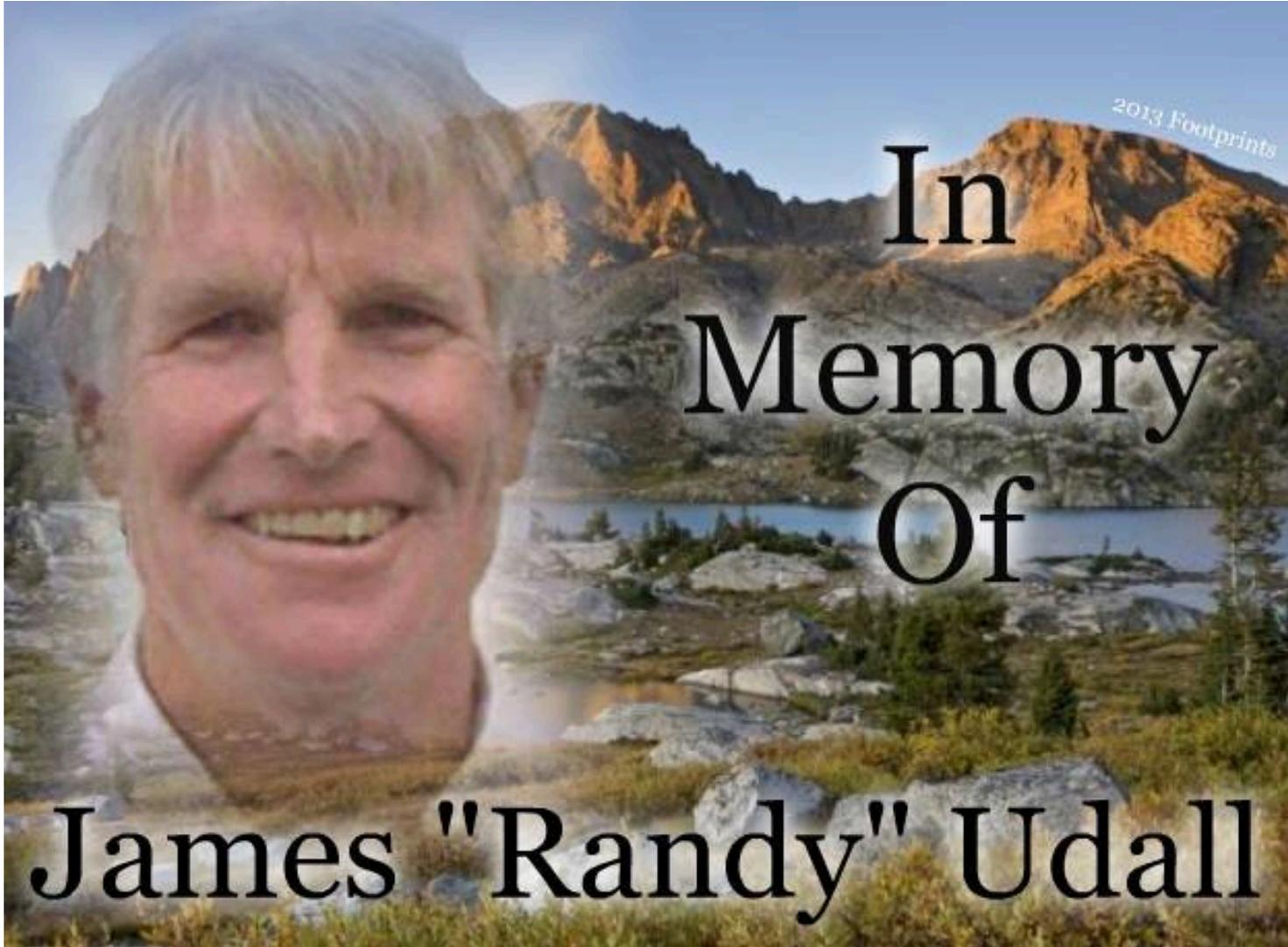




Thoughts on Modeling Renewable Energy

Tom Wilson, Vic Niemeyer, James Merrick, David Young
Energy and Environmental Analysis Group



Topics

- Background
 - EPRI Team
 - US-REGEN Model
- How we Model Wind
 - Wind Economics 101 – 8760 hours/1 year
 - Choosing Hours in US-REGEN
- Technology Characterization
 - US Technology Competition?? Got to Beat Gas
- Concluding Thoughts

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Vic Niemeyer



James Merrick



David Young



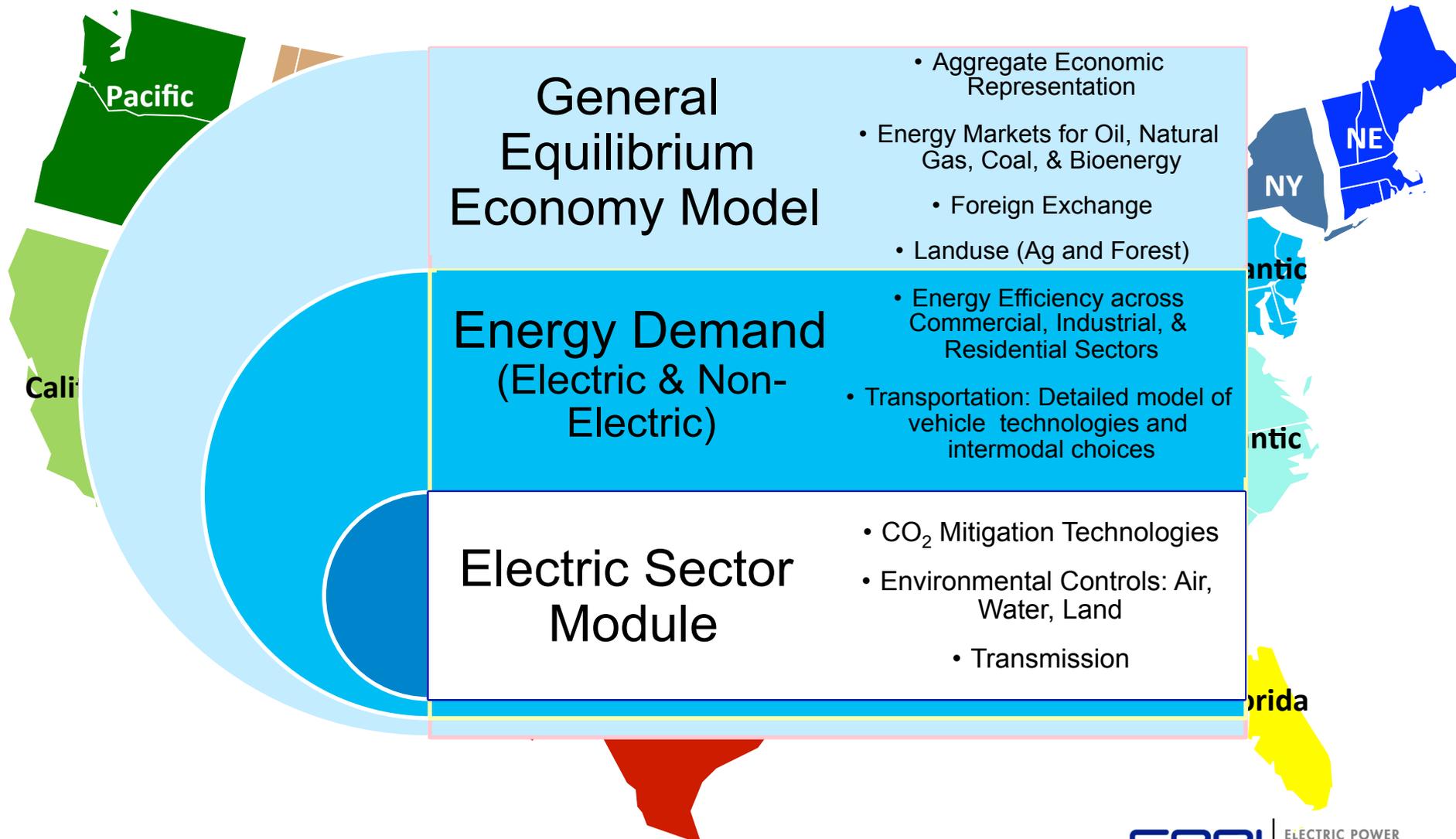
Ram Ramachandran



**Delavane Turner
(part time)**

*In March 2013. Geoff in Germany for 2 years, James to Stanford for PhD

US-REGEN Model Description



US-REGEN Information

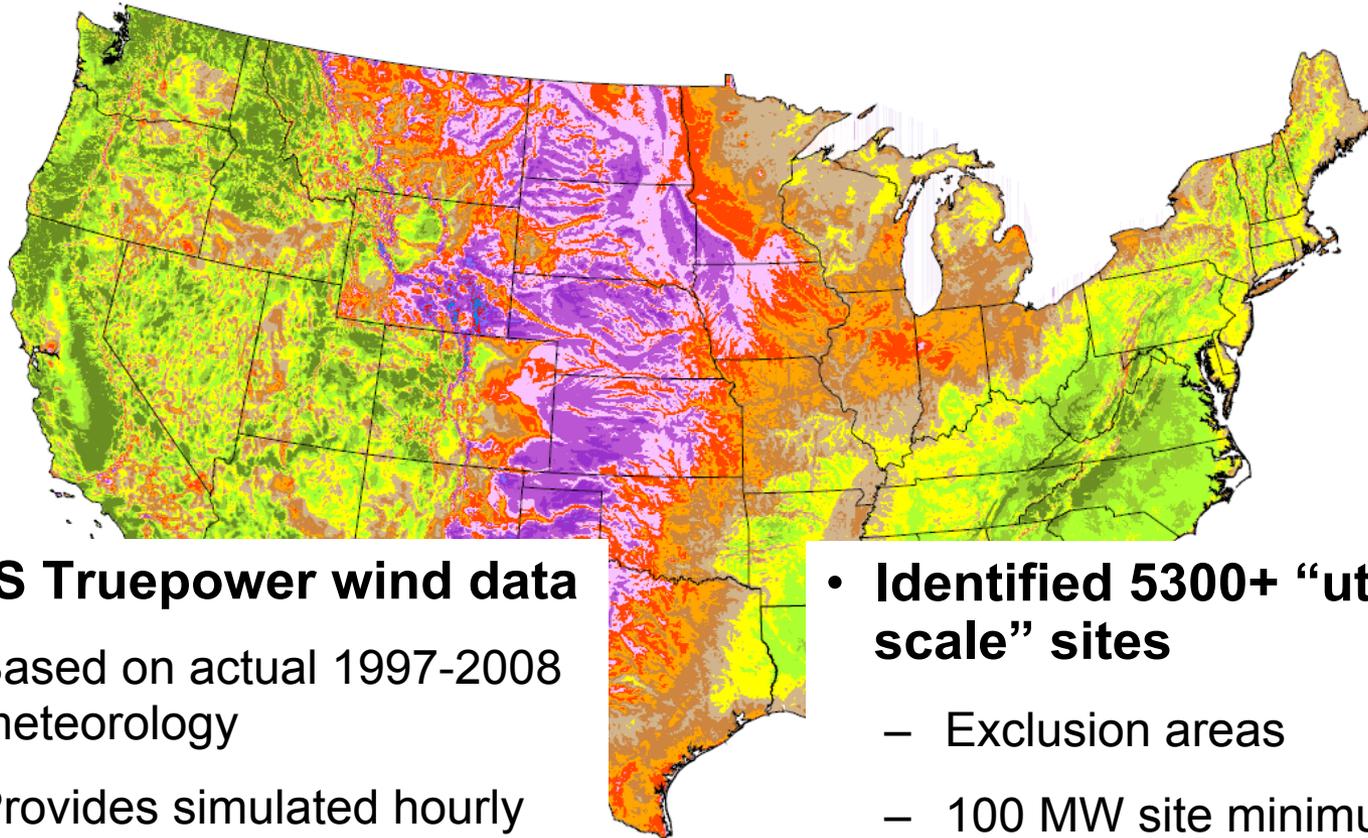
- Environmental Controls Analysis – Fall 2012
- CO2 Policy Analysis along with detailed model documentation and foundational studies – Fall 2013

- Next steps
 - Build out the demand side
 - Endogenous load shape, distributed generation, demand response, etc.
 - Examine business models
 - Improve analysis of plant cycling – fossil and nuclear
 - Build detailed natural gas supply and transport sector

Topics

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New AWS Truepower Data Set: Capturing the Variability of Wind



- **AWS Truepower wind data**

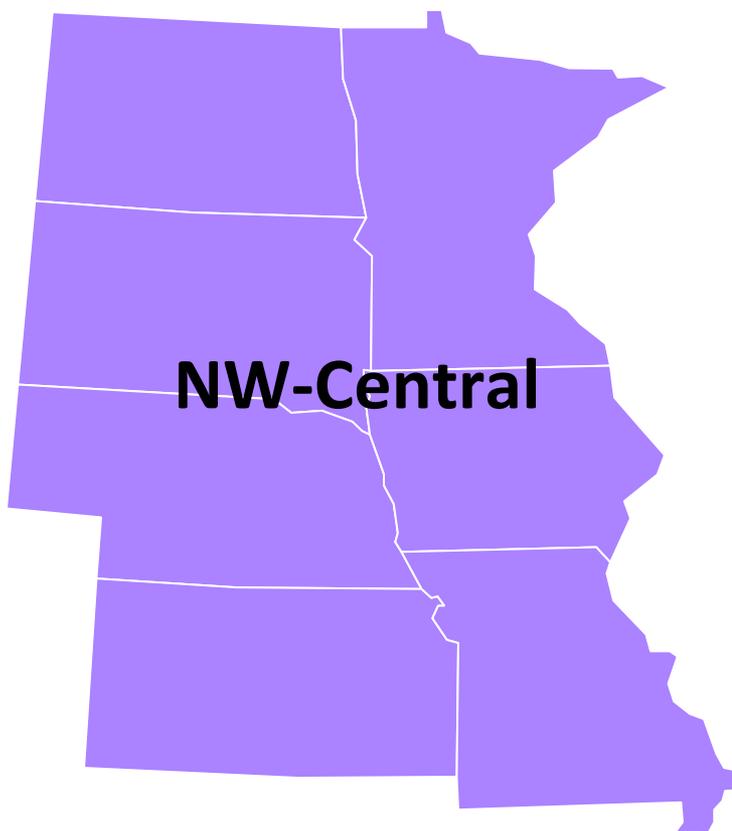
- Based on actual 1997-2008 meteorology
- Provides simulated hourly output for typical turbine (80m height, 1.5 MW)

- **Identified 5300+ “utility-scale” sites**

- Exclusion areas
- 100 MW site minimum
- Distance to grid
- Terrain/wake effects

wind,
.com |

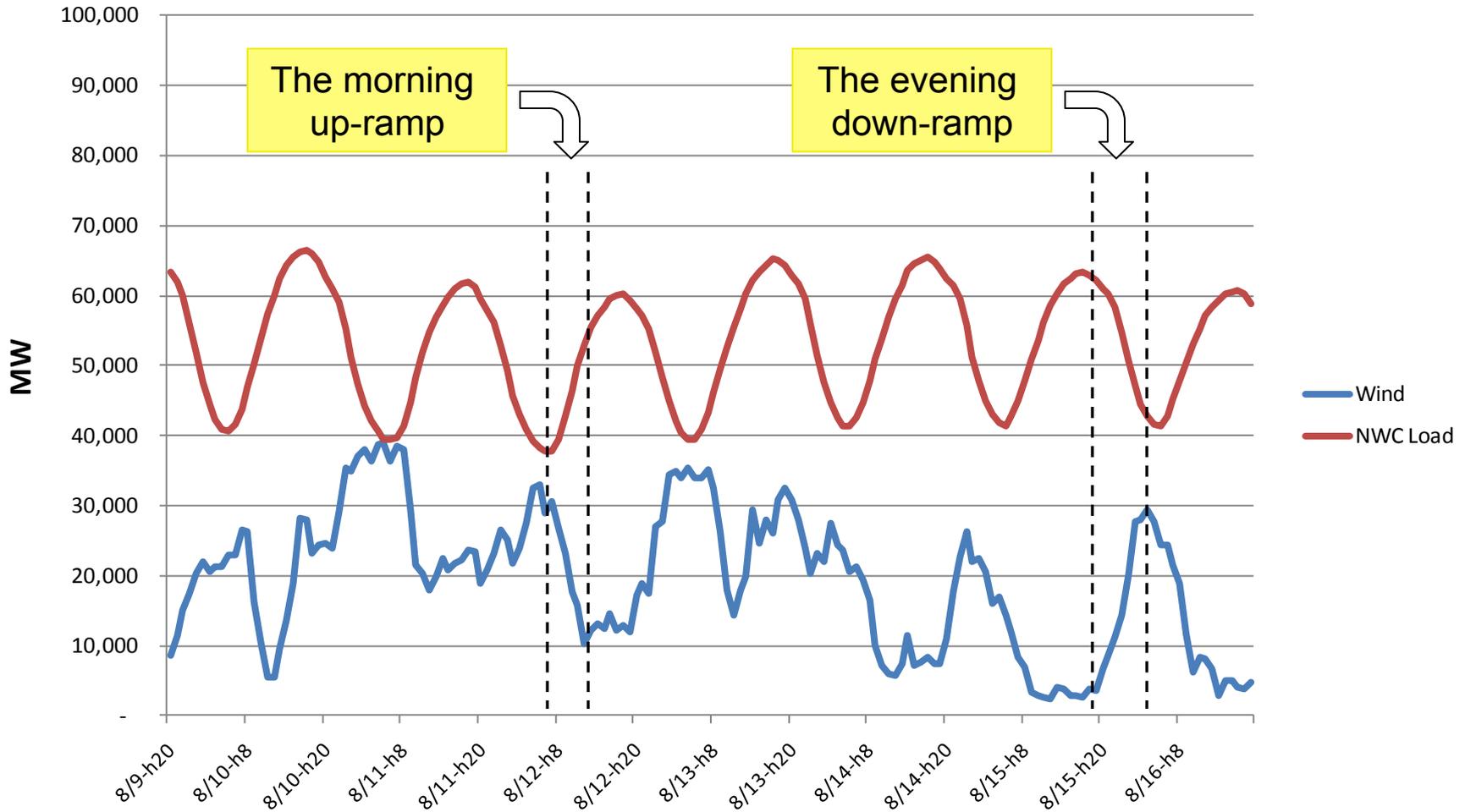
Example Analysis of NW-Central Region Using New Wind Data



- State hourly load data for 2007 from Energy Velocity
- Hourly loads and wind output synchronized so driven by same 2007 meteorology
- Add 50 GW new installed wind capacity within region
- Rank sites by capacity factor, build best sites first

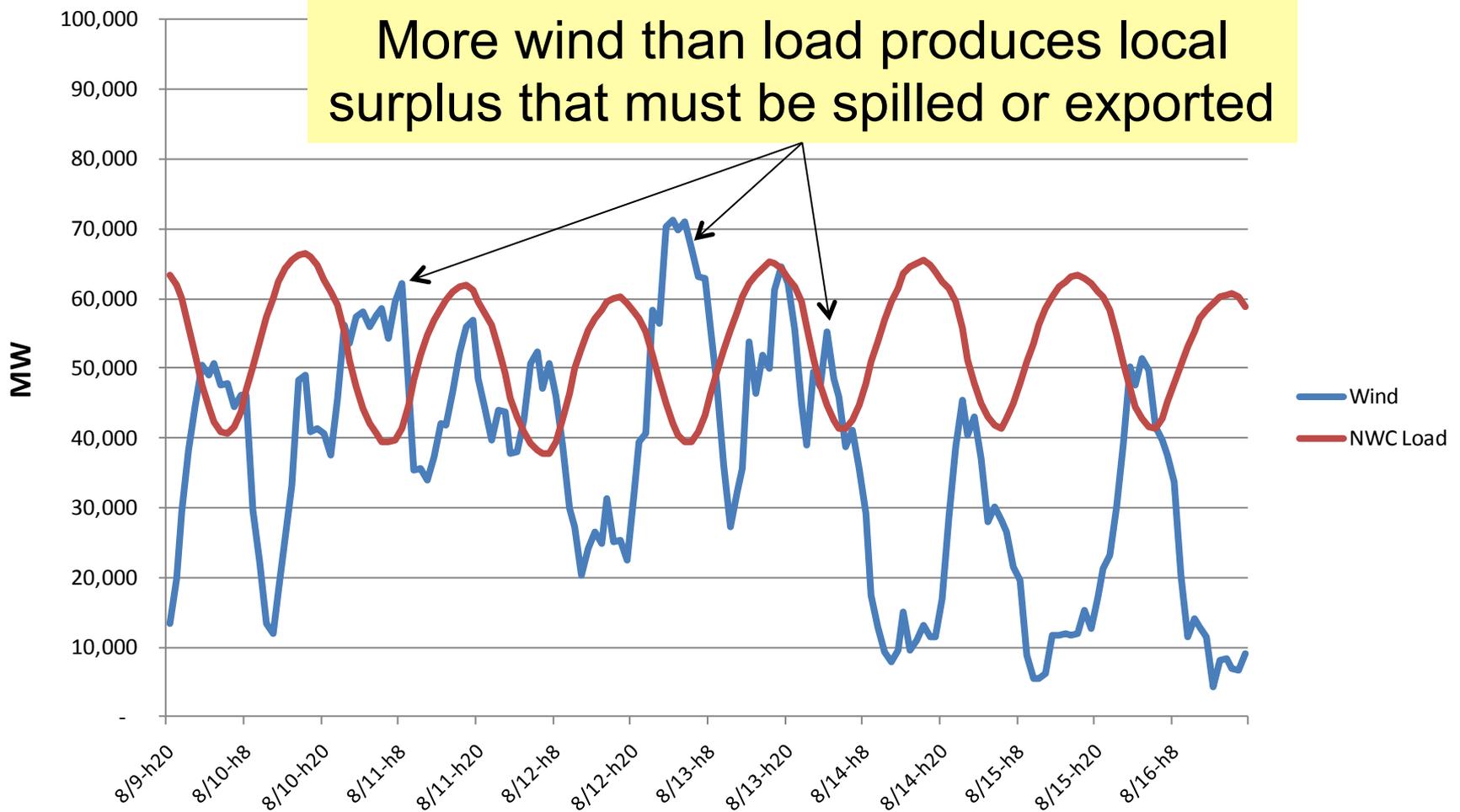
Anti-correlation of Wind with Load Creates Ramping Issues: 50 GW

NWC Time Series from 8/9/07 to 8/16/07 w 50 GW Added



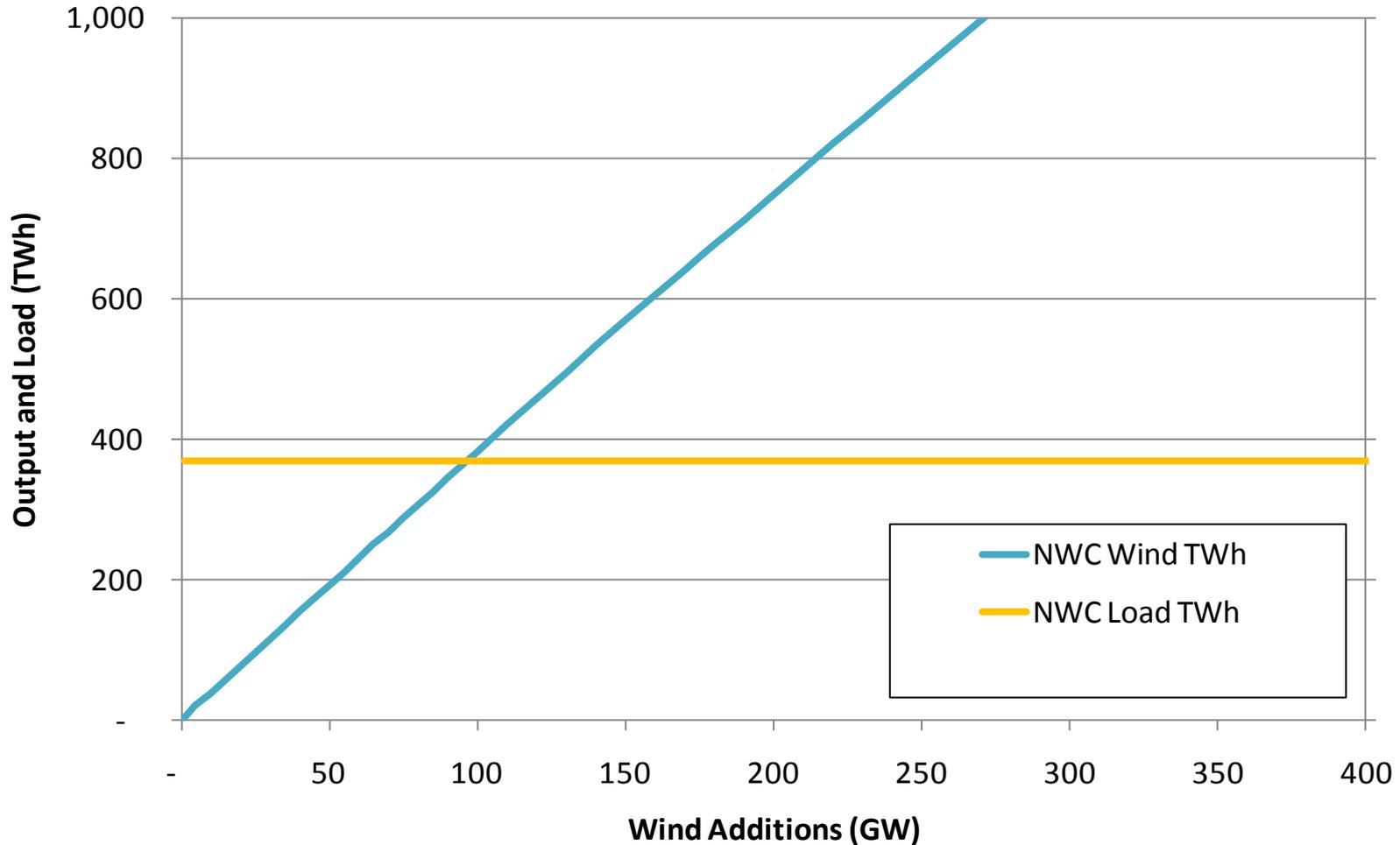
Anti-correlation of Wind with Load Also Forces Diminishing Returns to Wind Additions: 100 GW

NWC Time Series from 8/9/07 to 8/16/07 w 100 GW Added



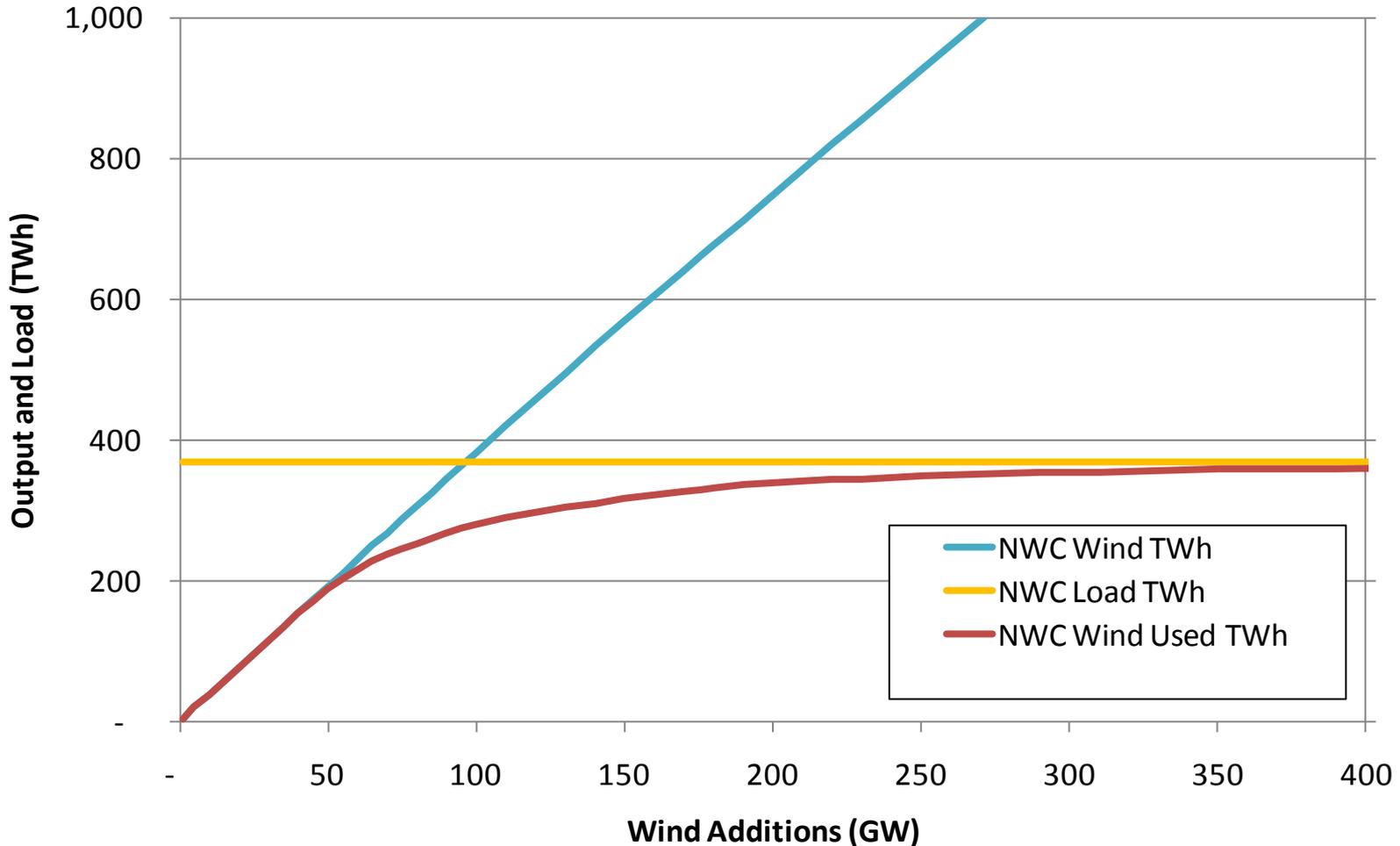
Potential Supply Far Outstrips Region Load

Annual Generation Output and Uses by GW of Wind Additions



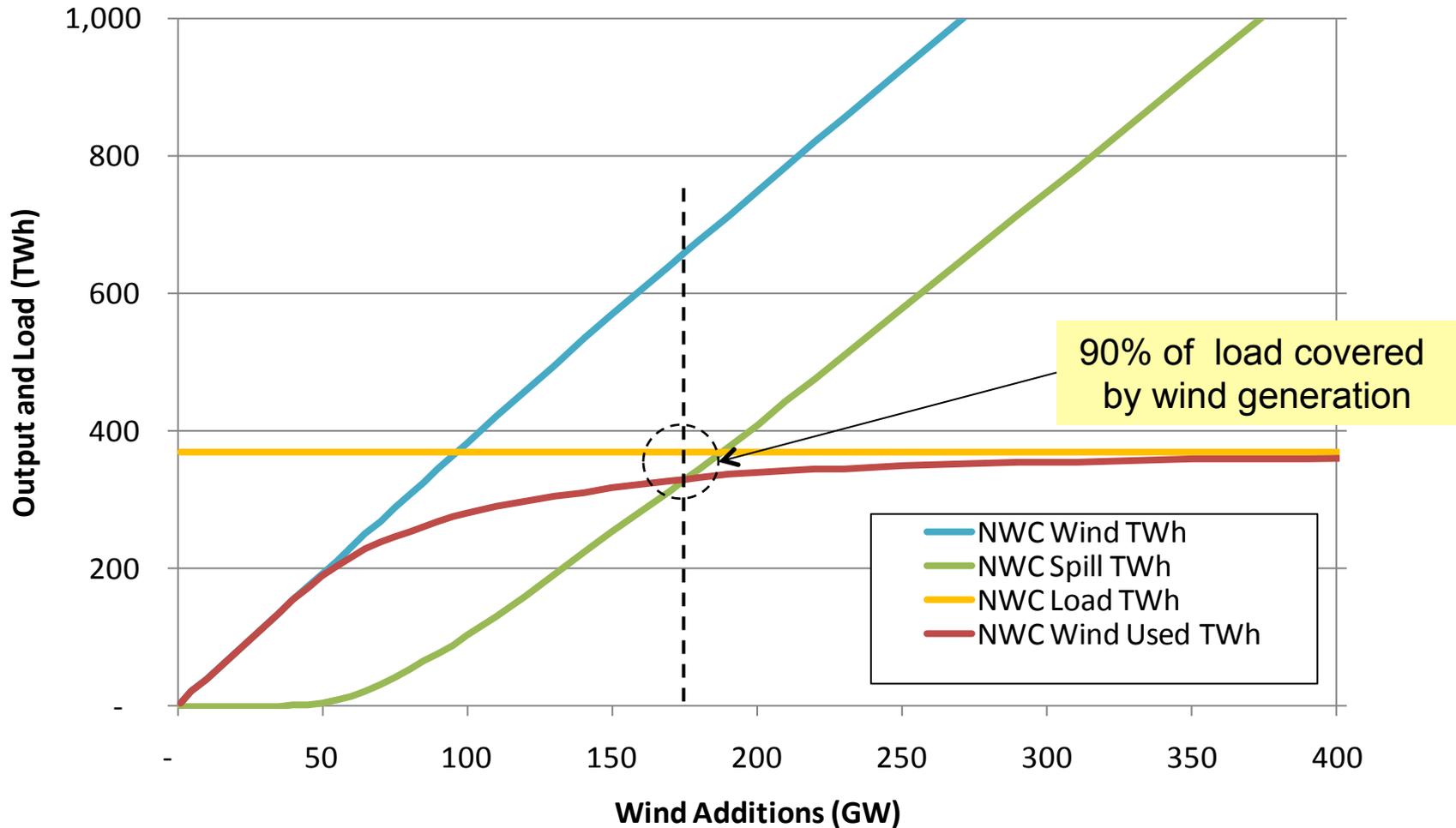
Starting At 50 GW, Additions Show Diminishing Returns in Meeting Region Load

Annual Generation Output and Uses by GW of Wind Additions



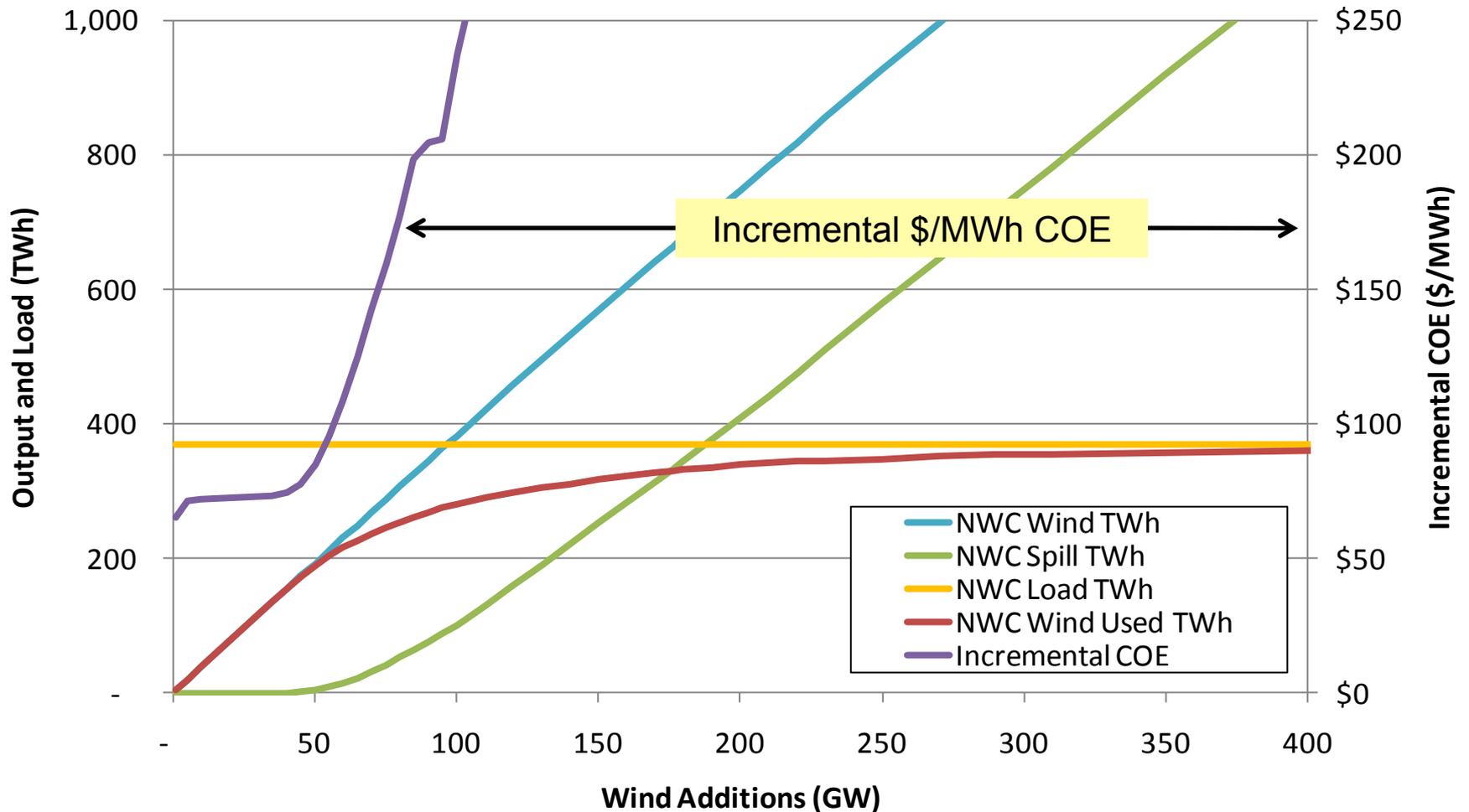
At 175 GW of Additions As Much Wind is Spilled as is Used to Serve Load

Annual Generation Output and Uses by GW of Wind Additions



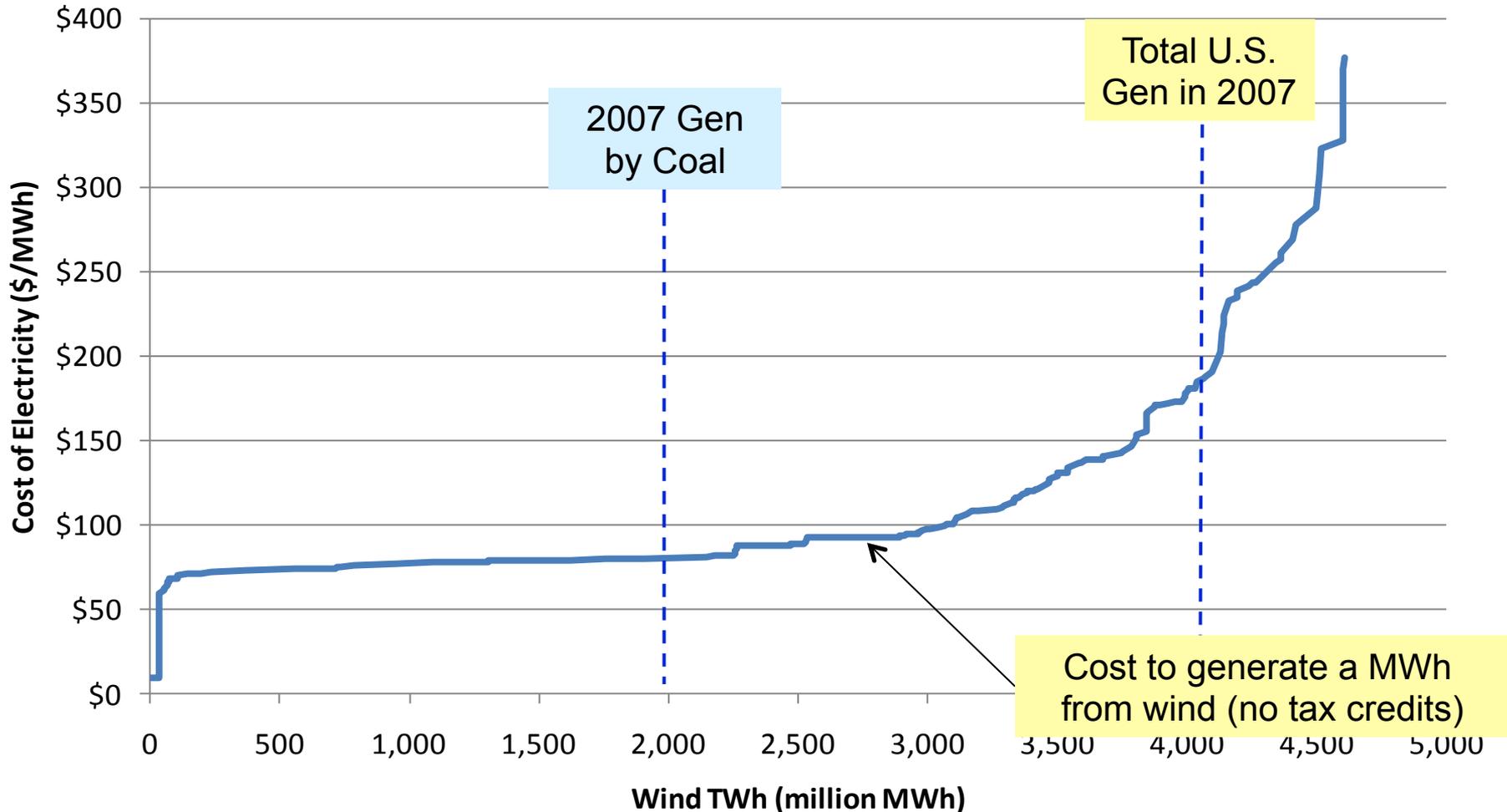
With Spills Incremental COE of Delivered Wind Generation Skyrockets

Annual Generation Output and Uses by GW of Wind Additions



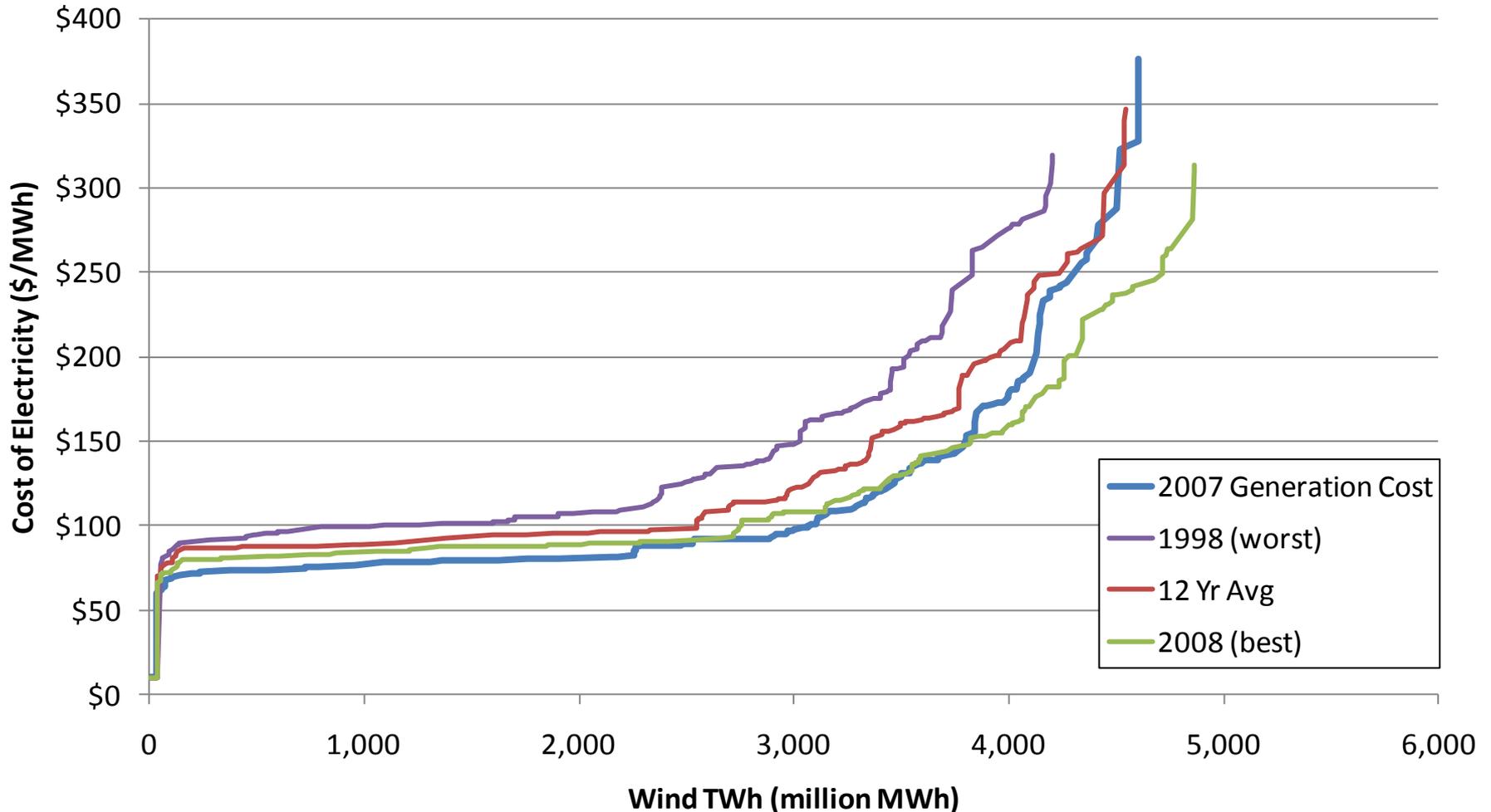
EPRI Wind Resource Assessment from Truepower Shows Vast Generation Potential

2007 Combined On- and Off-shore Wind Generation Supply

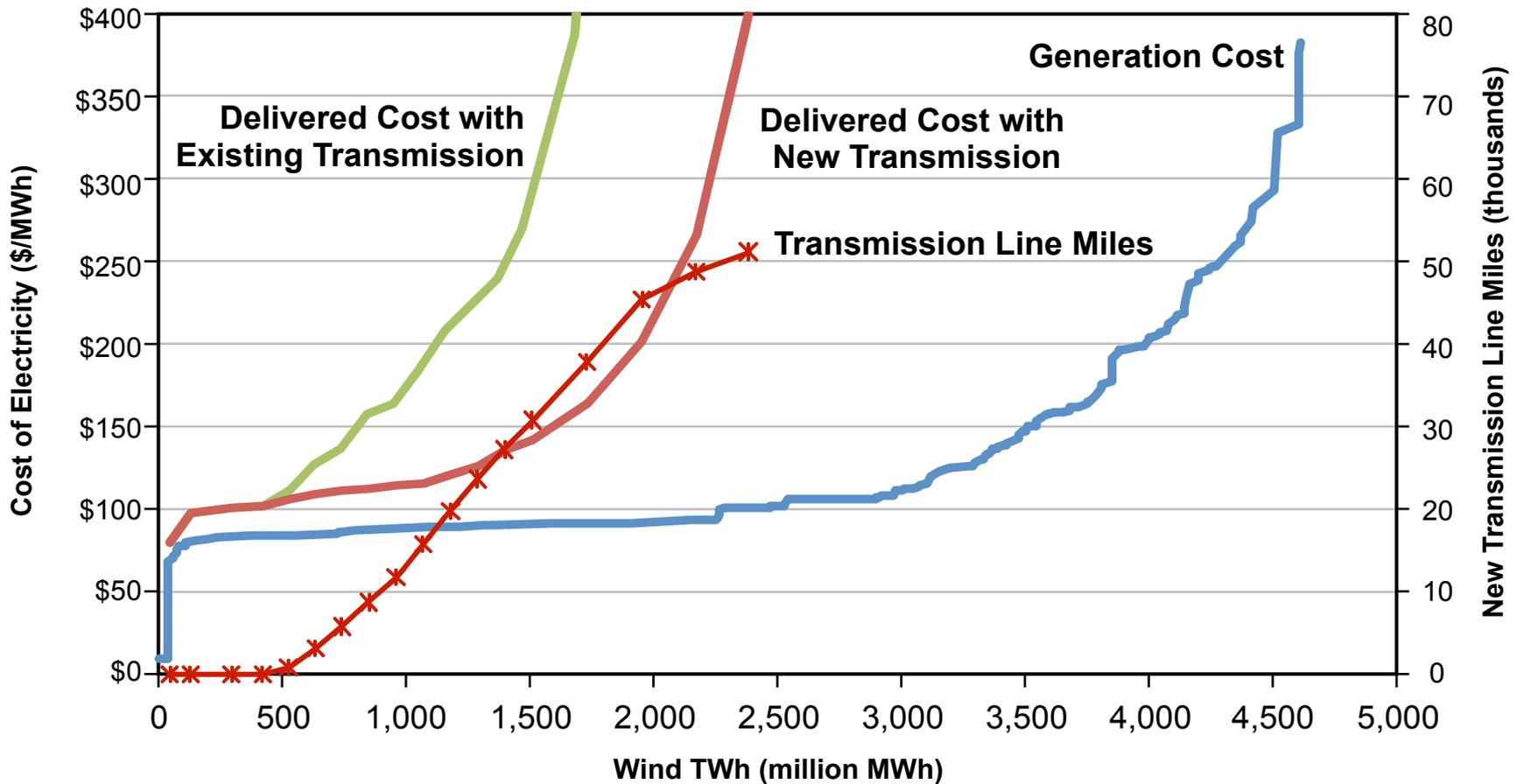


Considerable Year-to-year Variation in National Wind Energy Supply

Combined On- and Off-shore Wind Generation Supply for Selected Years



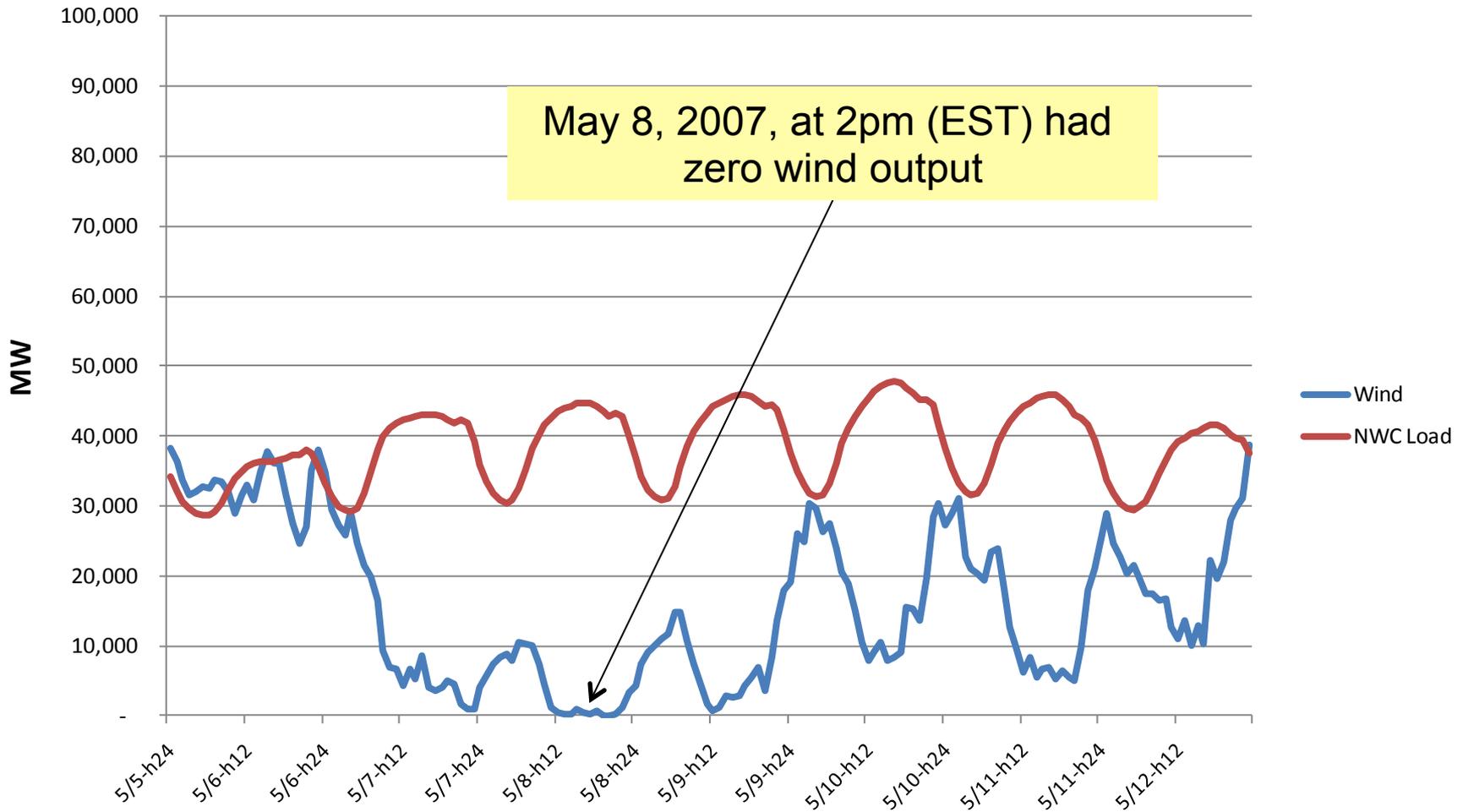
National Wind Energy Potential Supply Curves* (including delivery costs)



*EPRI – AWS TruePower National Wind Energy Supply Curves

NW-Central Region-wide (7 states) Low Output Can Continue for Extended Periods – Capacity Value??

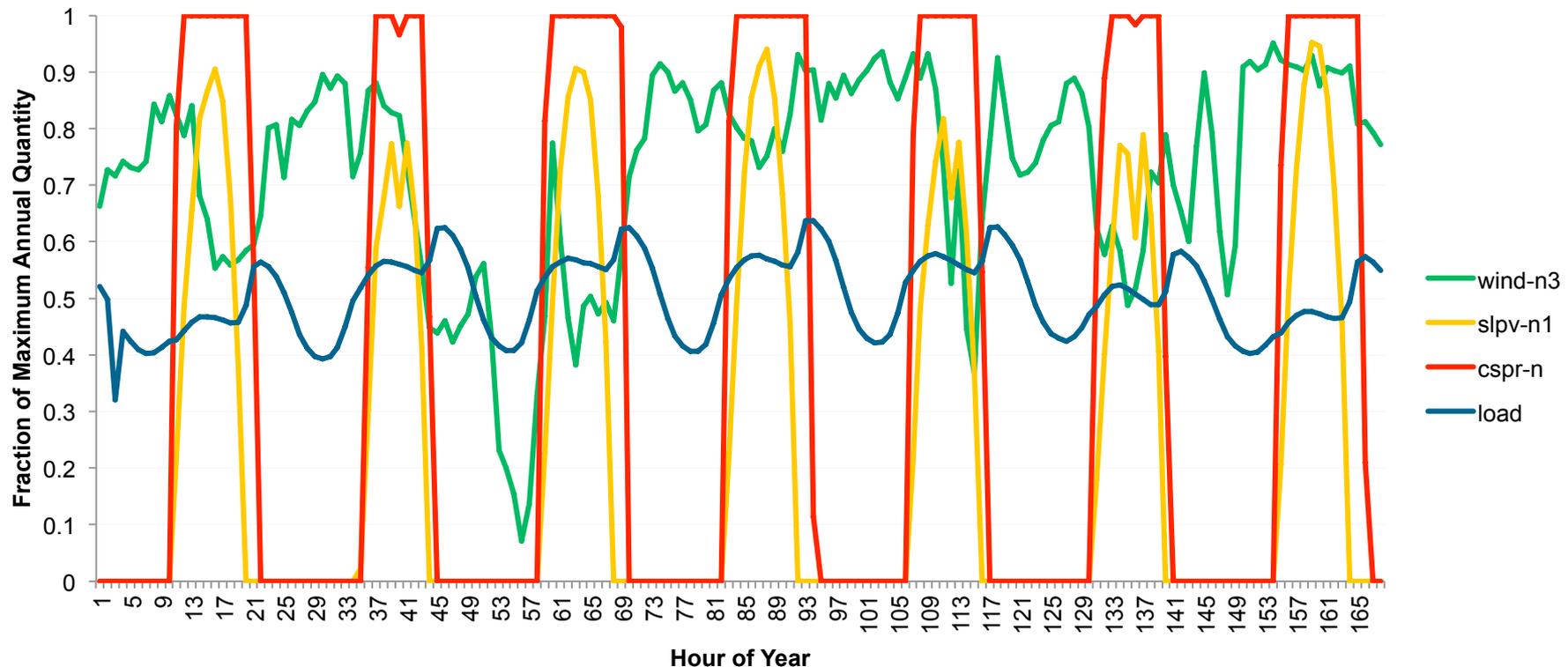
NWC Time Series from 5/5/07 to 5/12/07 w 50 GW Added



Temporal Distribution

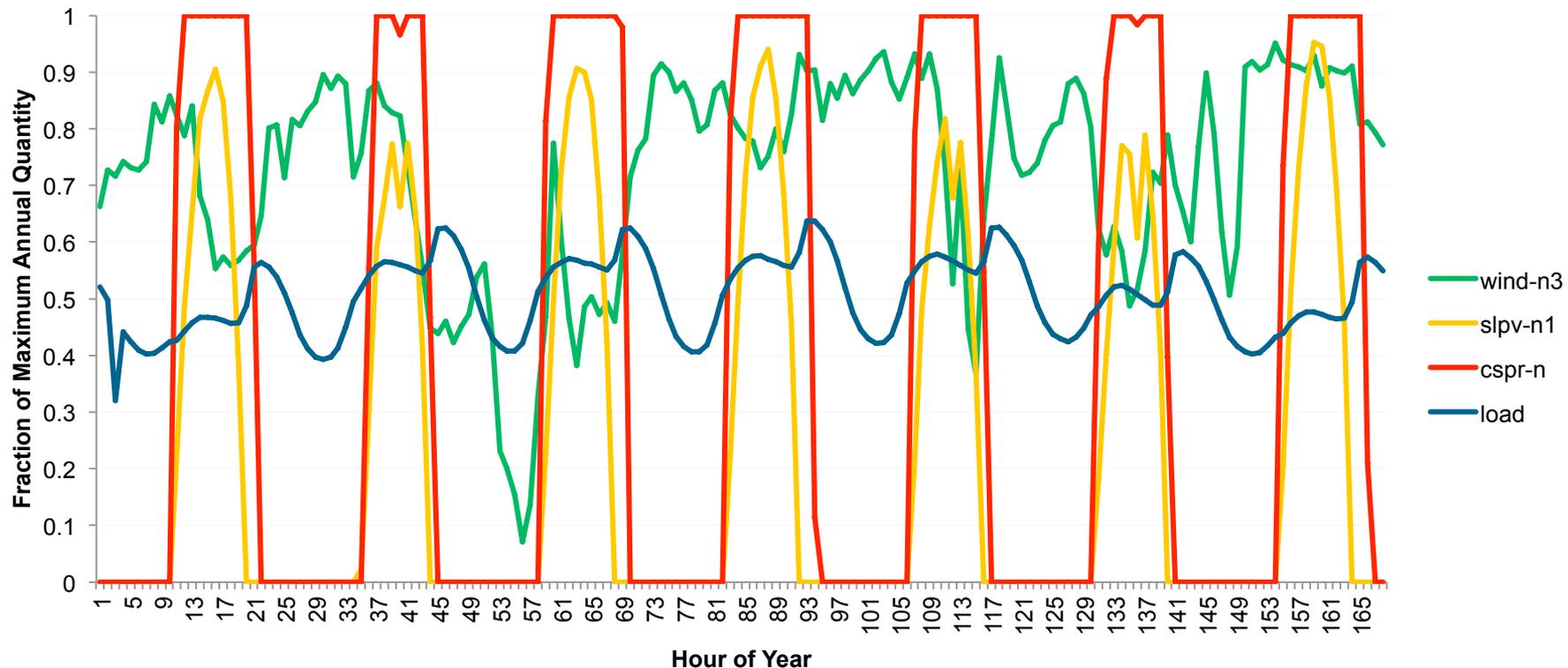
- 8760-profile developed **by region** for load, **8** classes of wind, **3** classes of solar PV, and solar CSP (sample below)

California Data 1/1/2007 - 1/7/2007



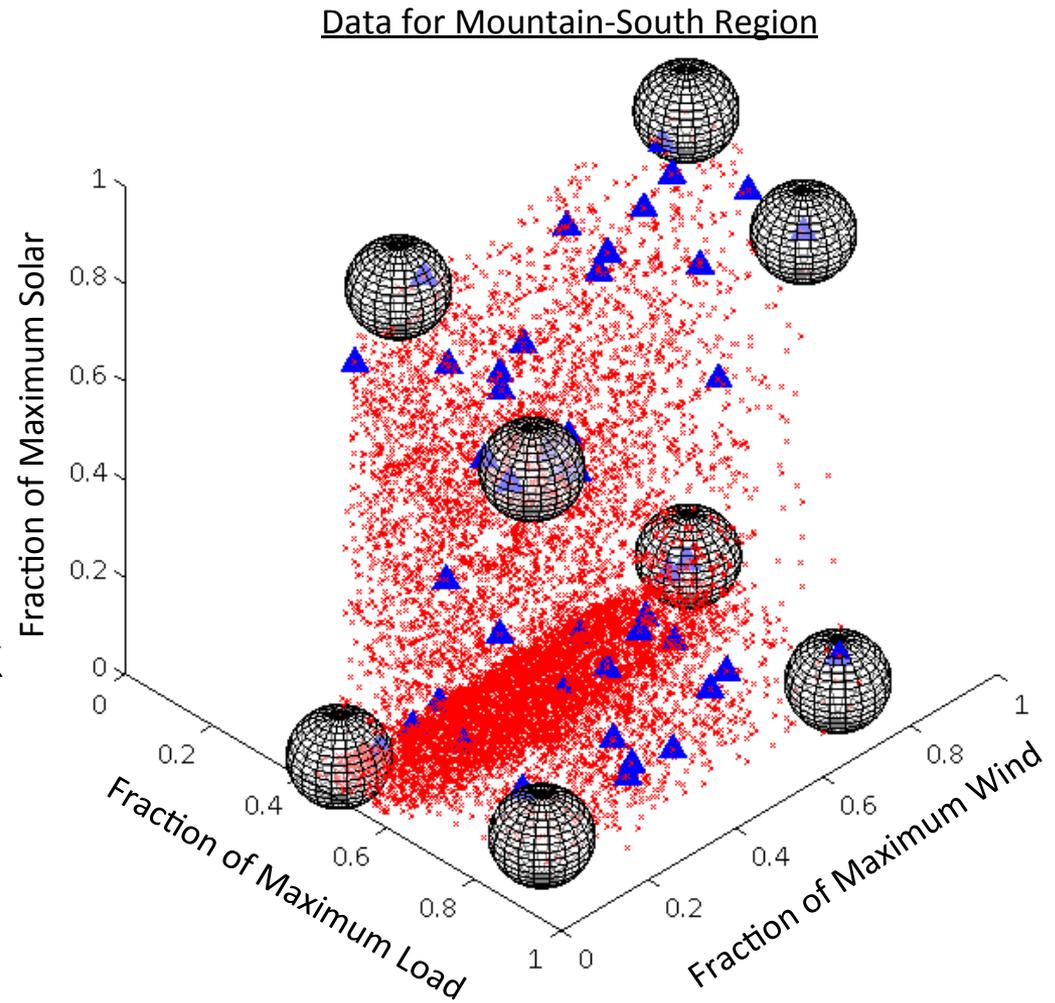
Temporal Distribution

- Our non-trivial computational capacity cannot solve electric model QCP at 8760 resolution (Limit: ~200, practical limit <100)

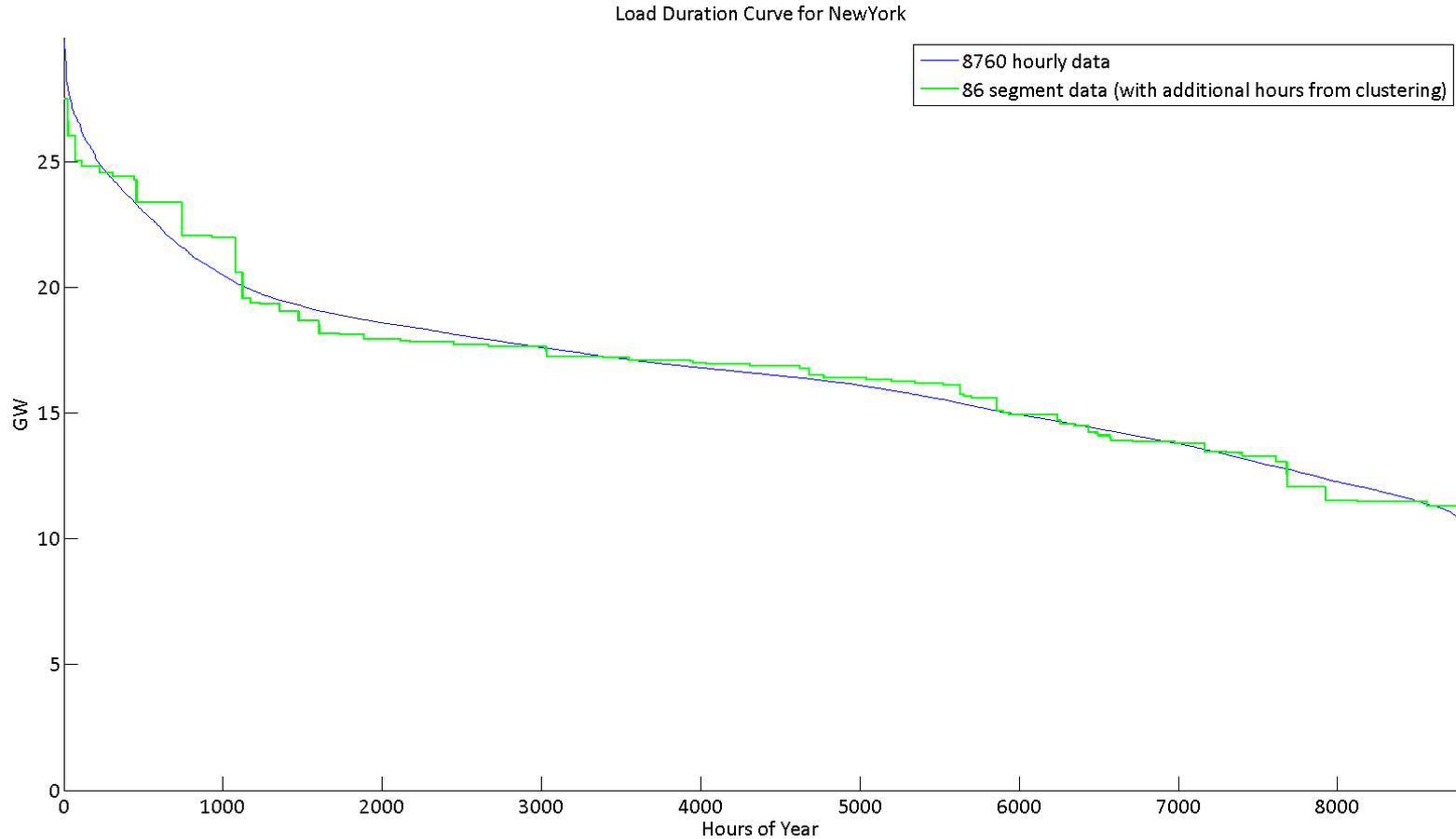


Hour Choosing Algorithm

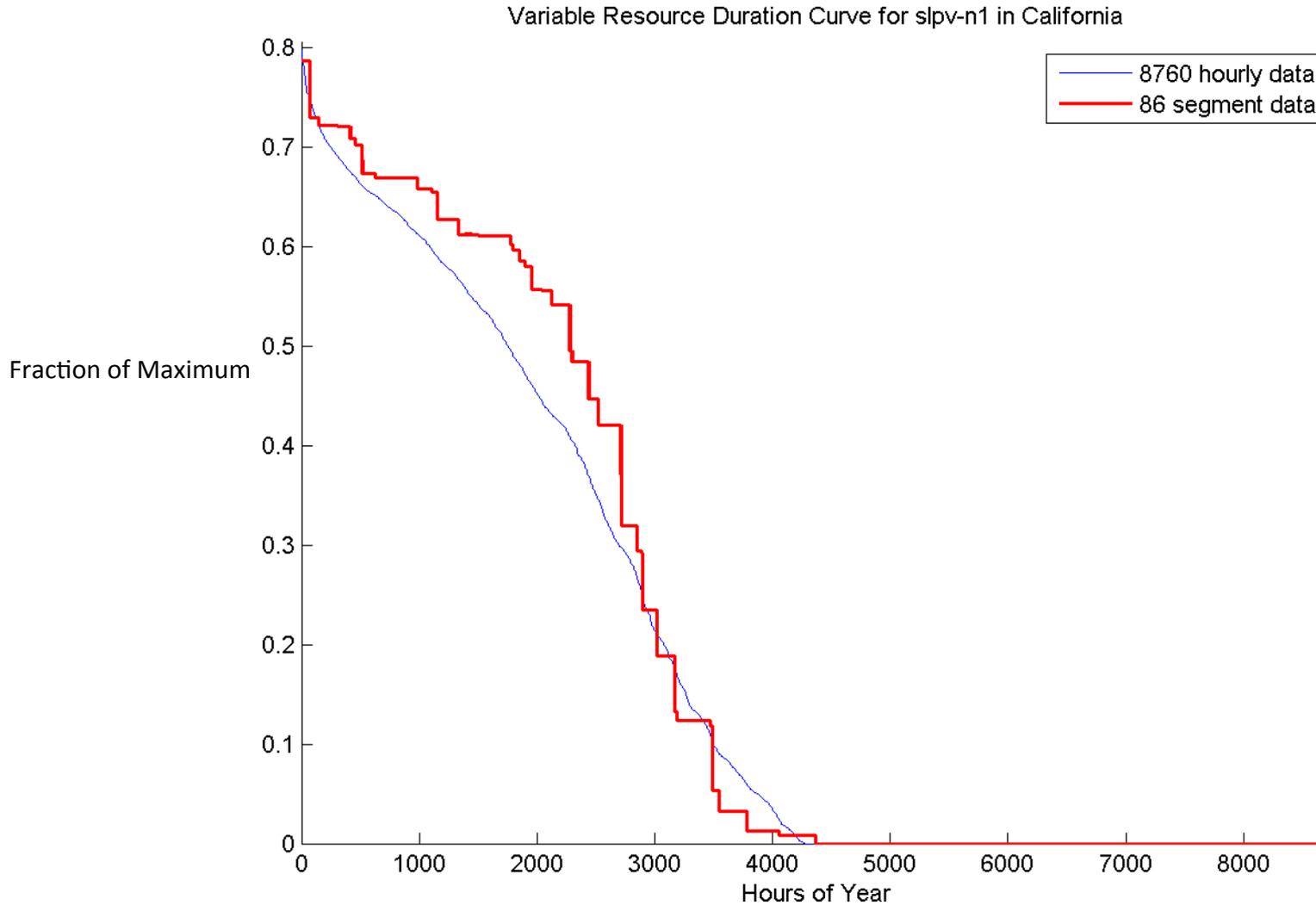
- Model solution – hours satisfying ‘bubble constraint’ in each of 15 regions:
- For this set of data, algorithm chooses 44 hours (upper bound: 8×15)
- Clustering algorithm provides 40 additional hours
- We additionally add the peak load hours of the eastern and western interconnects
- Weighting algorithm then applied



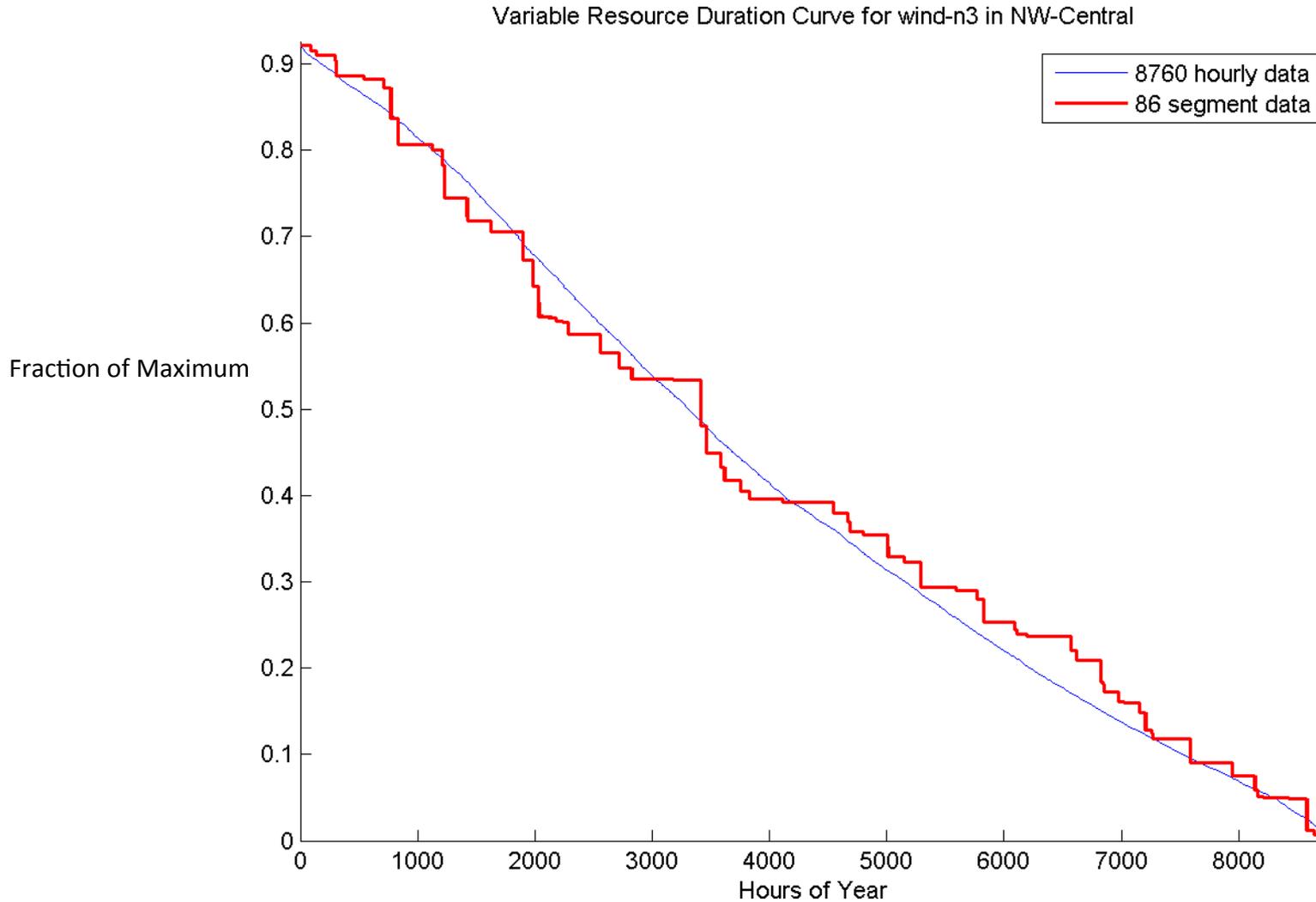
Some Sample Load Duration Curves



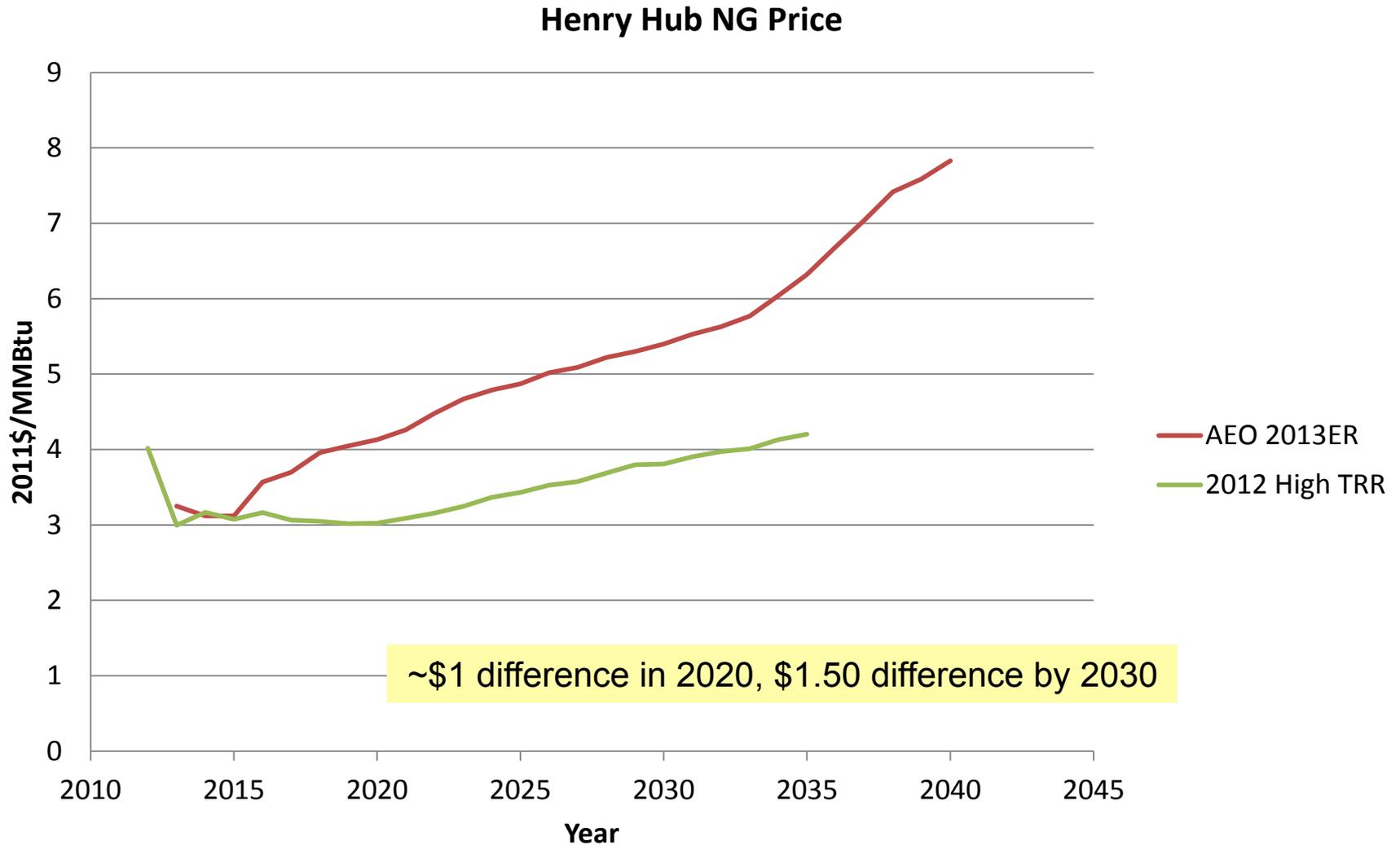
Some Sample Resource Duration Curves



Some Sample Resource Duration Curves

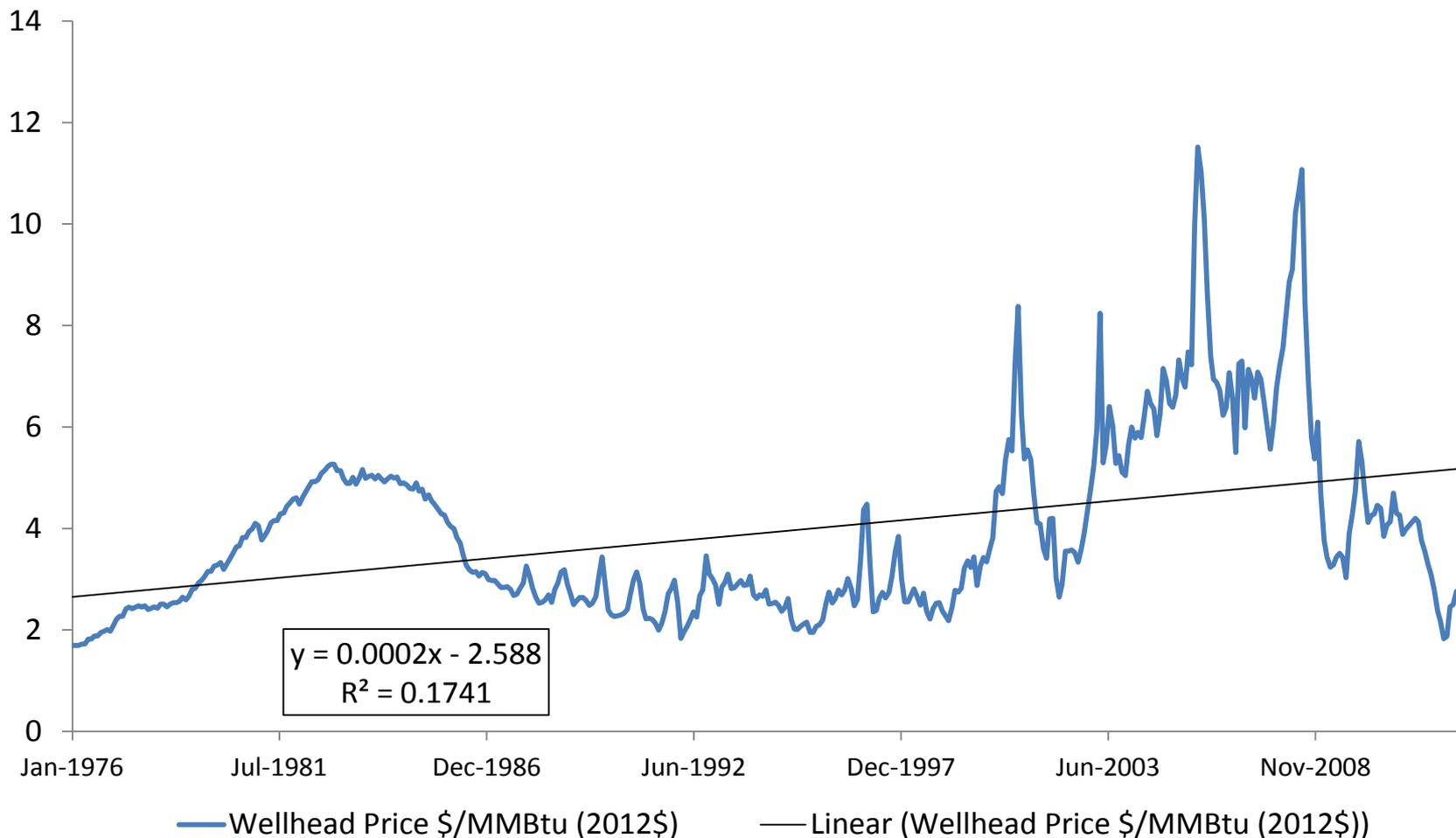


Alternative Gas Price Futures, Which Path are We On?

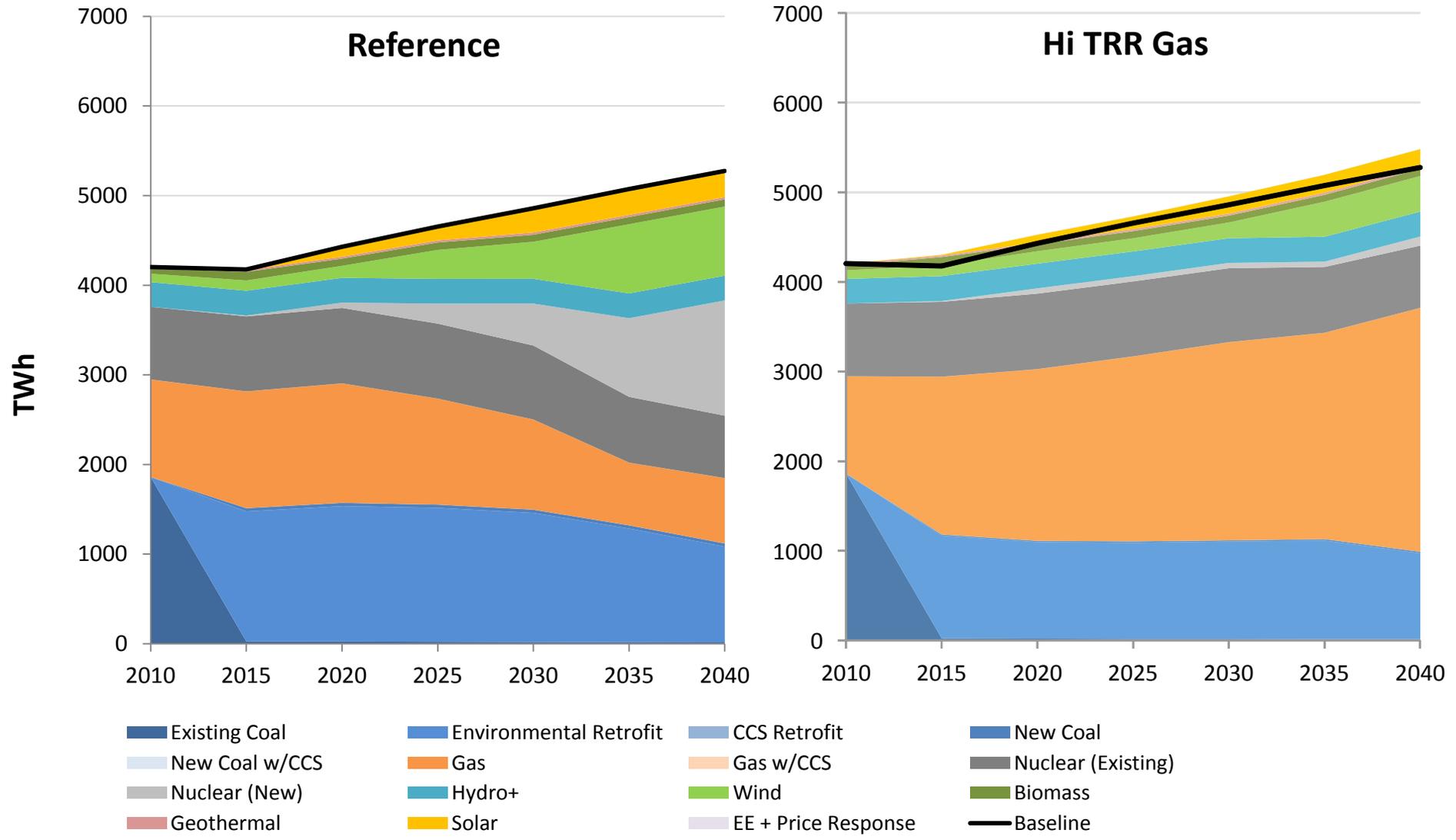


U.S. Wellhead Price History Shows a 7¢ per year Upward Price Trend, and Lots of Noise

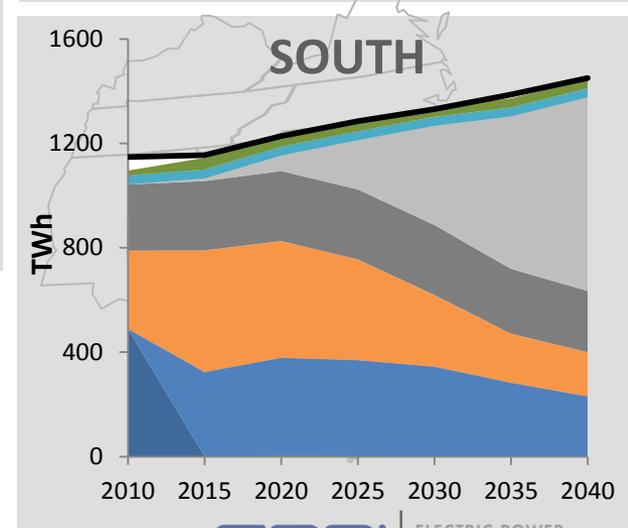
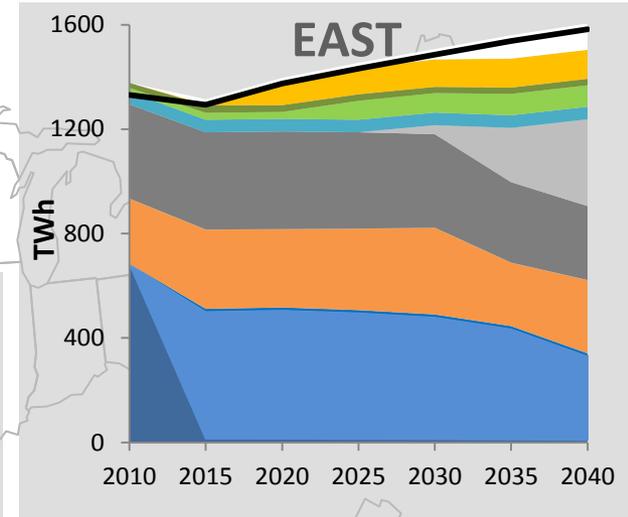
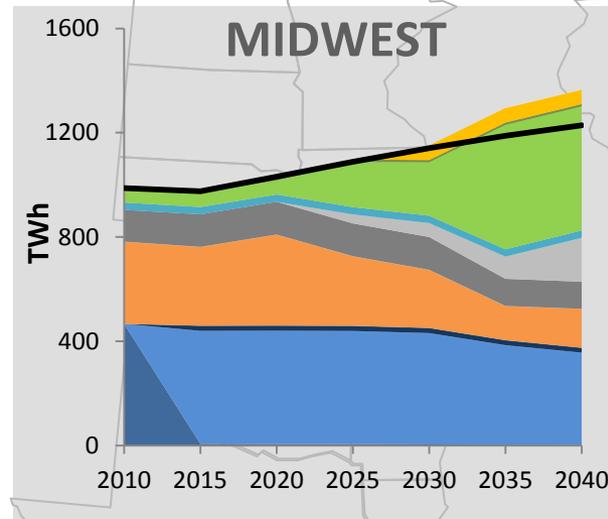
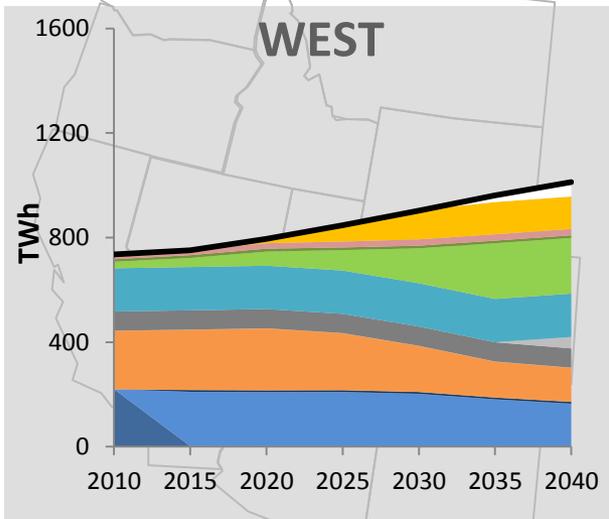
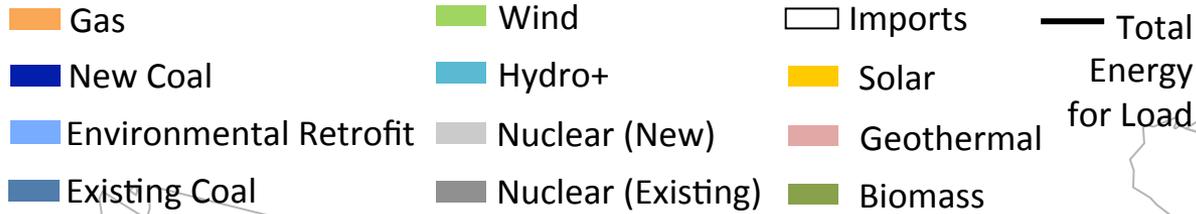
Wellhead Price \$/MMBtu (2012\$)



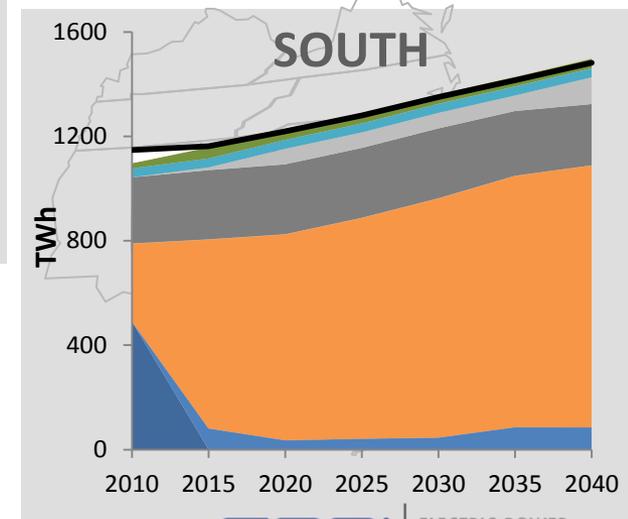
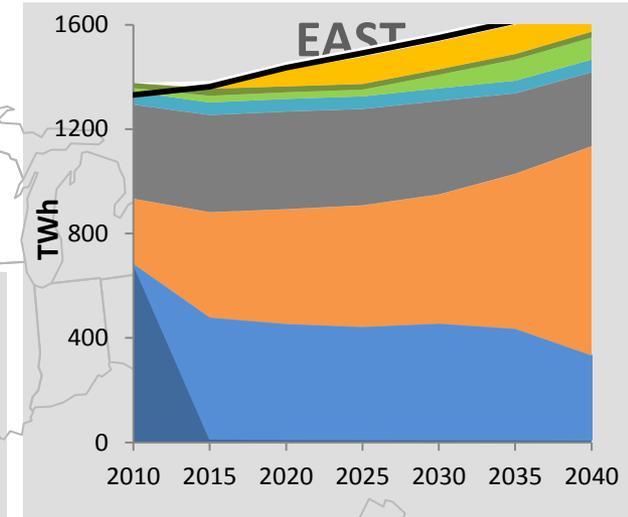
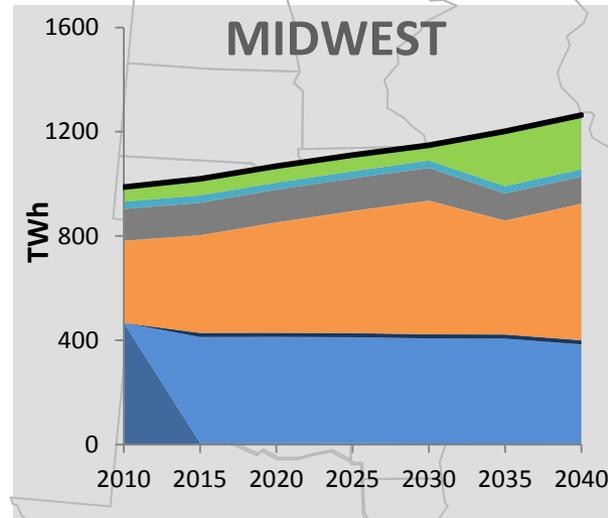
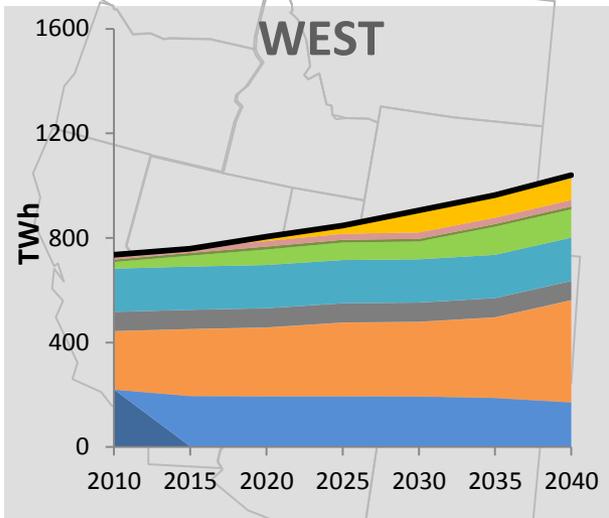
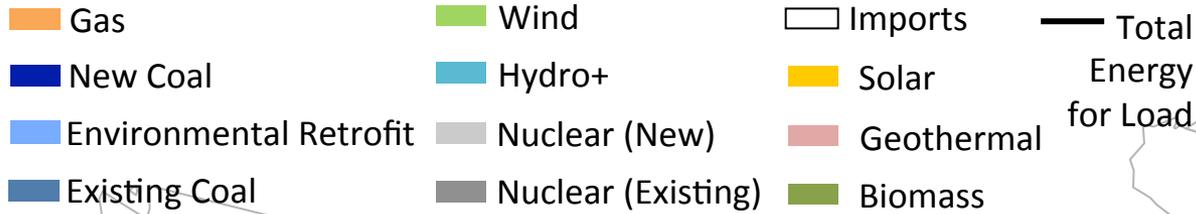
Different Price Paths Lead to Distinct Futures at the National-Level



Regional Reference



High TRR Gas



Concluding Thoughts

- US-REGEN can help us understand wind and solar deployment
 - Run intertemporal, 8760, and unit commitment versions to gain insights
- MERGE can be parameterized to mimic US-REGEN, but cannot replace it
 - Crosswalk is not straightforward, e.g., discount rates
- Analytical, financial and political battles over the “true cost” of renewables are just beginning and likely to persist

Together...Shaping the Future of Electricity

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