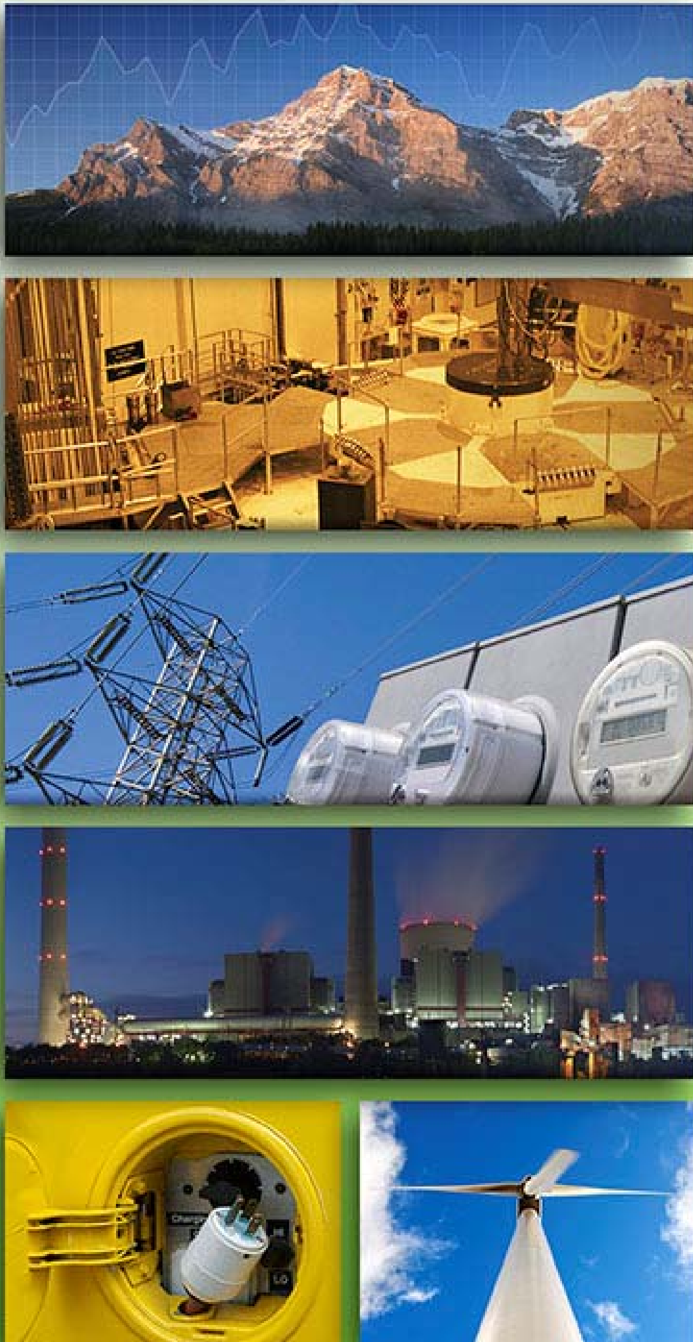

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Energy Policy, Climate Policy and the Electric Sector:
Understanding the challenges to wind's role in a low-carbon electric future

Victor Niemeyer
Technical Executive

EPRI GCC Research Seminar
May 18, 2010

How Much Wind in a Low-Carbon Future?

- A national policy to curb CO_2 emissions below existing levels will initiate a competition to replace existing coal
- Wind resource potential is huge
  - Exceeding 50% of U.S. electric energy needs at $80-$90/MWh
  - Potentially exceeding current generation from coal
- Potential is substantially limited by:
  - Variability and timing
    - hours of no output over region
    - rapid hour-to-hour changes
  - Location
    - high cost of transmission

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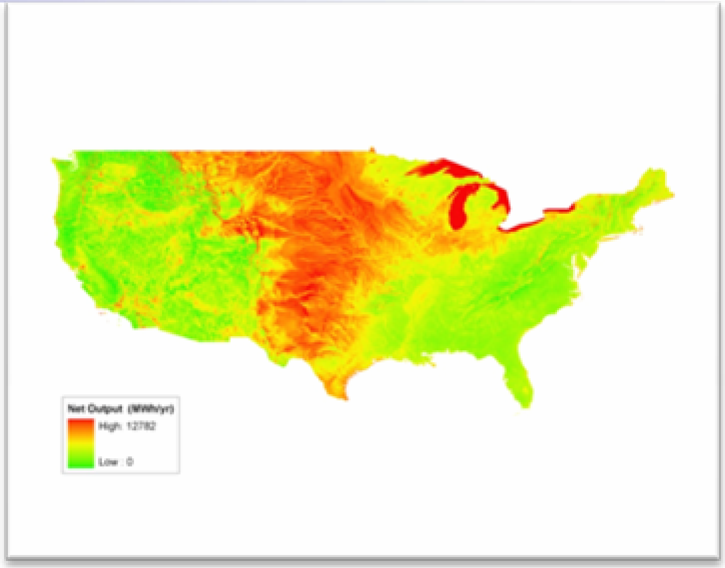
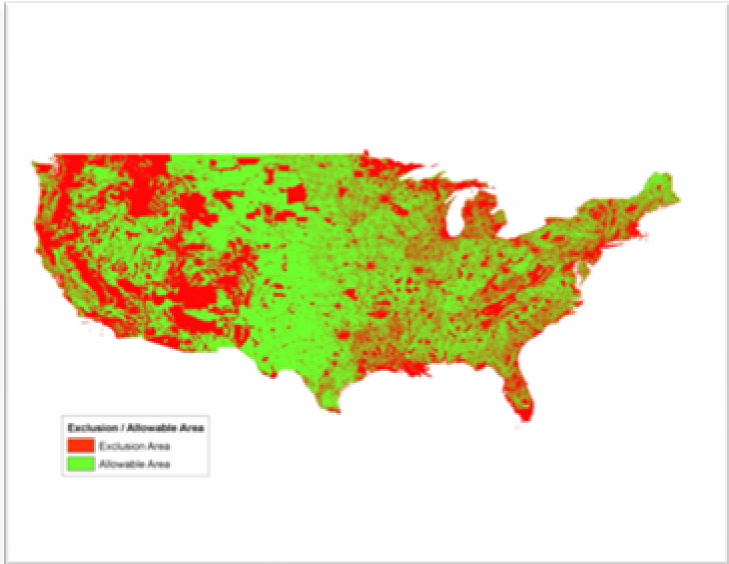
Truepower Data Reflect Realistic Meteorology, Resource Supply, and Turbine Technology

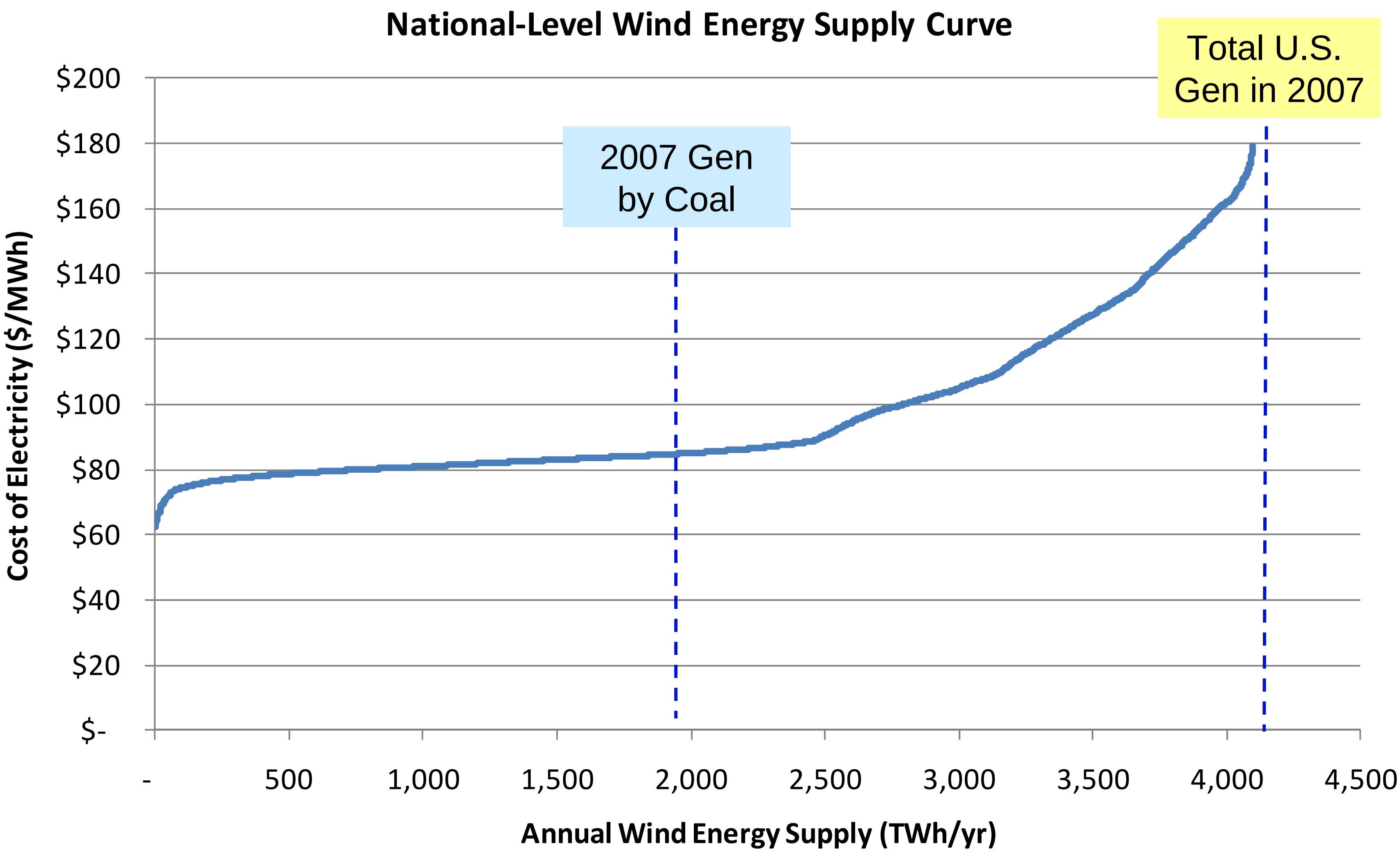
- 5,354 sites picked from 200m grid national survey
  - Exclusion areas
  - 100 MW site minimum
  - Distance to grid
  - Terrain/wake effects





- 12 year hourly simulation based on 1997-2008 meteorology for
  - 80m hub 1.5 MW turbine
  - Min/Max energy density
  - Power curves

Result: Wind Energy Supply Has Vast Potential



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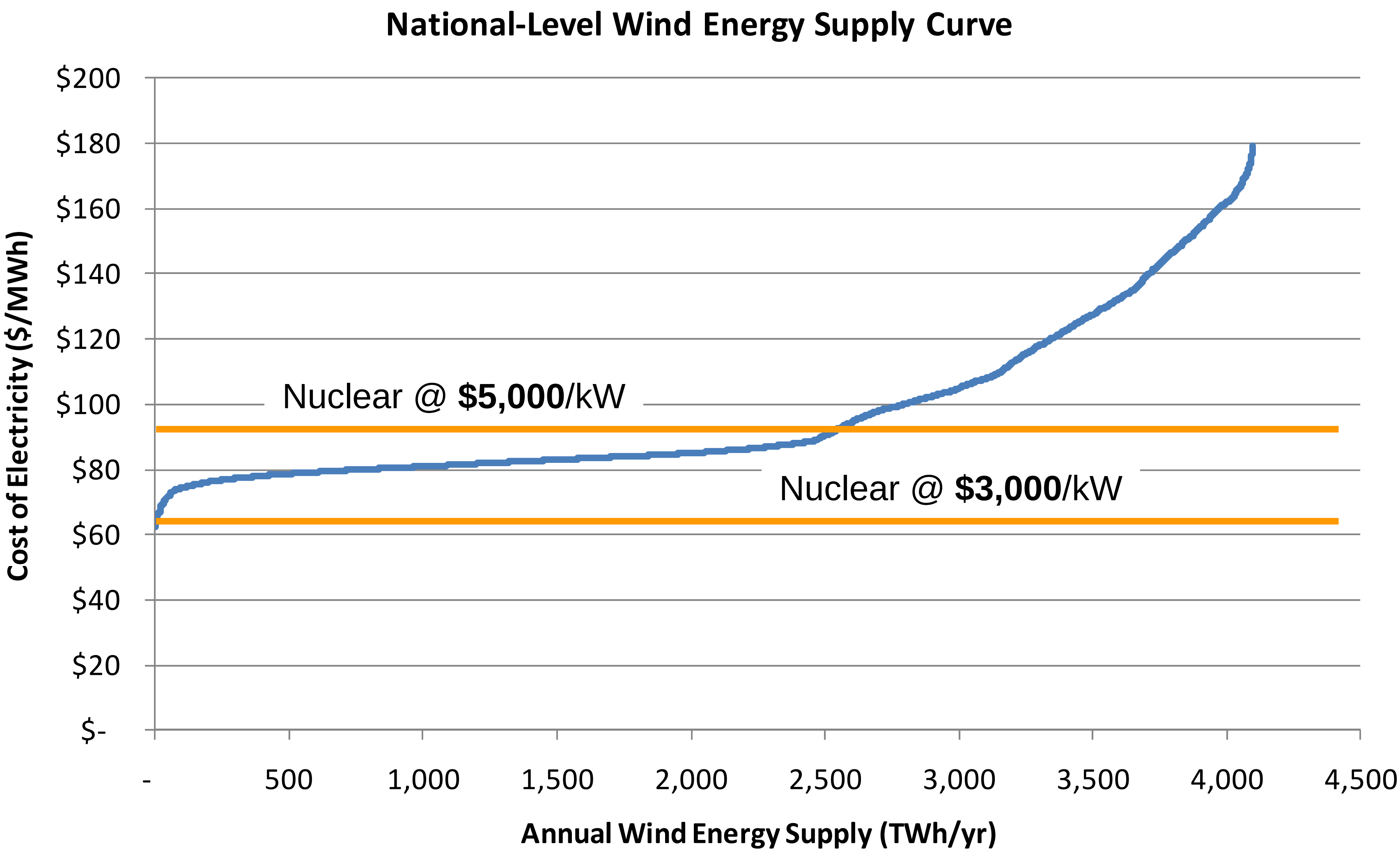
How the Wind Stacks Up Against New Nuclear



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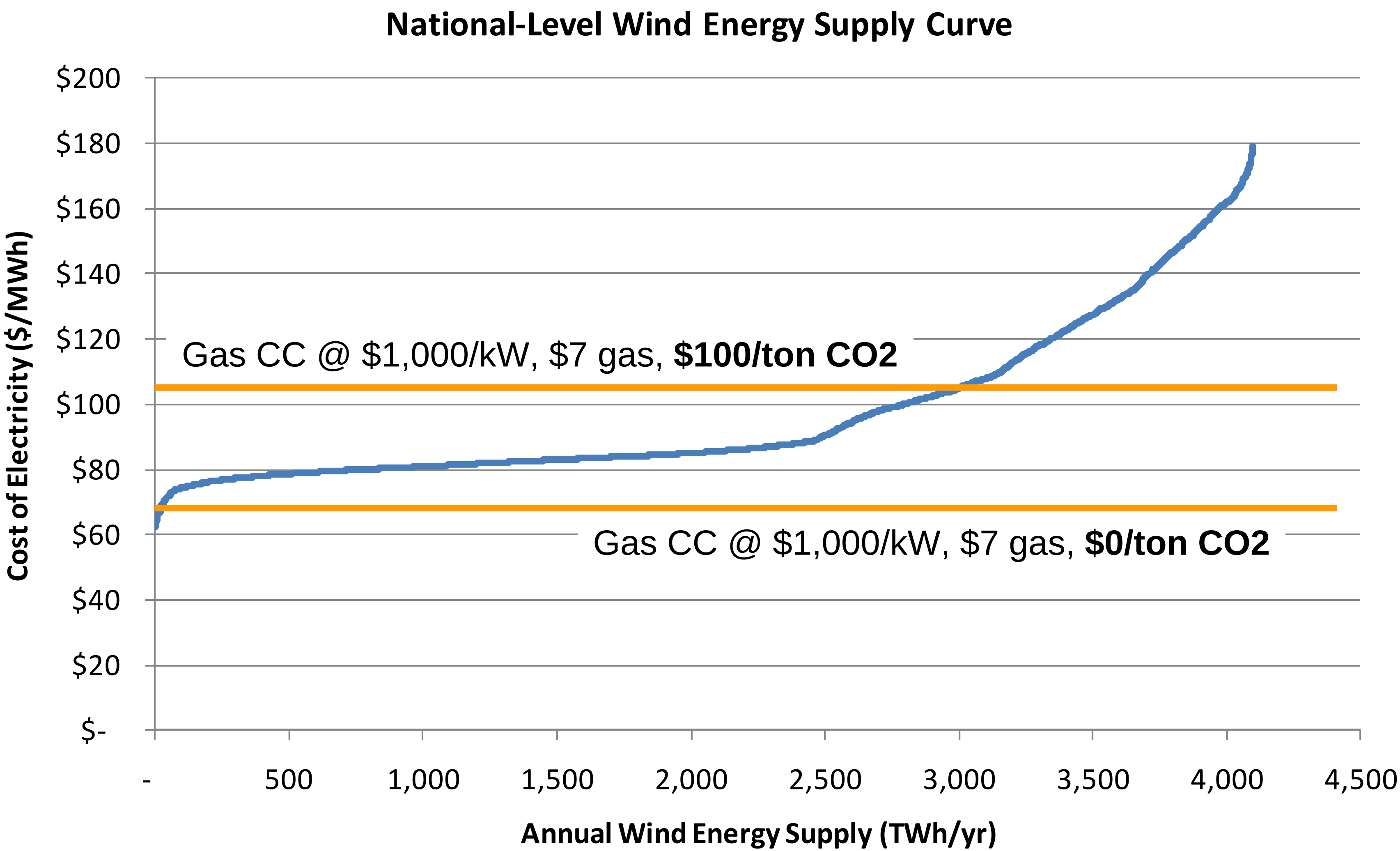
How the Wind Stacks Up New Gas CCs



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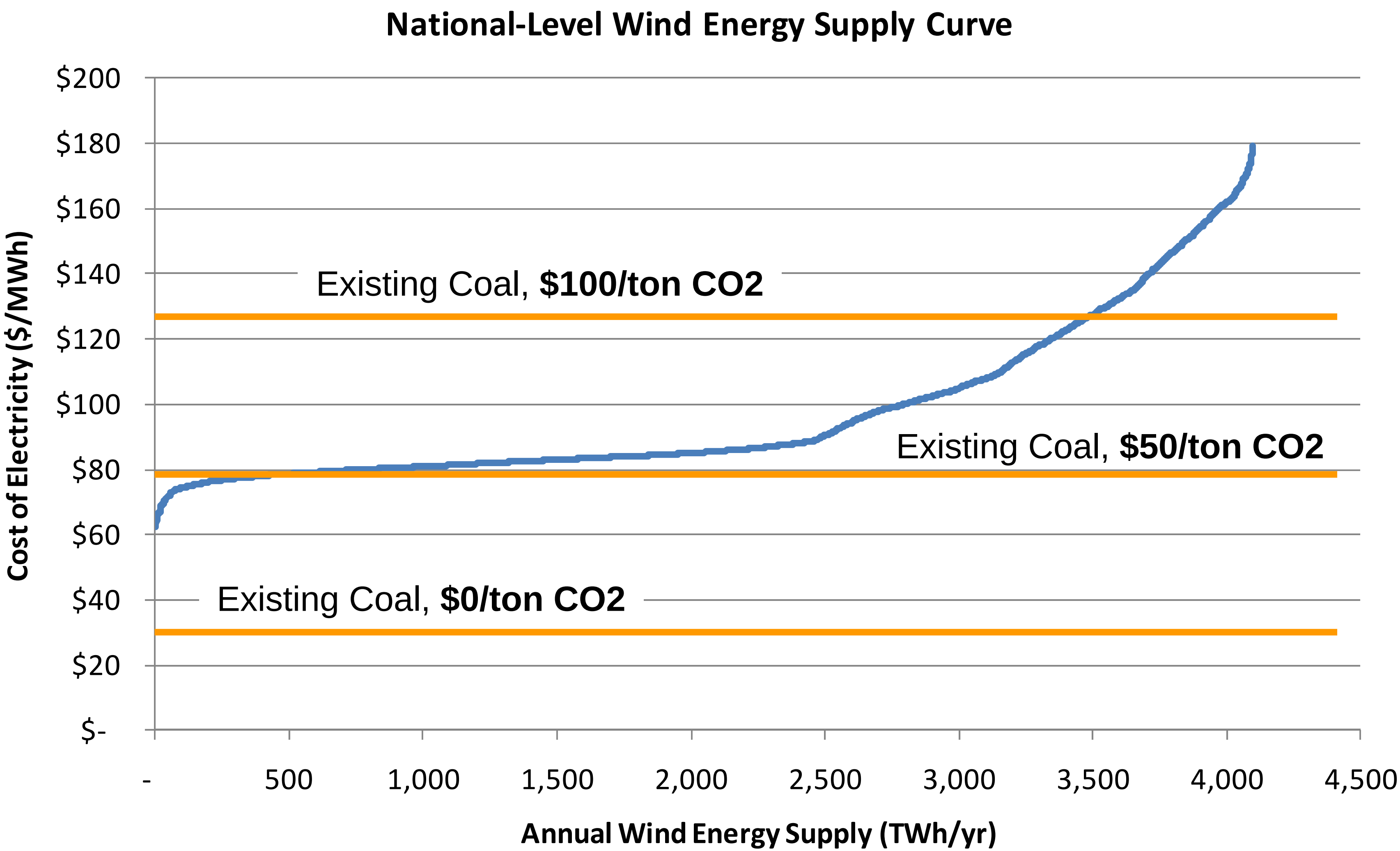
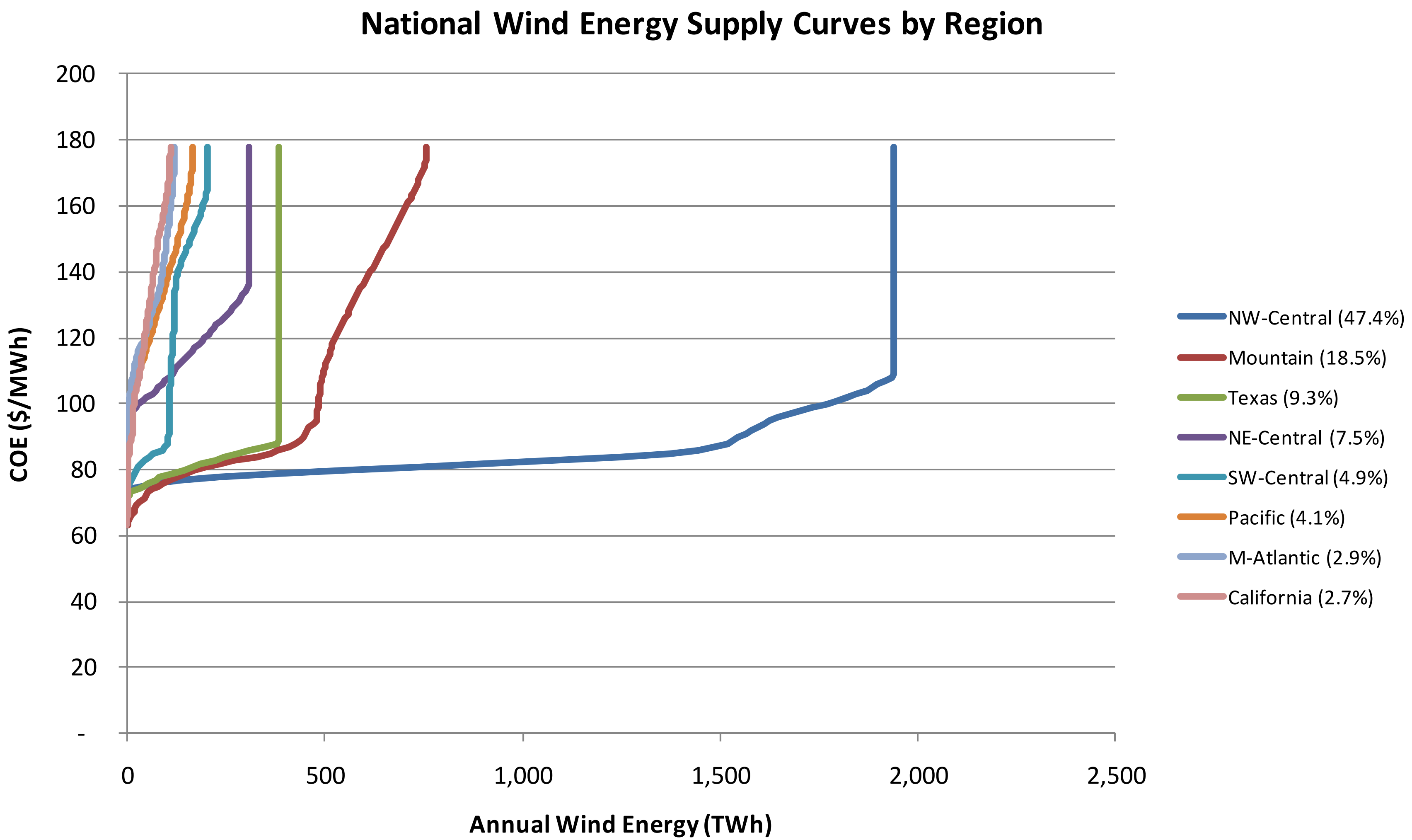
How Wind Stacks Up Against Existing Coal



Regional Supply Curves Show Dominant Role of Great Plains (NW-Central)



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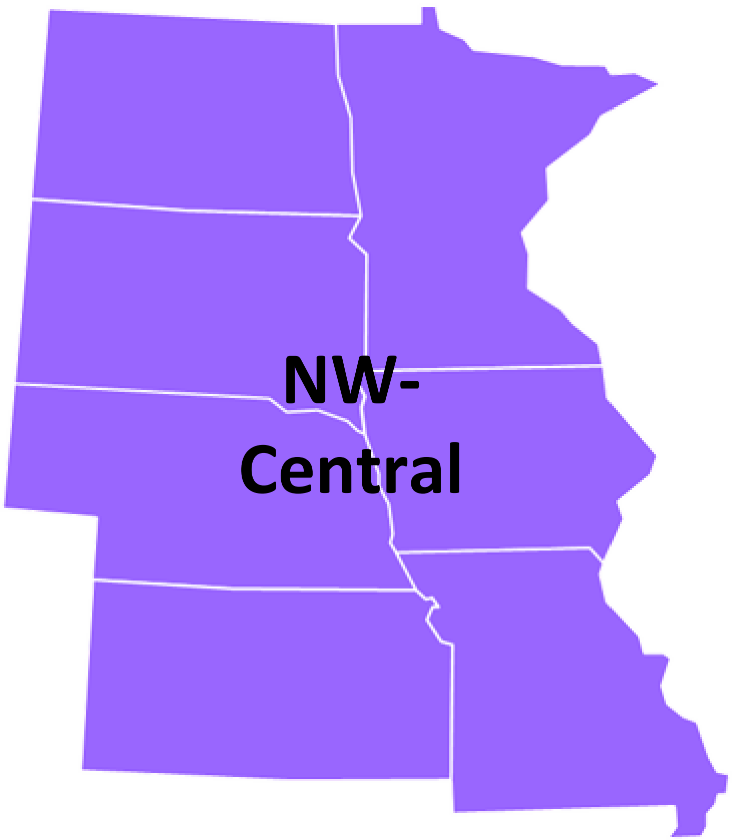
Four Challenges to Exploiting this Resource

Variability 1:	hours of no output over entire region
Variability 2:	rapid hour-to-hour changes
Location:	high cost of transmission to load centers
Timing:	anti-correlation with load

- Context is adding wind in sufficient quantities to displace bulk of U.S. CO2 emissions

"What are the limits to wind's role in a low-carbon electricity future?"

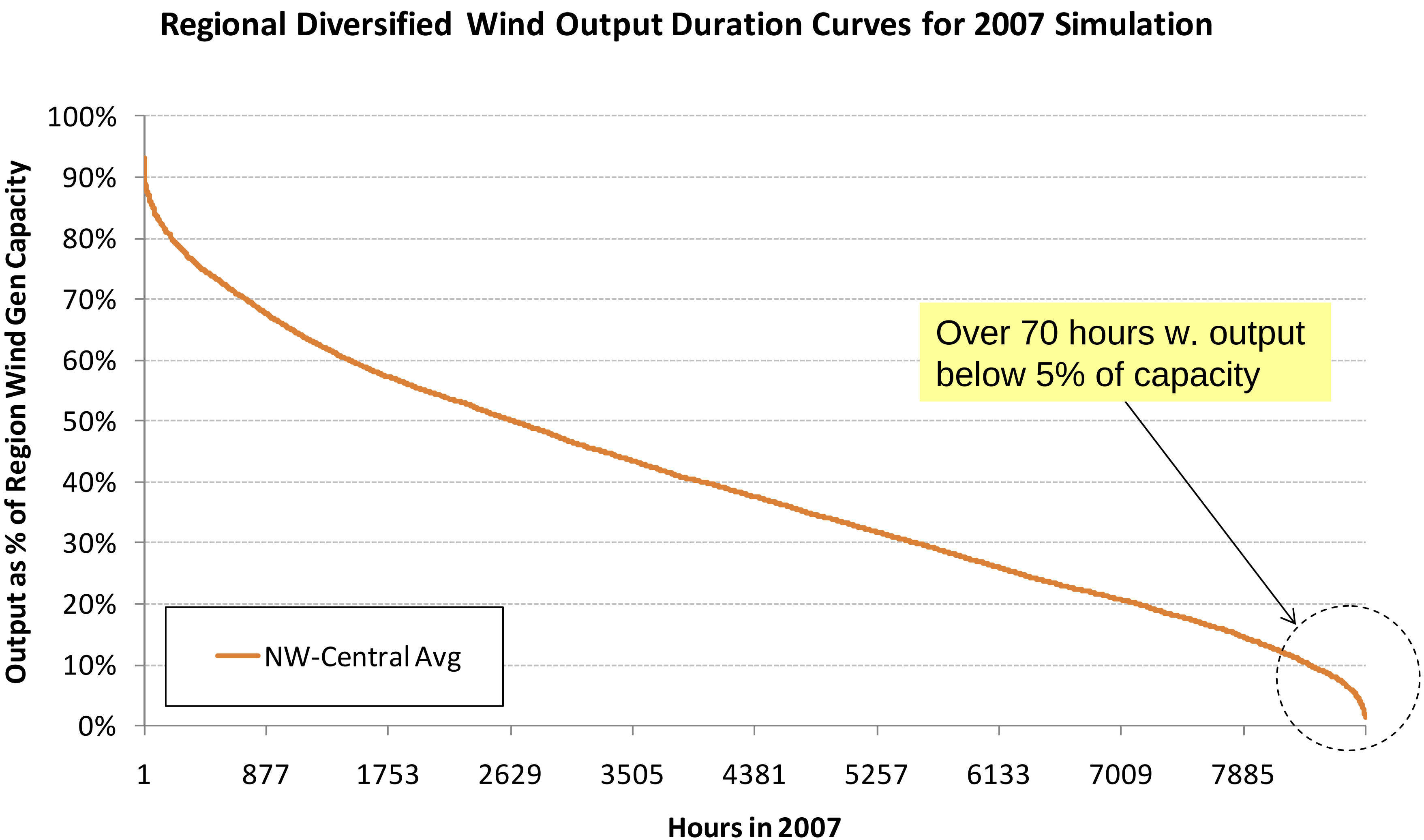
Analysis Based on Wind Data for Great Plains Represented by NW-Central Region



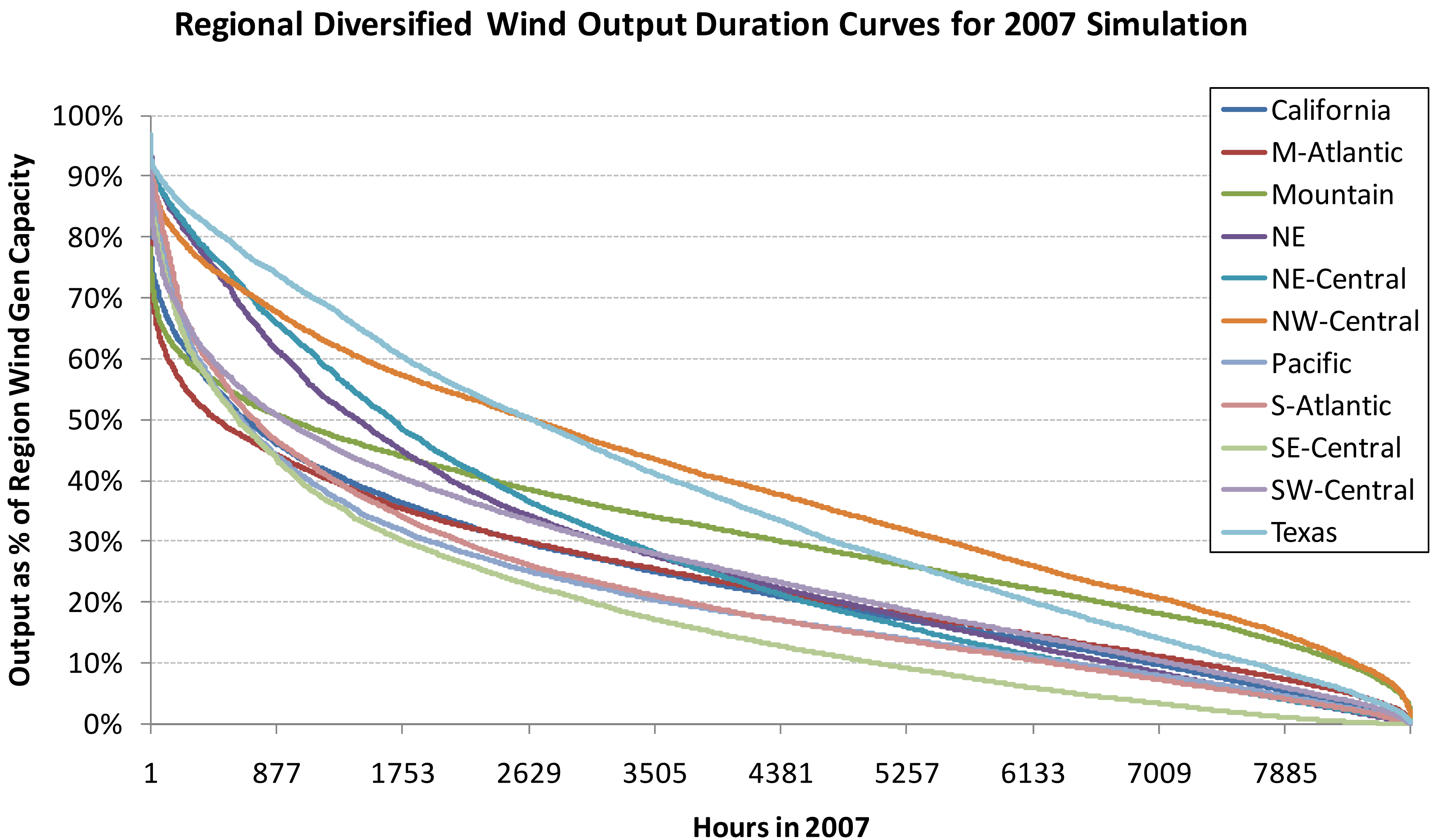
- Hourly wind output from 23 “bins” by state and capacity factor (i.e., ND w. 40-45% CF)
- 582 GW in 1,509 sites, avg. CF 39%
- Each bin has own hourly shape but bin shapes are highly correlated
- State hourly load data for 2007 from Energy Velocity
- Hourly loads and wind output synchronized so driven by same 2007 meteorology
- Scenarios vary installed wind capacity within region, ranked by capacity factor

Variability Issue 1: Output Dips to Near-zero

NW-Central Region Has Abundant Wind But Low Minimums



All Regions Experience Near-zero Minimum Wind Output Levels a Few Hours



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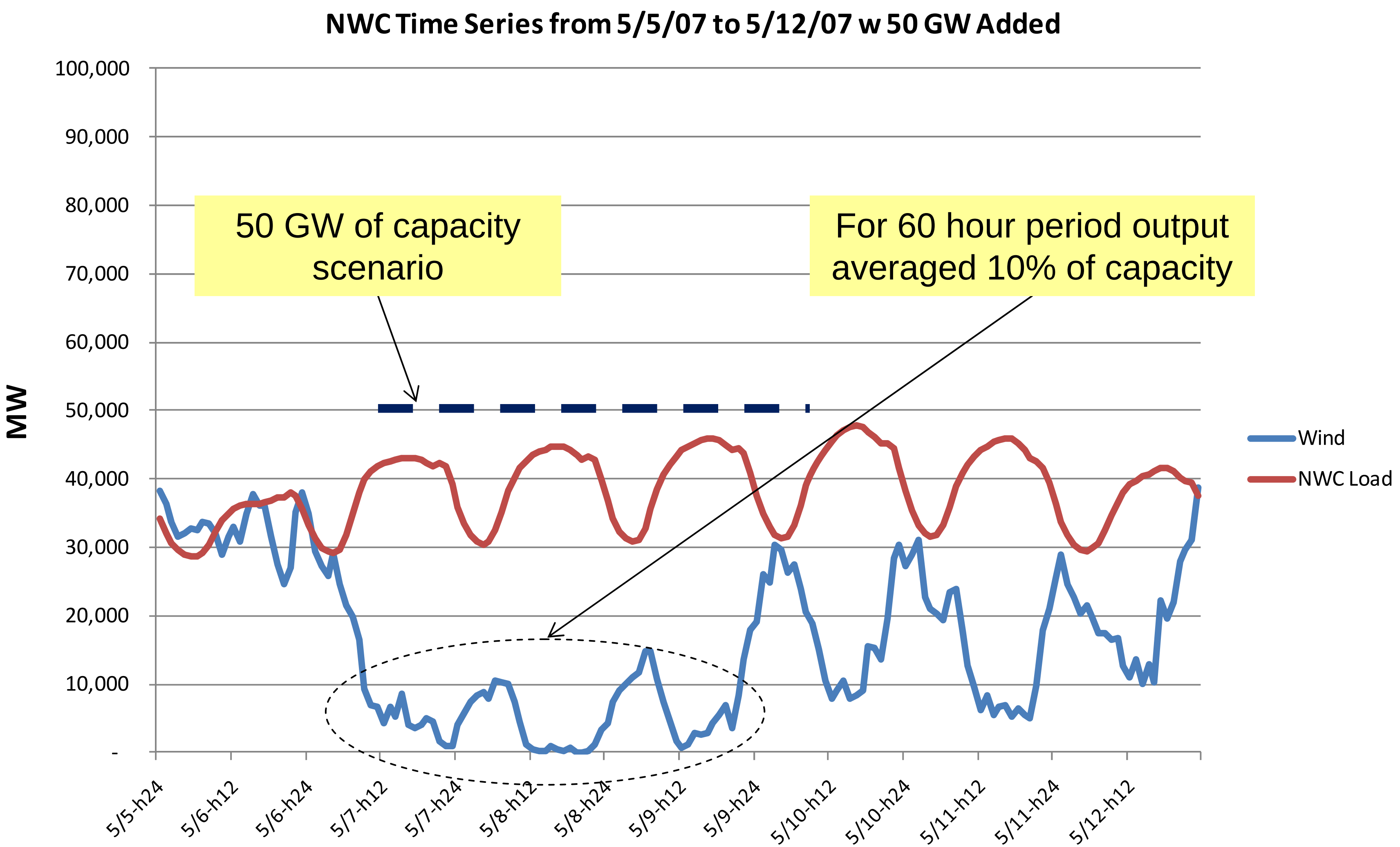
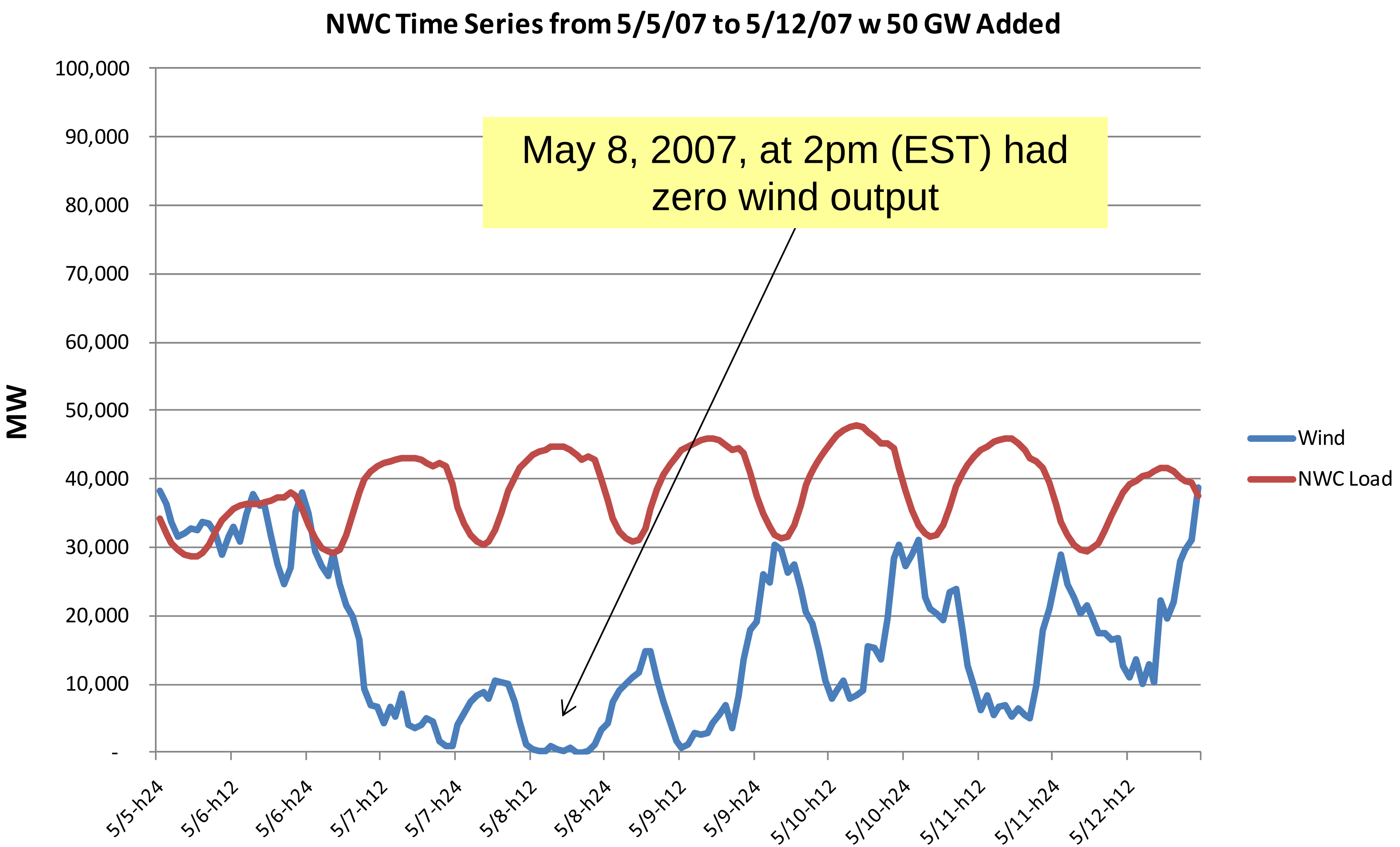
Region-wide (7 states) Low Output Can Continue for Extended Periods



Region-wide (7 states) Low Output Can Continue for Extended Periods



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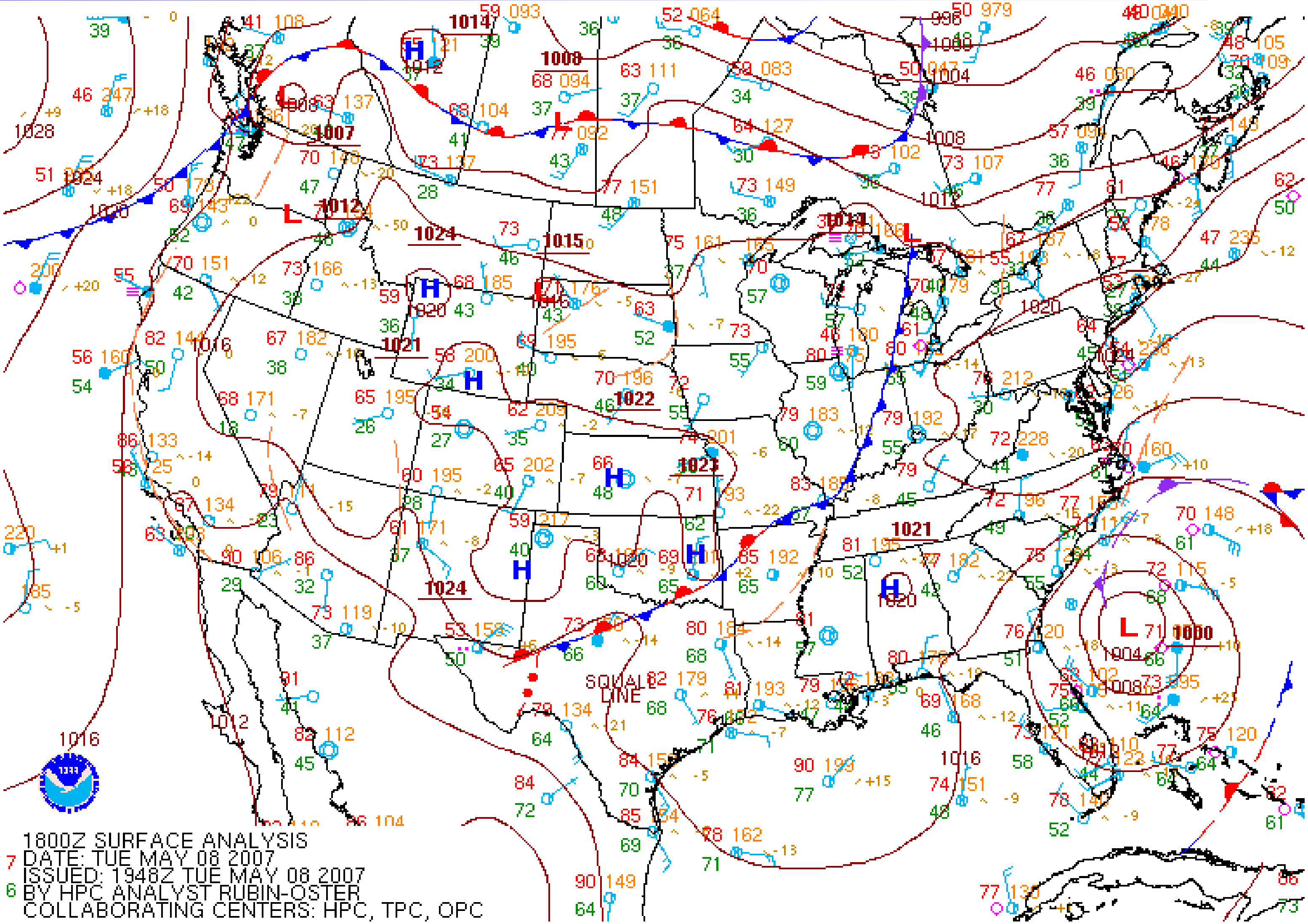
Weather Chart for 5/8/2007, 1800Z (2pm EST)



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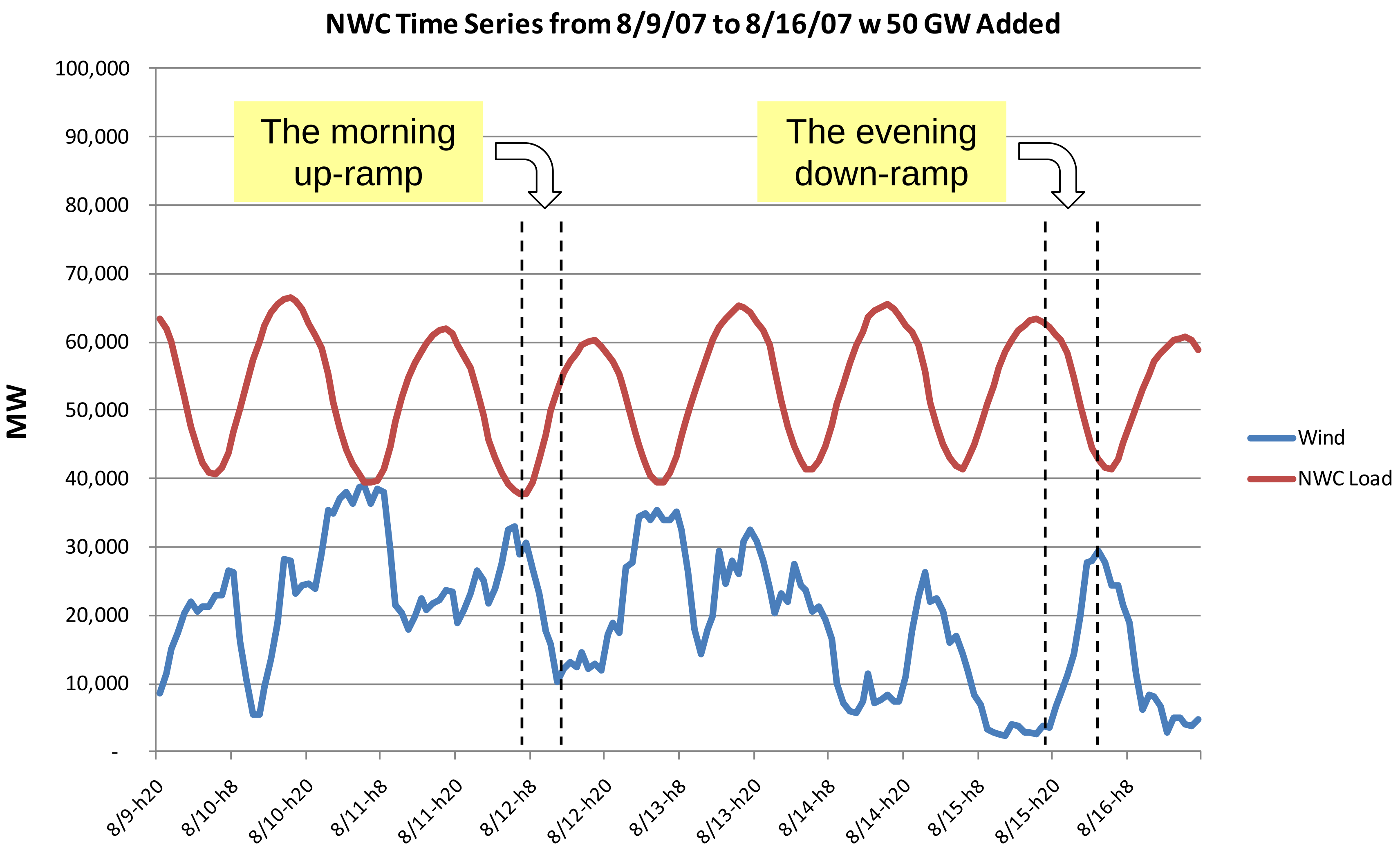
Observations and Insights on Low Minimums

- Data show near-zero minimums despite aggregation of output over broad geographic regions
  - Sub-hourly minimums can only be lower
  - Minimums occur for many hours
- Will need essentially 100% back up for reliability
- Sources of backup
  - Keeping existing fossil fleet and adapting it to new operating role (fast starts, low minimums)
  - Adding new reserve capacity (new CTs?)
  - Adding electricity storage
- All of these sources of reserve services will add additional cost to using wind

Variability Issue 2: Increased Requirements for Ramping

Anti-correlation of Wind with Load Creates a Ramping Nightmare



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Observations and Insights on Ramping

- Hour-to-hour wind output can vary greatly up or down
  - Greater relative changes than load
- Anti-correlation of wind with load exacerbates the problem
  - Rapid drop in output during day when loads growing
  - Rapid increase in output in evening when loads falling
- Presents a tremendous challenge to system operators trying to maintain frequency
- Imposes tremendous stress on fossil generation
- Challenge exists even with 20-20 wind forecasting
- Increased need for regulation/load-following will add to cost of using wind if significant fraction of system
  - Adapting existing fleet, new CTs, new storage?

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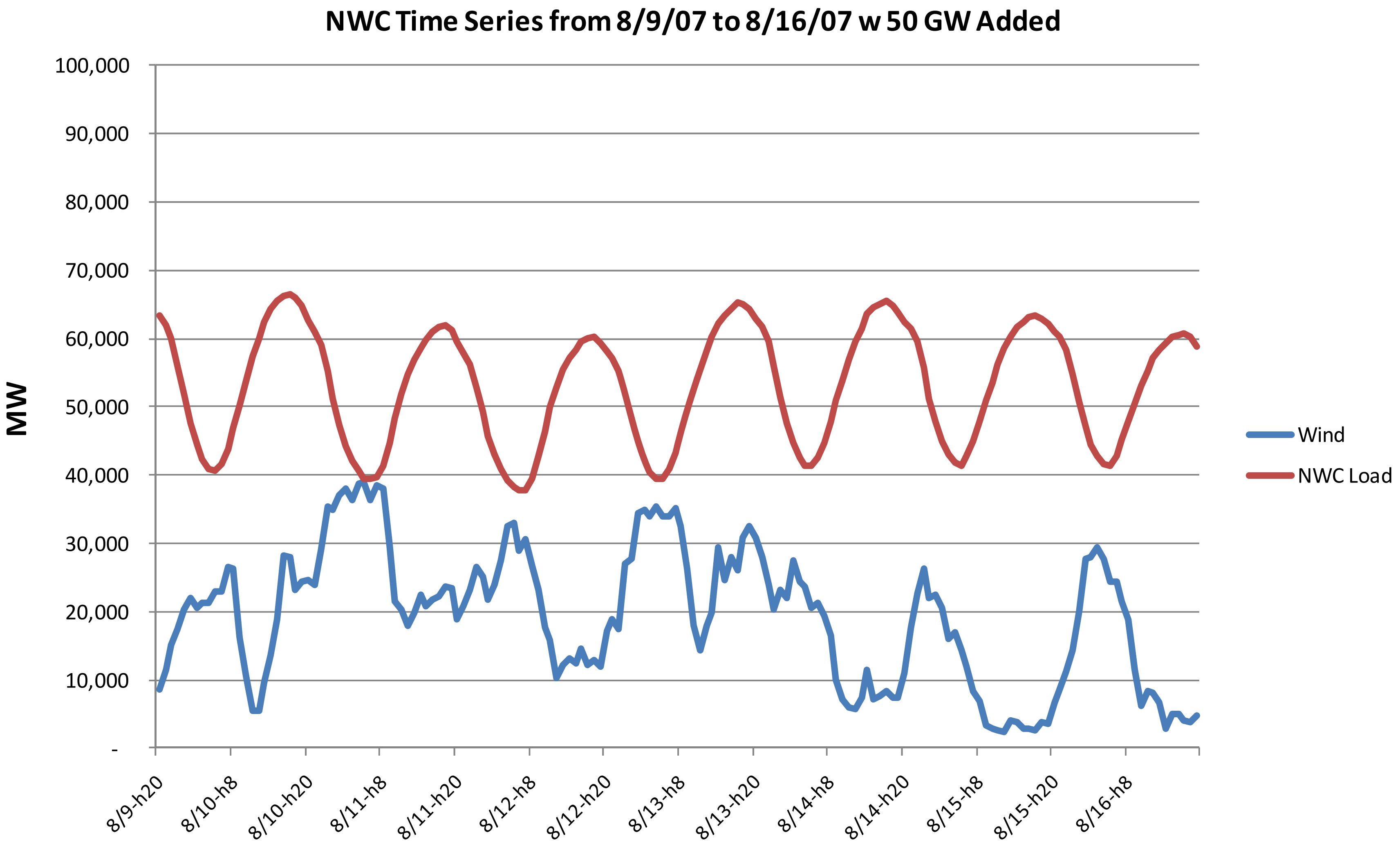
Anti-correlation of Wind with Load Also Forces Diminishing Returns to Wind Additions: 50 GW



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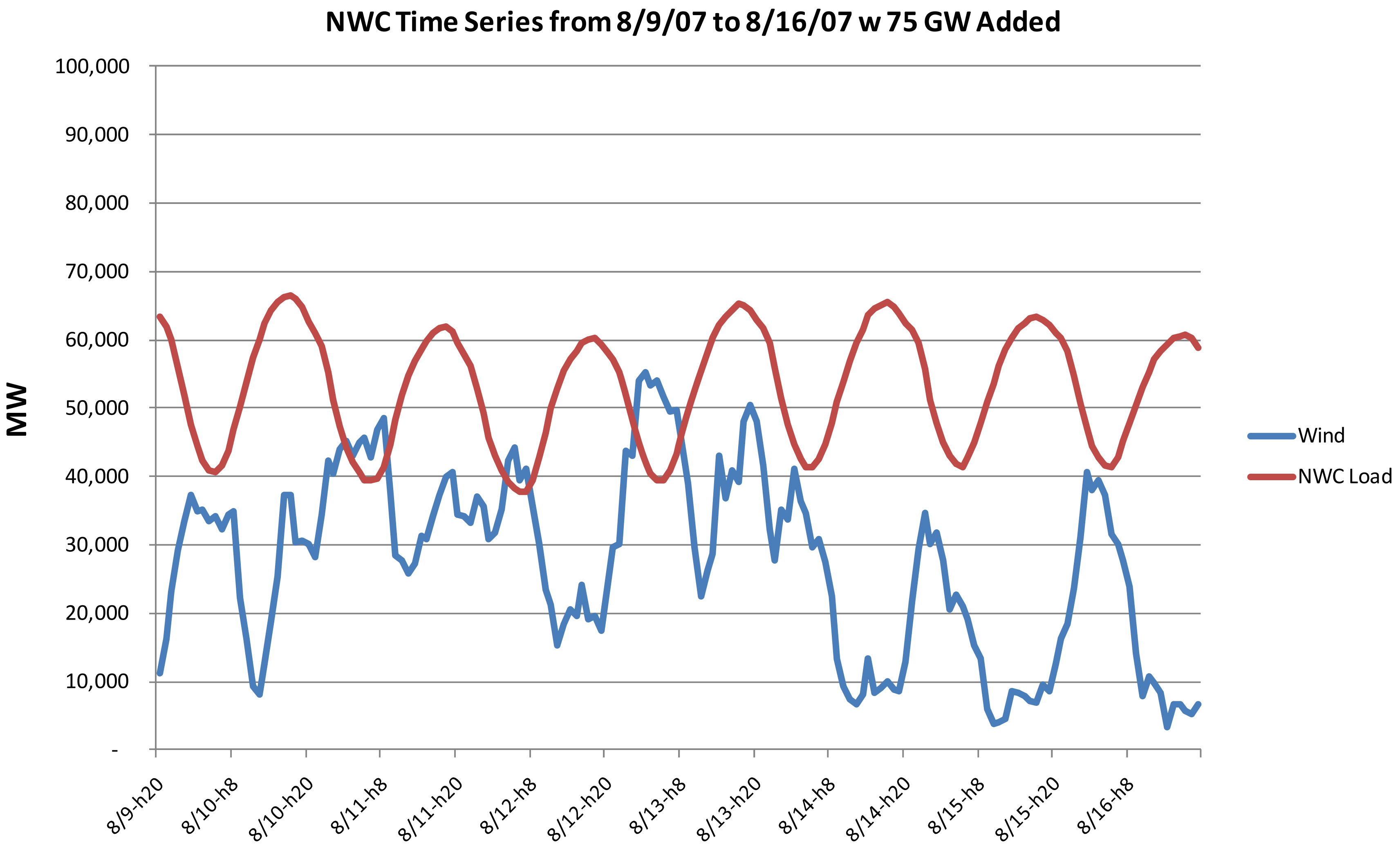
Anti-correlation of Wind with Load Also Forces Diminishing Returns to Wind Additions: 75 GW



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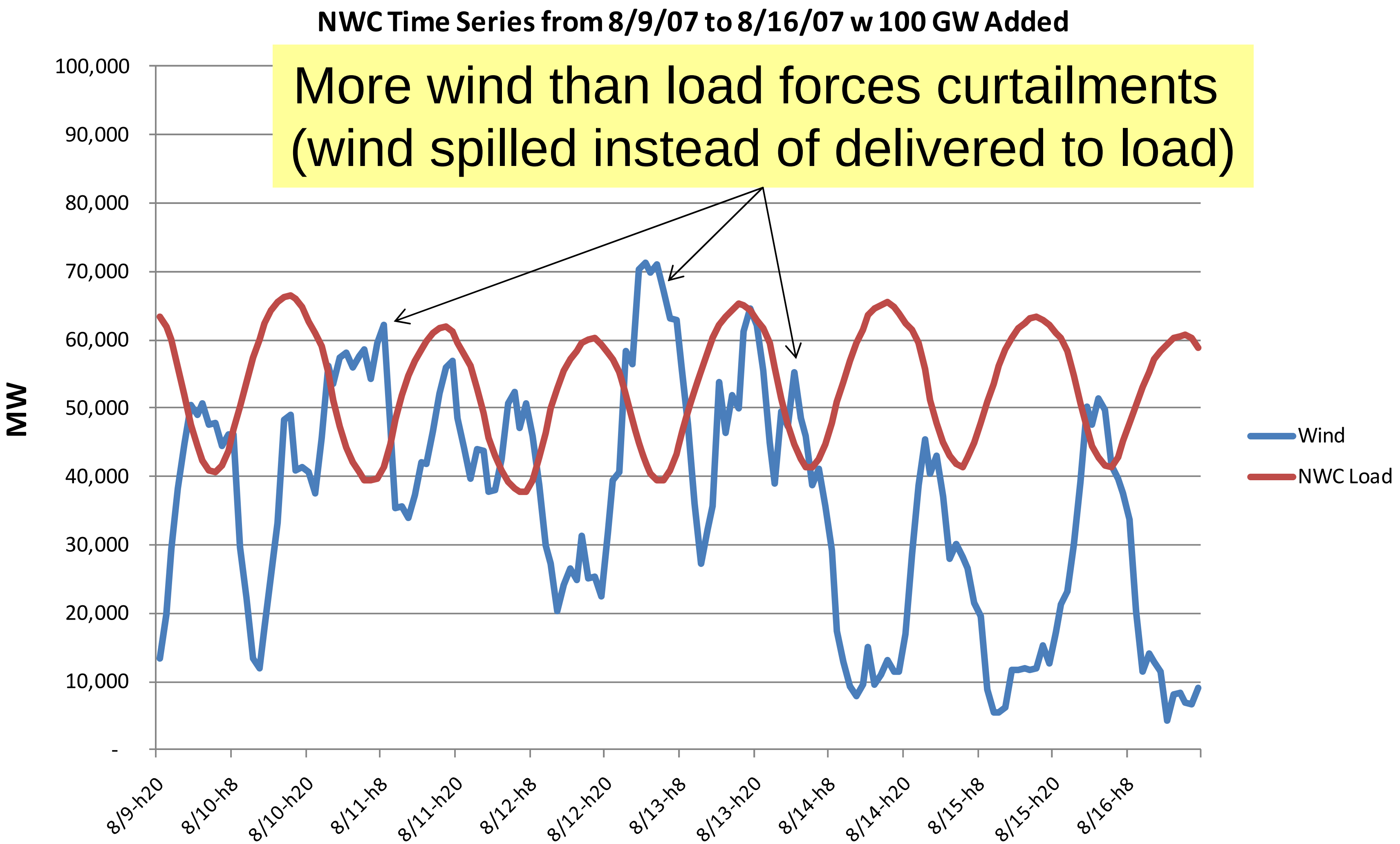
Anti-correlation of Wind with Load Also Forces Diminishing Returns to Wind Additions: 100 GW



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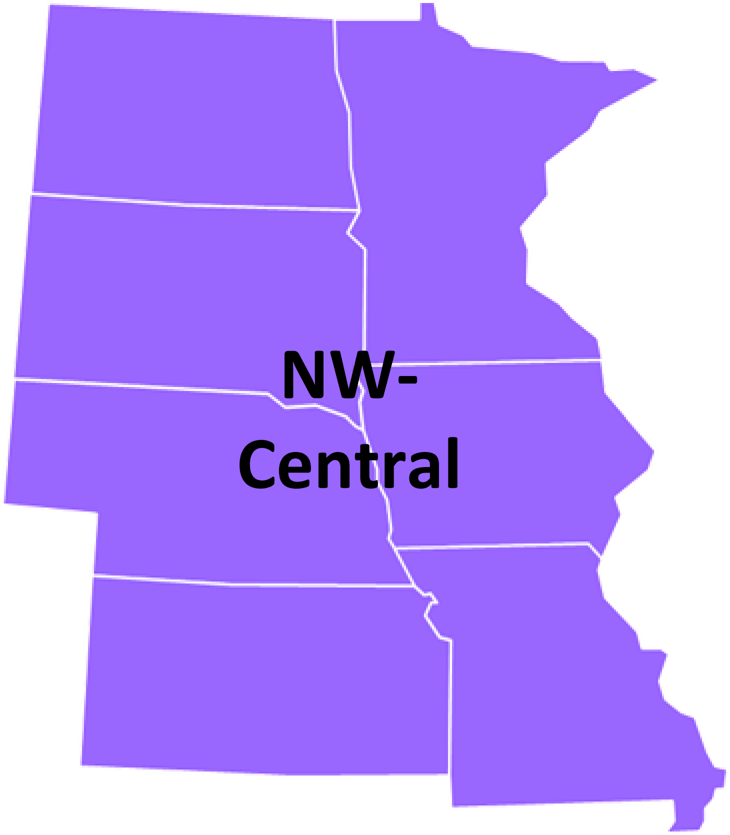
Economic Analysis

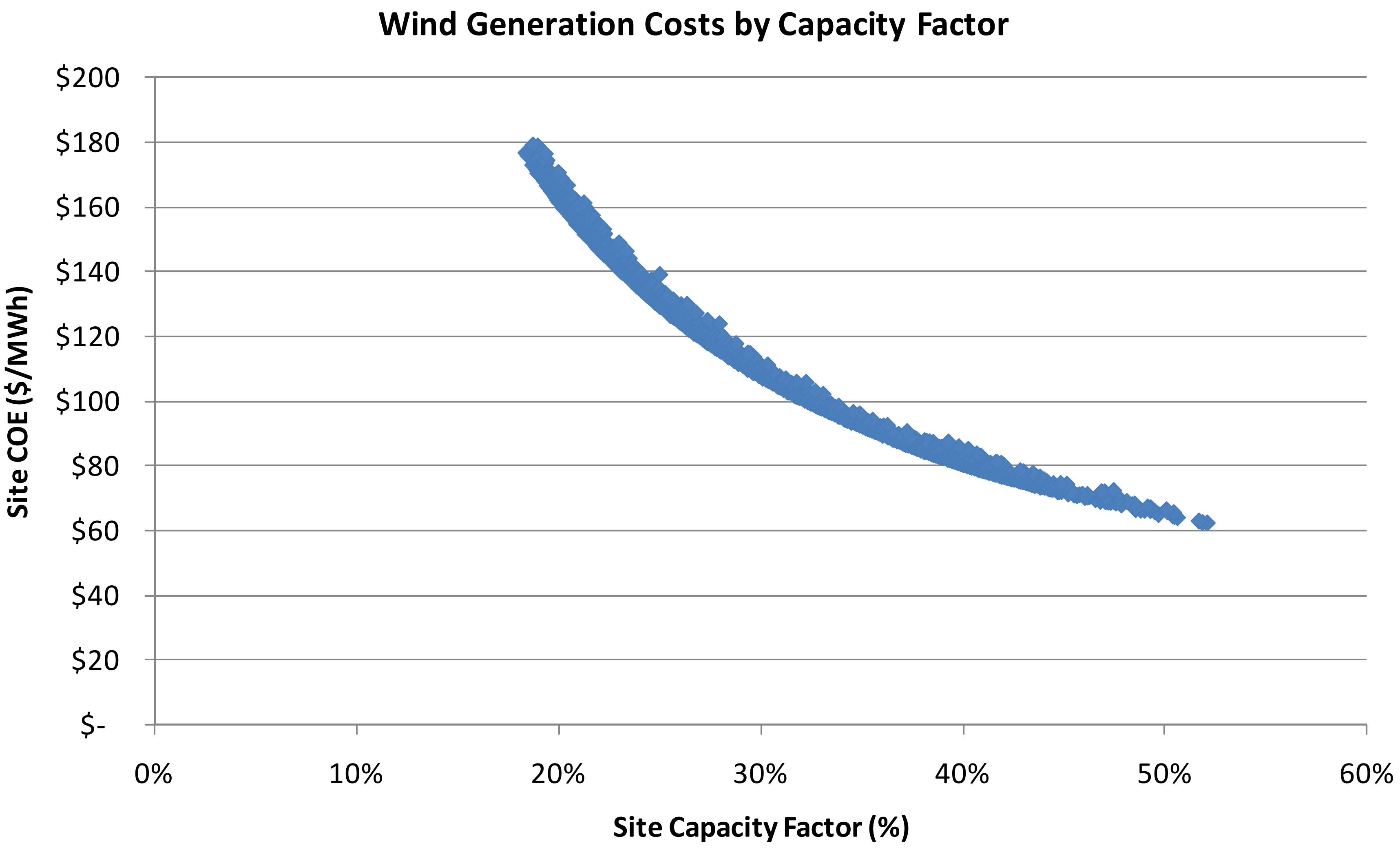


Cost of Electricity (COE) Working Assumptions

- Capital Cost: $2,000/kW (onshore)
- Connection Cost*:
  trans distance (km to 115kV)
  * $138 (cost of line in $000/km)
  + $3,200,000 (new substation)
- Fixed Charge Rate: 0.128
- Fixed O & M: $25/kW-year

* Depends on site MW, example here representative for 100MW site

Site Capacity Factors Drive Average Costs of Generation; Distance to Grid is Secondary



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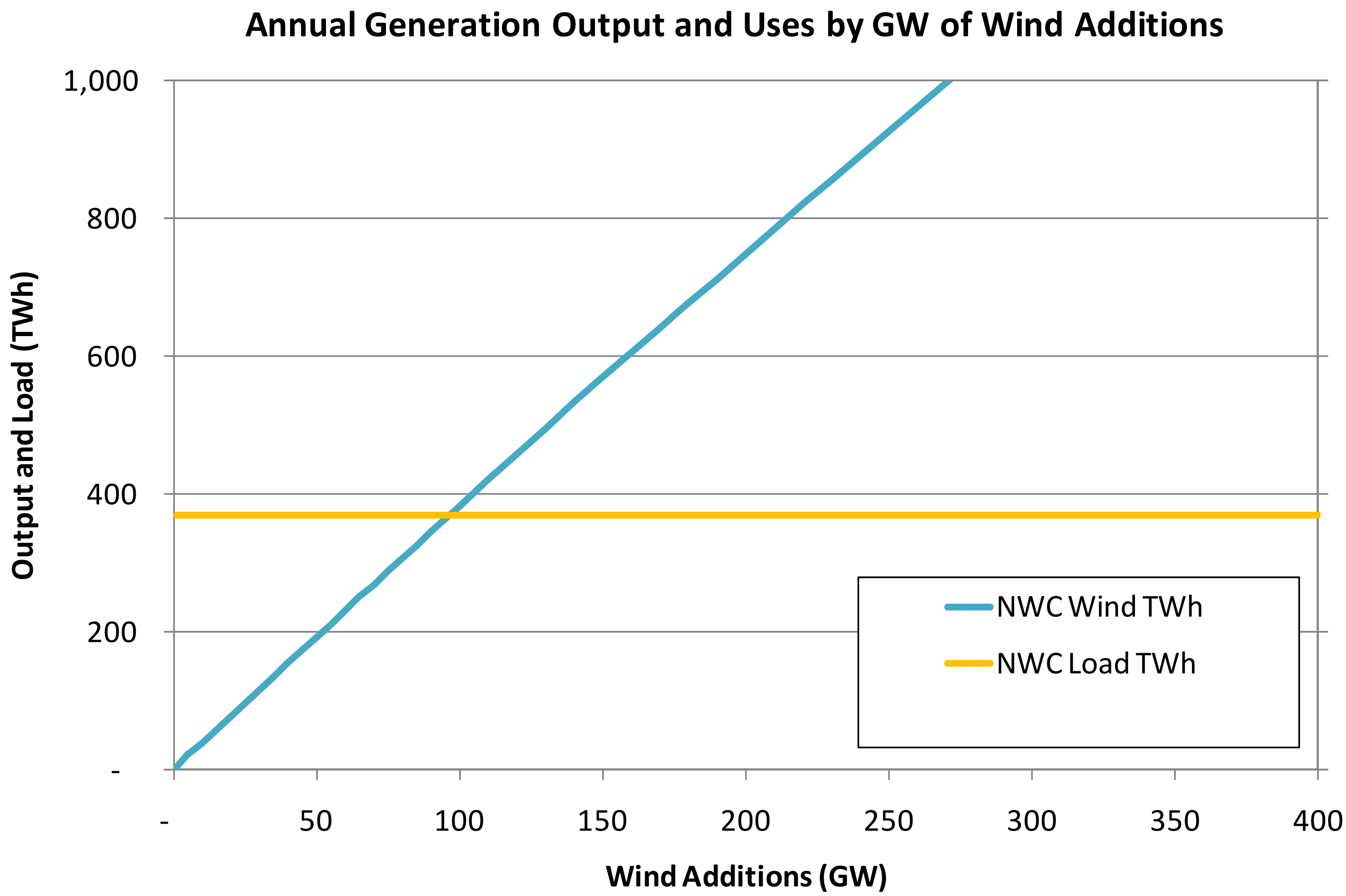
Potential Supply Far Outstrips Region Load



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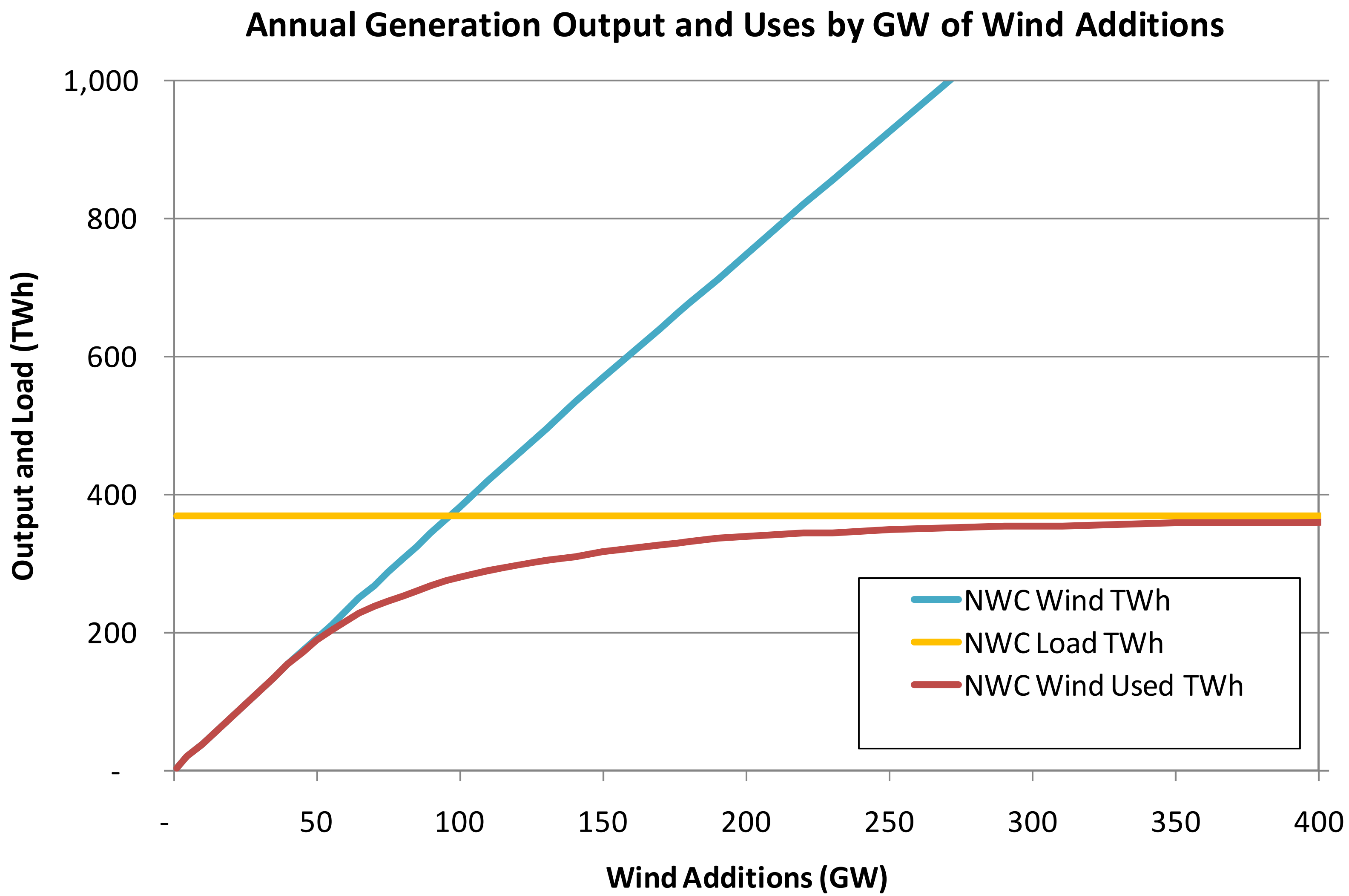
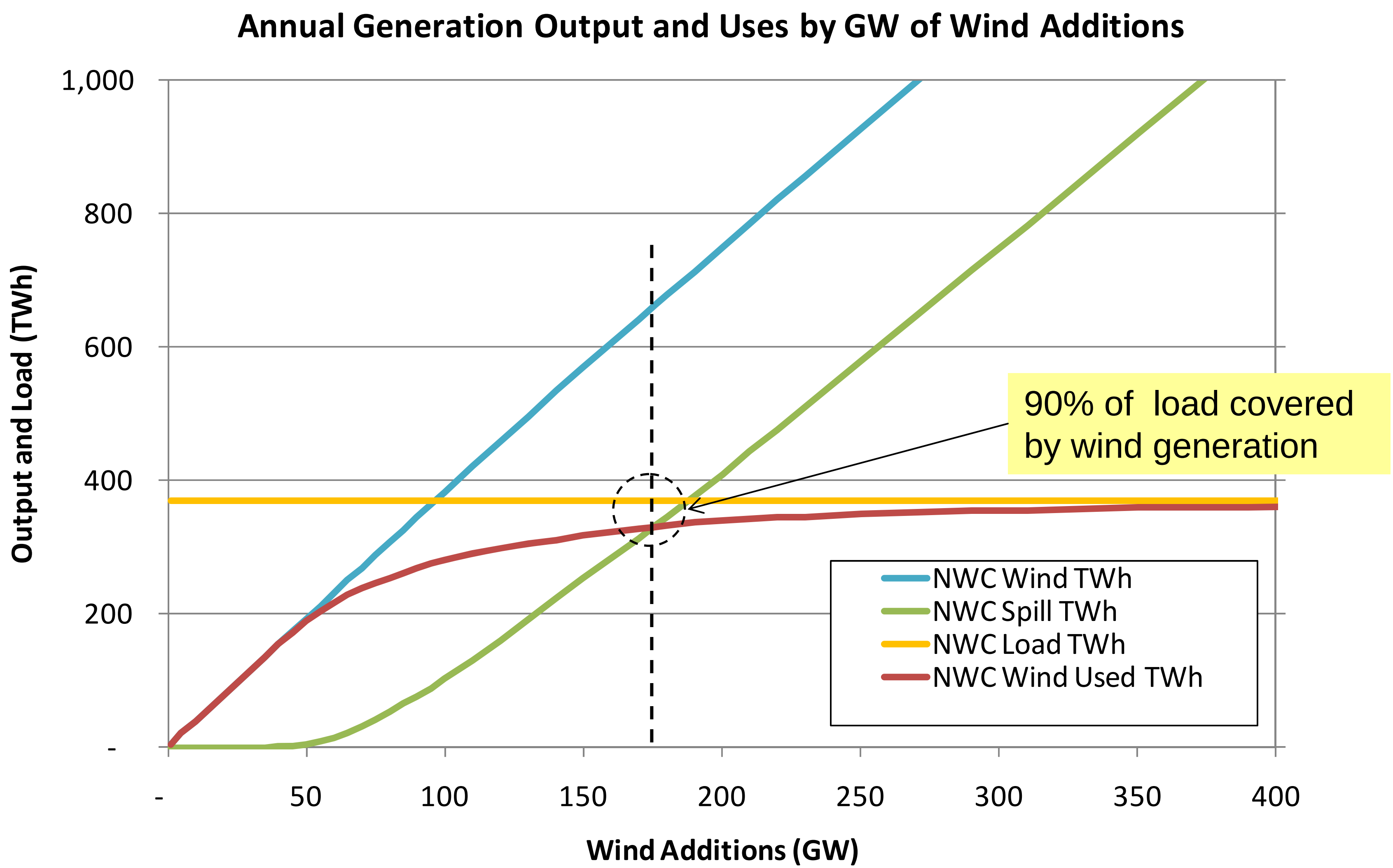
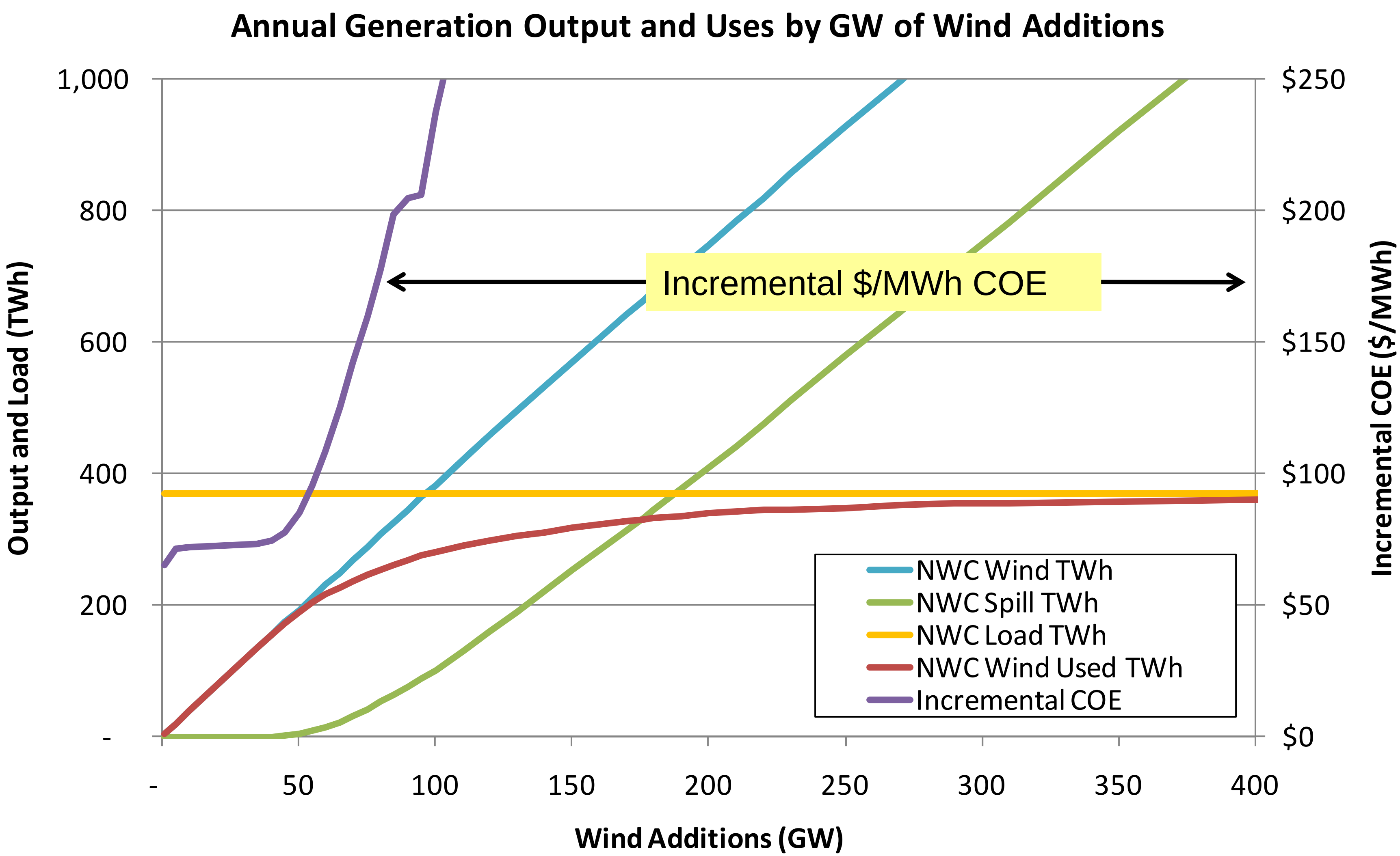
Starting At 50 GW, Additions Show Diminishing Returns in Meeting Region Load



At 175 GW of Additions As Much Wind is Spilled as is Used to Serve Load



With Spills Incremental COE of Delivered Wind Generation Skyrockets



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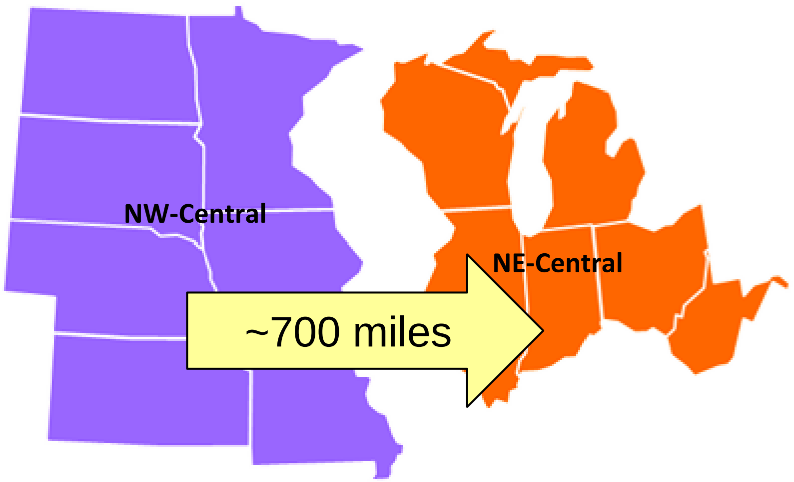
Observations

- NW-Central is the wind breadbasket
- Wind saturates region load starting at about 50 GW of additions (about 10% of economic resource base)
- As wind is added residual load to be met by fossil and other dispatchable power becomes highly variable
  - Rapid hour-to-hour changes due to negative correlation of wind and load increases ramping demand
  - Periods with no wind region-wide require reserves able to fully meet load
  - High value to operators in forecasting wind output
- Utilization of unused 90% of economic resource will require transmitting wind energy to other regions
- So, how does long distance transmission impact economics of wind generation delivered to meet loads in other regions?

Illustrative Transmission Costs



Assumptions and calculations

- Cost of transmission: ~ $3-5 million/mile for 800kV DC
- Losses: ~ 5%
- MW transmitted: 6,400
- Resulting assumed cost: $35,000/MW-year

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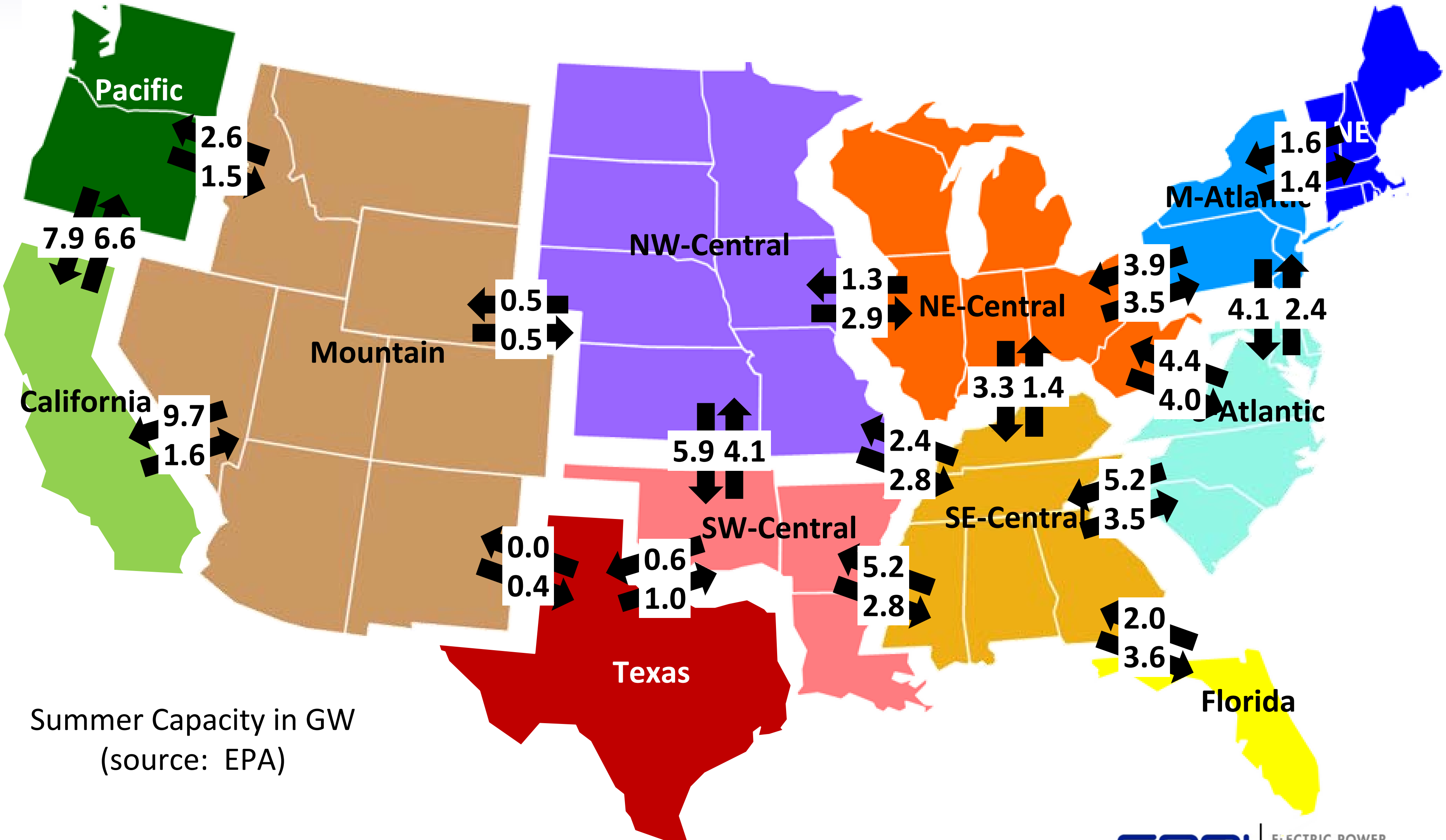
REGEN Analysis Provides Preliminary Realistic Assessment of Wind's Strategic Potential

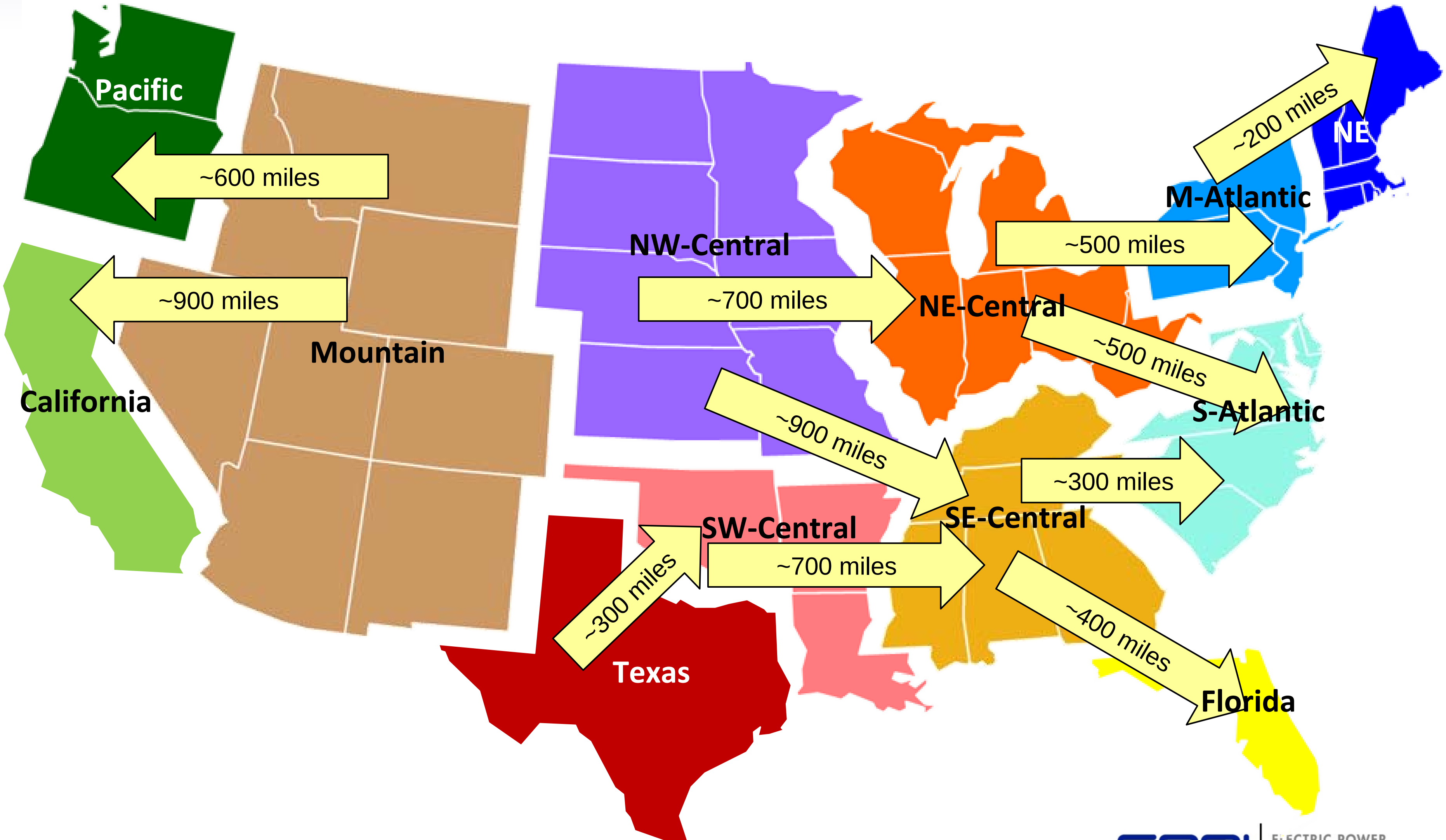
- Analysis based on
  - 8,760 hourly wind resource potential based on 2007 meteorology from AWS Truepower
  - Simultaneous 2007 hourly loads from Energy Velocity
- REGEN used to estimate wind supply vs. cost per MWh for varying quantities of wind resource use
  - Include spill effects as wind surpasses dispatchable load within 12 REGEN regions
  - Include costs for new transmission to move wind energy across regions (cuts local spill)
- Result is estimate of what it costs to deliver strategic quantities of wind energy to major load centers

Existing Inter-Region Transmission Capacity

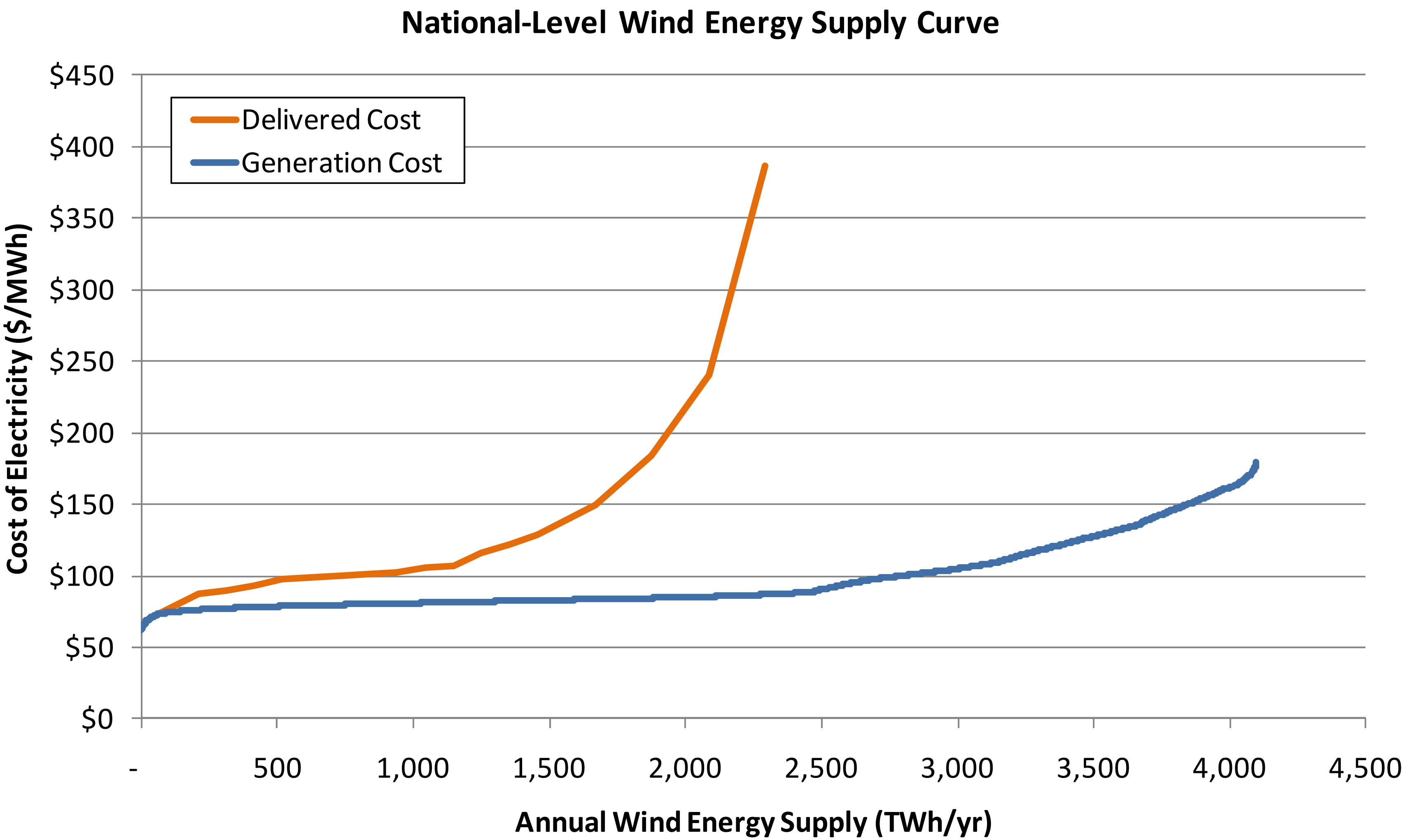


Summer Capacity in GW
(source: EPA)

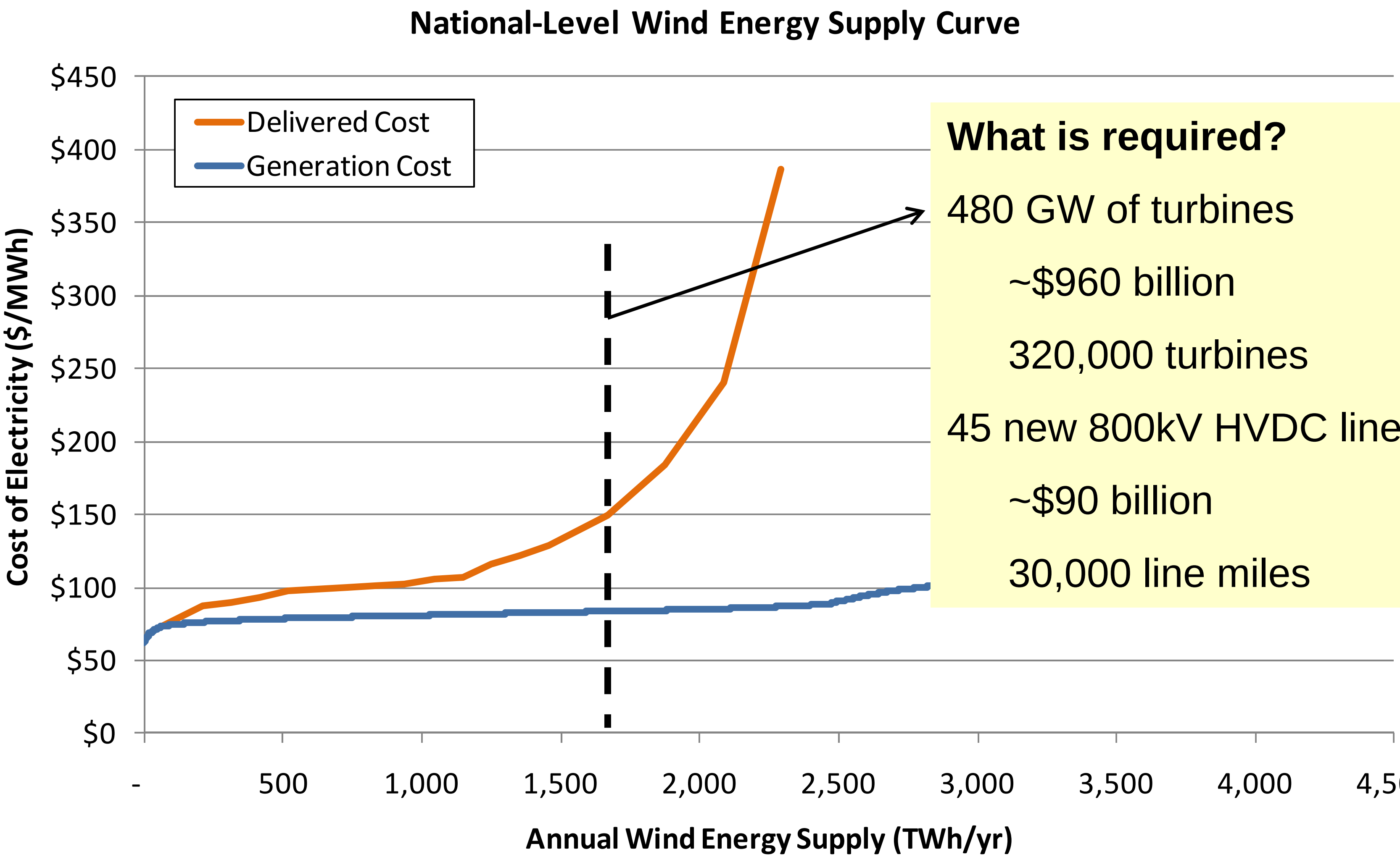
Distance and Investment Cost per Mile Drives New Transmission Costs Between Regions



Preliminary Analysis of National Wind Supply with Transmission Costs and Spillage Effects



A Sense of the Challenges (What does it take to deliver potential wind below $150/MWh?)



What is required?

480 GW of turbines

~$960 billion

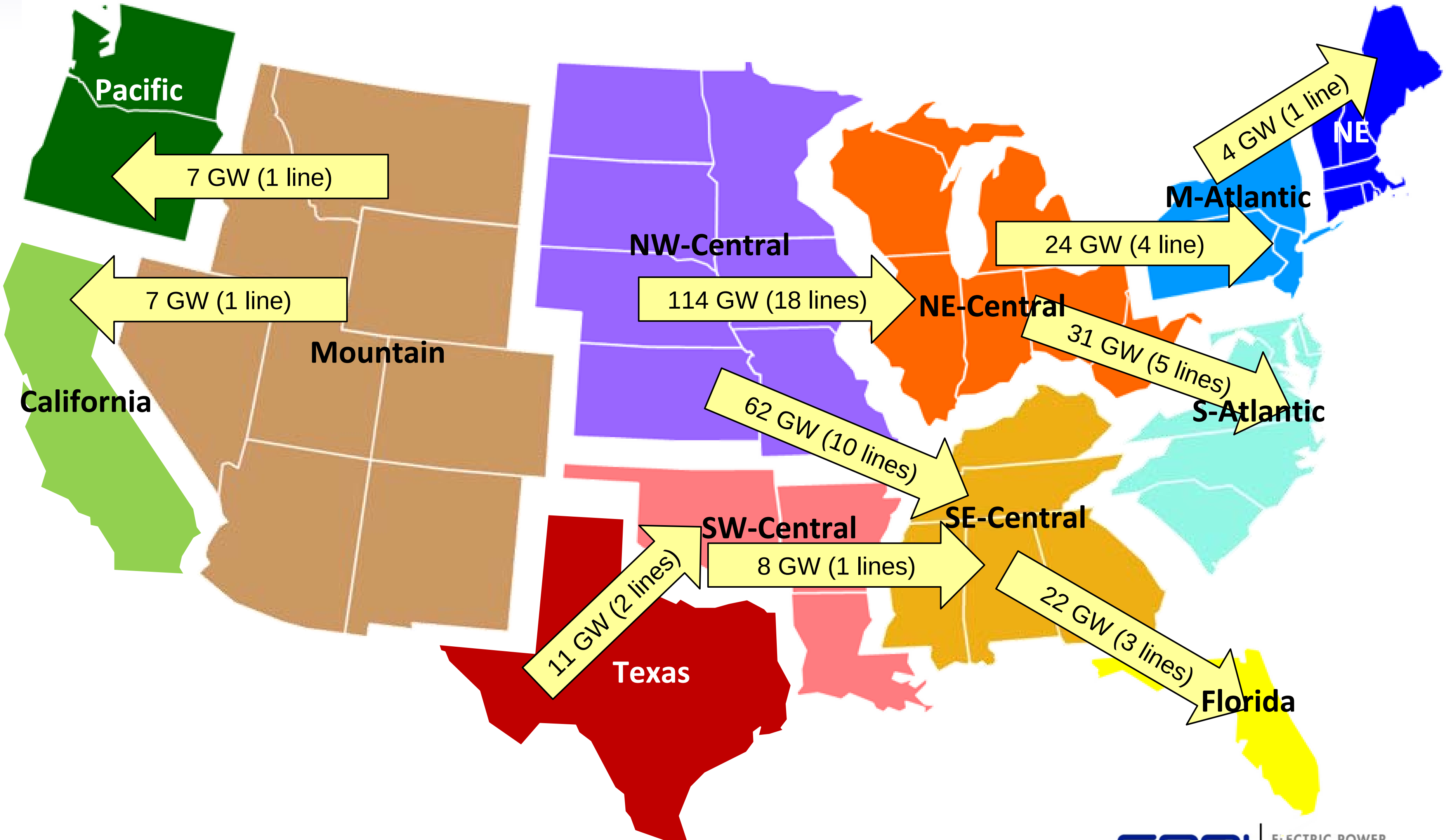
320,000 turbines

45 new 800kV HVDC lines

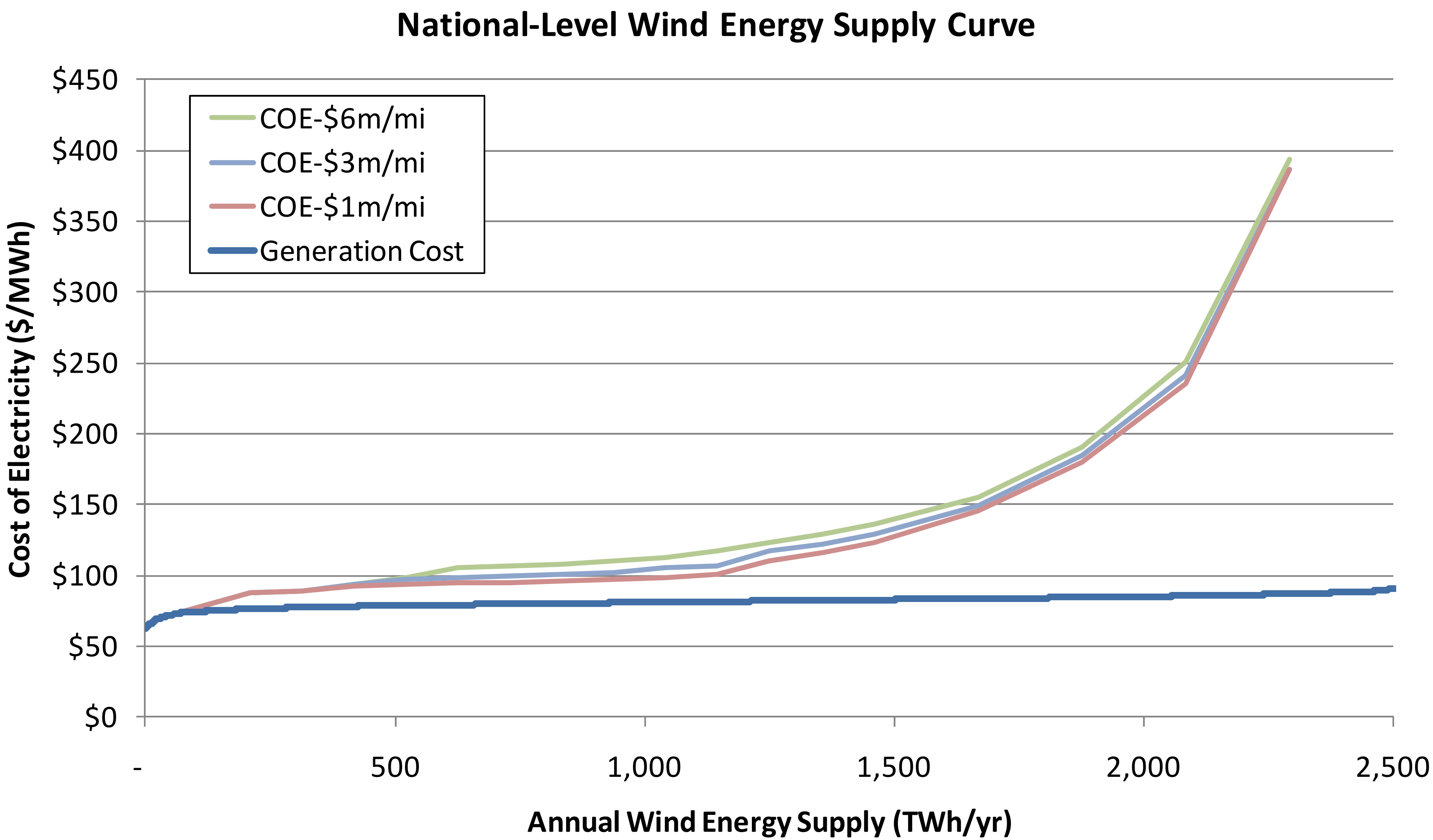
~$90 billion

30,000 line miles

Resulting New Transmission Investment in $150/MWh Wind Case



How Does Transmission Cost Affect Delivered Supply?



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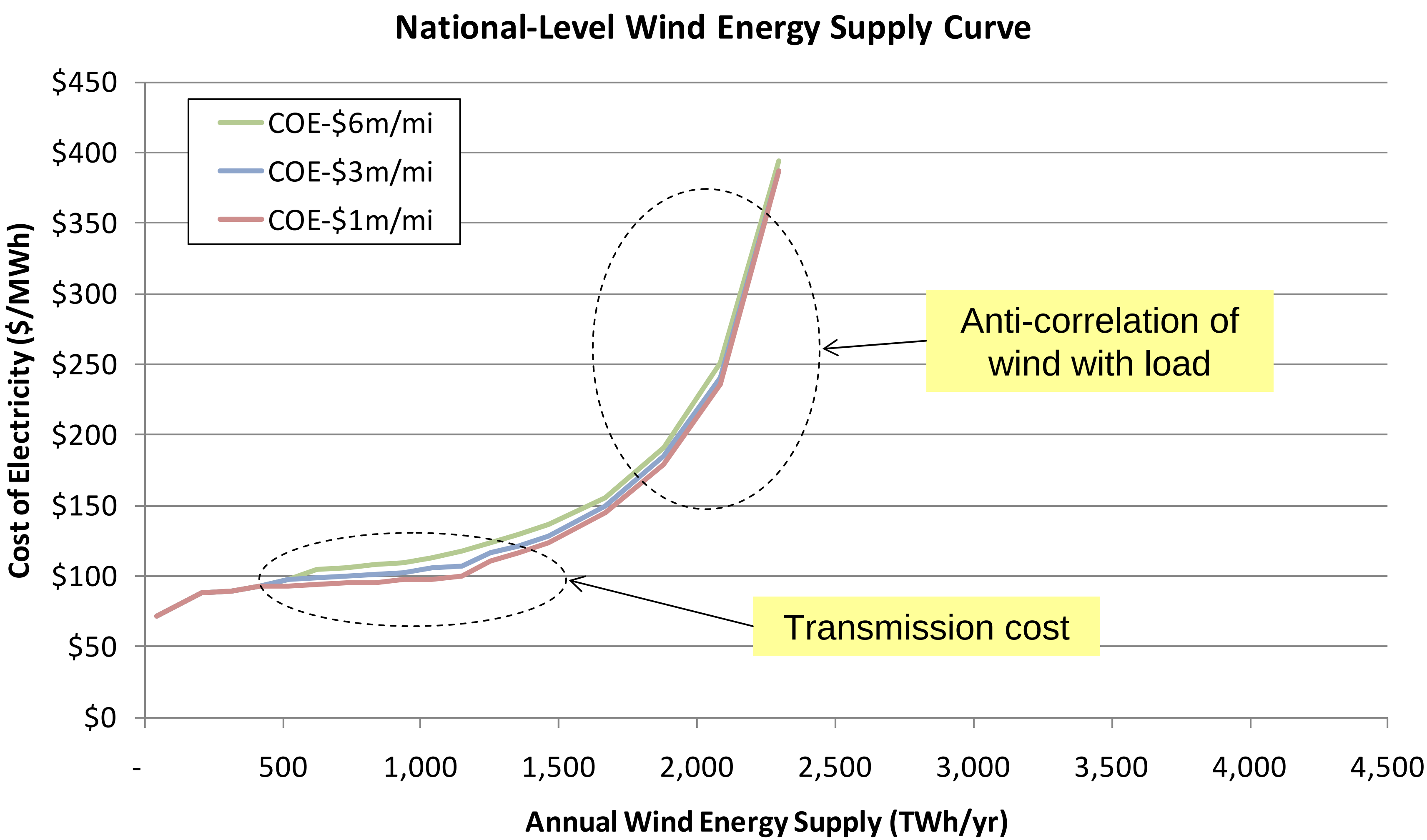
So What Drives Increases in Delivered Cost?



So, How Much Wind?

- Adding transmission enables greater utilization of wind
- Delivered COEs are significantly higher than generation costs
- Anti-correlation with load limits the fraction existing coal wind can displace in a decarbonized electric future