HVDC: Pathway to America's Sustainable Future

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University of Illinois ECE 590I

CLEAN LINE
ENERGY PARTNERS

It’s an election year: Who remembers 1992?

It’s the ~~economy~~ *wires*, stupid!

-- with respects to Jim Carville

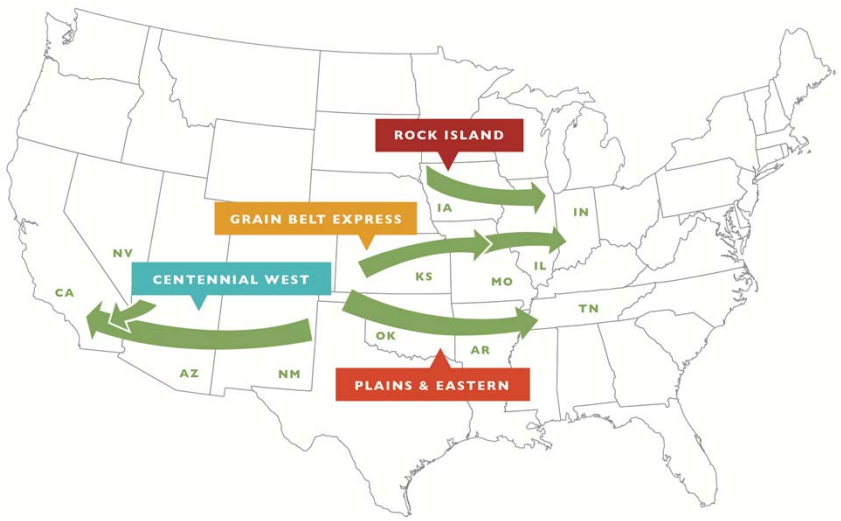
But let’s take a closer look at *why* with a brief video introduction to Clean Line…

Introduction Clean Line through the eyes of one of our projects

This and other videos available at:
cleanlineenergy.com/media/videos

Who is Clean Line Energy Partners?

Clean Line Energy's Projects



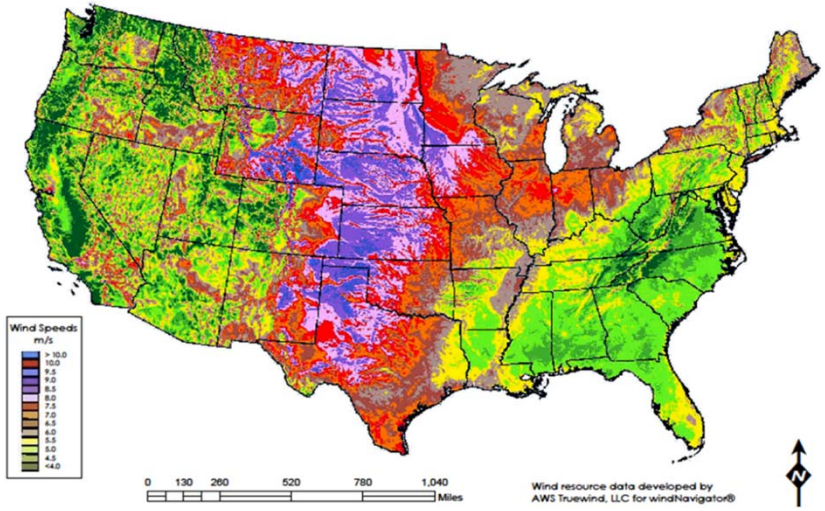
CLEAN LINE ENERGY PARTNERS

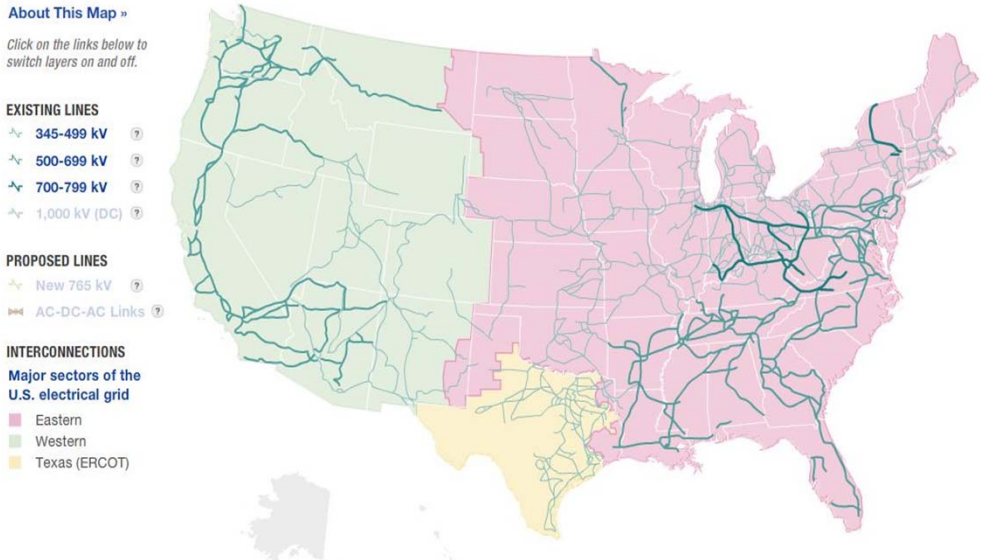
- Founded in 2009
- Headquartered in Houston
- 37 full-time employees
- Four projects under active development
- Investors have a long term vision and patient capital

- 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

Why do we need new transmission to support renewable energy?

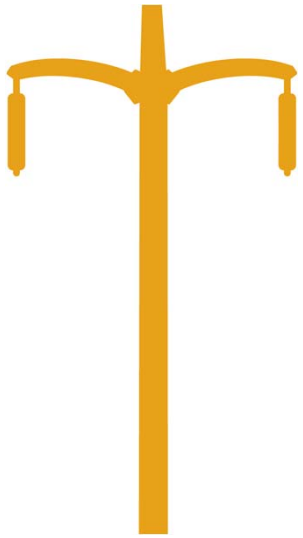
Best wind resources are in “wind belt” of the United States away from population centers





…with very limited access to robust transmission systems

Each of Clean Line's projects will deliver the same amount of energy from the wind as three Hoover Dams

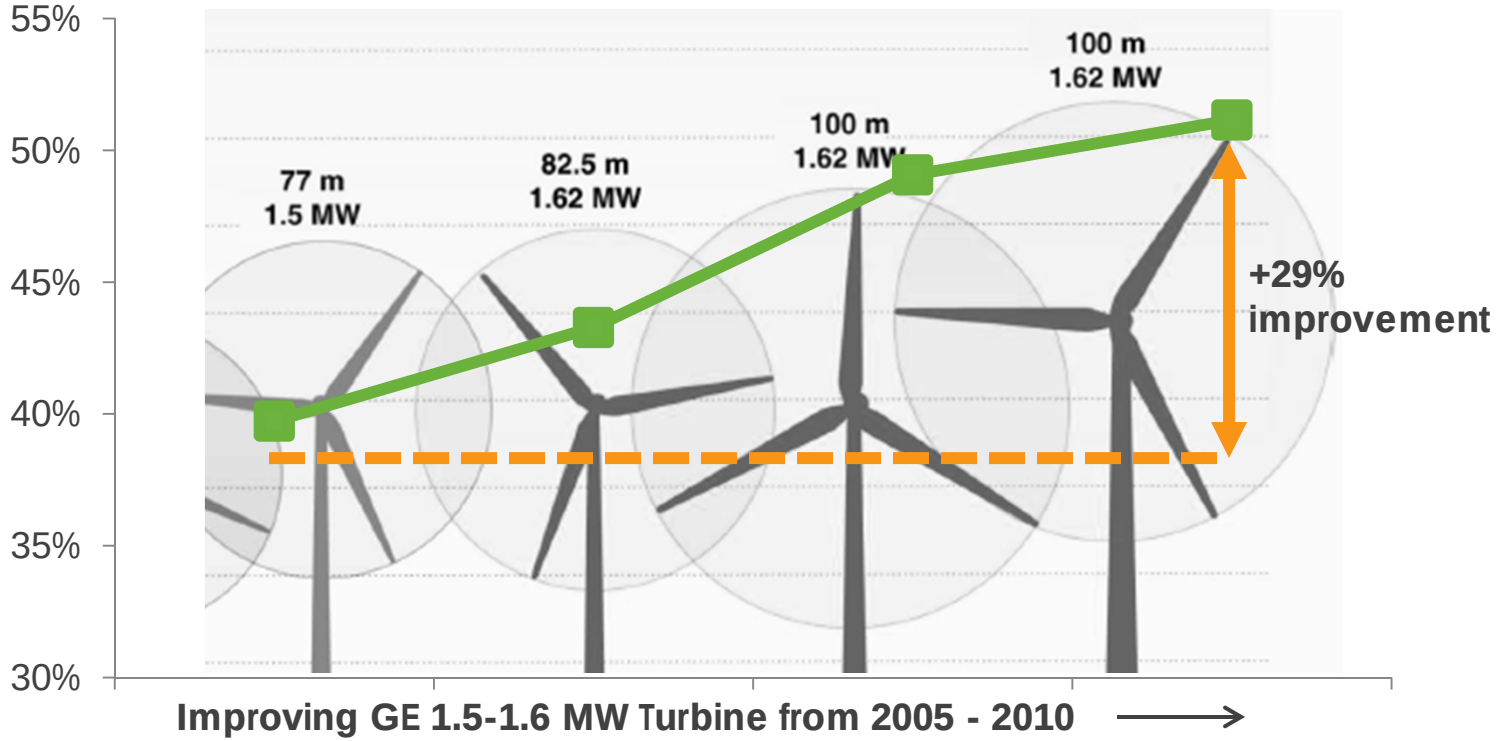


= **15,000,000 MWh**

Wind Energy Coming of Age

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

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

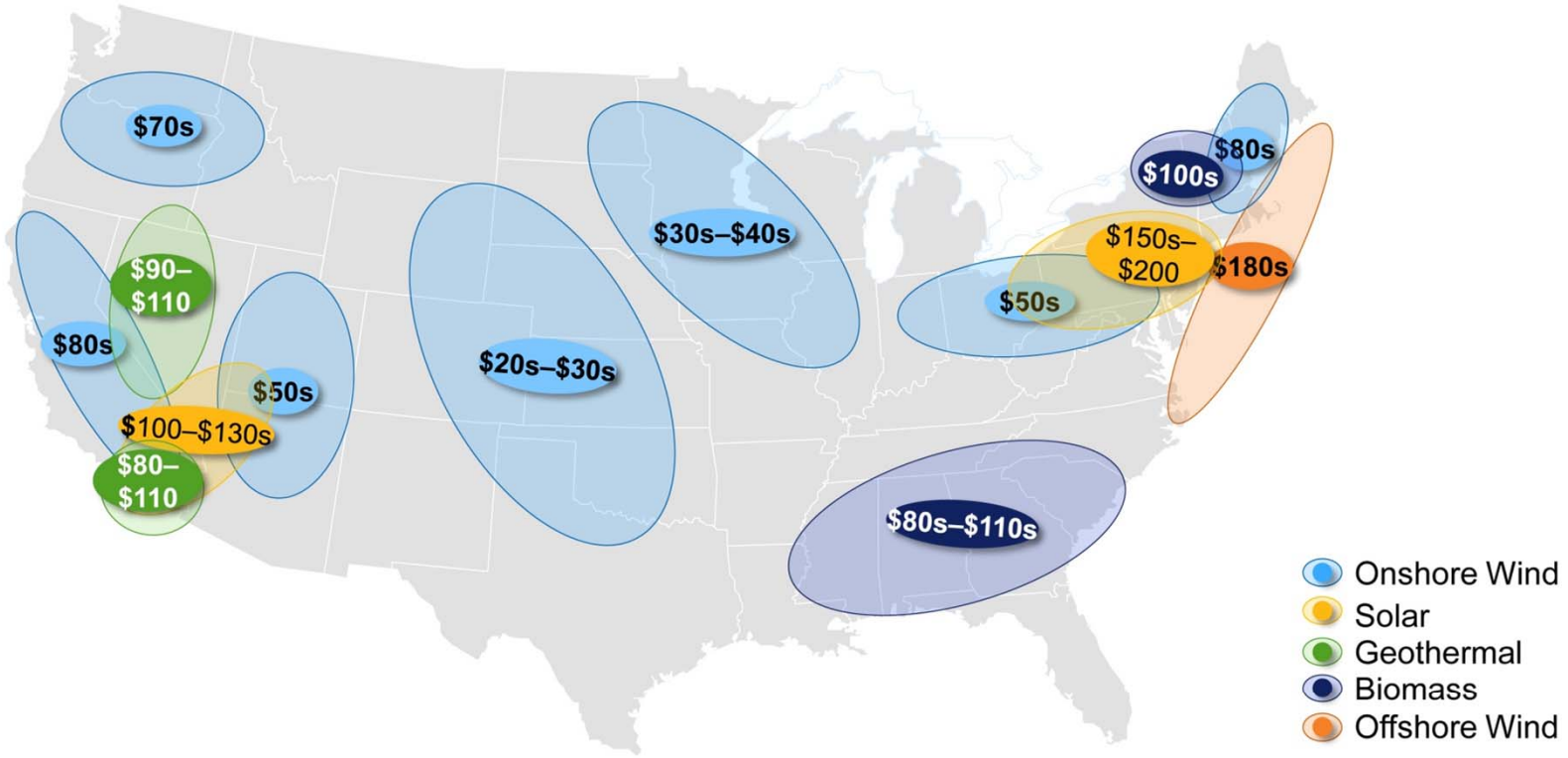


In meters

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

Renewable energy cost trends



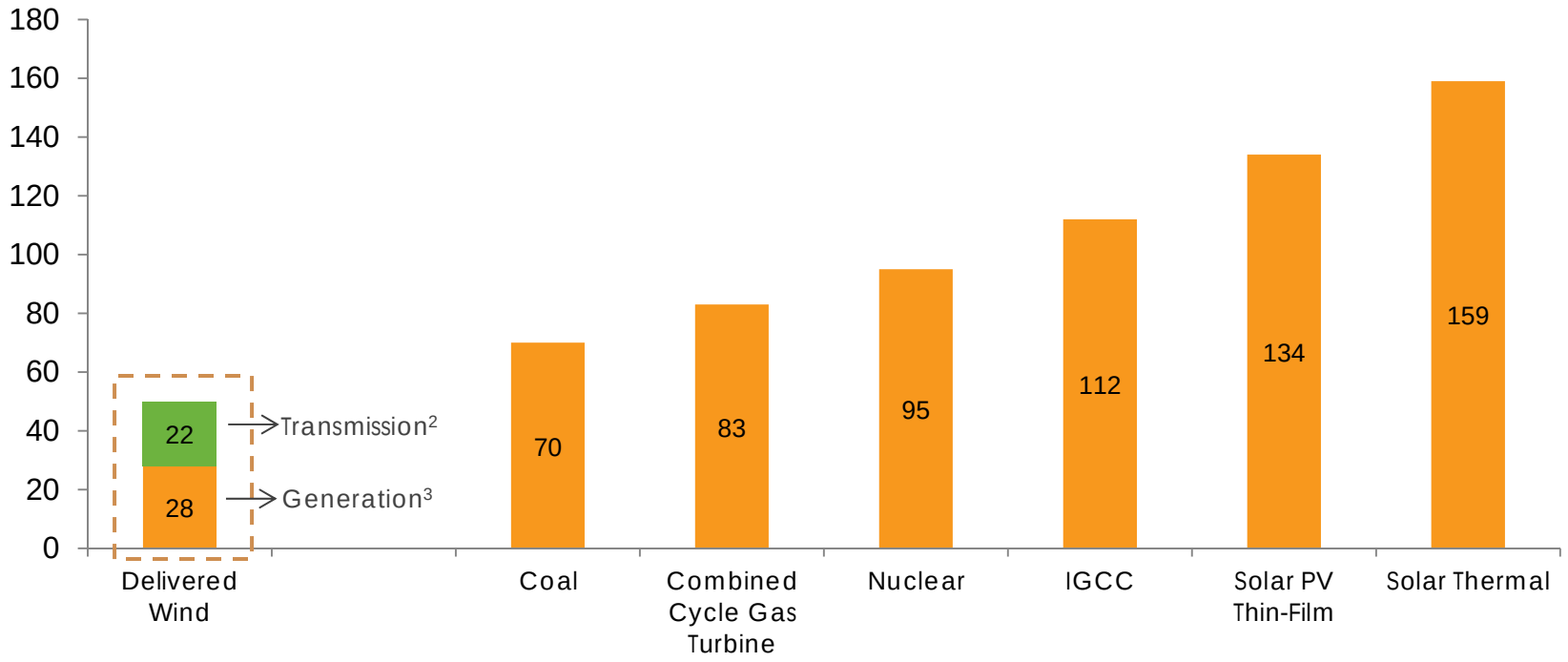
Declining technology costs combined with increased efficiency is pushing the price for renewables to new lows, intensifying competition to build transmission to connect low-cost regions with demand

emerging energy research

Clean Line's delivered cost to a utility is competitive with other sources of generation

Levelized Cost of Energy[1]

$ / MWh

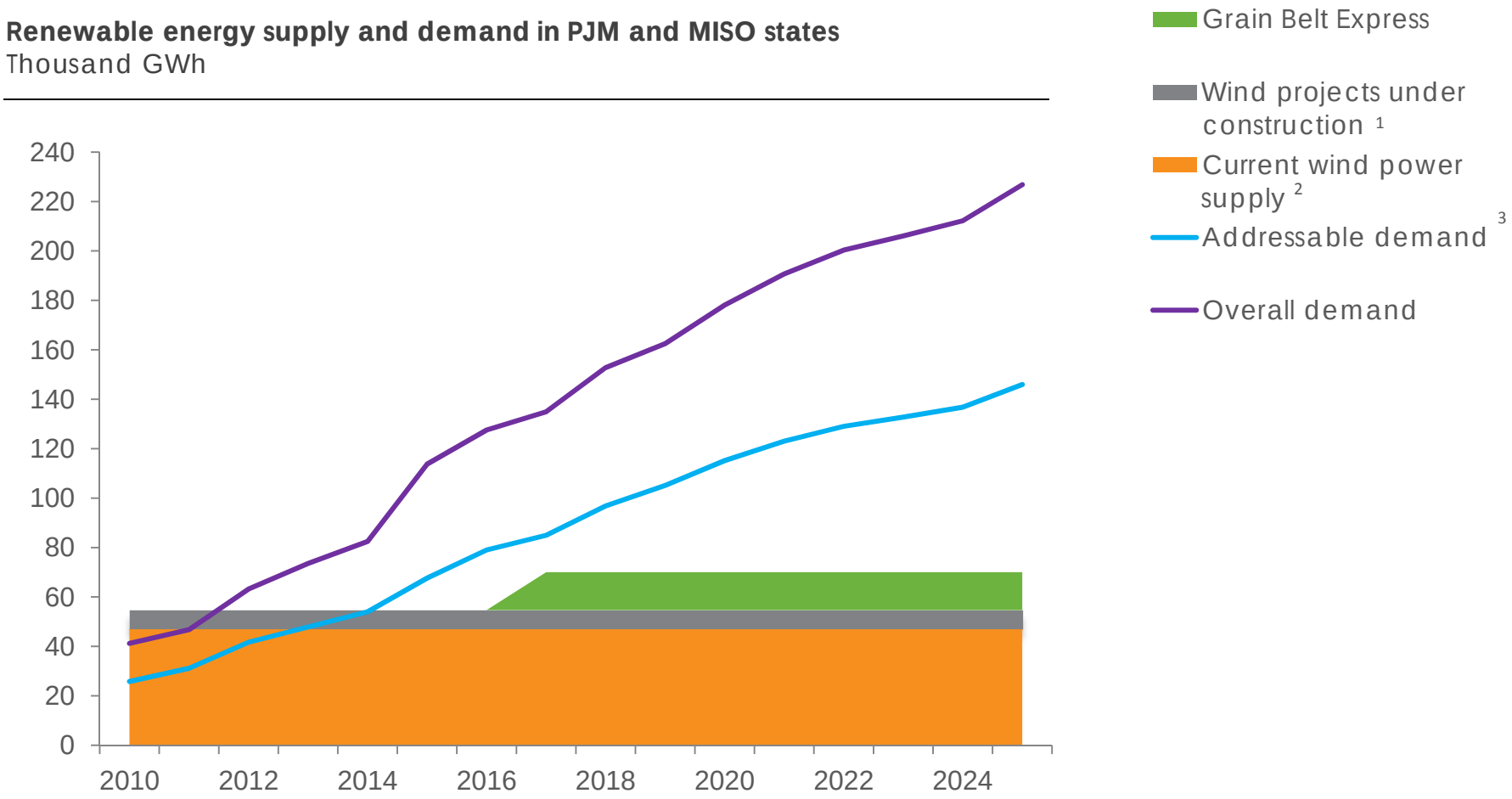


1. Cost of other sources of generation based on Lazard's LCOE estimates in 2011$, except for lower-end for coal (no carbon capture)
2. Assumes ~725 miles of transmission at $2 MM per mile, endpoint converter cost of $250 MM each, mid-converter cost of $150 MM, & development cost of ~$80 MM
3. Assumes capex costs of $1700/KW, O&M costs of $10/MWh, wind Production Tax Credit, cost of capital of 9%

Source: Lazard; Clean Line Energy

Demand for clean energy is large enough for both in-state and out-of-state resources

Renewable energy supply and demand in PJM and MISO states
Thousand GWh

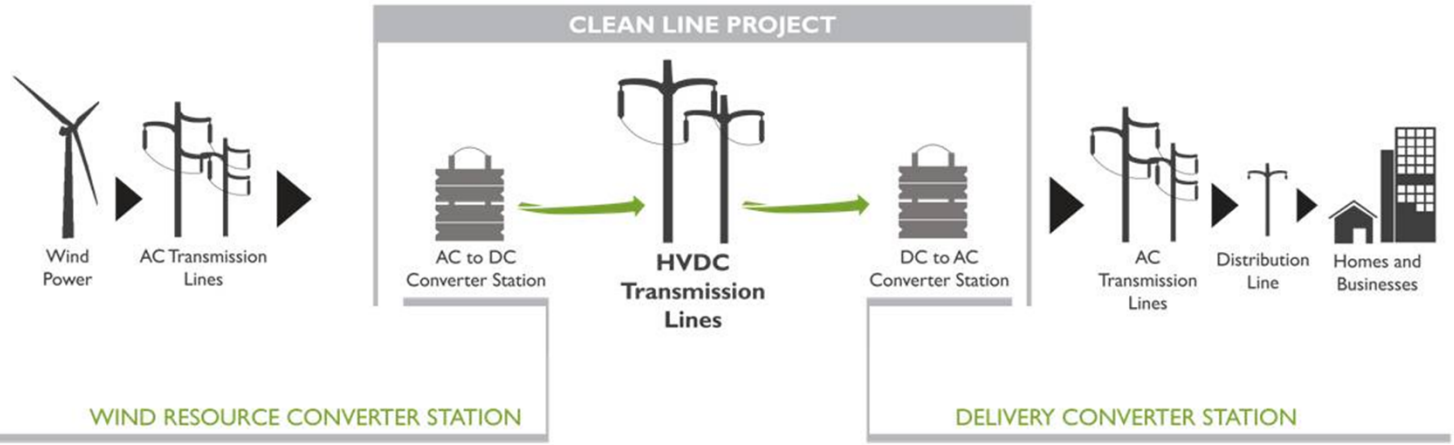


1. Wind projects currently under construction within the PJM and Midwest ISO states
2. Energy from existing wind projects within the PJM and Midwest ISO states
3. Demand for renewable energy credits within PJM and MISO states for which imported wind delivered by Grain Belt Express would be eligible

Source: EIA, DSIRE, AWEA; November 4, 2011

HVDC delivery of renewable energy will augment the existing grid

DELIVERING RENEWABLE ENERGY WITH HVDC



WIND RESOURCE CONVERTER STATION

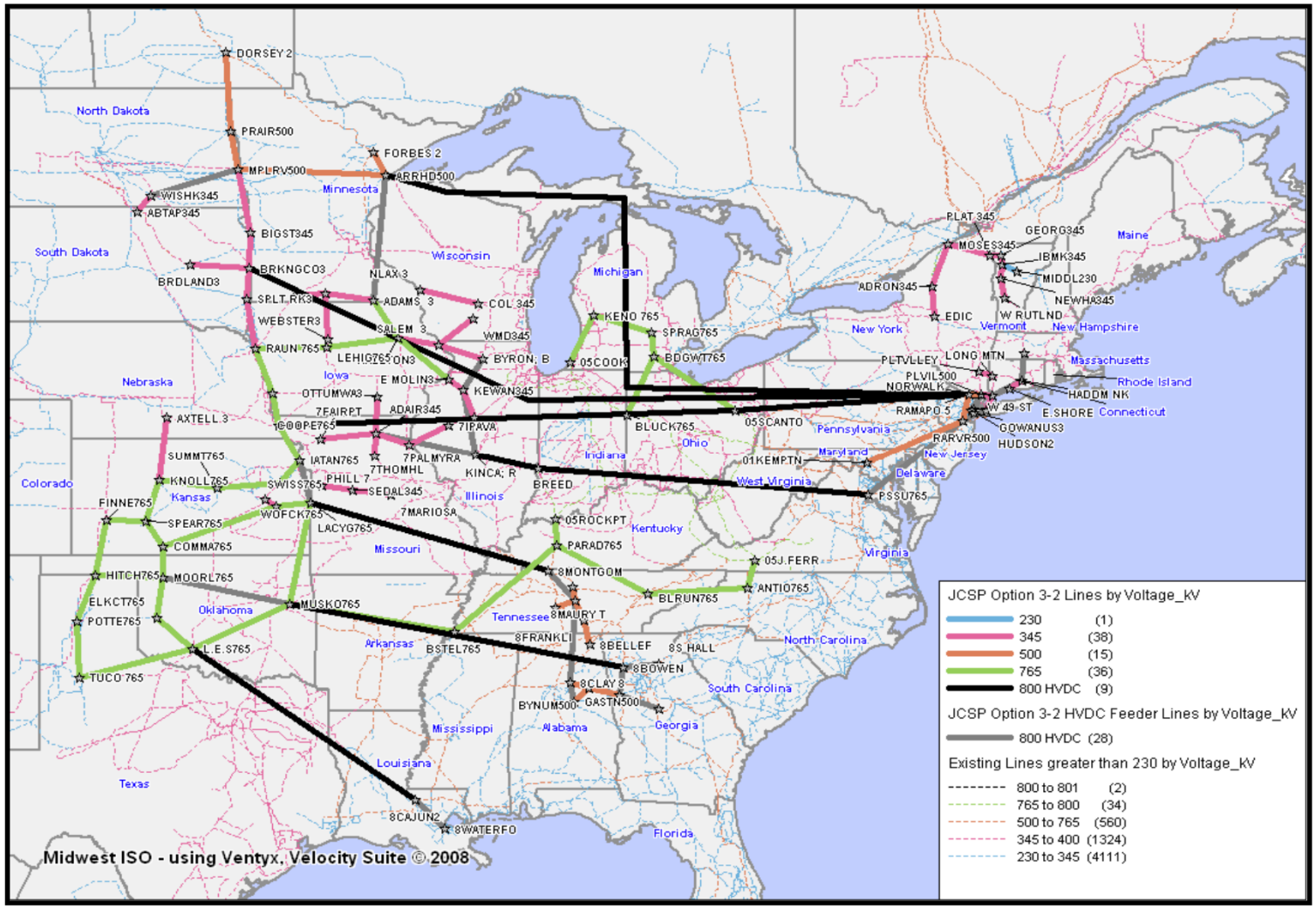
- Converts energy from AC power to DC power
- Energy is transmitted on the transmission line

DELIVERY CONVERTER STATION

- Energy is received from the transmission line
- Converts energy from DC power to AC power
- Connects with existing transmission system

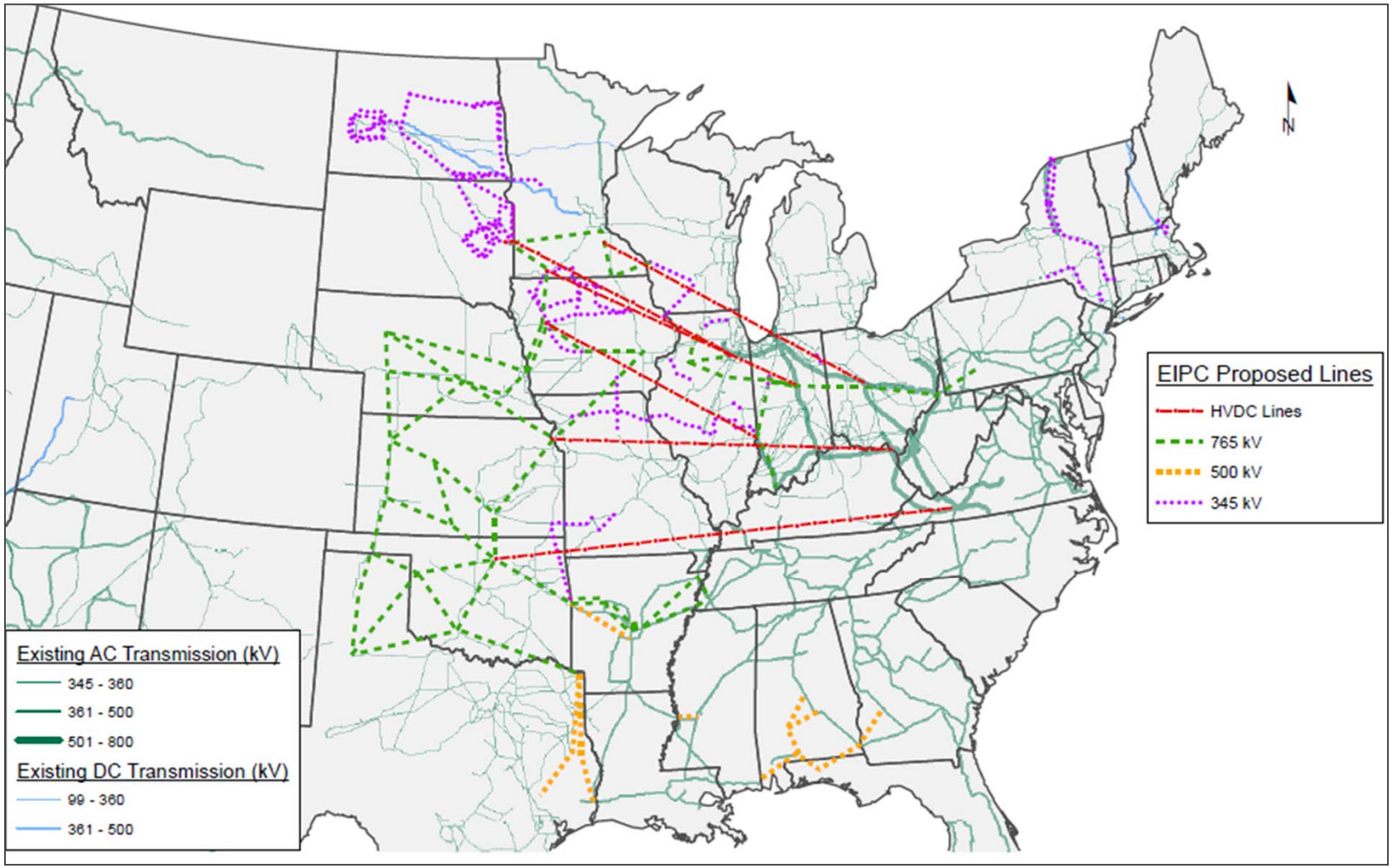
Typical Converter Station

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

HVDC is the ideal technology to move large amounts of power over long distances

More efficient – Over long distances, DC transfers more power with lower line losses than comparable AC lines

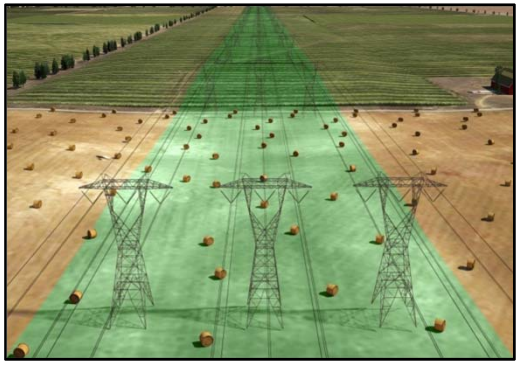
Smaller footprint – DC requires a narrower right of way to move an equivalent amount of power over AC lines

Lower cost – Less infrastructure and lower line losses result in lower cost transmission and lower prices for renewable energy

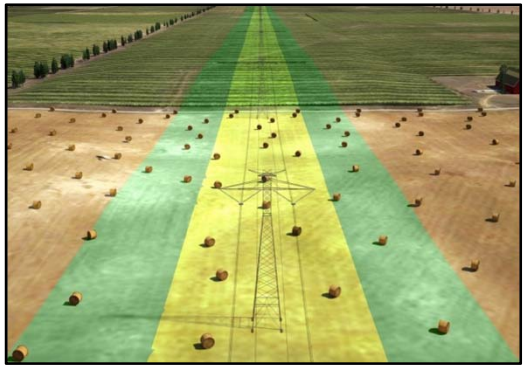
Improved reliability – DC gives power operators complete control over energy flow

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

AC **3000-4000 MW Capacity** **DC**



Three 500 kV lines
600 foot ROW



One ± 500 kV bipole
150-200 foot ROW

DC transmission removes LMP risk

- Historically, the **installation of wind turbines in the windiest areas** has outstripped native demand and available transmission capacity.
- **Oversupply of wind** results in depressed LMP, decreasing the value of the energy, and often results in curtailments.
- With an HVDC solution, the **value of energy** is determined by the delivery location, not the wind farm location
- This **removes a key risk** to output purchasers and plant owners.
- DC transmission – unlike AC transmission with an LMP component – is a **truly fixed cost**

Wind energy delivered by Clean Line Projects will result in health and environmental benefits

EMISSIONS REDUCTIONS PER YEAR*

CO_2 — 10 MILLION TONS

CARBON DIOXIDE

SO_2 — 14,000 TONS

SULFUR DIOXIDE

NO_x — 10,000 TONS

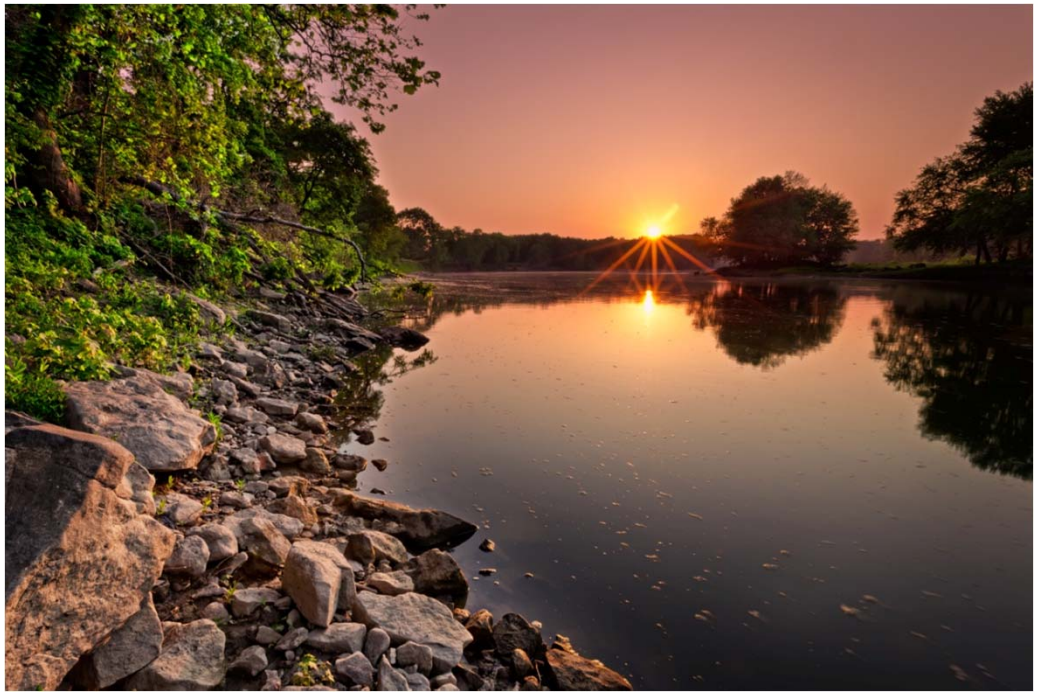
NITROGEN OXIDE

Hg — 170 POUNDS

MERCURY

WATER WITHDRAWAL REDUCTION PER YEAR*

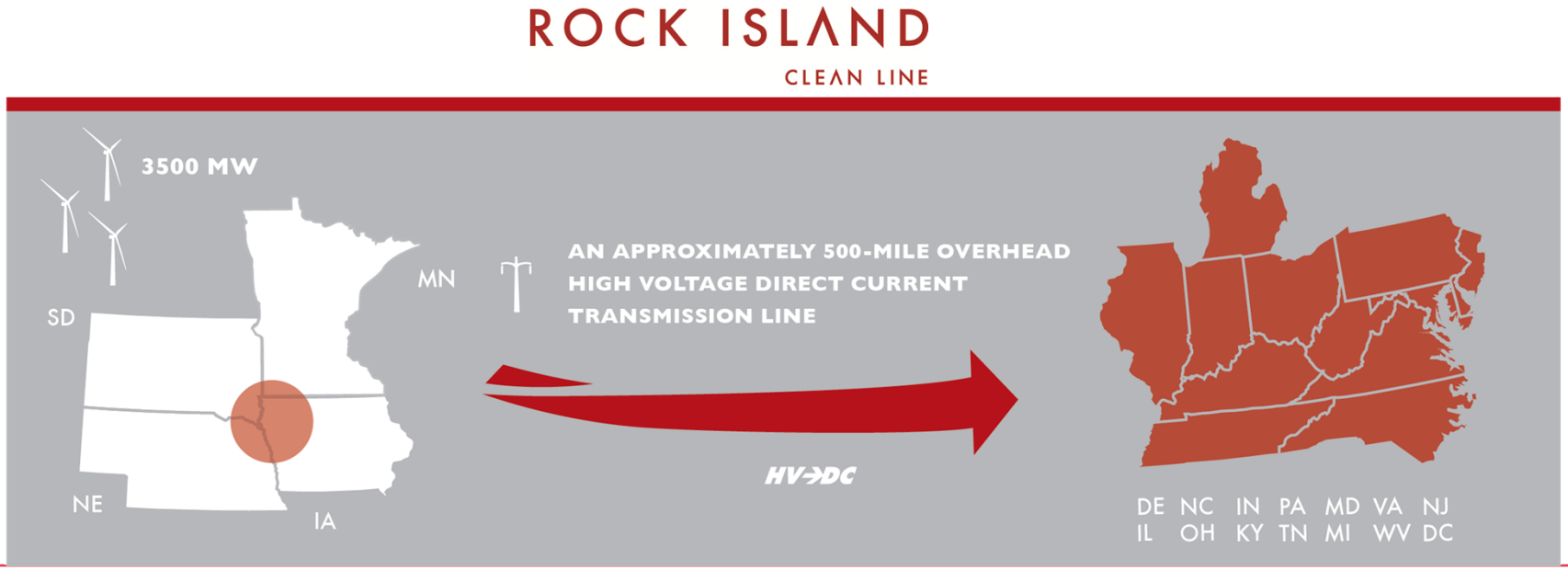
H_2O — 4 BILLION GALLONS



Sunrise on the Wabash River - Chris Harnish Photography, Lafayette, IN

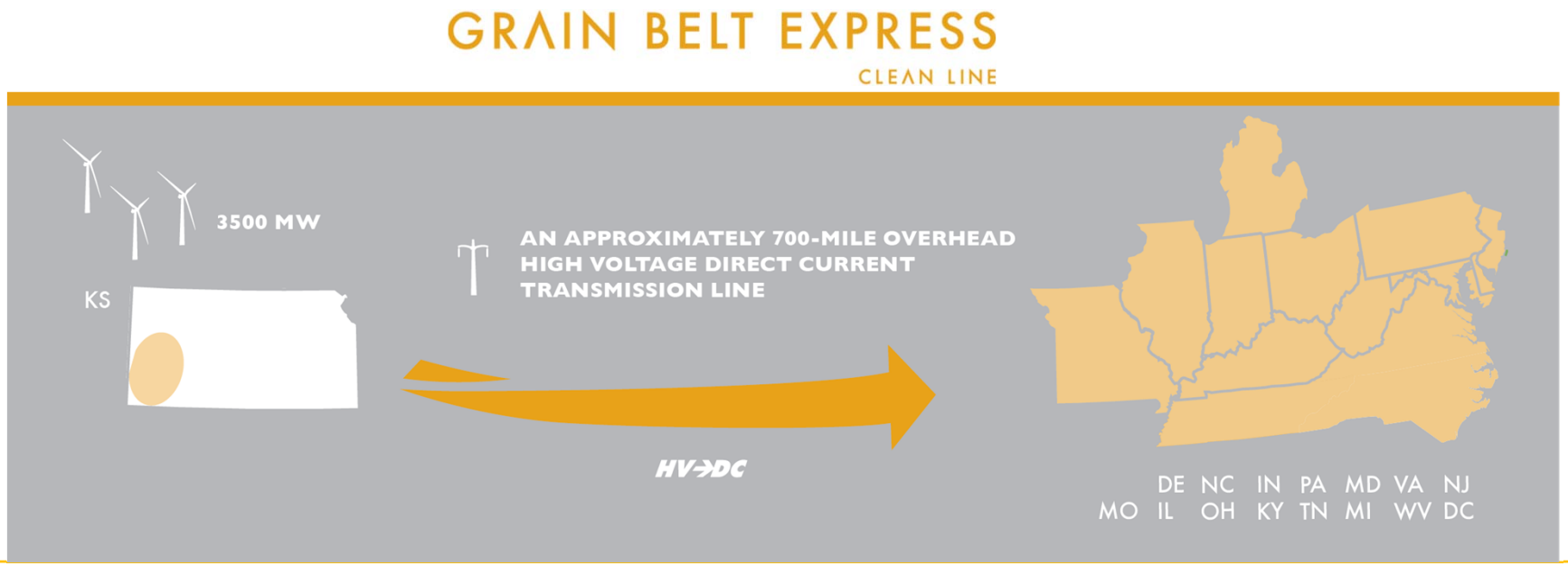
*Source: Clean Line Energy Partners for Grain Belt Express Project

Rock Island Clean Line will Connect Western Iowa with PJM 765 kV System



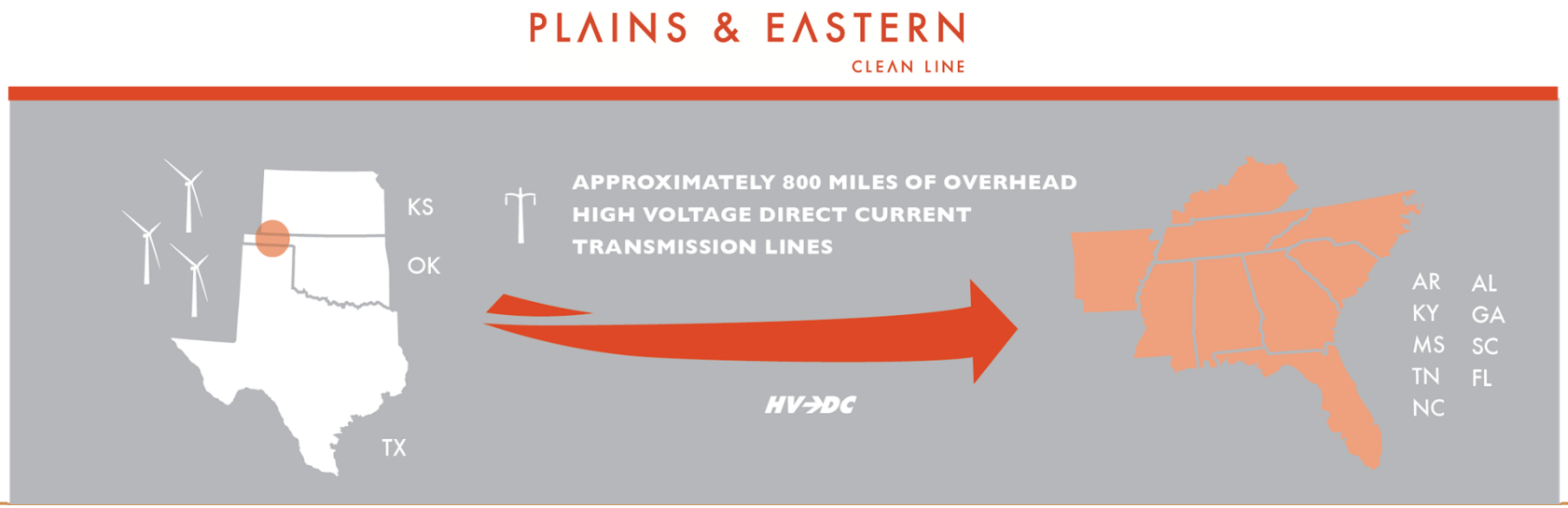
KEY MILESTONES	STATUS
Regulatory Approvals	• FERC granted Clean Line authority to negotiate rates with customers • Submitted preferred routes to the Illinois Commerce Commission in Oct 2012; will submit preferred routes to the Iowa Utilities Board in 2013
Interconnection	• Acquired 2007 vintage PJM queue positions at 765 kV Collins substation • MISO reliability studies underway
Converter Options	• Purchased land option for Illinois and Iowa converter sites • Preferred supplier agreement with Siemens for HVDC converter
Outreach	• Invited more than 40,000 property owners and residents within study corridors to 26 open house meetings—more than 2,000 invitees attended
Environmental & Routing	• Route alternatives established
Agreements & Partnerships	• MOU with Kiewit for EPC development support • Preferred supplier agreement with Southwire (IL)

Grain Belt Express Clean Line will Deliver Wind Energy from Western Kansas to MO, IN, IL, and points East



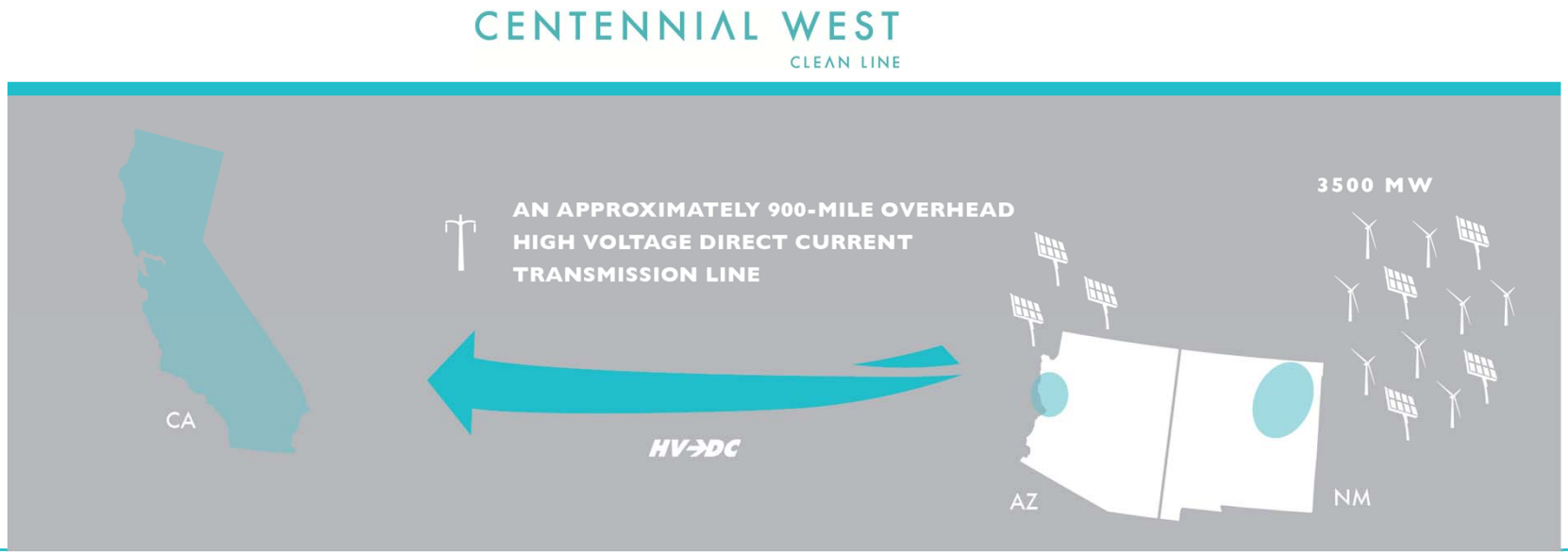
KEY MILESTONES	STATUS
Utility Applications	• Obtained public utility status in Kansas on December 7th 2011 • Will file with the Indiana Utility Regulatory Commission in 2012
Interconnection	• PJM interconnection studies underway at Sullivan substation in Indiana • MISO interconnection studies underway at Palmyra Tap 345kV substation in Missouri • Reliability studies with SPP have begun
Outreach	• Nearly 800 community leaders from more than 100 Kansas, Missouri and Illinois counties provided input on routing at roundtable meetings
Environmental & Routing	• Route alternatives established

Plains & Eastern Clean Line will Deliver Wind Power from Kansas, Oklahoma and Texas to TVA and the Southeast



KEY MILESTONES	STATUS
Utility Applications	• Filed utility application in Oklahoma and Arkansas; obtained public utility status in Oklahoma in October 2011 • FERC granted Clean Line authority to negotiate rates with customers
Interconnection	• Undergoing SIS at 500 kV substations in TVA • Reliability studies with SPP underway; seeking approval in November 2012
Converter Options	• Purchased land option for Oklahoma converter site
Outreach	• Held over 1,200 meetings in more than 30 counties across OK, AR and TN • Held ten Public Open House meetings across OK in October 2012
Environmental & Routing	• Route alternatives established
Agreements & Partnerships	• Signed supplier agreements with Pelco Structural (OK) and General Cable (AR) • Entered into agreements with The Nature Conservancy of Arkansas and The Nature Conservancy of Oklahoma • MOU with TVA • MOU with Fluor for EPC development support

Centennial West Clean Line will Deliver Renewable Energy from New Mexico and Arizona to California

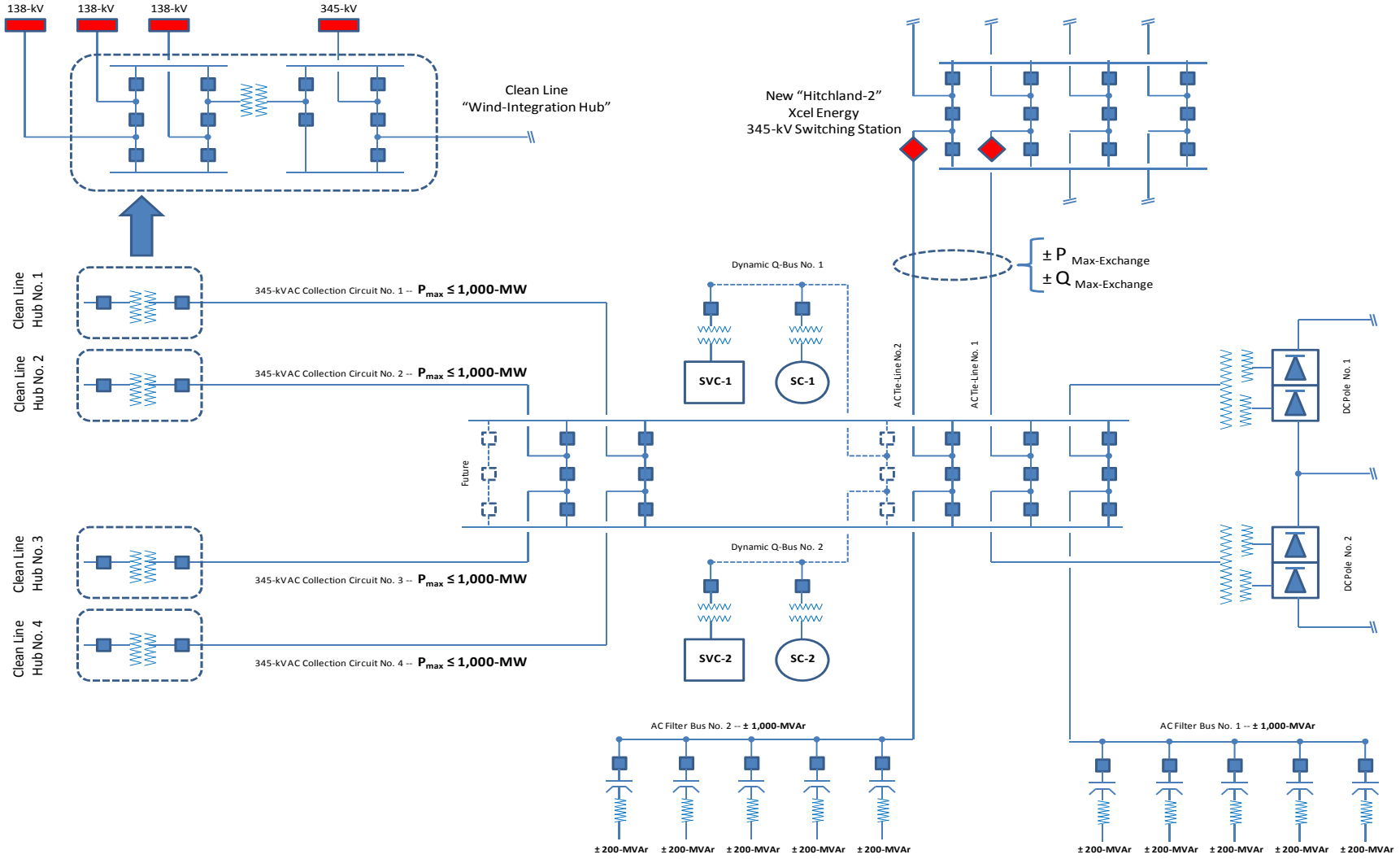


KEY MILESTONES	STATUS
Interconnection	• CAISO interconnection request filing planned for 2013 or 2014; WECC Project Coordination Review completed
Federal Procedure	• Signed development agreement with Western Area Power Administration
Outreach	• Held 18 community leader workshops in four states and two tribal nations to gather information about local routing opportunities and constraints
Environmental & Routing	• BLM and USFS project managers working jointly under NEPA process
Agreements & Partnerships	• MOU signed with New Mexico Renewable Energy Transmission Authority; proceeding with rulemaking

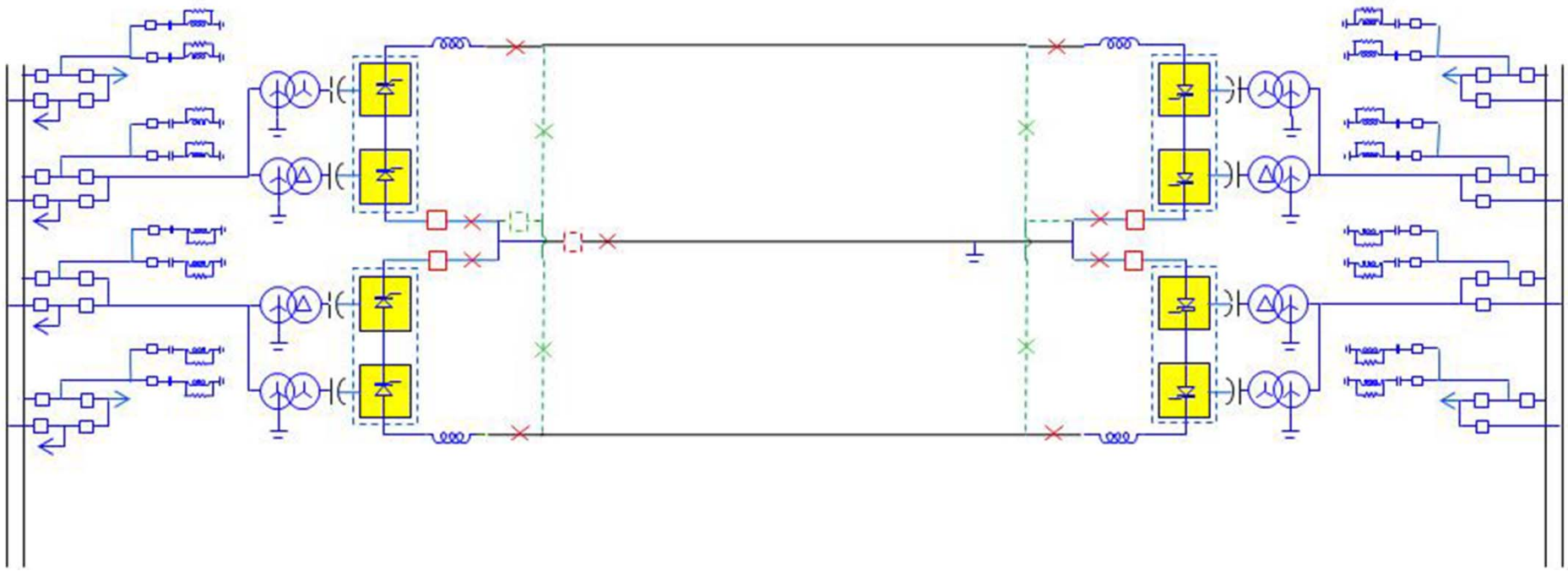
Technical Challenges – some of what tends to keep me up at night

- Low short-circuit levels, thus 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
- Possible Multi-terminal configurations
- Variability of resources
  - Wind integration concerns – lots of scientific answers, policy makers don't always like physics

Weak grid interactions: typical "windward" connection diagram for Clean Line Projects

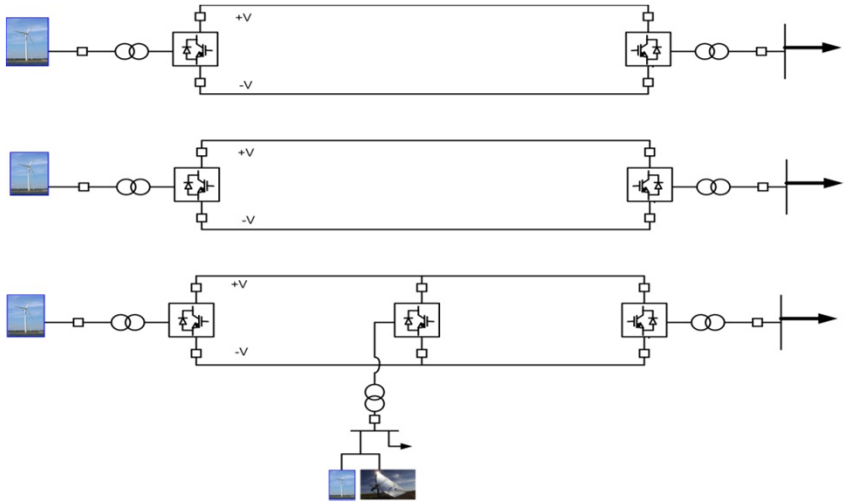


Weak grid interactions: Use of Capacitor Commutated Converters (CCC)



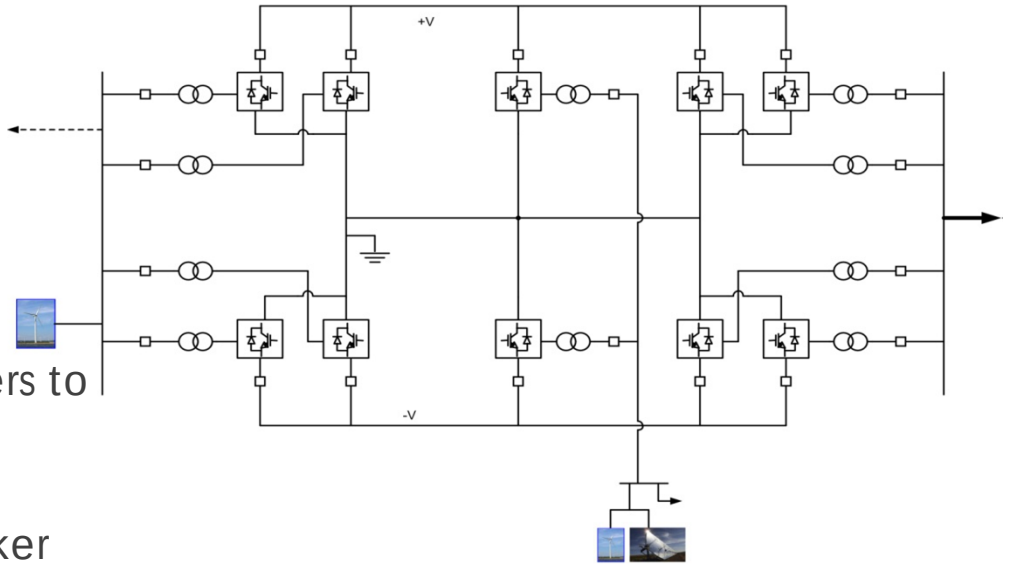
- Reduces/removes need for synchronous condensers.
- Single vendor has patent on topology?
- Untested on overhead lines and at such high voltages
- Only a “slight” premium over standard LCC, but huge savings over adding synchronous condensers

Weak grid interactions: possibility of applying VSC technology in new schemes

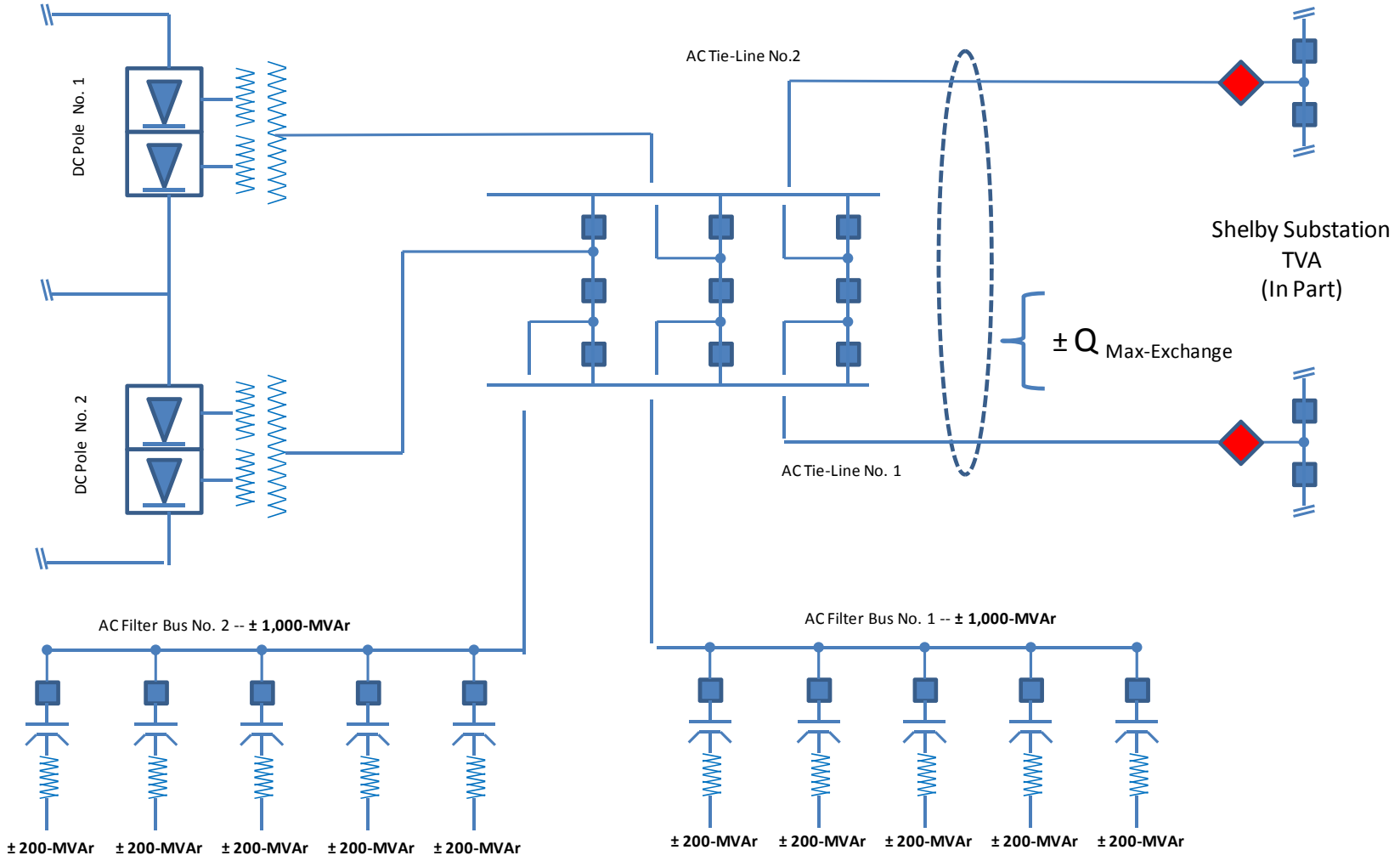


- "Tri-pole" configuration
- Three independent symmetrical monopoles
- Each pole rated ~1100 MW
- Independent placement of terminals
- Overhead still requires either full bridge converter or high speed HVDC breaker

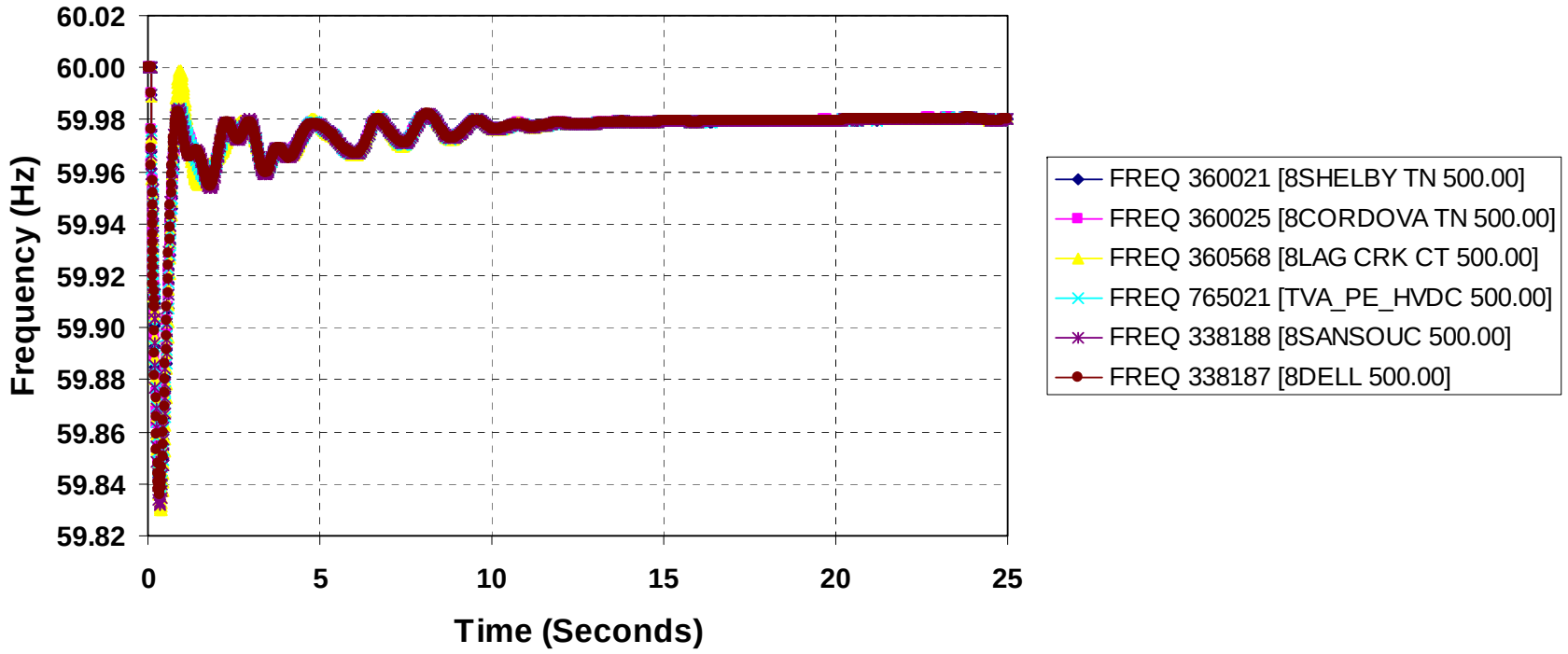
- Bi-pole configuration with parallel converters.
- Each pole rated ~2400 MW for total power of ~4800 MW
- Same configuration as HVDC classic except the need for parallel converters to achieve more that 2200 MW.
- Overhead still requires full bridge converters or high speed HVDC breaker



Large injections: typical “load end” connection diagram for Clean Line Projects

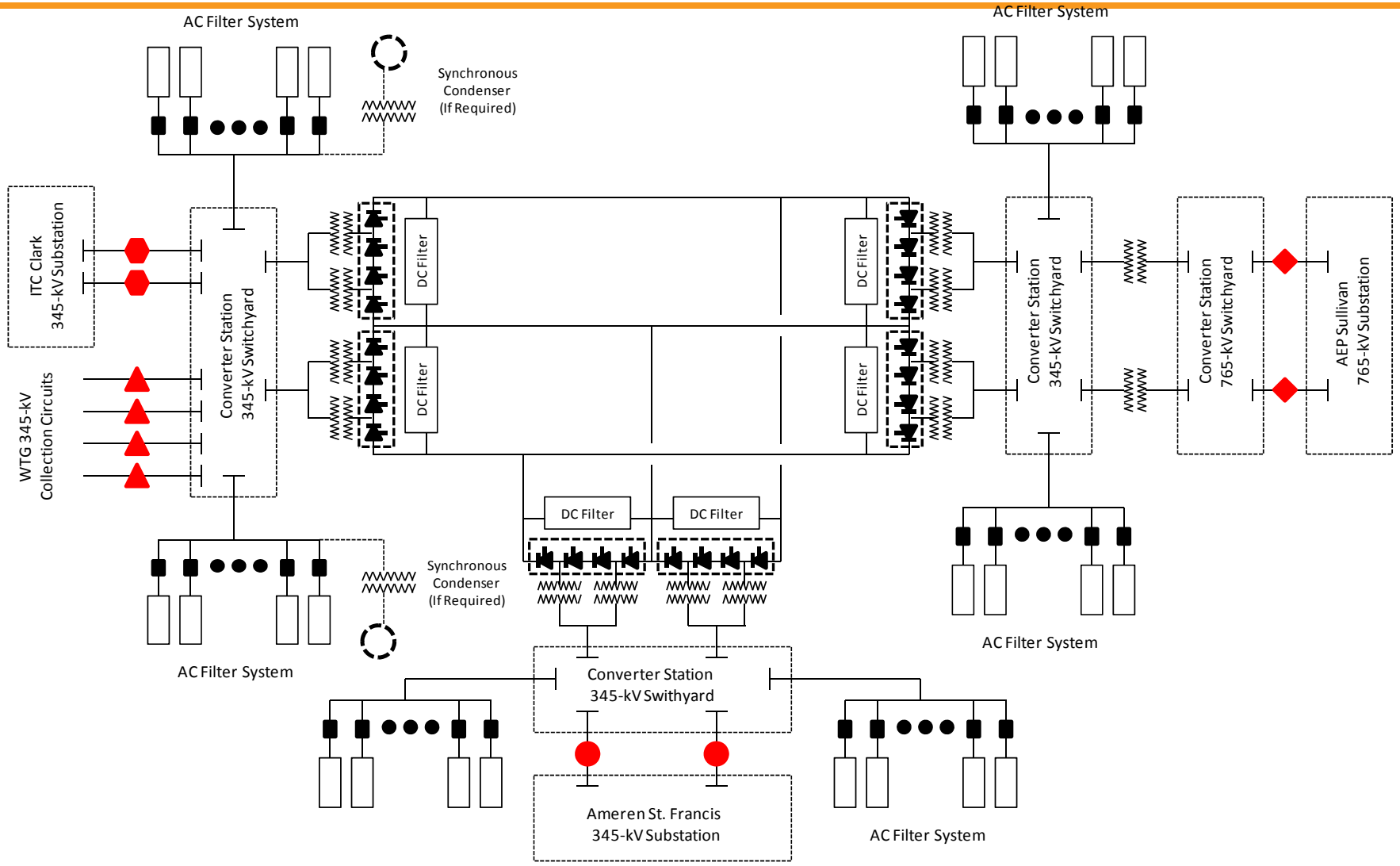


Large injections: 3500 MW contingency

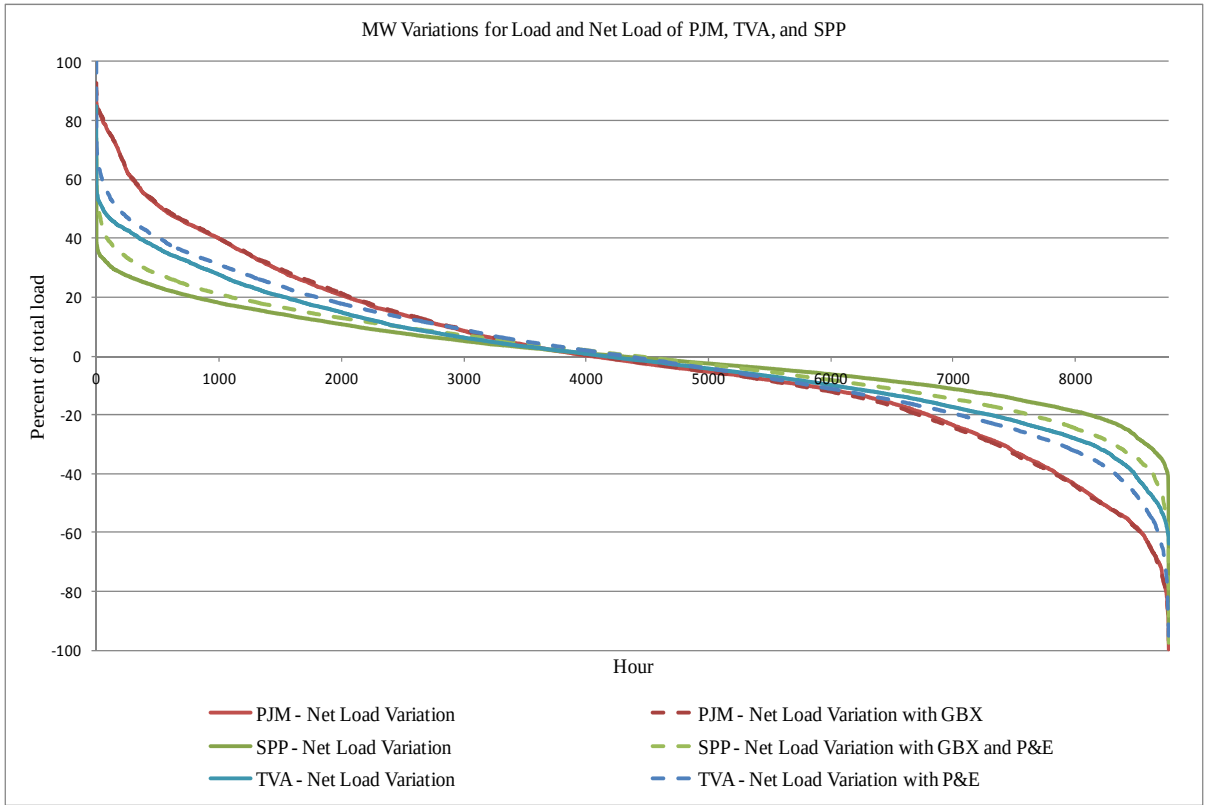


- Significant coordinated planning must be involved with these projects.
- N-1, N-1-1, N-2 concerns on both load end and receiving end from a planning perspective.
- Loss of 1750 or 3500 MW of generation on the eastern interconnect.

Multi-terminal configurations may be desirable



Integration: Possible need for additional reserves, questions of capacity value



	Three-Sigma Variation		
	Net Load	Net Load w/Clean Line Projects	**Delta**
SPP	3,187	4,006	**819**
TVA	2,395	2,764	**369**
PJM	10,280	10,410	**130**

Source: Galli, et al "Role of HVDC for Wind Integration," CIGRE Grid of the Future Conference, October 2012

- How much, and over what time periods does power output change? How does this affect system operators ability to match generation to load?
- How valuable are different zero fuel cost resources, in displacing existing resources?
- What ability do renewables have to produce power when the system needs it most?

Integration: Diversity is an important component, Illinois/Indiana and Kansas wind are complementary

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

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