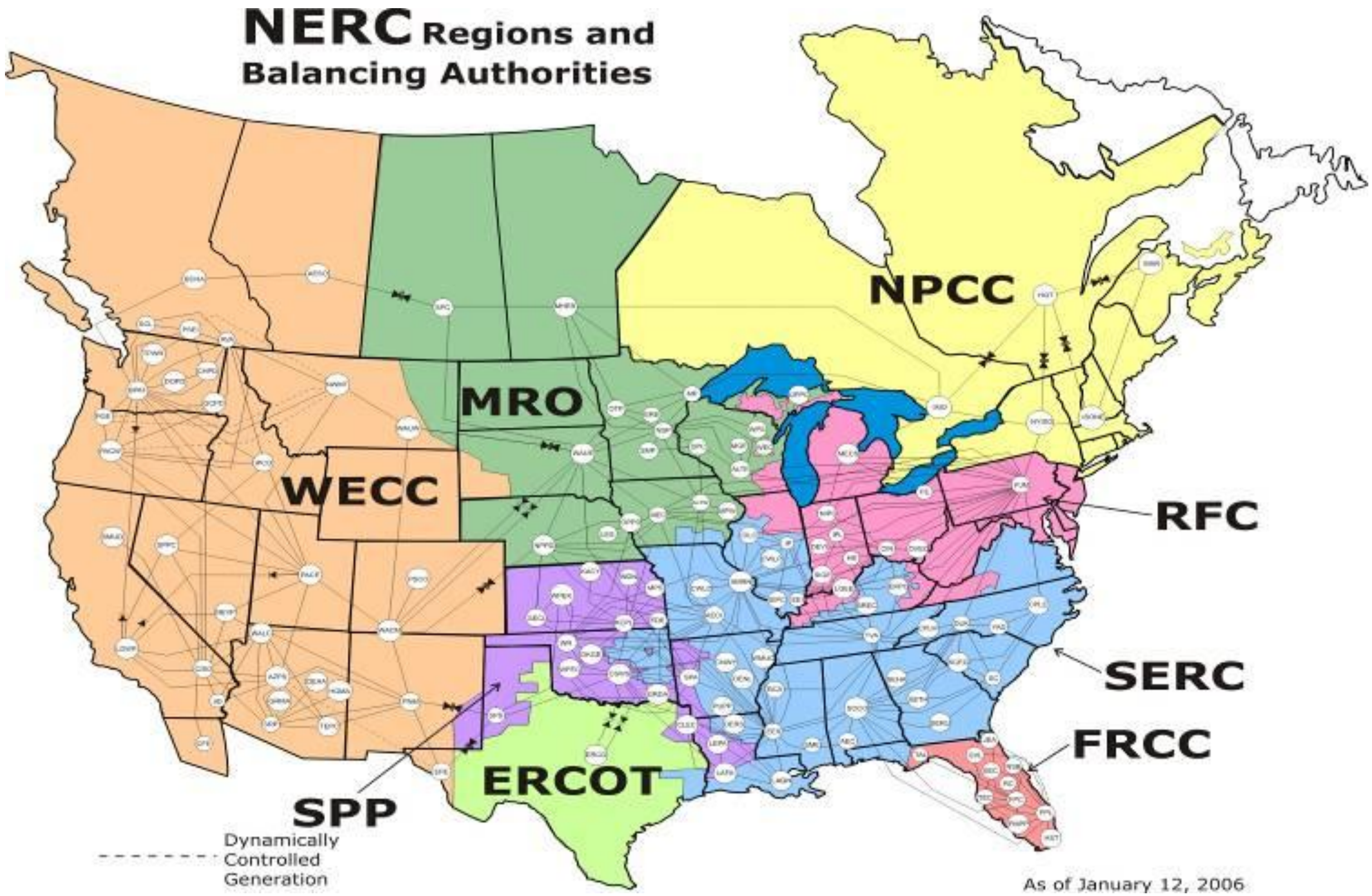
- Clean Line Energy develops long-haul, high-voltage direct current ("HVDC") transmission lines to connect the best wind resources in North America to communities that lack access to low-cost renewable power
- HVDC is the lowest cost, least land intensive, most reliable transmission technology to integrate large amounts of renewable energy
- Clean Line's management team brings a track record of success in energy project development
- Supported by investors who bring long-term perspective, patient capital and an understanding of siting and building interstate infrastructure projects


HUDSON BAY
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
QUEBEC
ONTARIO
NEW BRUNSWICK
NOVA SCOTIA
MAINE
NEW YORK
PA.
MD.
DEL.
WASHINGTON
OREGON
MONTANA
IDAHO
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
NEBRASKA
IOWA
WISCONSIN
MICHIGAN
OHIO
WEST VIRGINIA
KENTUCKY
KANSAS
MISSOURI
OKLAHOMA
ARKANSAS
TENNESSEE
TEXAS
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

3 Major Interconnections, 8 Regions



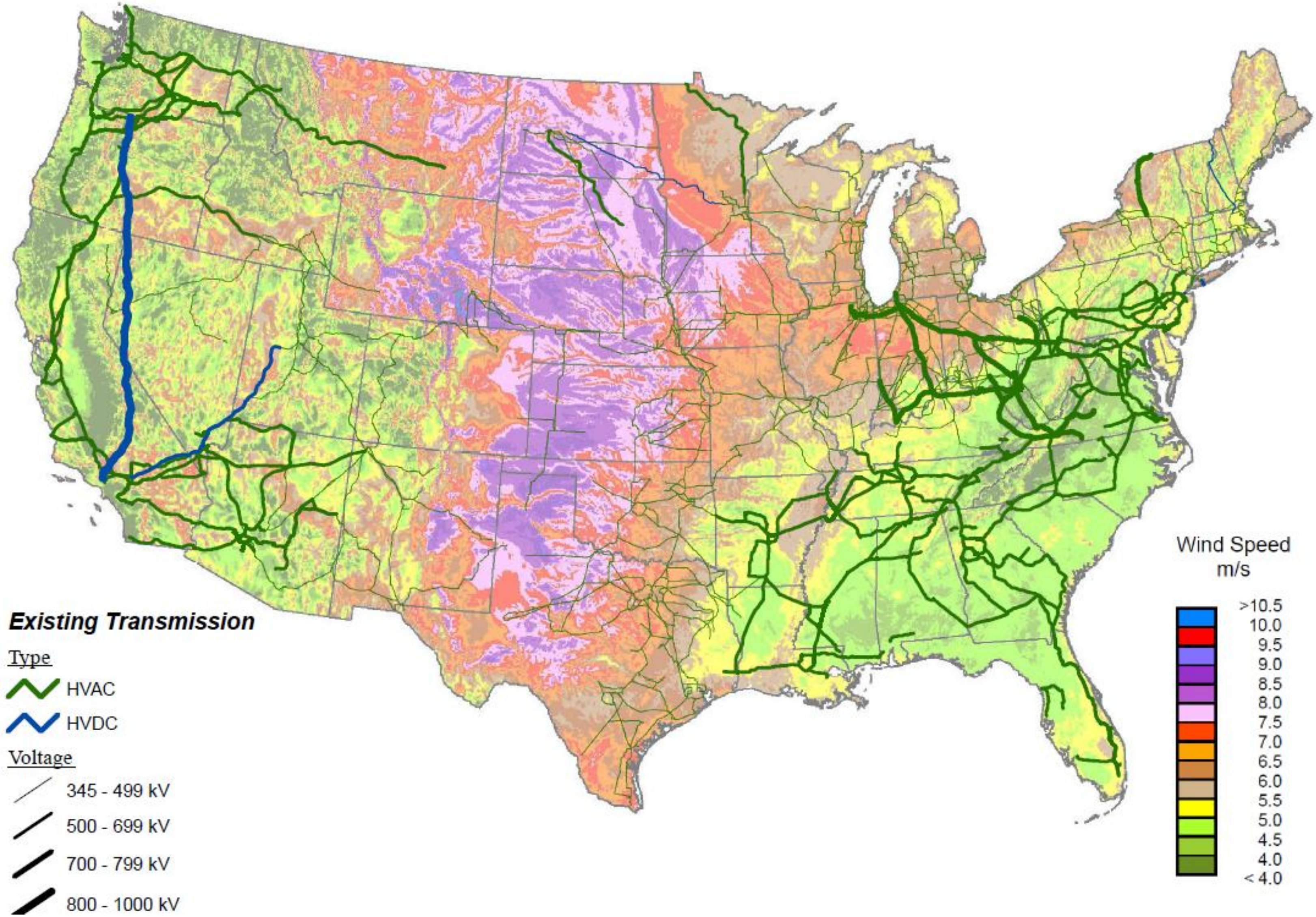
3 Major Interconnections, 8 Regions, 135 Balancing Authorities



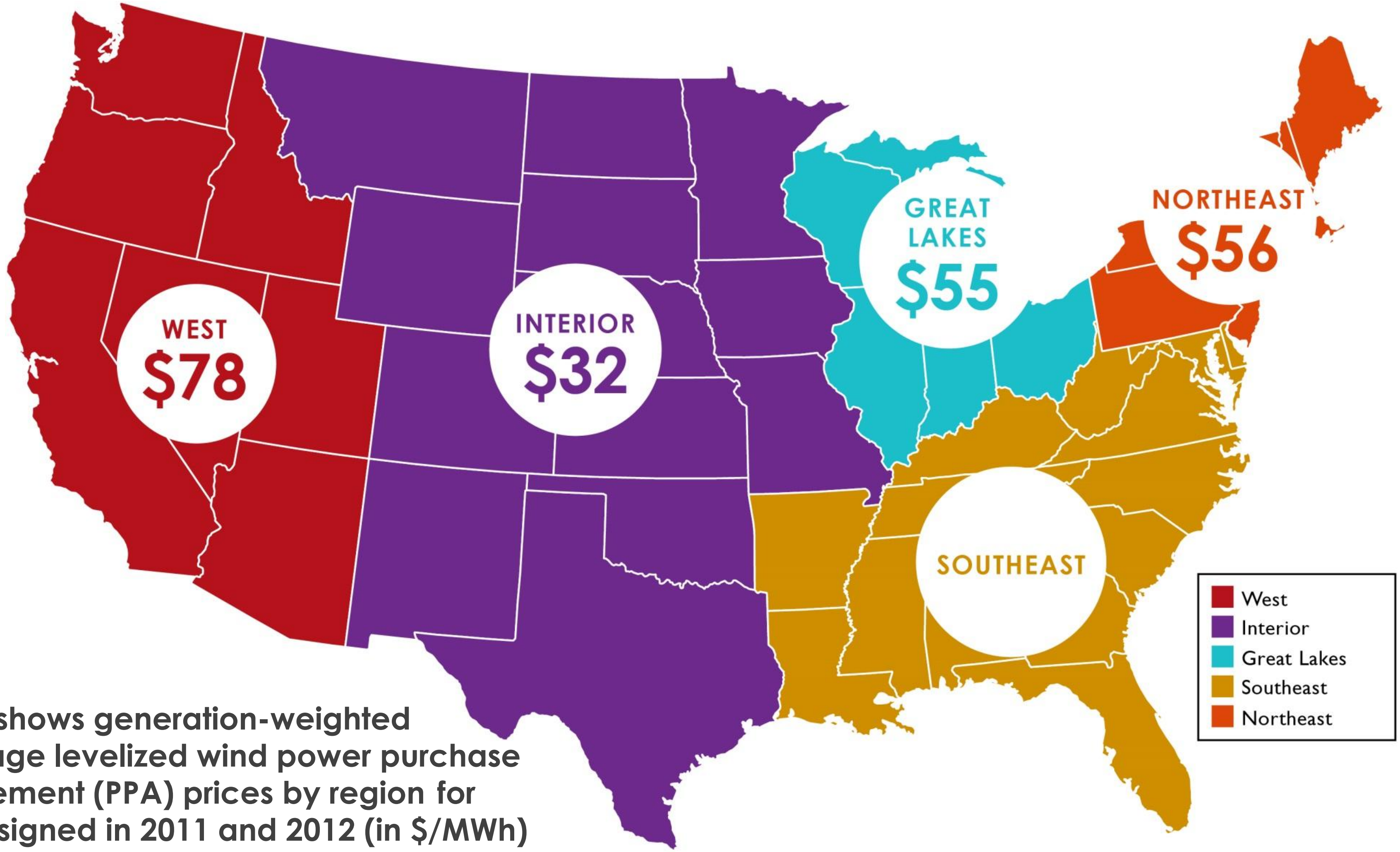
Topics

- **The challenge & our solution**
- Wind costs
- Project development approach
- Wind Integration

The best wind resources are located far from load centers and the existing grid infrastructure



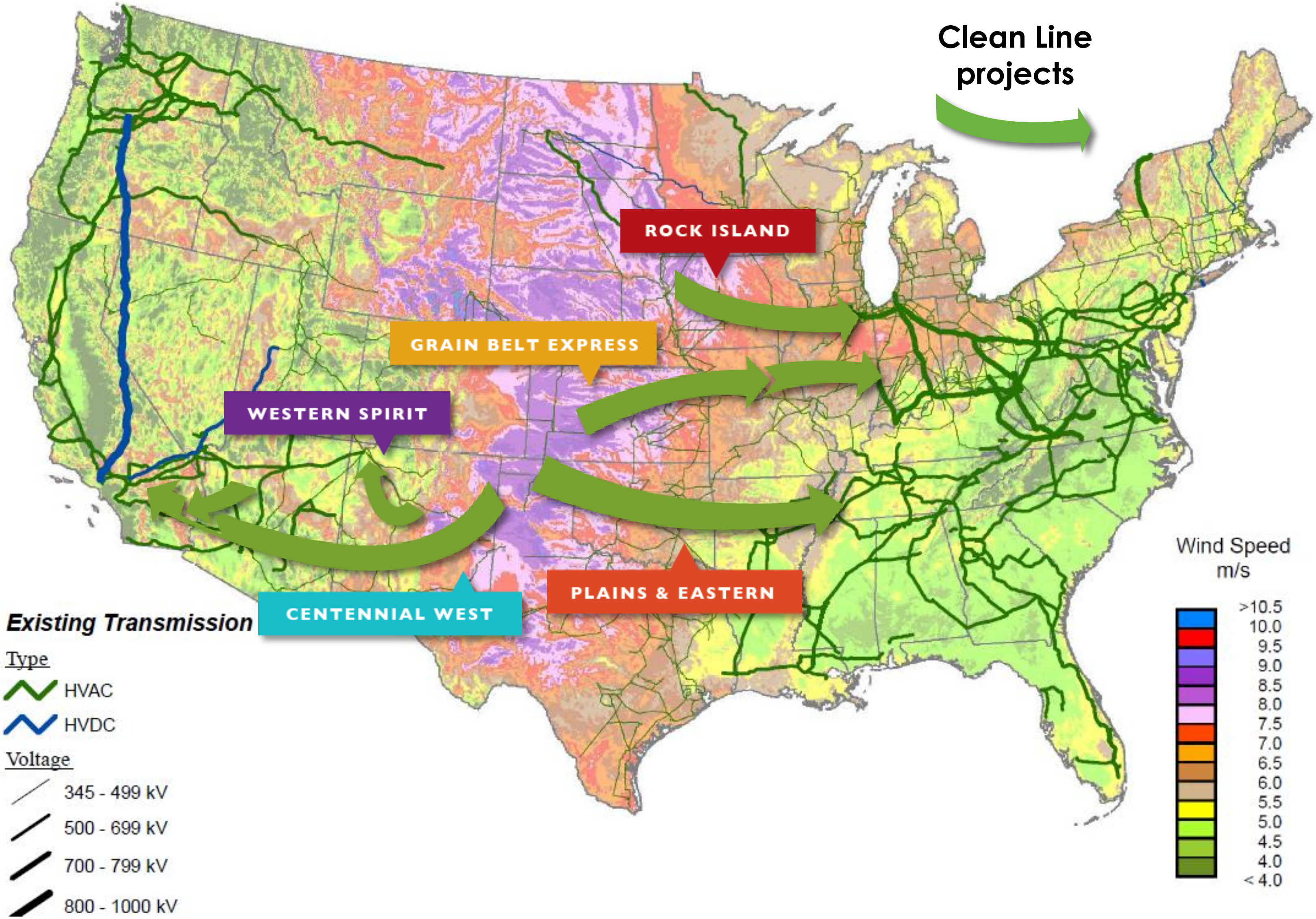
It is makes sense to build where it is windy…trends are downward



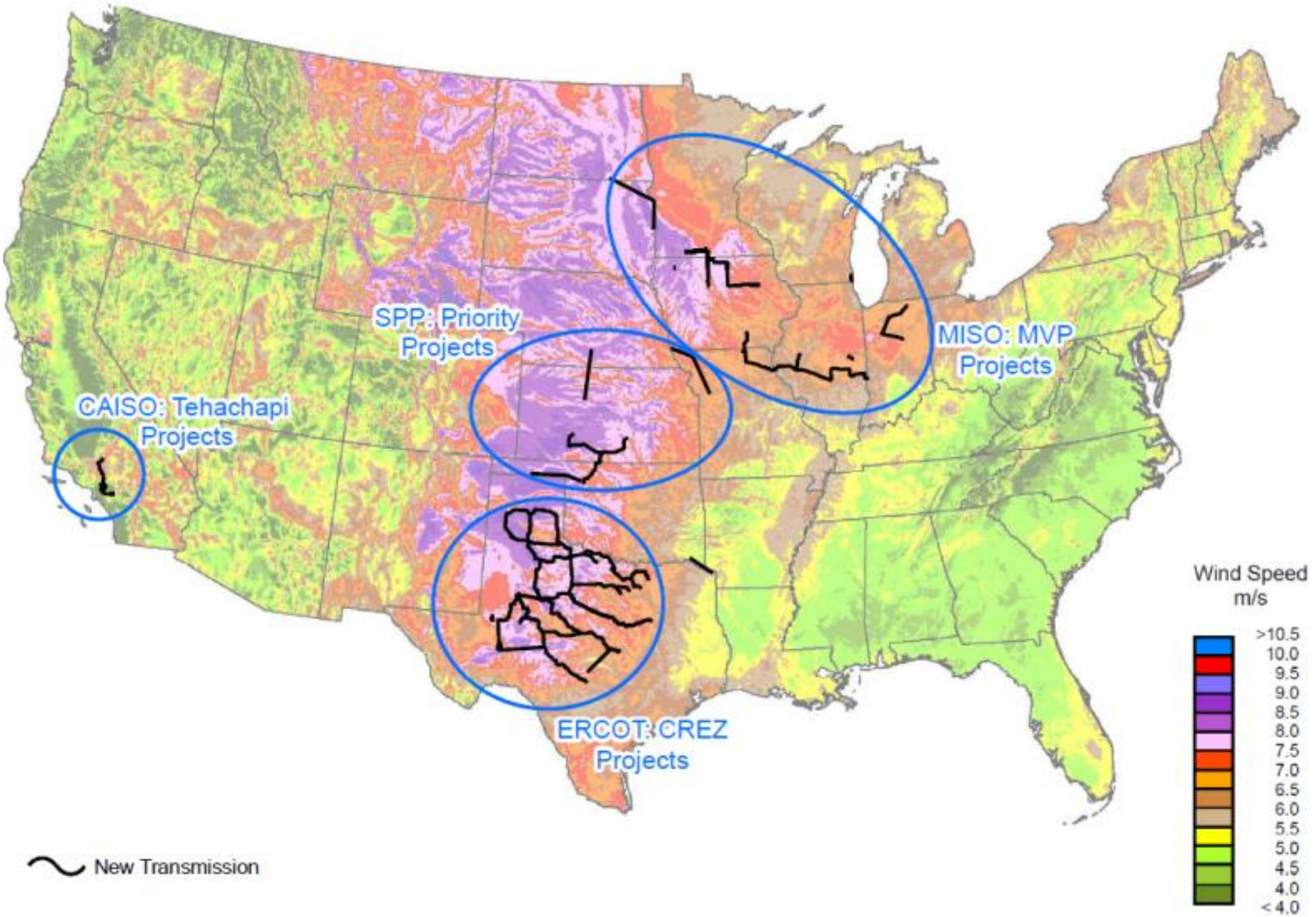
Map shows generation-weighted average levelized wind power purchase agreement (PPA) prices by region for PPAs signed in 2011 and 2012 (in $/MWh)

Source: DOE 2012 Wind Technologies Market Report published August 2013

Clean Line's projects connect the best wind resources to demand centers



Transmission is being built to meet state and regional needs, but need for interregional transmission remains



HVDC transmission lines bring economic, environmental and electric reliability benefits

More Efficient – Over long distances, transfer power with less infrastructure and lower line loss than AC lines moving a comparable amount of power

Lower Cost – Require less infrastructure and have lower line losses, resulting in lower costs and lower prices for renewable energy

Improved Reliability – Give operator complete control over power flow and facilitate the integration of wind energy from different resource areas

Smaller Footprint – Use narrower right-of-way than comparable AC lines

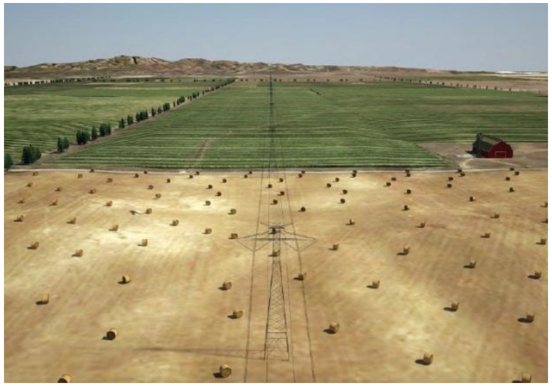
Merchant model – Clean Line will fund the costs of the transmission projects and sell transmission capacity to wind generators and load serving entities

3000-4000 MW Capacity

AC

Three 500 kV lines
600 foot ROW

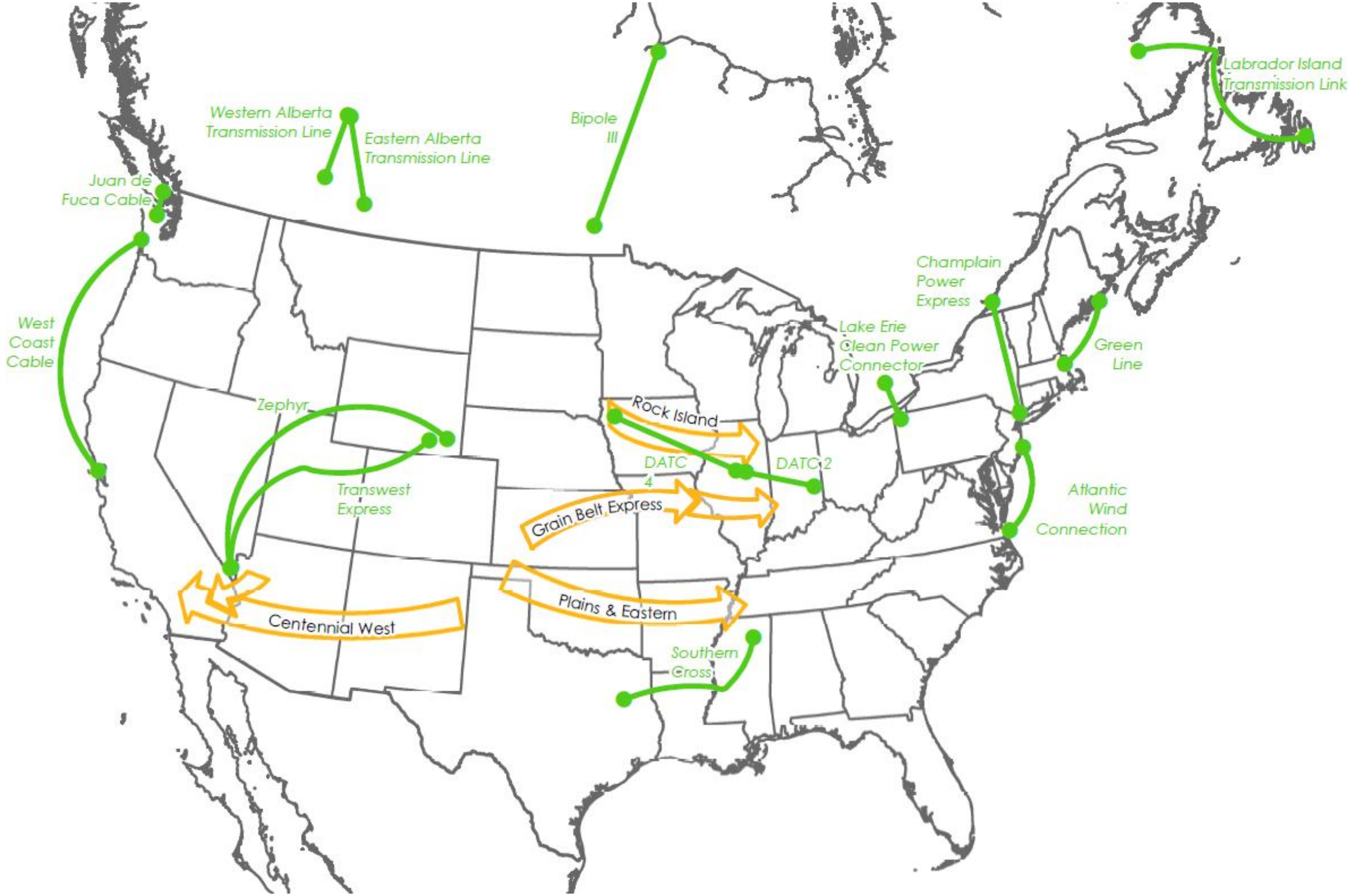
DC



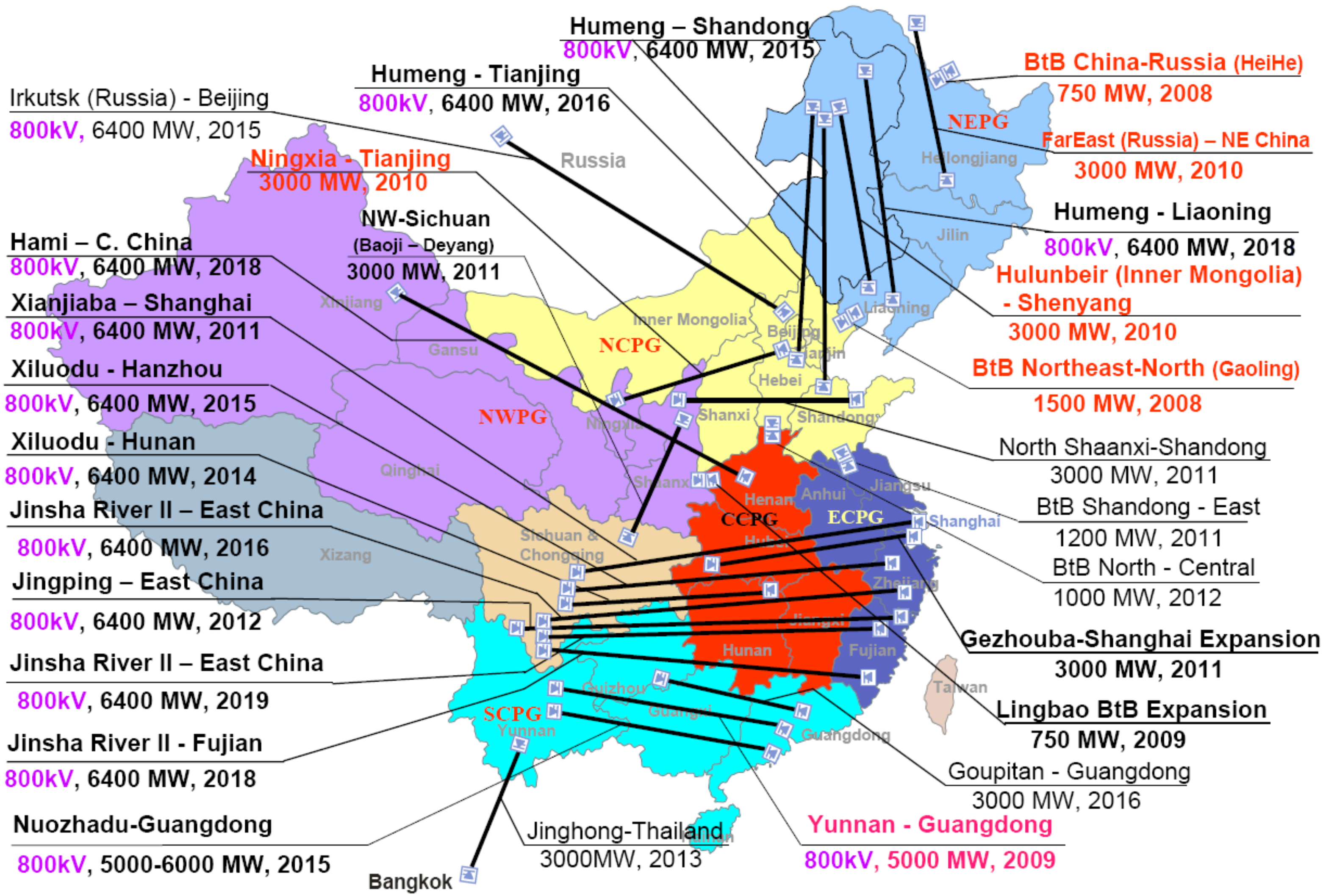
One ± 500 kV bipole
150-200 foot ROW

Over time DC applications have gained popularity across North America for appropriate applications…

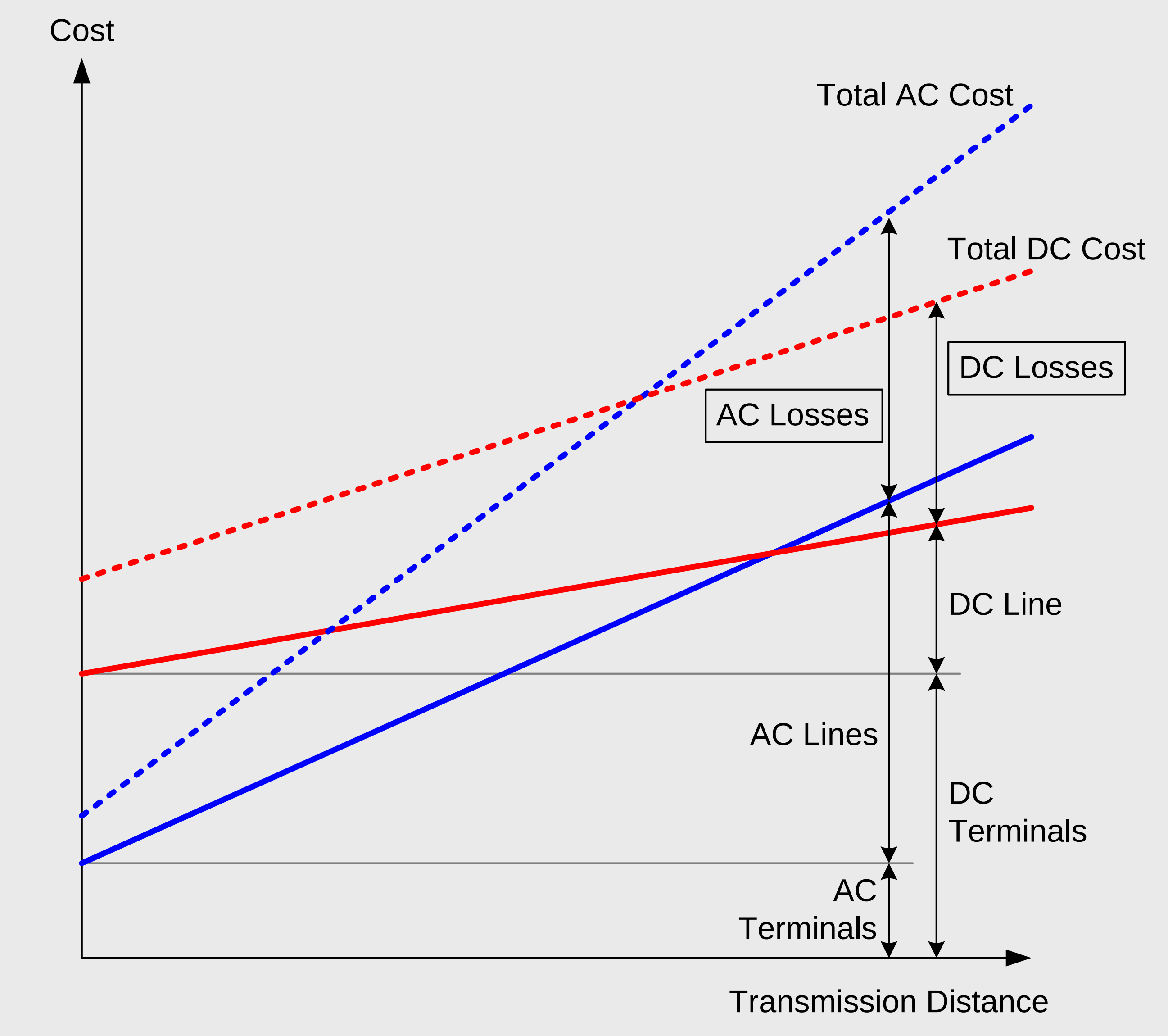
Though the grid is mostly AC, there are many recently proposed North American HVDC projects



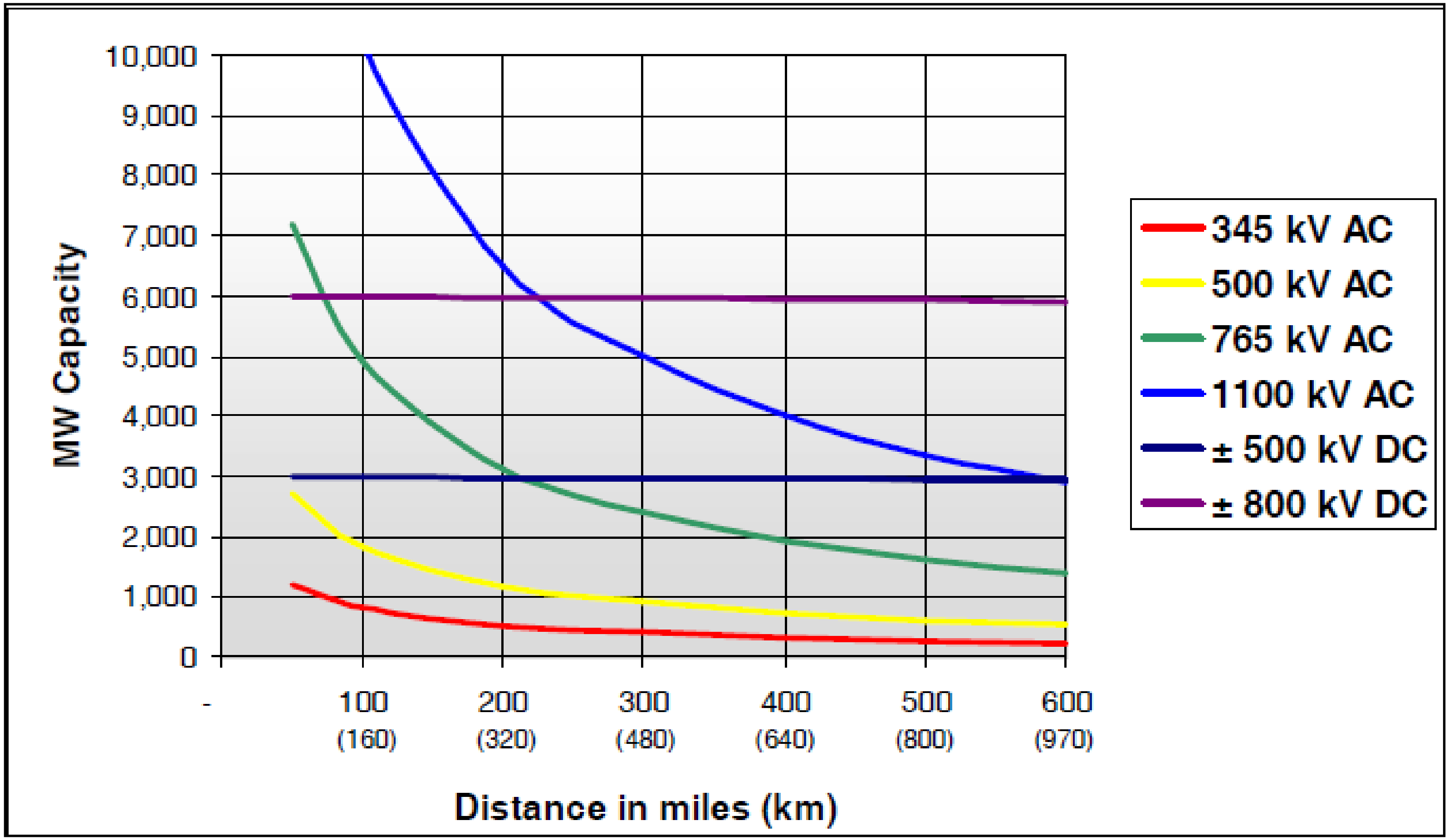
…and more recently HVDC has experienced a Renaissance internationally (especially in China)



Cost vs. Distance: when long distance makes sense

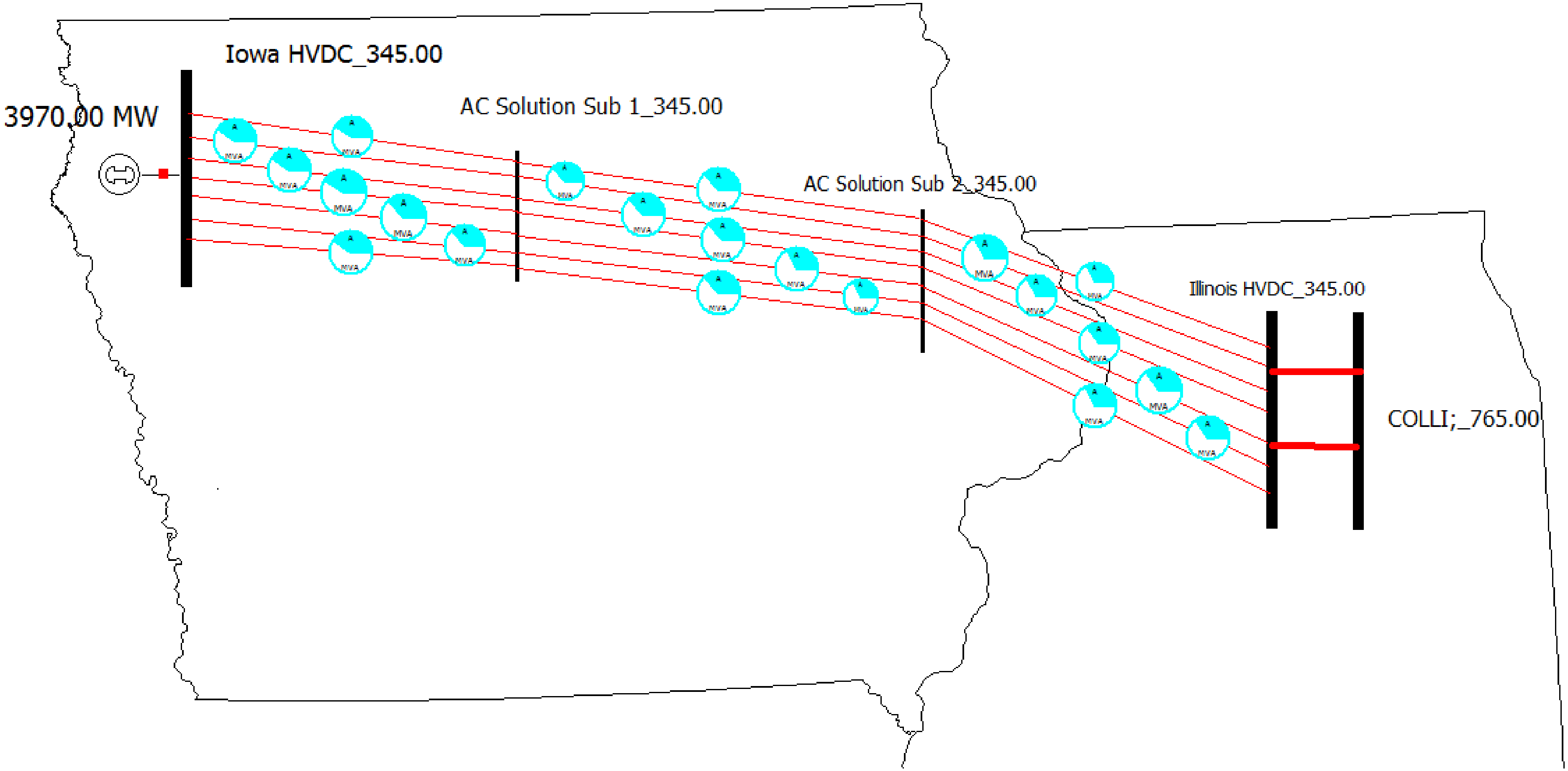


Line Loadability vs. Distance



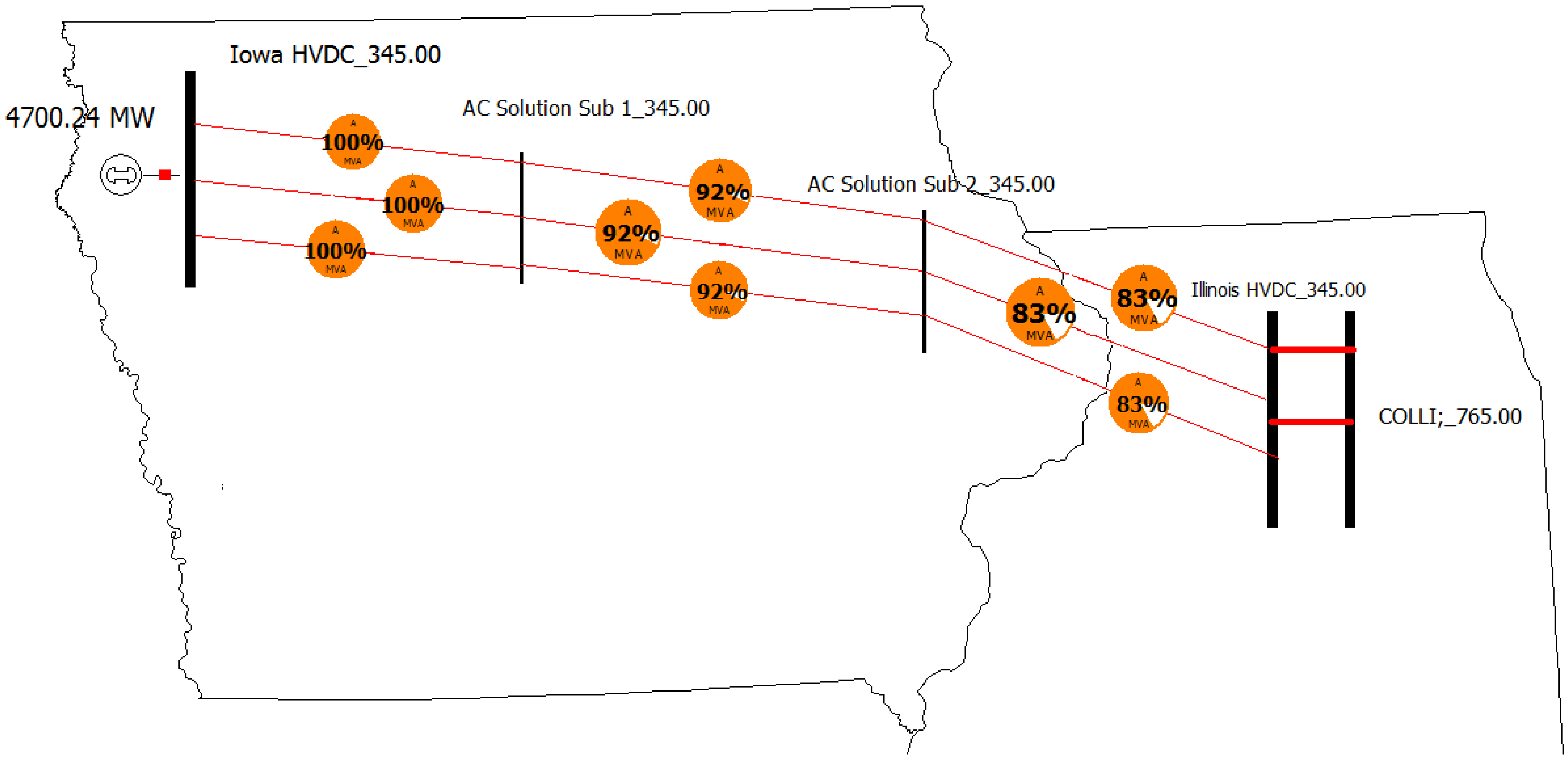
*source: Fleeman, et al, "**EHV AC and HVDC Transmission Working Together to Integrate Renewable Power," CIGRE, Calgary 2009**

What if we used radial AC lines?



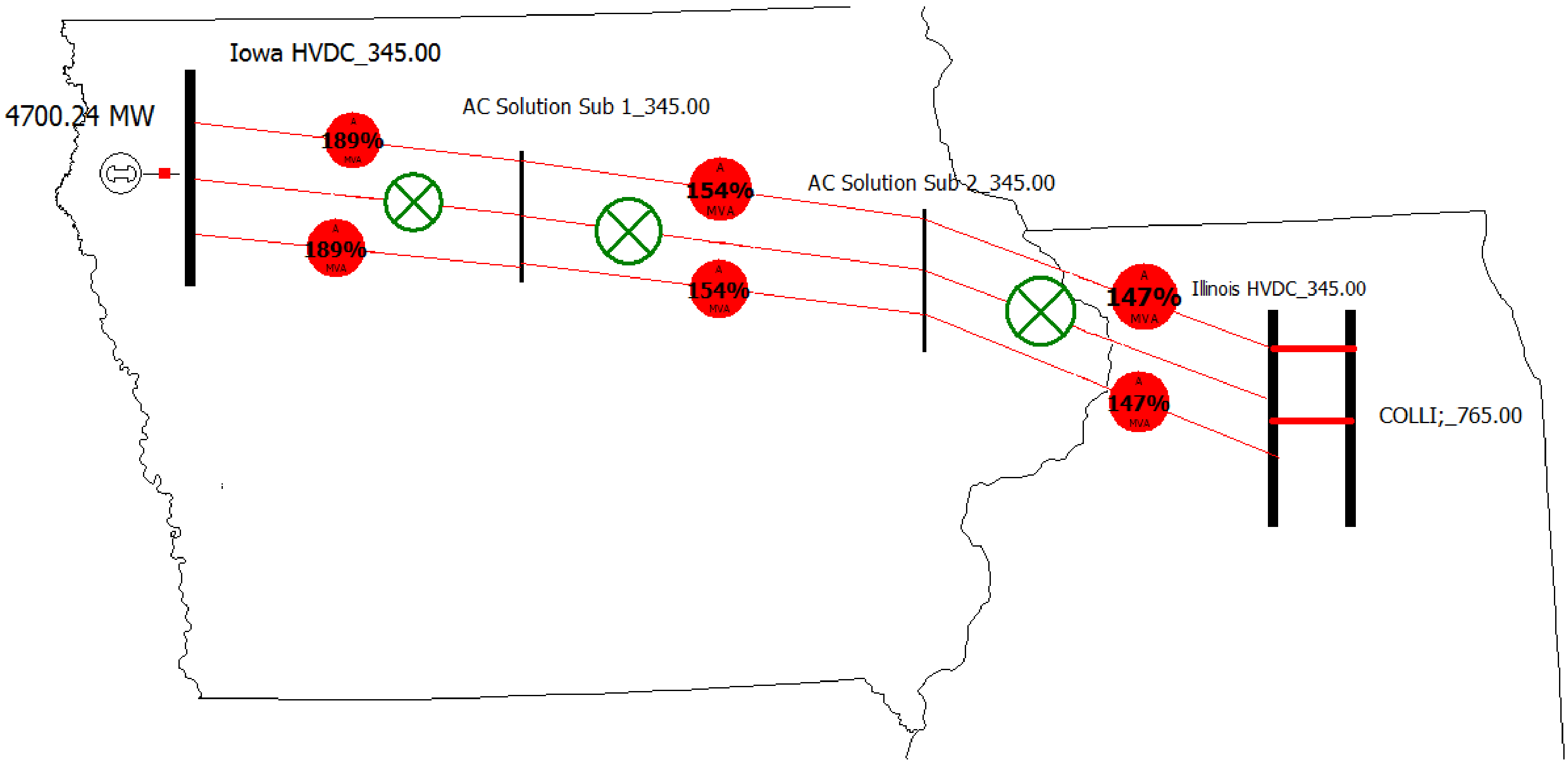
Assuming 345 kV AC lines, you'd need at least 7 circuits to deliver the power. Line losses are 470 MW.

Let's beef up the AC lines



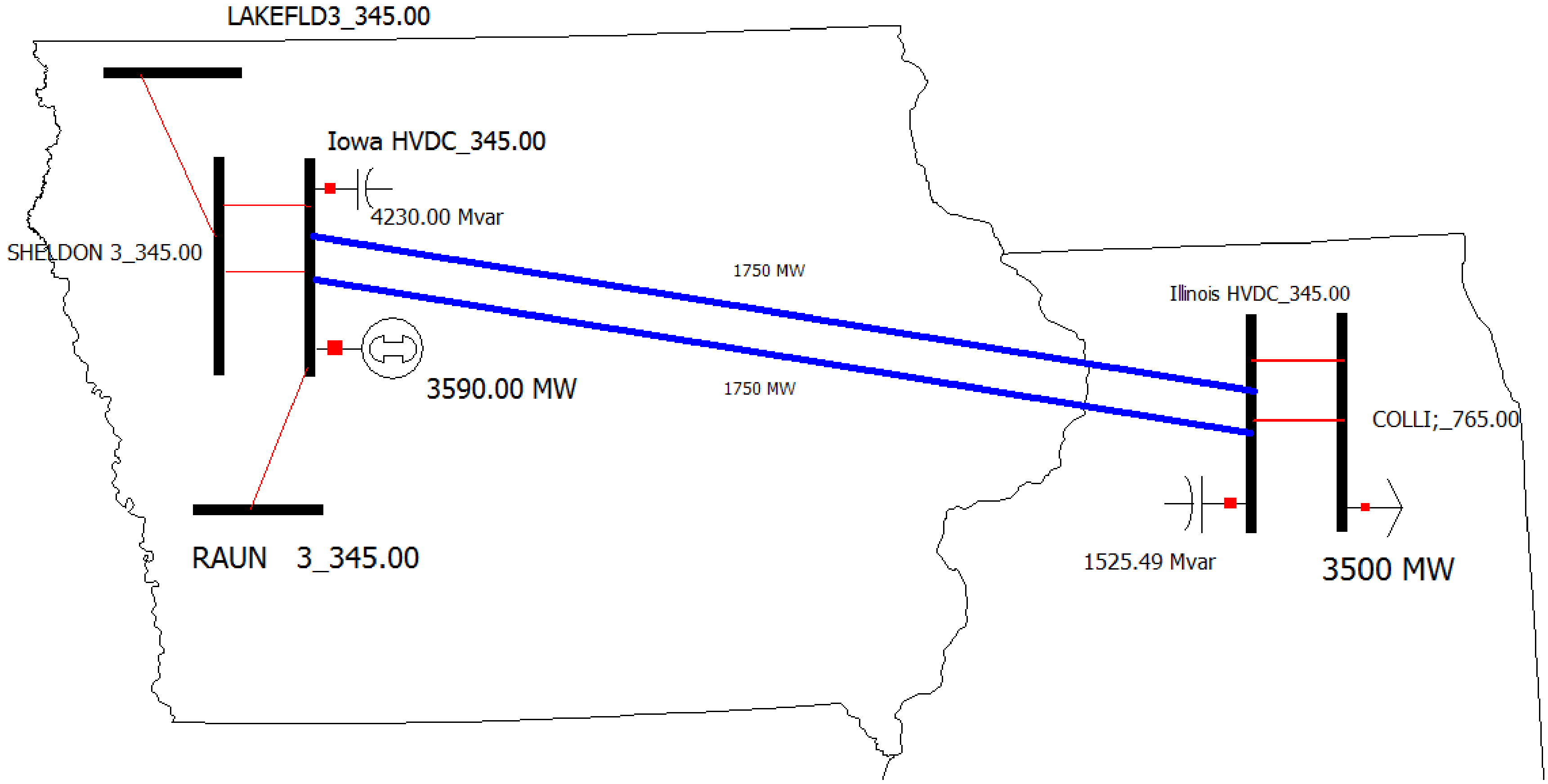
If you series compensate those 345 kV AC lines, you need a minimum of three circuits. Losses are huge…1200MW

What happens if you lose one of those lines?



The remaining lines are overloaded, voltage collapse ensues

Direct Current in action…Rock Island Clean Line



3500 MW of wind power is delivered from Iowa to Illinois via a 600 kV DC line. Line losses amount to 90 MW.

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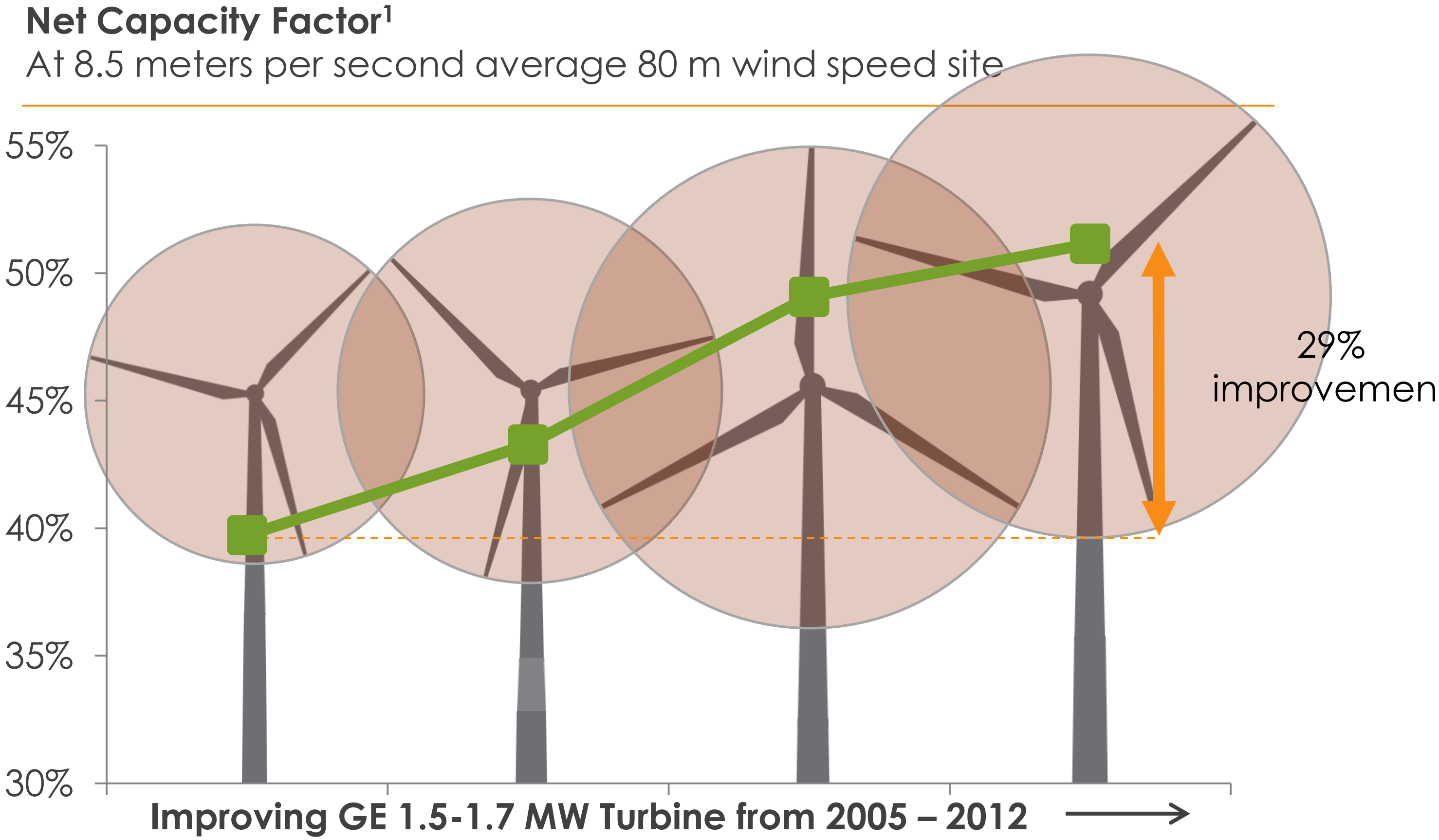
Improving wind turbine technology is increasing capacity factors and reducing wind costs



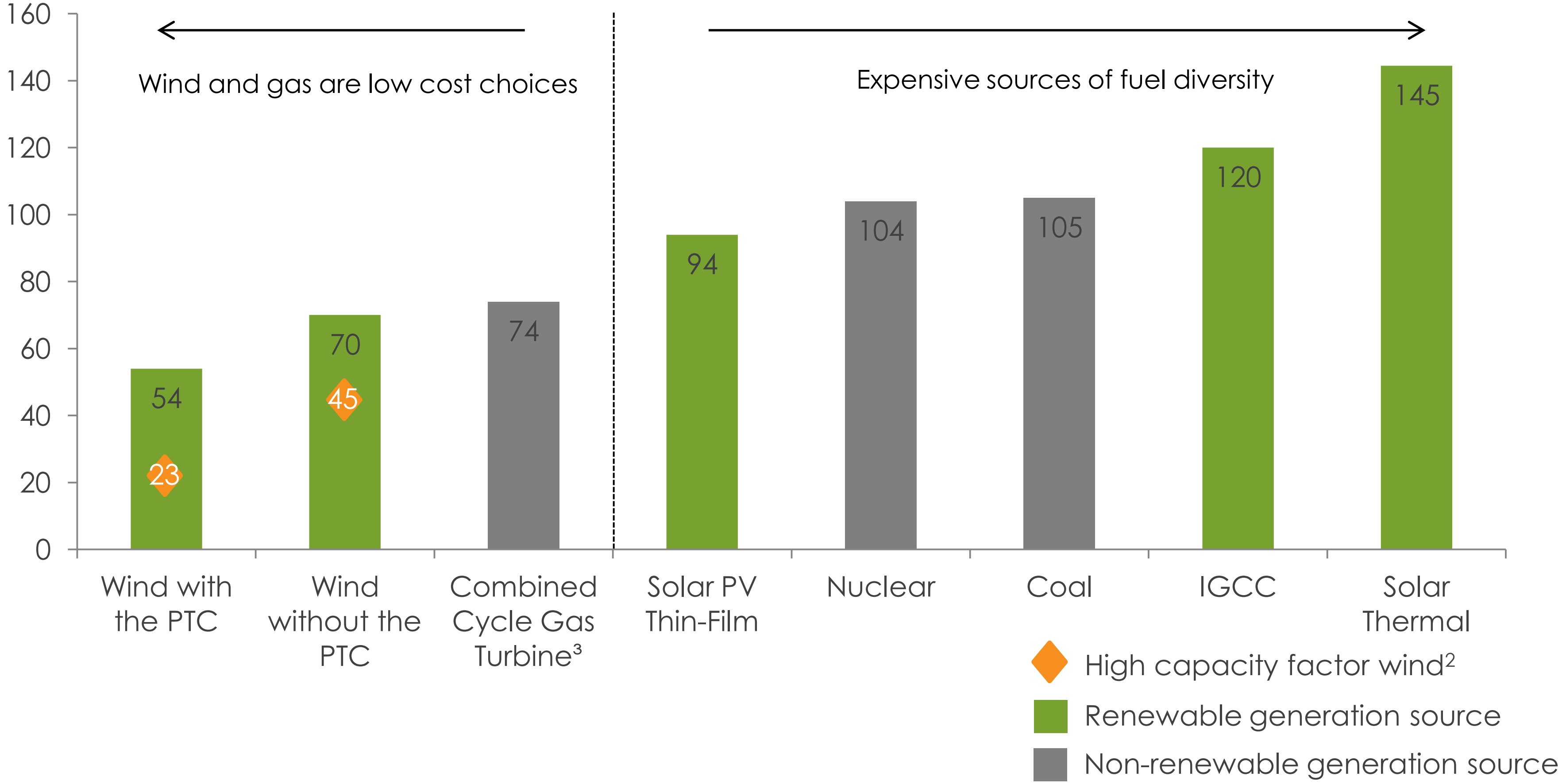
In meters

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

High capacity factor wind is competitive with other sources of new generation

Levelized Cost of Energy[1]
$ / MWh



1. Cost of generation based on mid-point of Lazard's LCOE estimates. Unless noted, costs shown are unsubsidized.
2. High capacity factor wind cost uses low-end Lazard estimates for which the capacity factor is 52% and capex cost is $1,500/kW.
3. Assumes $4.50/MMBtu gas price.

Source: Lazard's 2013 Levelized Cost of Energy Analysis

Impending carbon regulation makes low-cost wind energy even more valuable

Expected timeline of EPA rules on carbon emissions from existing power plants under §111(d) of the Clean Air Act

2014
- Proposed Rule due

2015
- Rule finalized

2016
- Legal challenges completed, state implementation plans due

2016-2017
- Rule is effective

- In June 2013, President Obama directed the EPA to implement new source §111(b) and existing source §111(d) rules of the Clean Air Act by June 2016
- EPA proposed Carbon Pollution Standard for New Power Plants under §111(b) in Sep. 2013
- Proposal for existing source limits will be issued in 2014
- Tradeable carbon allowances are a possible implementation method

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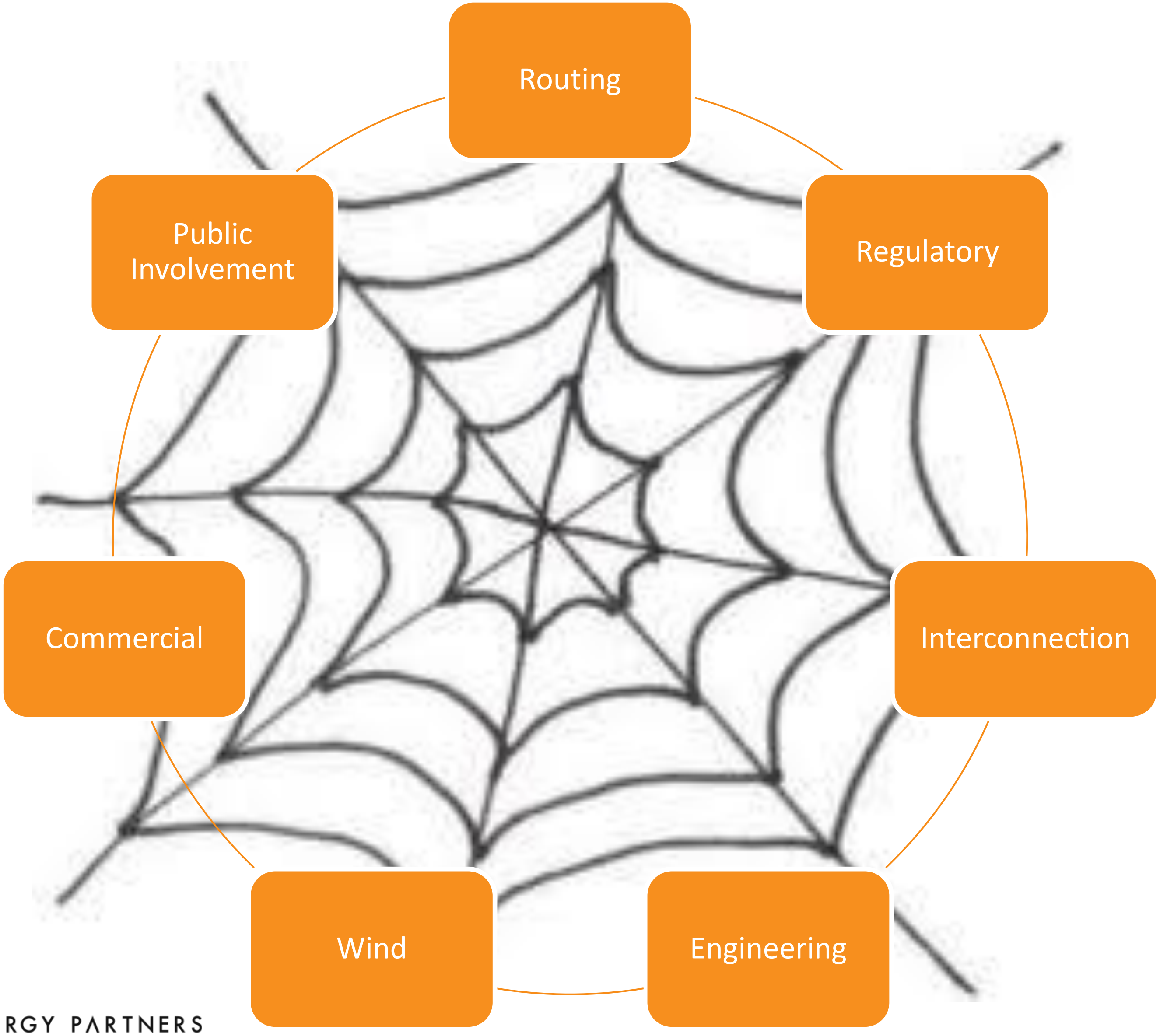
Interregional project develepment requires multi-faceted approach

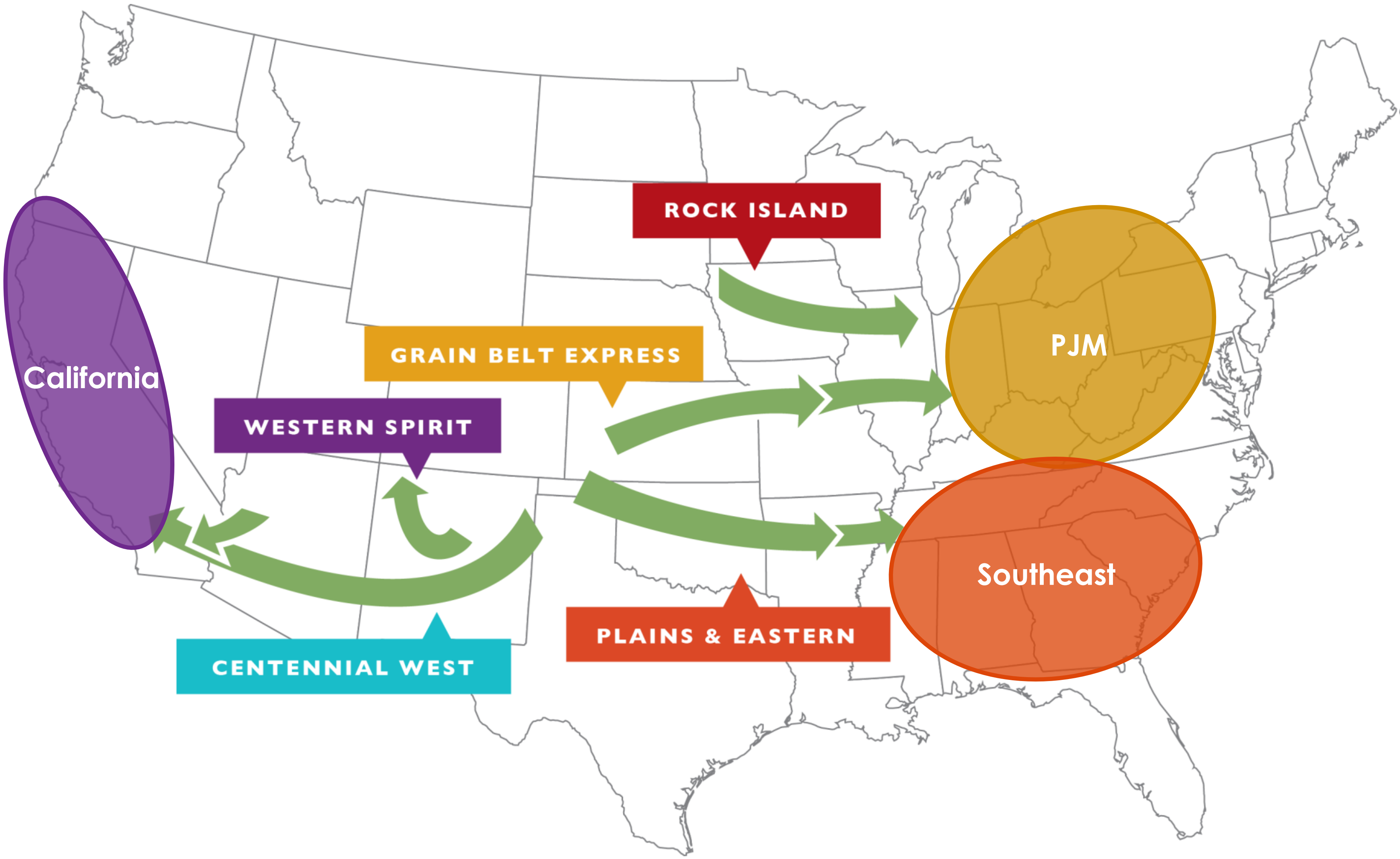


There is no replacement for shoe leather and one-on-one conversations

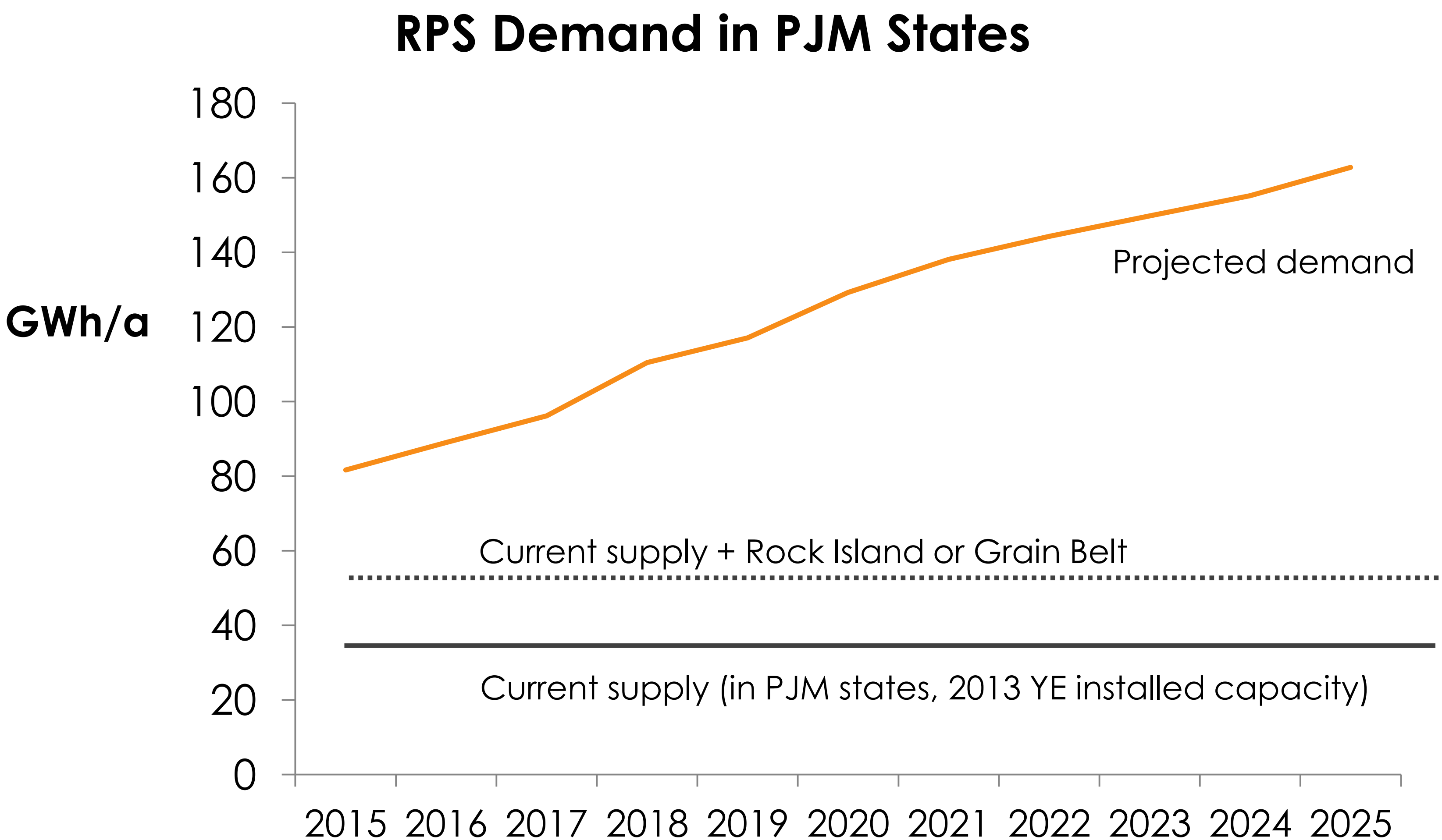
One on One Meetings

- Pre-siting county meetings
- Pre-design agency and NGO workshops
- County Roundtable Workshops
- Local Business Opportunity Meetings
- Public Open Houses

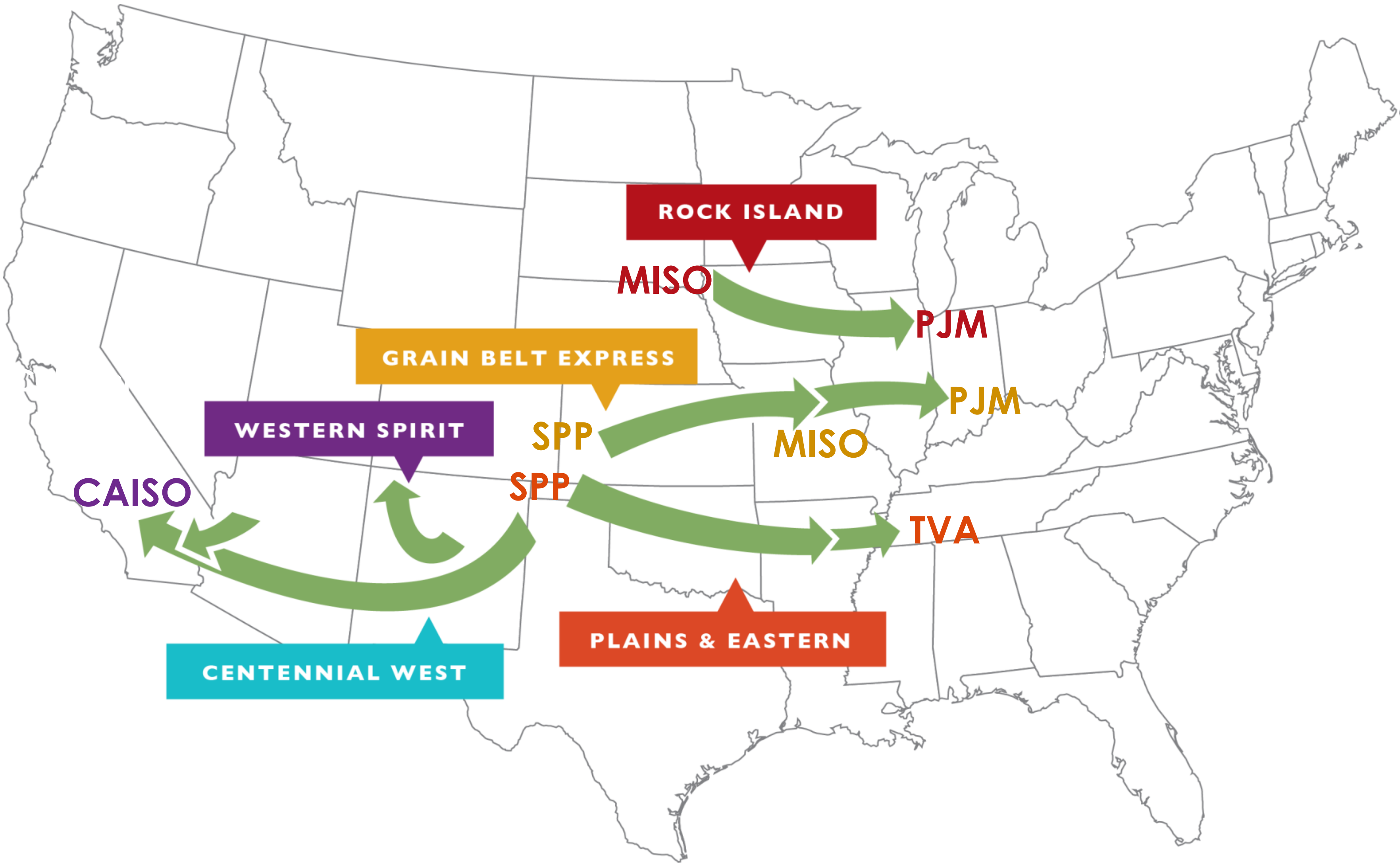
Clean Line's Projects deliver to three markets, demand drivers are unique to each market



RPS Demand in PJM will create need for new transmission

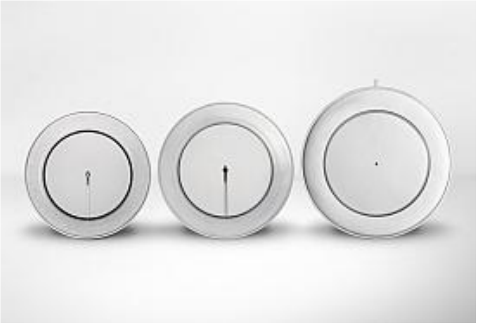


Clean Line Projects' endpoints also each have unique interconnection processes



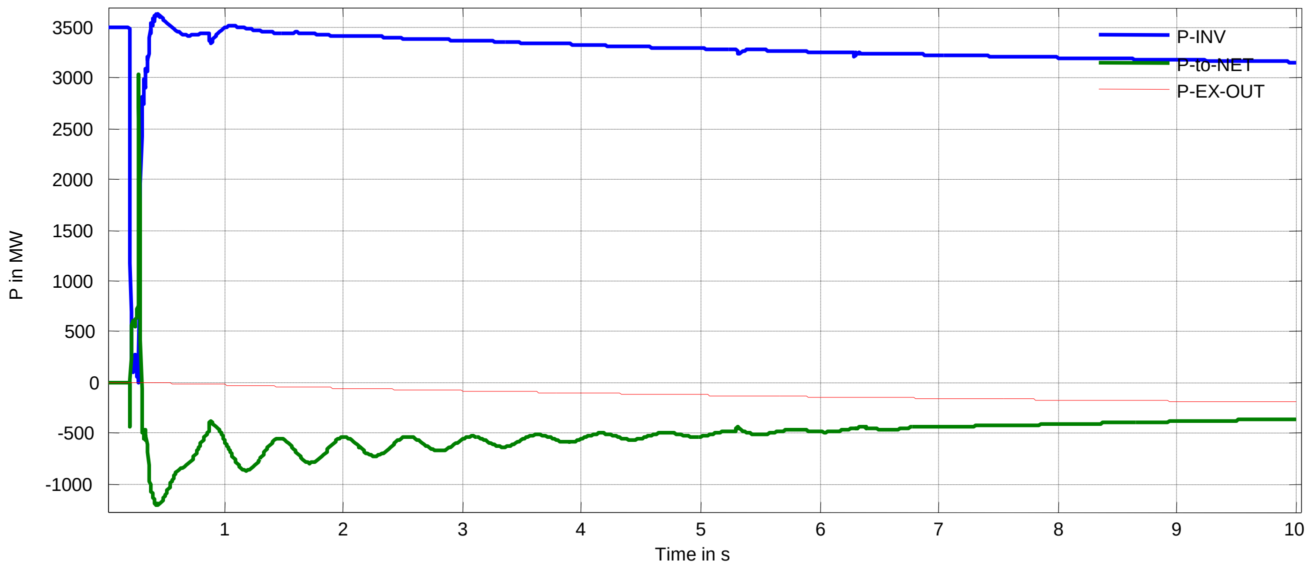
Technical Challenges…some of what keeps my life interesting

- **Integrating large amounts of wind using HVDC Classic has inherent challenges, but is a natural progression in the use of HVDC**
  - Need for optimized reactive power control scheme
  - Operating with low short circuit levels
  - Lack of significant inertia associated with wind generation
  - Need for fast communication between HVDC and wind park controllers



Project Specific Engineering Challenges

- Transient over-voltages
- Frequency deviations
- Stable DC power recovery
- Active power exchange with AC rectifier network
- Control Coordination



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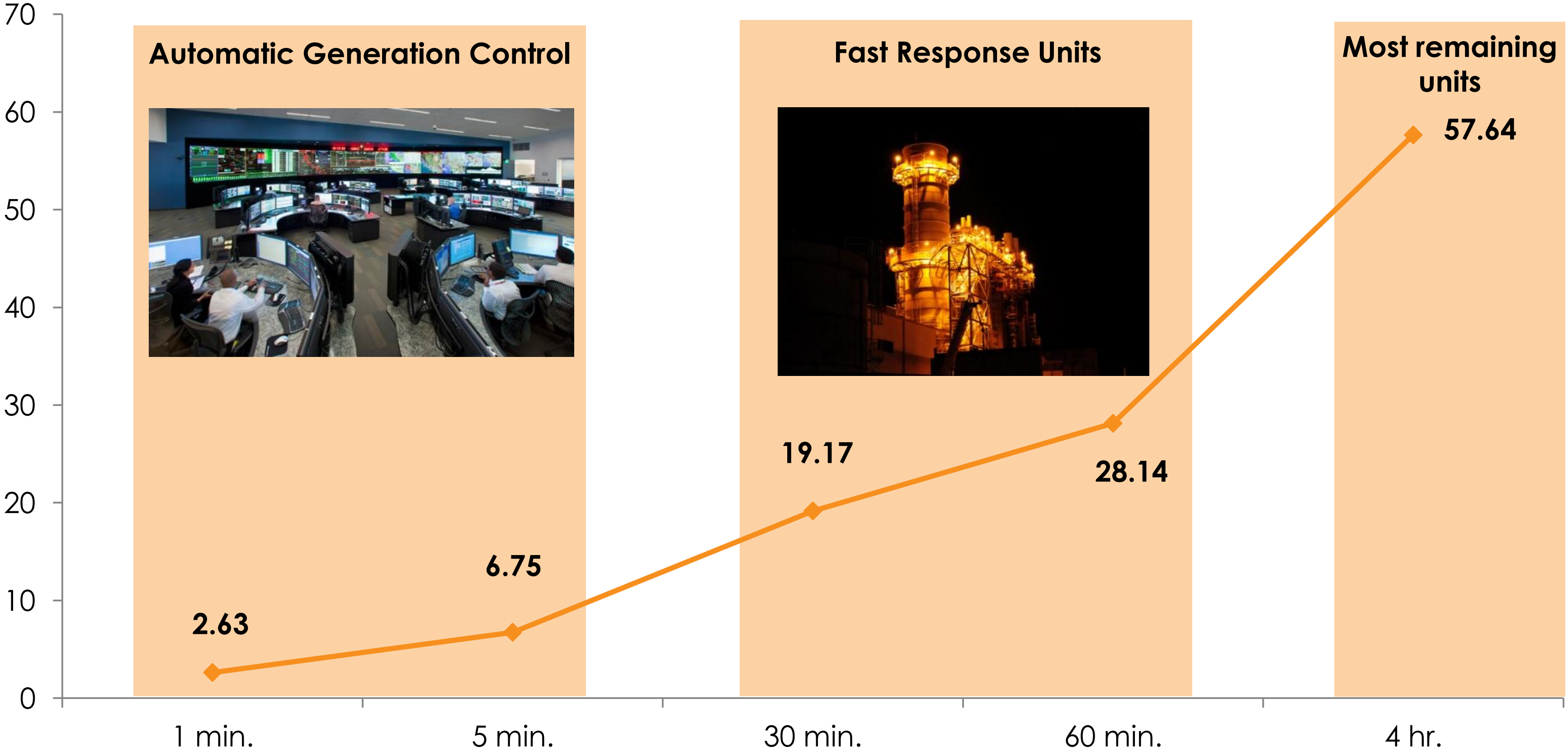
Over small time intervals, wind has low variability

Standard deviation of step-changes
MW vs. Time Interval (minutes)



Source: 2011 output from Buffalo Gap 2 Wind farm (230 MW near Abilene, TX)

Geographically diverse wind portfolio makes wind integration easier

Correlation of 10-Minute Wind Energy Generated

	KS	IA	IL	IN	PA
KS		0.37	0.09	0.03	.00
IA	0.37		0.19	0.07	.02
IL	0.09	0.19		0.75	.15
IN	0.03	0.07	0.75		.19
PA	.00	.02	.15	.19	

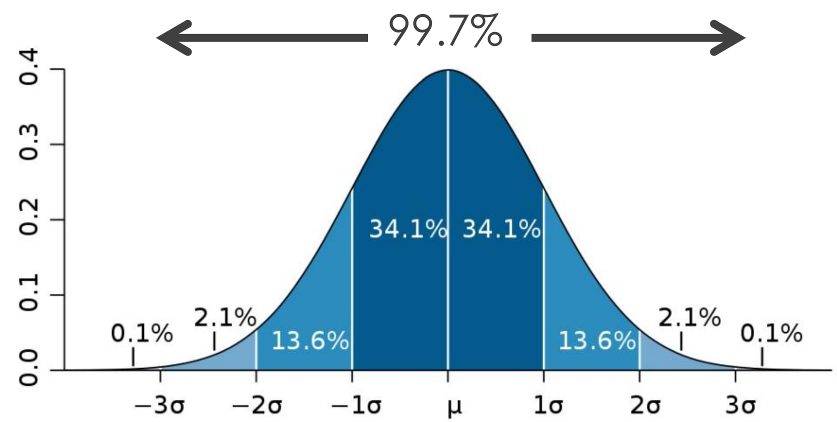
Low correlation
Medium correlation
High correlation

1. "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: EWITS; Clean Line analysis

Integrating wind does not require large increases in operating reserves

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**

No more energy only - many methodologies exist to calculate the capacity value of wind

Method	Who does it this way?
Effective load carrying capacity (ELCC)	MISO, ERCOT, Northern States Power Co. (Xcel), Public Service Company of Colorado, PacifiCorp, Puget Sound Energy
Peak period contribution	TVA, PJM, SPP
Percentage of capacity factor or nameplate capacity	NYISO, Public Service of New Mexico, Arizona Public Service, Portland General Electric, Idaho Power, Dominion, Entergy

Thank you …. QUESTIONS?

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