Costs of Integration for Wind and Solar Energy: Large-scale studies and implications

MIT Wind Integration Workshop

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Topics

Large-scale integration studies:

Western Wind and Solar Integration Study

Eastern Wind Integration and Transmission Study

What does it take to integrate variable generation (wind and solar)?

Wind and solar integration cost issues

Large-scale wind integration studies: WWSIS and EWITS

- Managed by NREL – large project teams
- Western Wind and Solar Integration Study, in collaboration with WestConnect
- Eastern Wind Integration and Transmission Study, in collaboration with the Joint Coordinated System Plan and Midwest Independent System Operator

WWSIS www.nrel.gov/wwsis

- Large team, Debbie Lew project manager
- NREL, GE Energy, 3Tier, Northern Arizona University, Exeter, SUNY
- Project partner: WestConnect
- Large stakeholder group
- Technical Review Committee

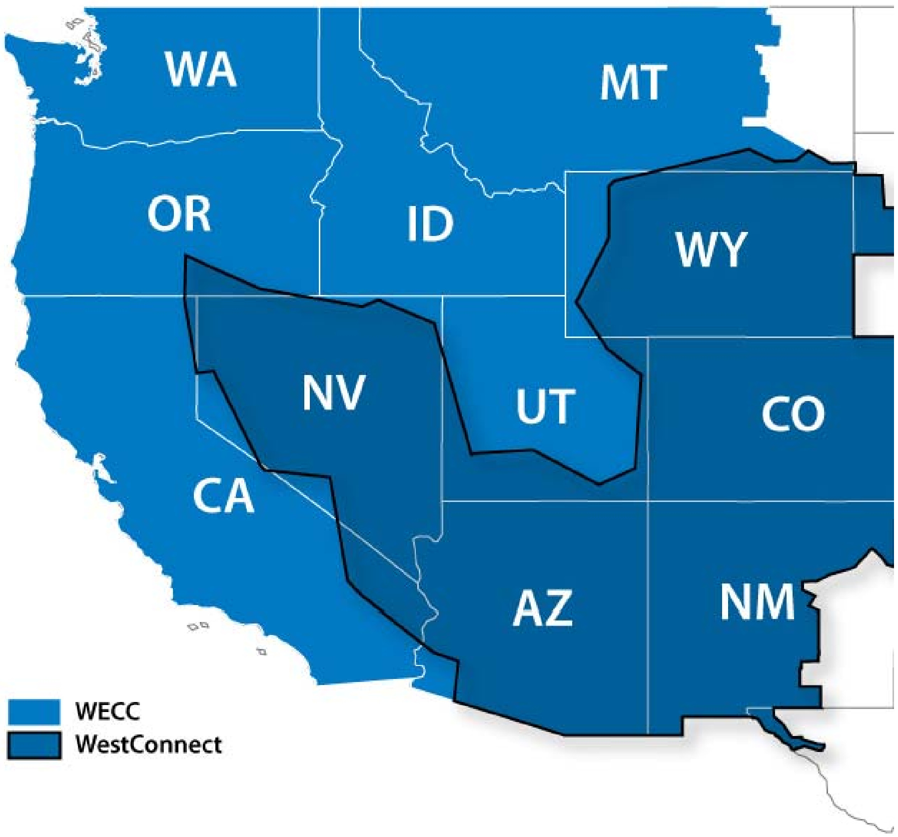
Overview

Goal

- To understand the costs and operating impacts due to the variability and uncertainty of wind, PV and concentrating solar power (CSP) on the WestConnect grid

Utilities

- Arizona Public Service
- El Paso Electric
- NV Energy
- Public Service of New Mexico
- Salt River Project
- Tri-State G&T
- Tucson Electric Power
- Xcel Energy
- WAPA



Scenario Overview

In Footprint		Rest of WECC	
Wind	Solar	Wind	Solar
10%	1%	10%	1%
20%	3%	10%	1%
30%	5%	20%	3%

Baseline – no new renewables

In-Area – each transmission area meets its target from sources within that area

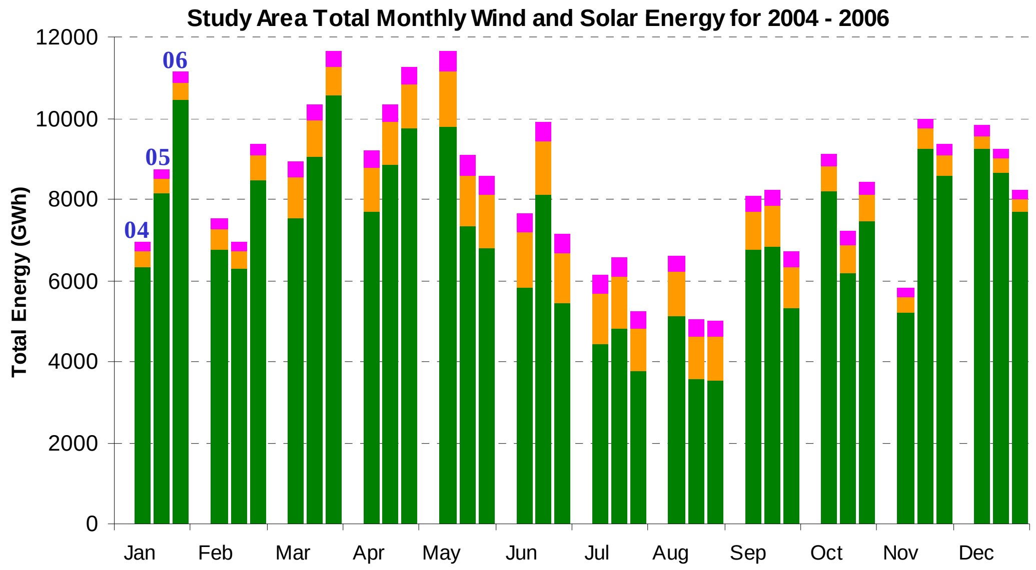
Mega Project – concentrated projects in best resource areas

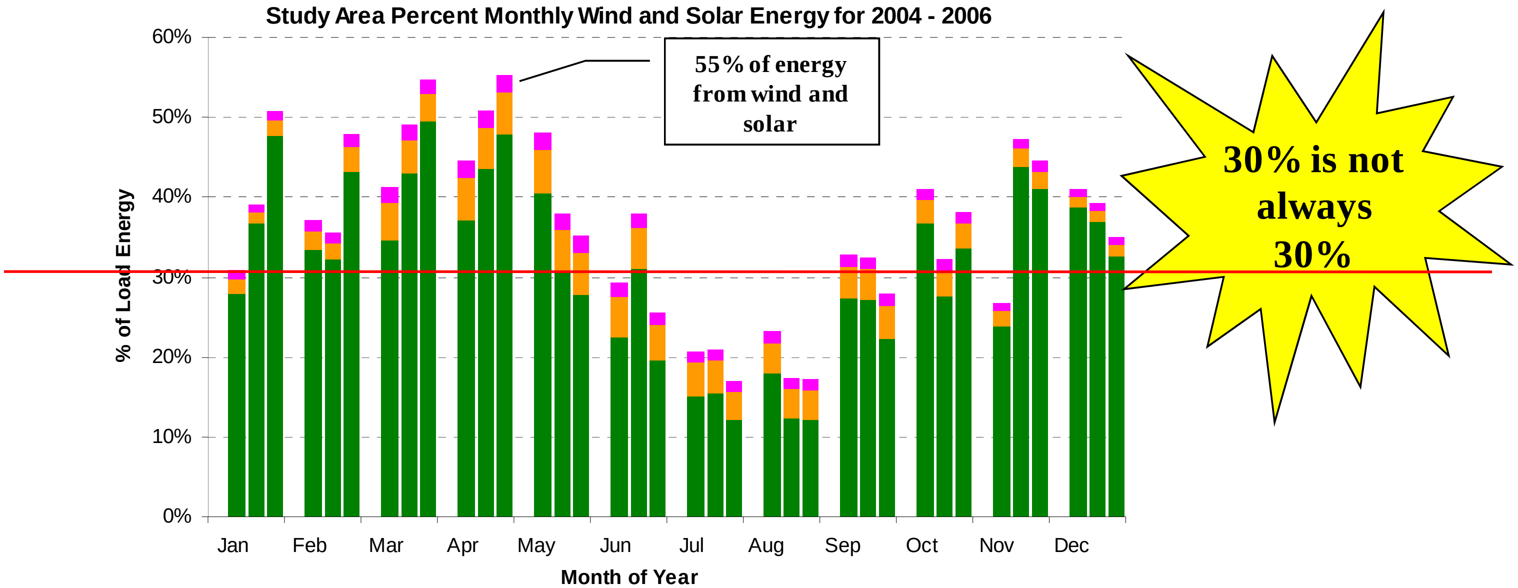
Local Priority – Balance of best resource and in-area sites

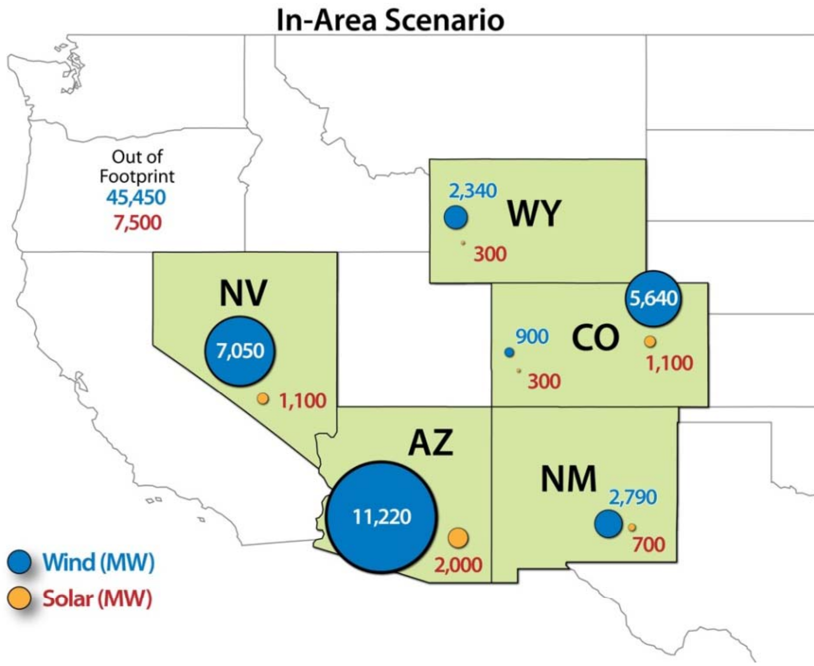
Plus other scenarios yet to be determined (high solar, high capacity value, high geographic diversity)

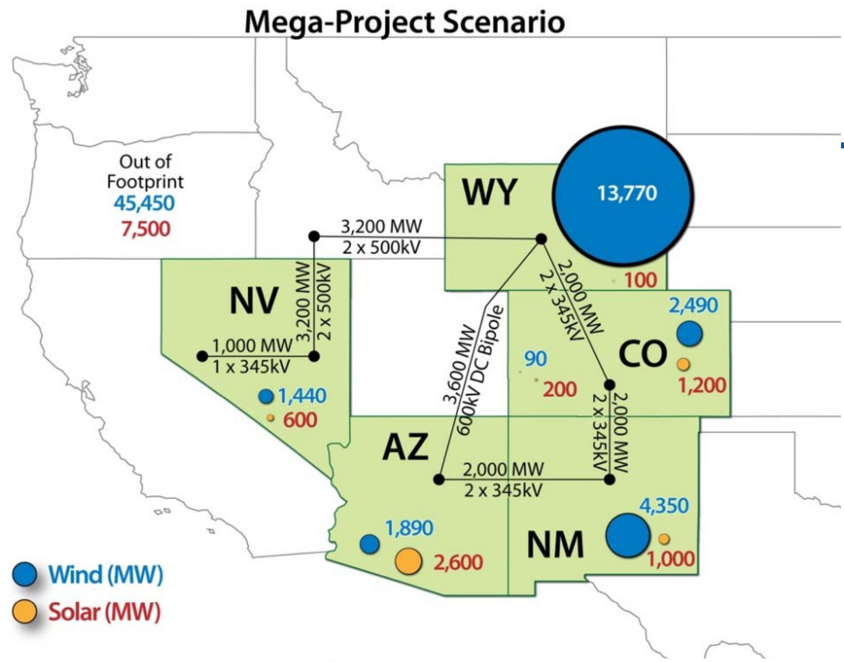
Solar is 70% CSP and 30% distributed PV. CSP has 6 hours of thermal storage. Penetrations are by energy.

Study Area Monthly Energy from Wind and Solar for 2004 – 2006 (30% In Area Scenario)

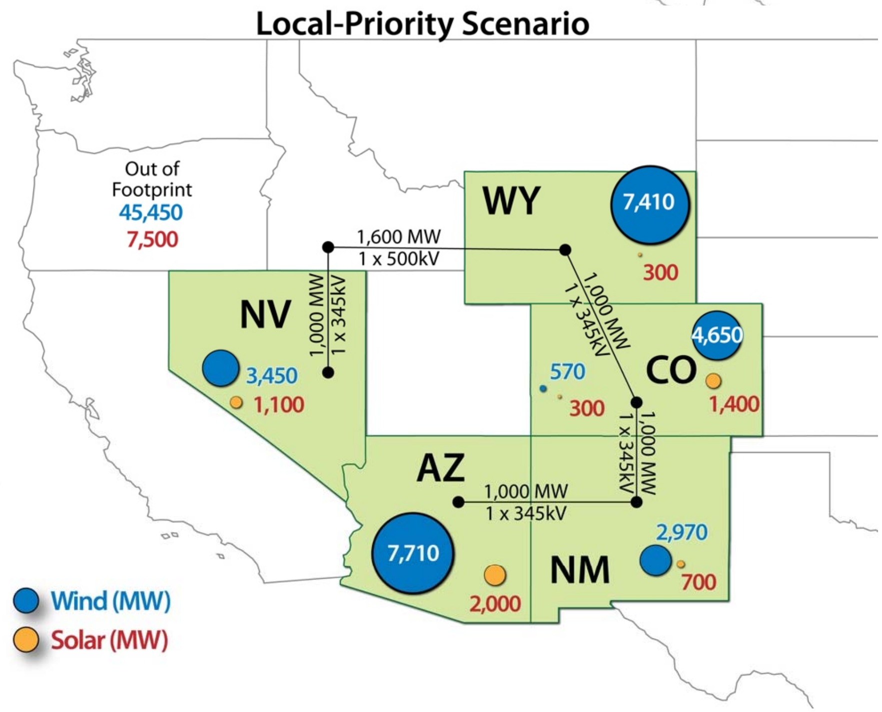








Geographic Scenarios
(high renewables case)



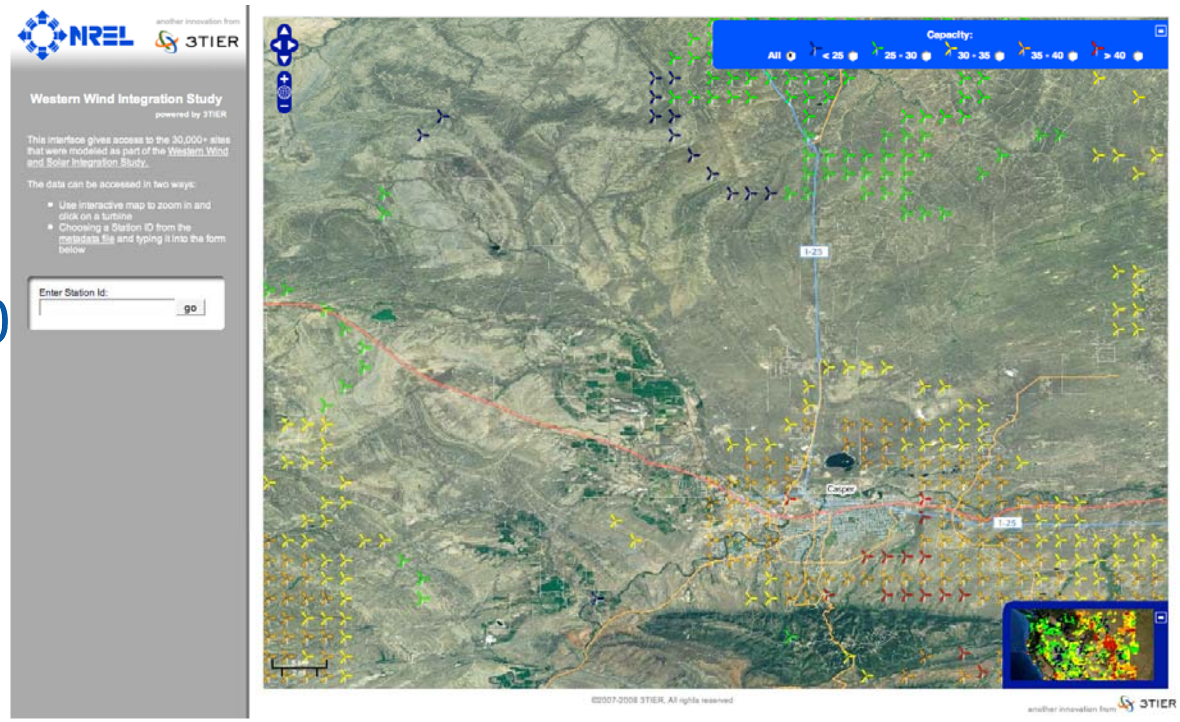
In-Area - each state meets target from sources within that state.

Mega Project - concentrated projects in best resource areas.

Local Priority - Balance of best resource and In-Area sites.

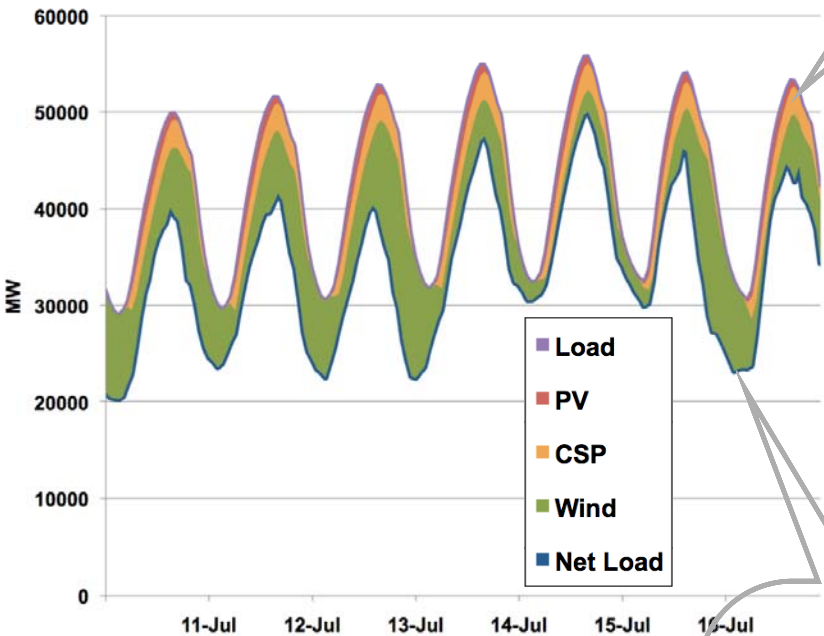
Wind data

- 3TIER Group ran weather model to recreate weather for 2004, 2005, 2006
- 10 minute wind power output for 960 GW of wind sites in WECC.
- Power profiles were based on Vestas V90 3MW turbine at 100m height.
- Hourly day-ahead power output forecasts.



How does the system operate in the high renewables case?

Mid-July



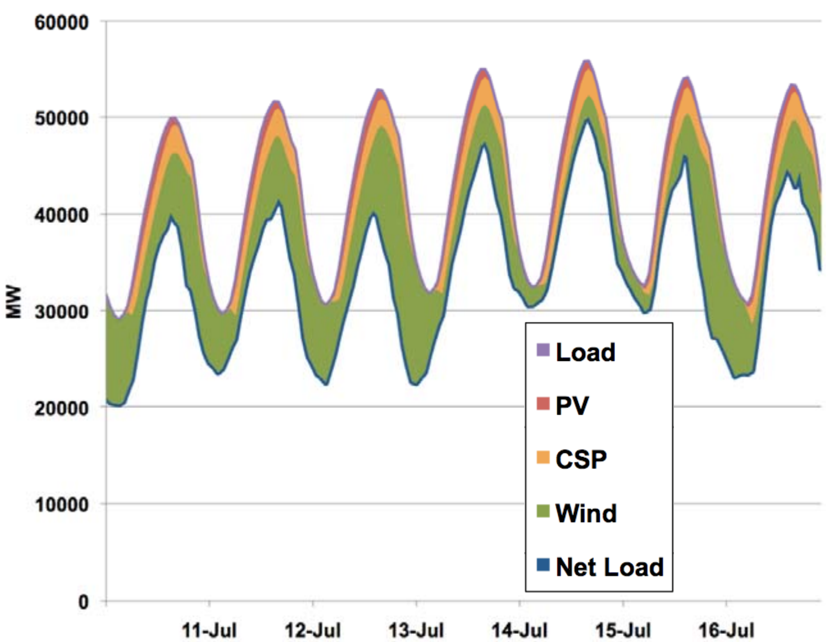
Load

The operator formerly managed to load but now has to manage the net load.

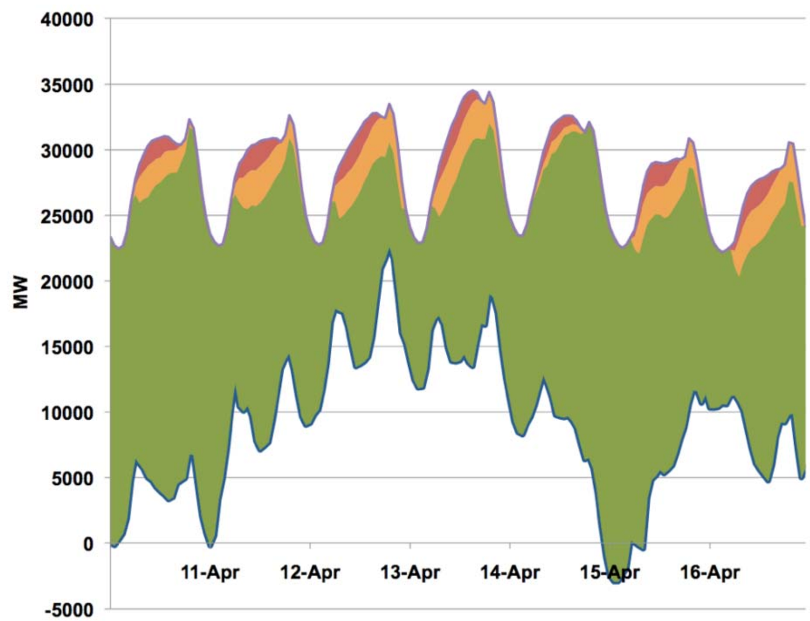
Net Load = Load - Wind - Solar

How does the system operate in the high renewables case?

Mid-July



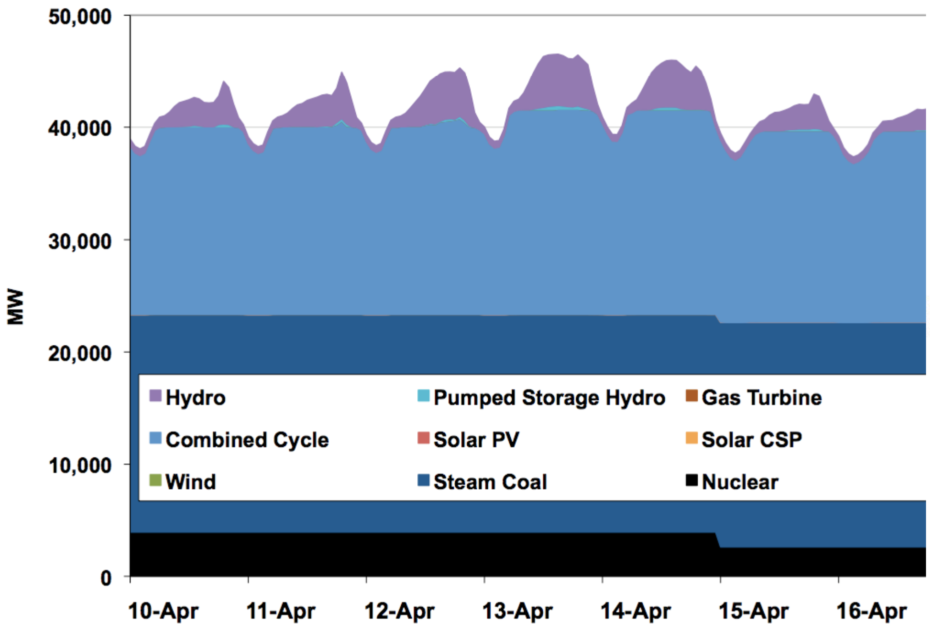
Mid-April



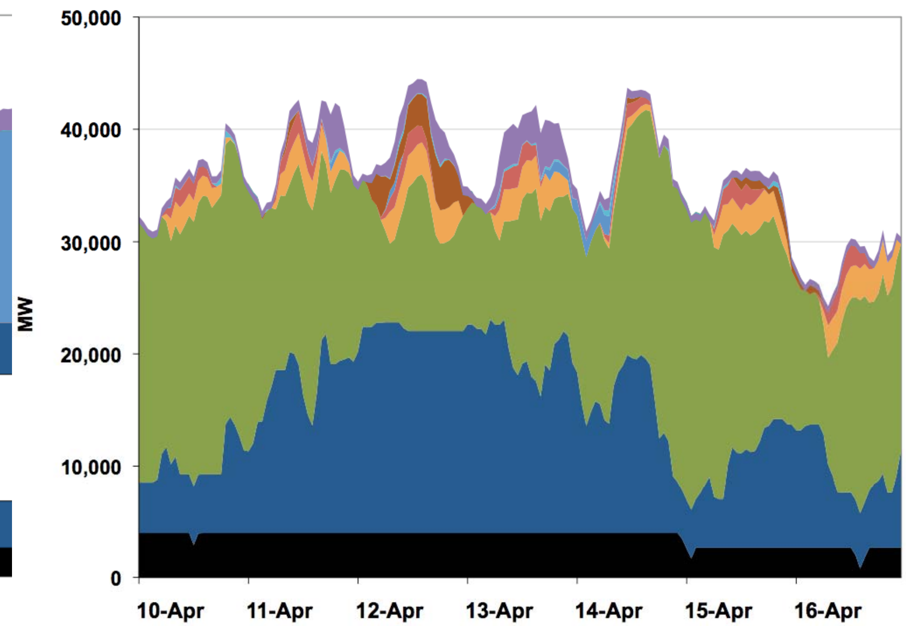
Mid-April shows the challenges of operating the grid with 35% wind and solar. This was the worst week of the 3 years studied.

Operations during mid-April

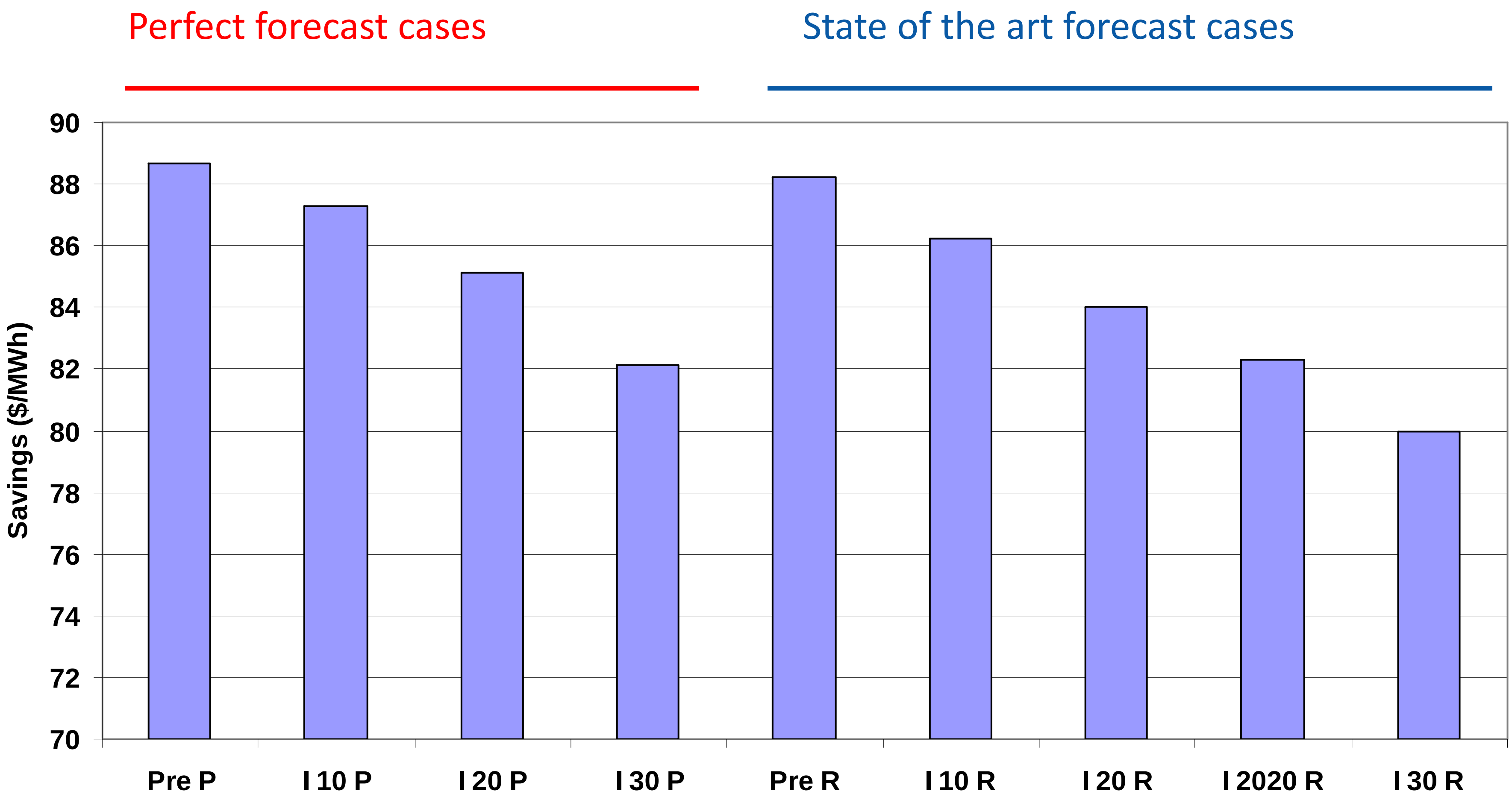
No Wind/Solar



High renewables case



Operating Cost Savings per MWh of Renewable Energy ($/MWh) - WECC - 2006

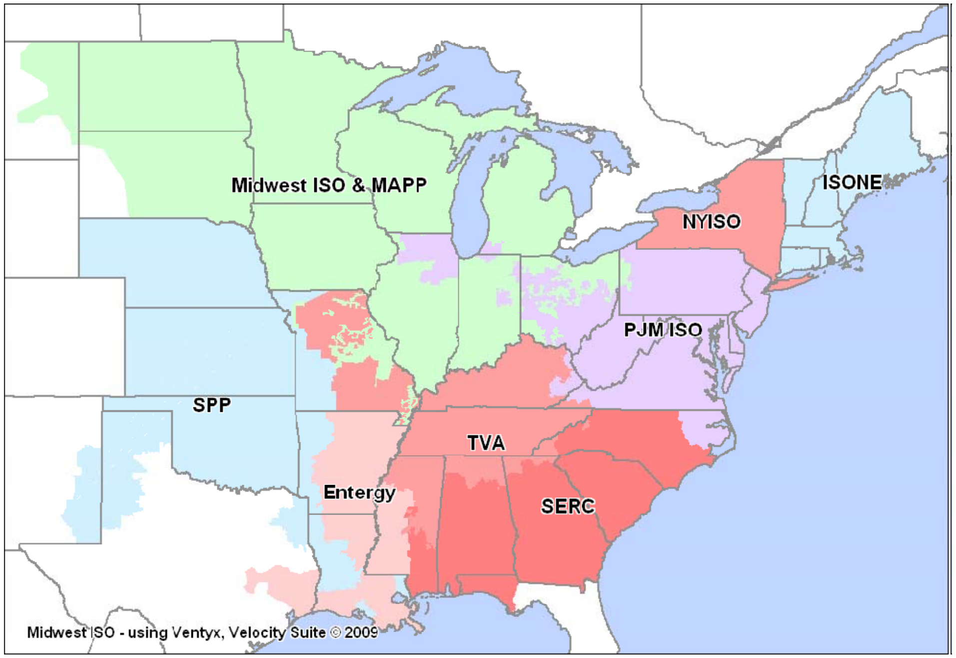


EWITS www.nrel.gov/ewits

- Built on Joint Coordinated System Plan
- Large project team, Dave Corbus project manager
  - NREL, MISO, EnerNex, AWS True Power, University of Stuttgart, Riso (stochastic model)
  - Representation from RTOs/ISOs, utilities
  - Technical Review Committee

What is Needed to Integrate 20% Wind in the Eastern Interconnection?

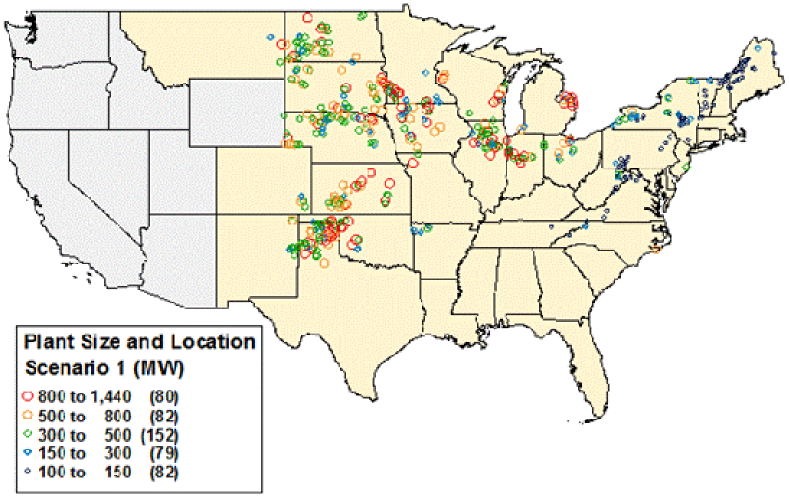
- Evaluate the power system operating impacts and transmission associated with increasing wind energy to 20% and 30%
    - Impacts include operating with the variability and uncertainty of wind
- Build upon prior wind integration studies and related technical work;
- Coordinate with current regional power system study work;
- Produce meaningful, broadly supported results
    - Technical Review Committee



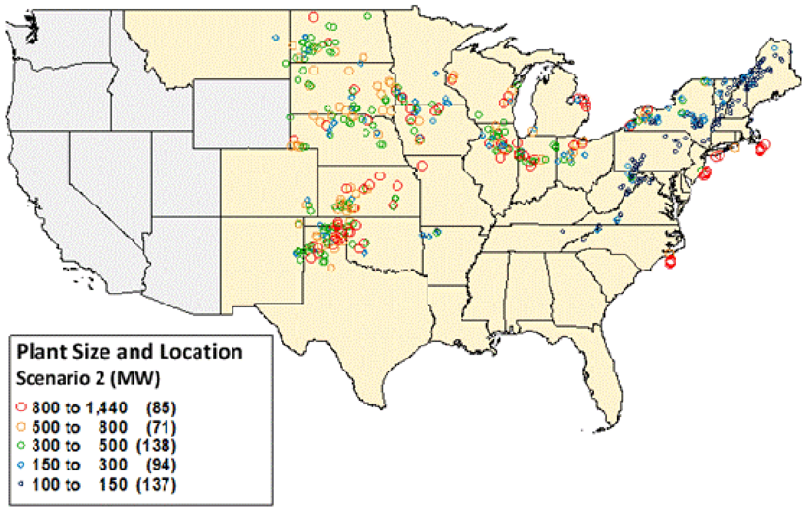
EWITS Analysis Provides Detailed Information on

- Wind generation required to produce 20% and 30% of the projected electric energy demand over the U.S. portion of the Eastern Interconnection in 2024
- Transmission concepts for delivering energy economically for each scenario
- Economic sensitivity simulations of the hourly operation of the power system with wind generation, future market structures and transmission overlay
- The contribution made by wind generation to resource adequacy and planning capacity margin

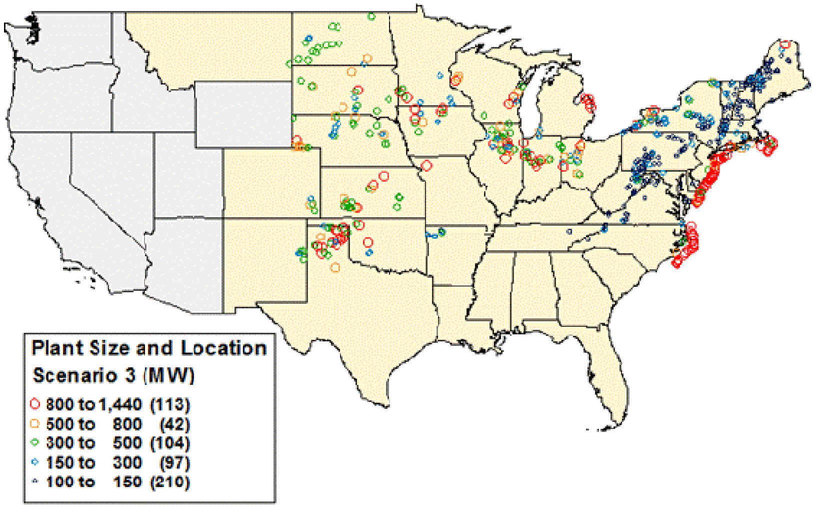
Scenario 1: 20% high capacity factor



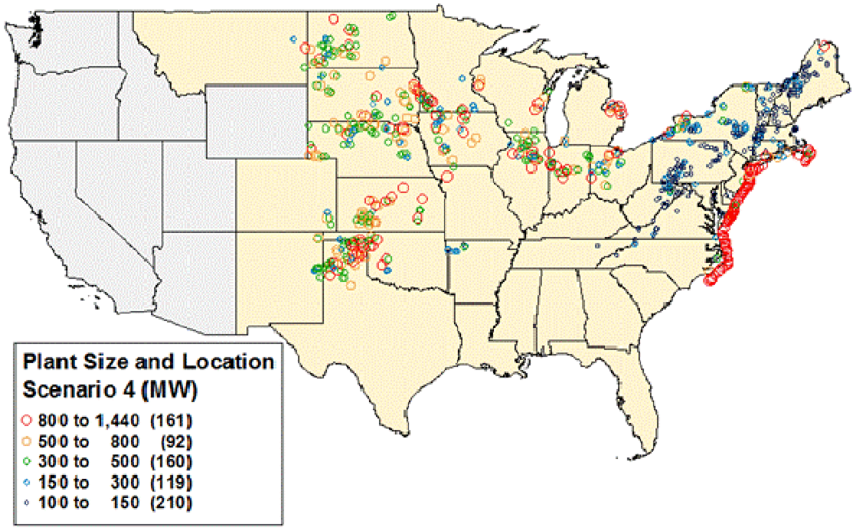
Scenario 2: Hybrid w/off-shore

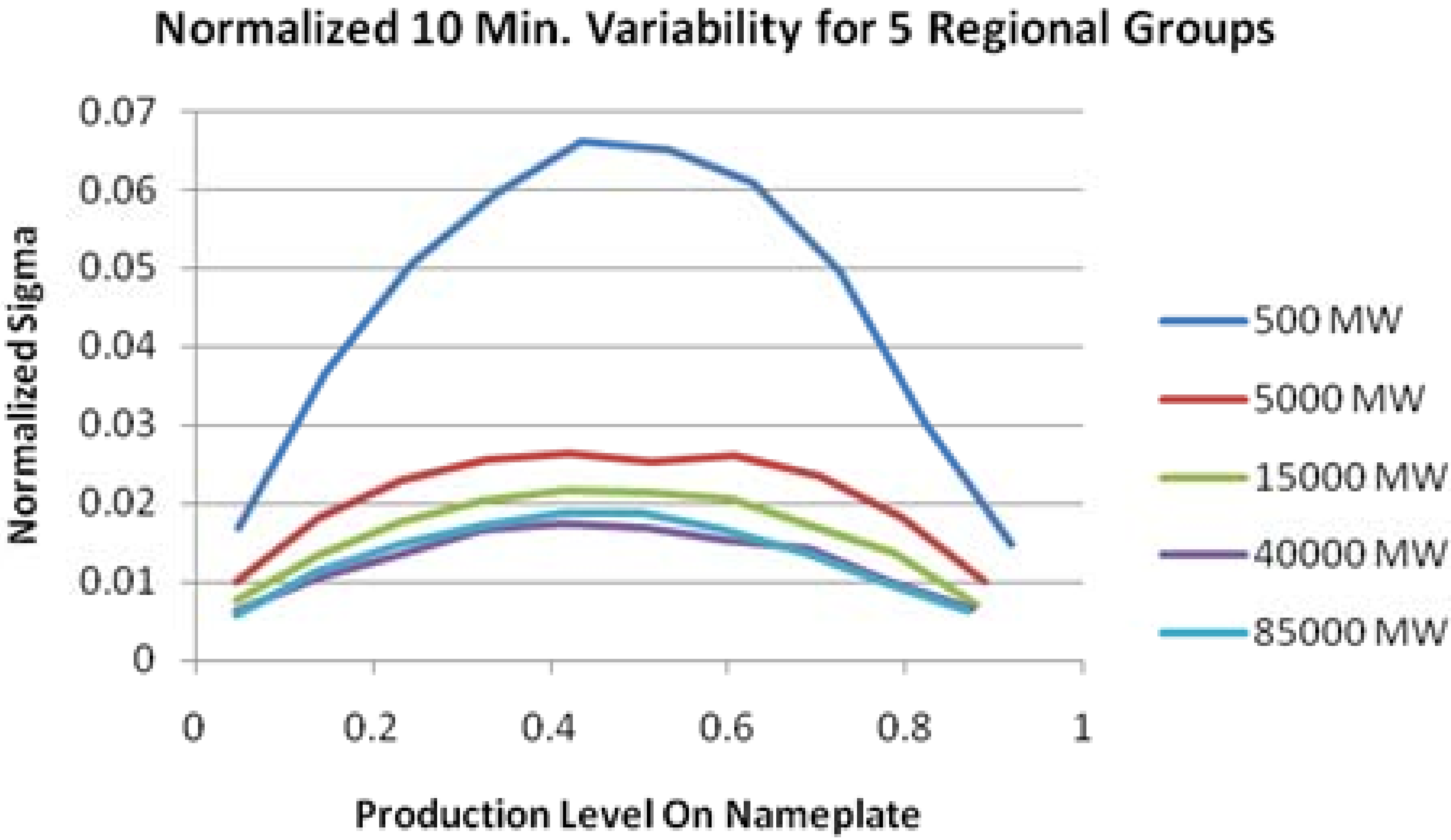


Scenario 3: 20% local, aggressive offshore



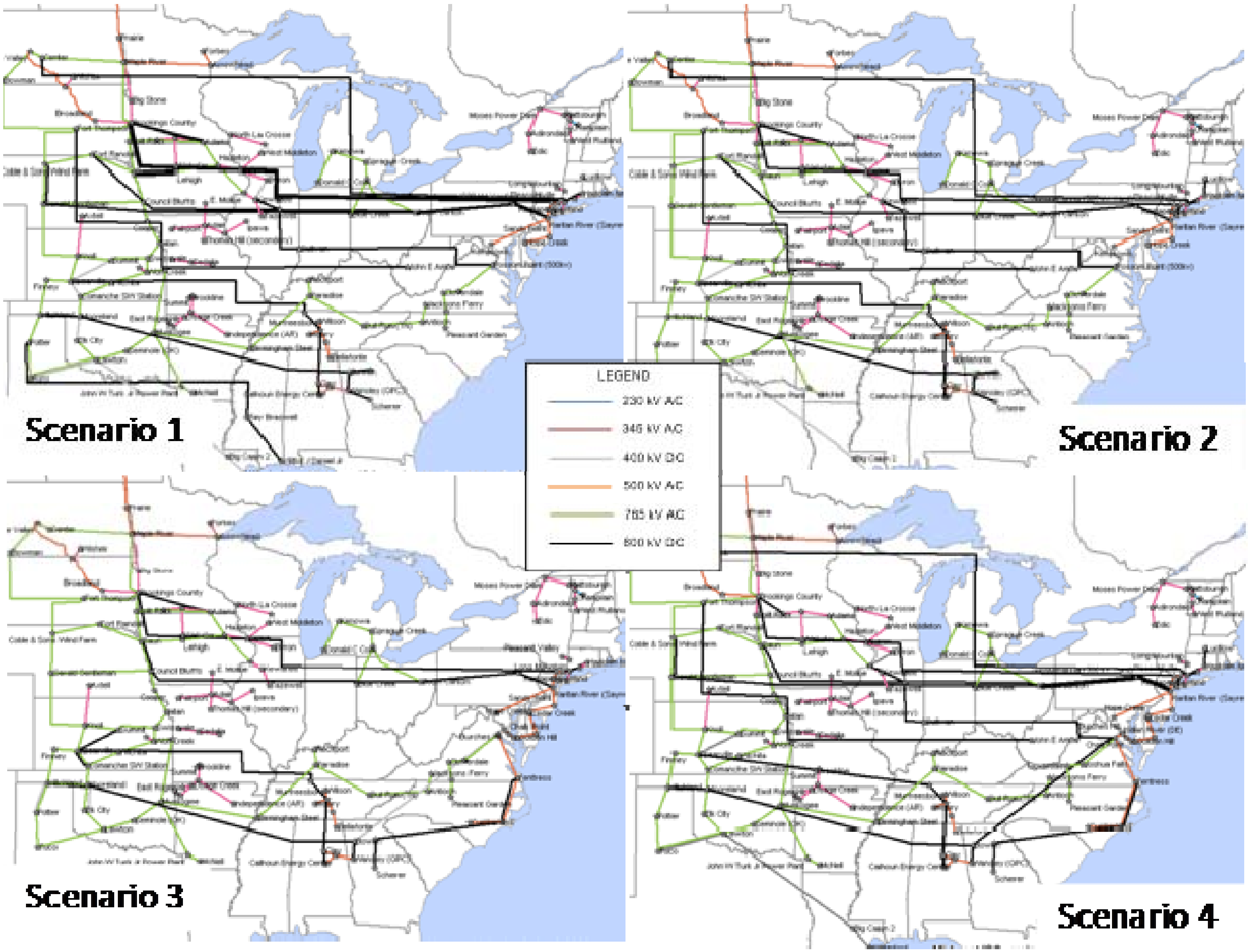
Scenario 4: 30% aggressive





Normalized 10 Min. Variability for 5 Regional Groups
Normalized Sigma
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.2
0.4
0.6
0.8
1
Production Level On Nameplate
500 MW
5000 MW
15000 MW
40000 MW
85000 MW

Conceptual Transmission Overlays

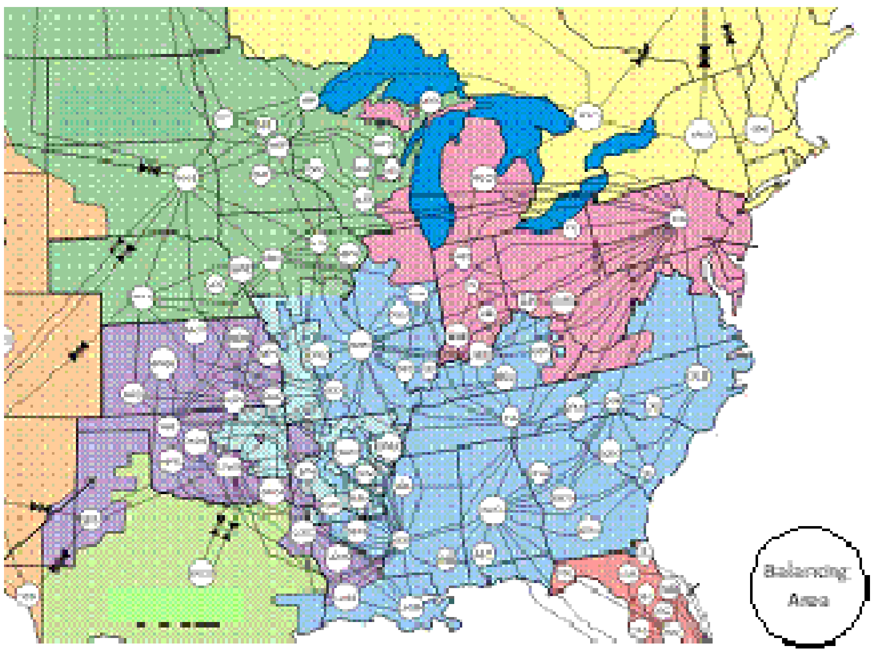


Transmission - Why are We Always Jumping Through Hoops

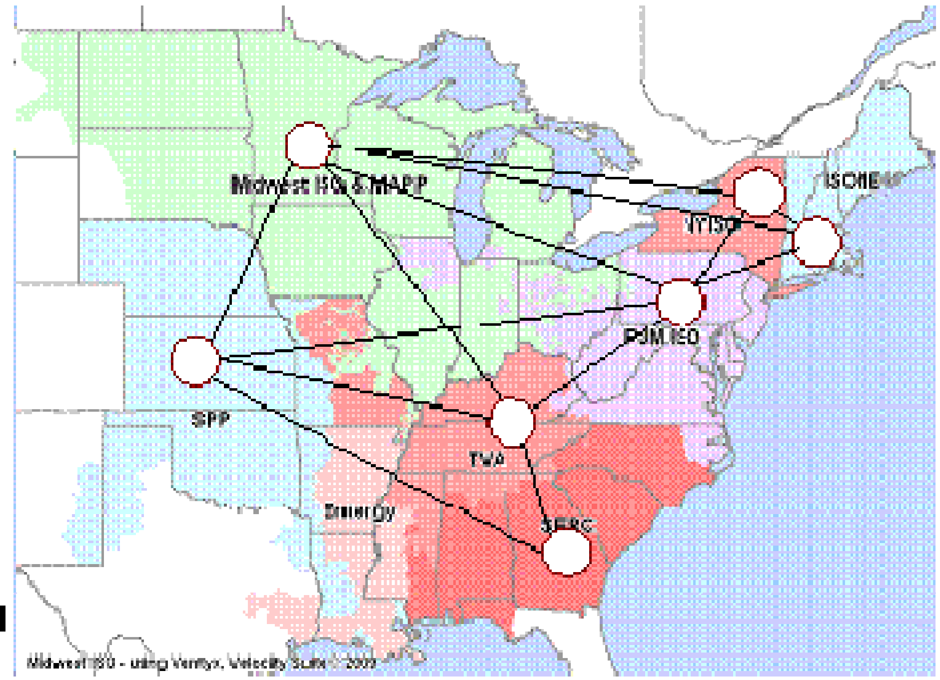
Key Task – Wind Integration

- Approach
  - Hourly simulation of operational planning and power system operation using PROMOD
    - Synchronized wind and load
  - Day-ahead unit commitment and scheduling based on load and wind generation forecasts
    - Real-time operations (hourly simulations)
    - Operational structures

Assumed operational structure for the Eastern Interconnection in 2024 (white circles represent balancing authorities)

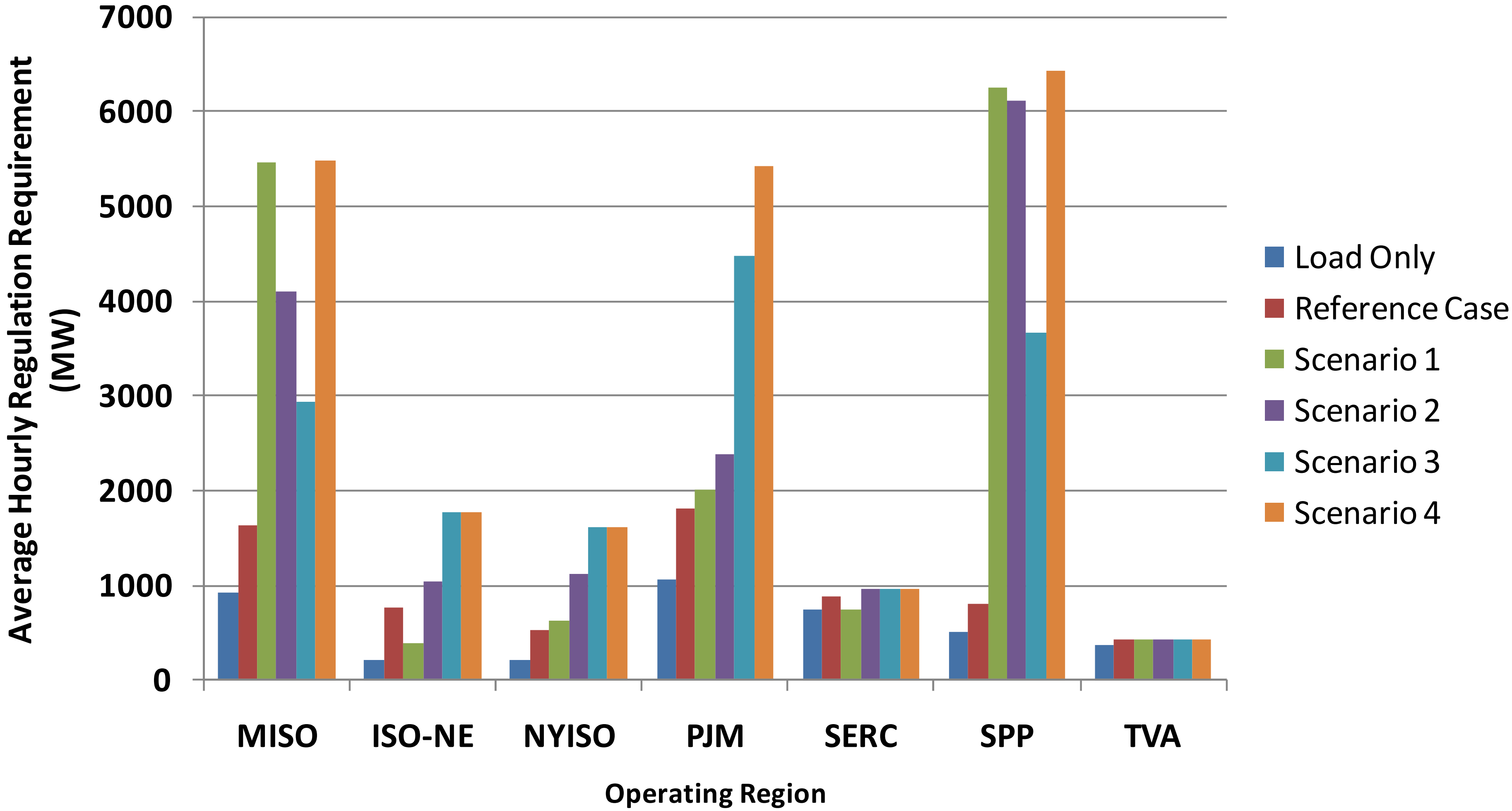


As of August 1, 2007



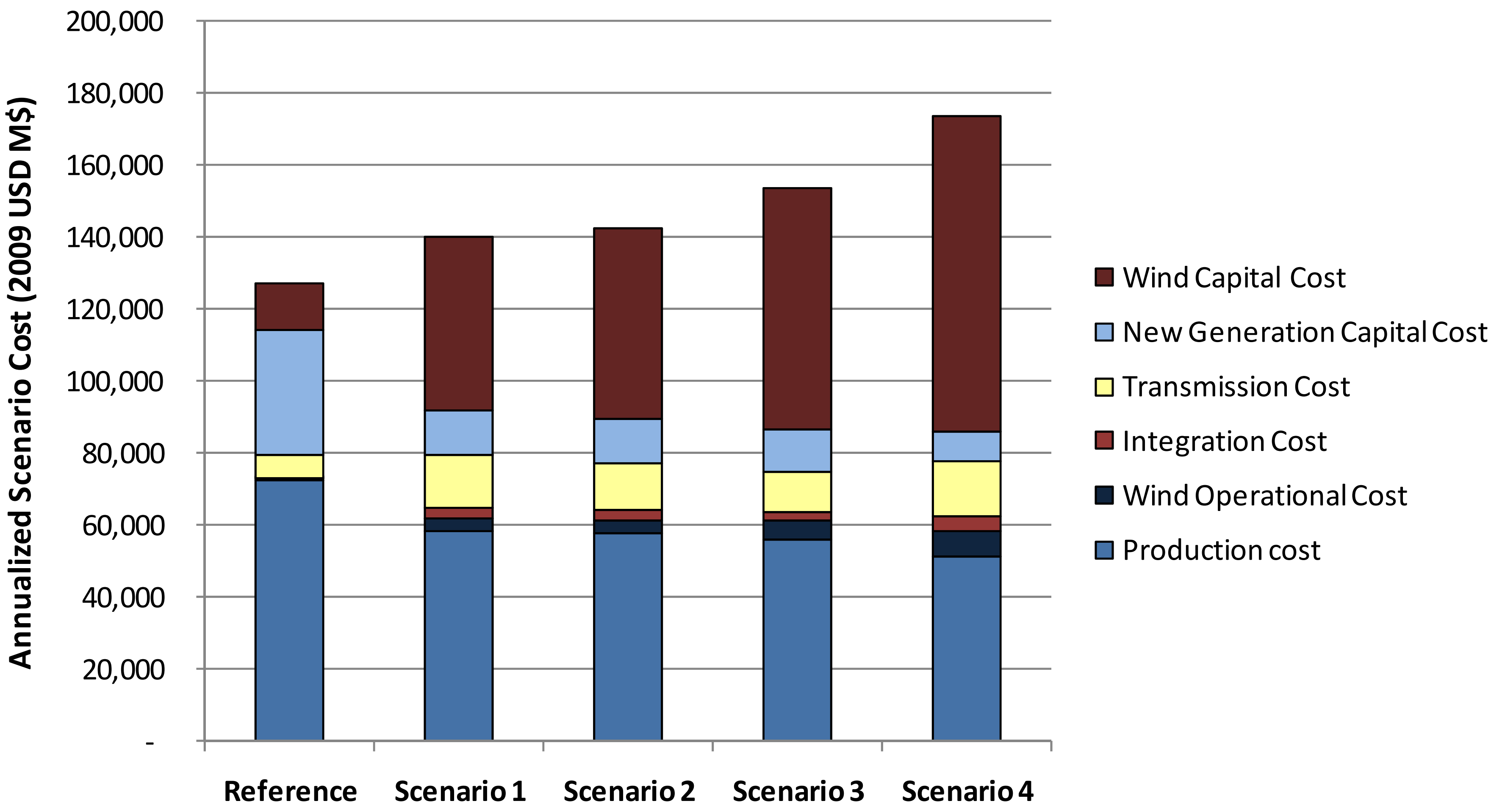
Assumption for 2024

Additional Reserve Requirements by Region and Scenario



Increased reserve does not imply increased installed or committed capacity over and above the no-wind case. It implies some generation that would be used for energy in the no-wind case is now used for reserve (or possibly different mix of units in the stack).

Total Annualized Scenario Costs



EWITS Conclusions

- 20 and 30% wind penetrations are technically feasible with significant expansion of the transmission infrastructure.
  - New transmission will be required for all the future wind scenarios in the Eastern Interconnection
- Without transmission enhancements, substantial curtailment of wind generation will occur
- Interconnection-wide costs for integrating large amounts of wind generation are manageable with large regional operating pools, where benefits of load and wind diversity can be exploited and large numbers of supply resources are efficiently committed and dispatched.

EWITS Conclusions

- Transmission helps reduce the impacts of the variability of the wind and….
  - Reduces wind integration costs
  - Reduces need for building conventional generation
  - Increases reliability of the electrical grid
  - Helps make more efficient use of the available generation resources
- Costs for aggressive expansions of the existing grid are significant, but they make up a relatively small piece of the total annualized costs in any of the scenarios studied
- Wind generation displaces carbon-based fuels, directly reducing carbon dioxide (CO_2) emissions

What is needed for large-scale integration of wind and solar?

Technical

Physical Sources of Flexibility

Alternative generation mix with more flexibility

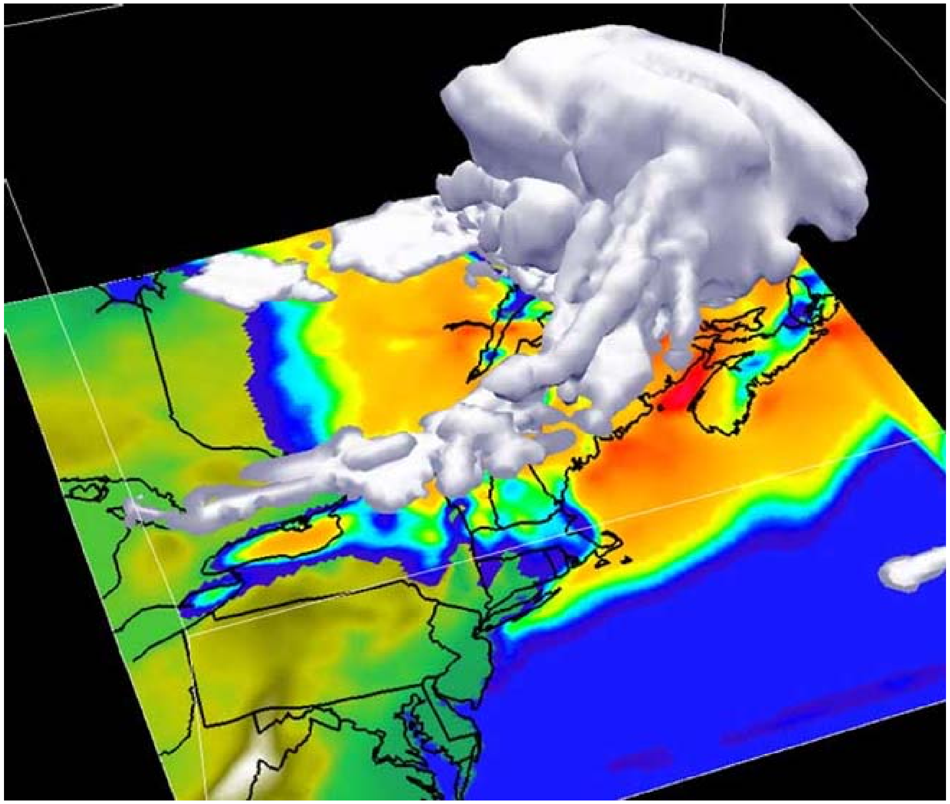
- Less base-load (or modified for flexibility)
- Aero derivative/fast-response turbines (GE, Siemens)
- Reciprocating engines (Wartsilla)
- Pumped storage

Wind/solar provide regulation

Responsive load

Electric vehicles

Forecasting

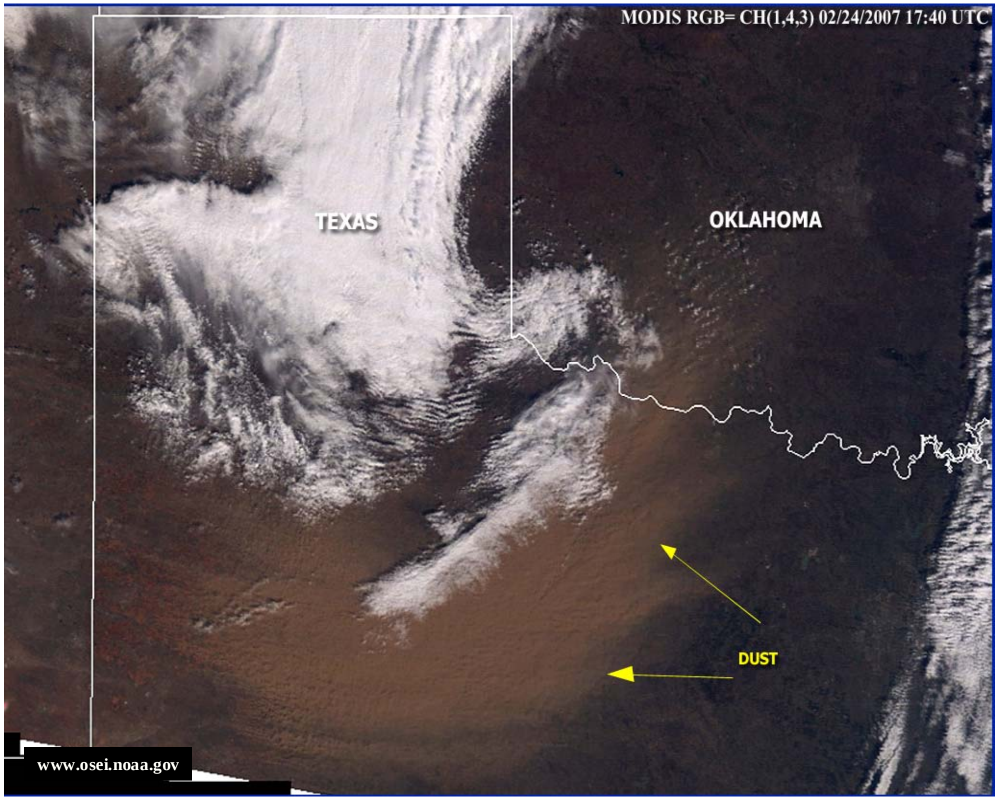


Courtesy: WindLogics, Inc. St. Paul, MN

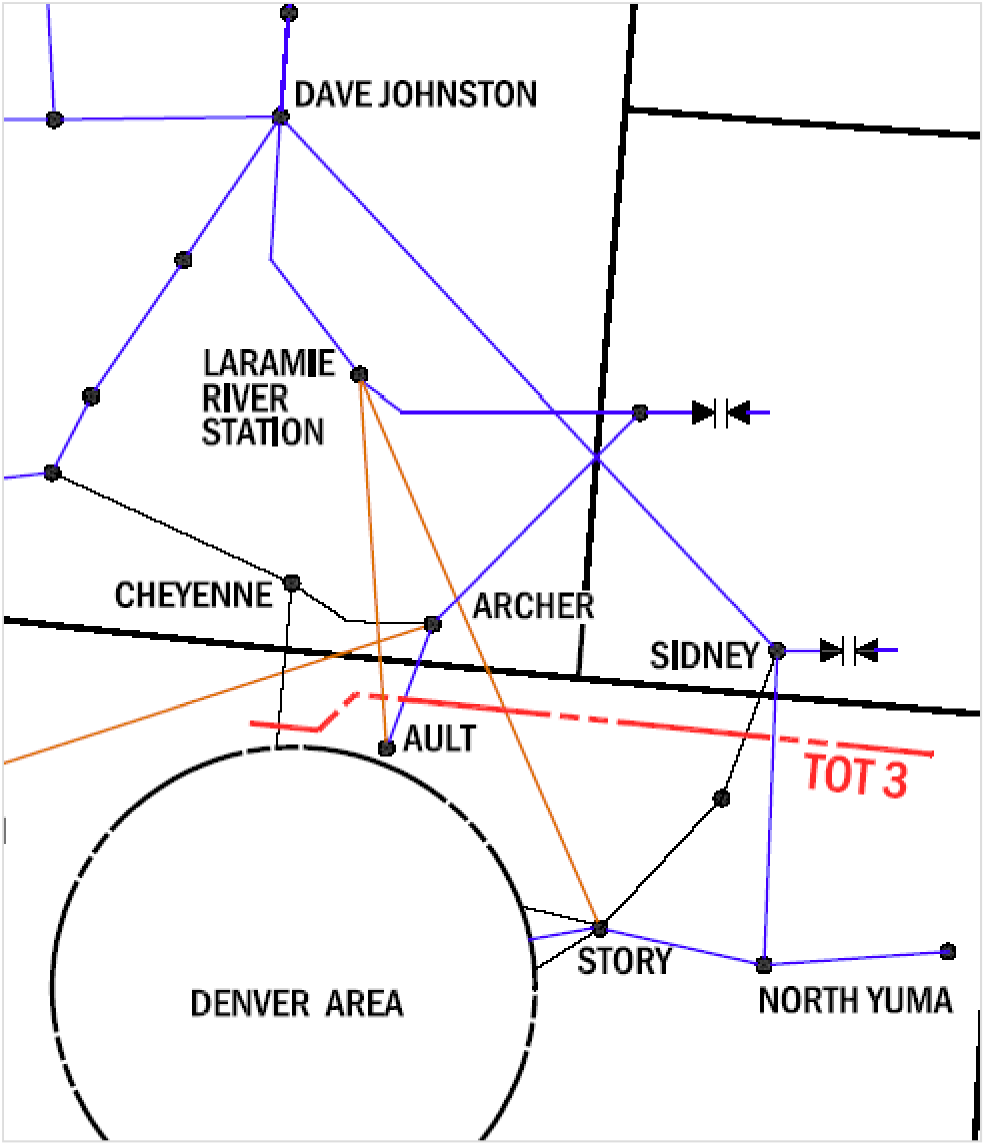
Institutional

Energy scheduling rules and other institutional factors

- Transmission protocols/scheduling in the Western Interconnection
- Fast energy markets
- Ancillary services market (and possible new AS)
- Smarter about reserves
- Smarter about wind forecasts and how to use/visualize them



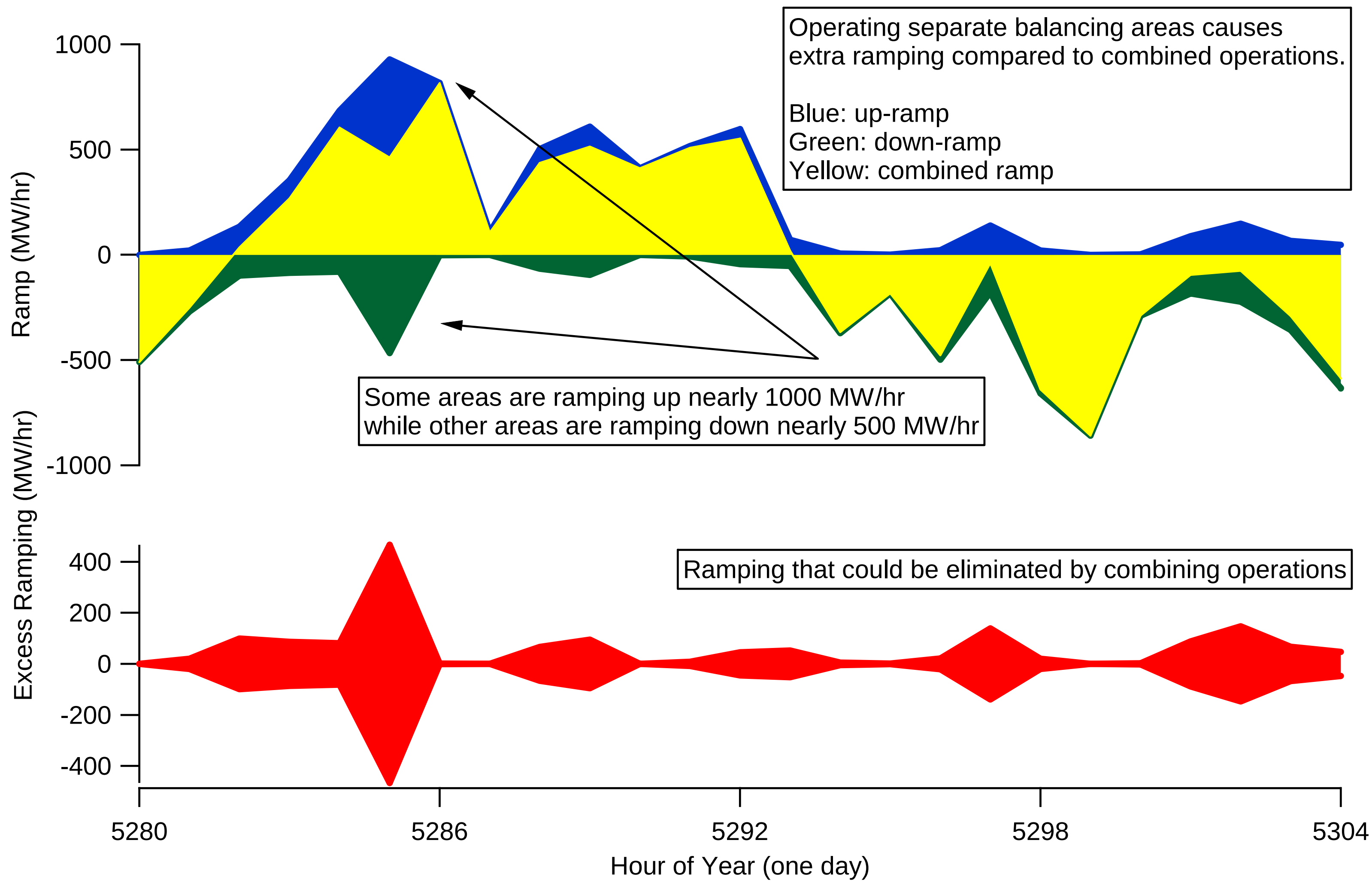
Smarter Transmission Usage



Non-spin and Supplemental reserves are 10 to 20 times cheaper than regulation and better match wind ramping characteristics

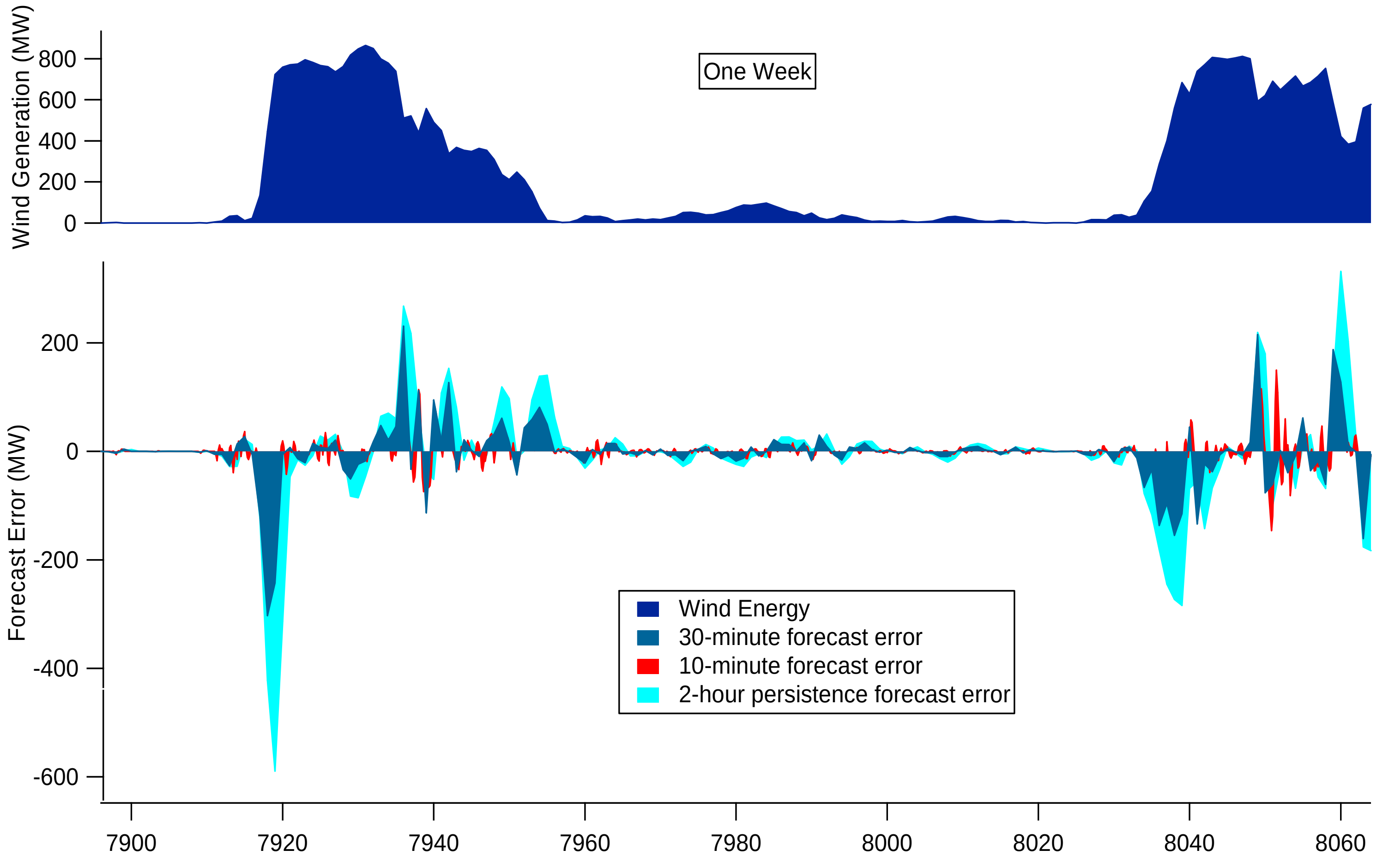
	2002	2003	2004	2005	2006	2007	2008
			Annual Average $/MW-hr				
			California (Reg = up + dn)				
Regulation	**26.9**	**35.5**	**28.7**	**35.2**	**38.5**	**26.1**	**33.4**
Spin	**4.3**	**6.4**	**7.9**	**9.9**	**8.4**	**4.5**	**6.0**
Non-Spin	**1.8**	**3.6**	**4.7**	**3.2**	**2.5**	**2.8**	**1.3**
Replacement	**0.90**	**2.9**	**2.5**	**1.9**	**1.5**	**2.0**	**1.4**
			ERCOT (Reg = up + dn)				
Regulation		**16.9**	**22.6**	**38.6**	**25.2**	**21.4**	**43.1**
Responsive		**7.3**	**8.3**	**16.6**	**14.6**	**12.6**	**27.2**
Non-Spin		**3.2**	**1.9**	**6.1**	**4.2**	**3.0**	**4.4**
			New York				
Regulation	**18.6**	**28.3**	**22.6**	**39.6**	**55.7**	**56.3**	**59.5**
Spin	**3.0**	**4.3**	**2.4**	**7.6**	**8.4**	**6.8**	**10.1**
Non Spin	**1.5**	**1.0**	**0.3**	**1.5**	**2.3**	**2.7**	**3.1**
30 Minute	**1.2**	**1.0**	**0.3**	**0.4**	**0.6**	**0.9**	**1.1**
			New England (Reg +"mileage")				
Regulation			**54.64**	**30.22**	**22.26**	**12.65**	**13.75**
Spin					**0.27**	**0.41**	**1.67**
10 Minute					**0.13**	**0.34**	**1.21**
30 Minute					**0.01**	**0.09**	**0.06**

Larger Balancing Areas (real or virtual)



Kirby, B.; Milligan, M. (2008). Impact of Balancing Area Size, Obligation Sharing, and Energy Markets on Mitigating Ramping Requirements in Systems with Wind Energy. Wind Engineering. Vol. 32(4), 2008; pp. 399-414;

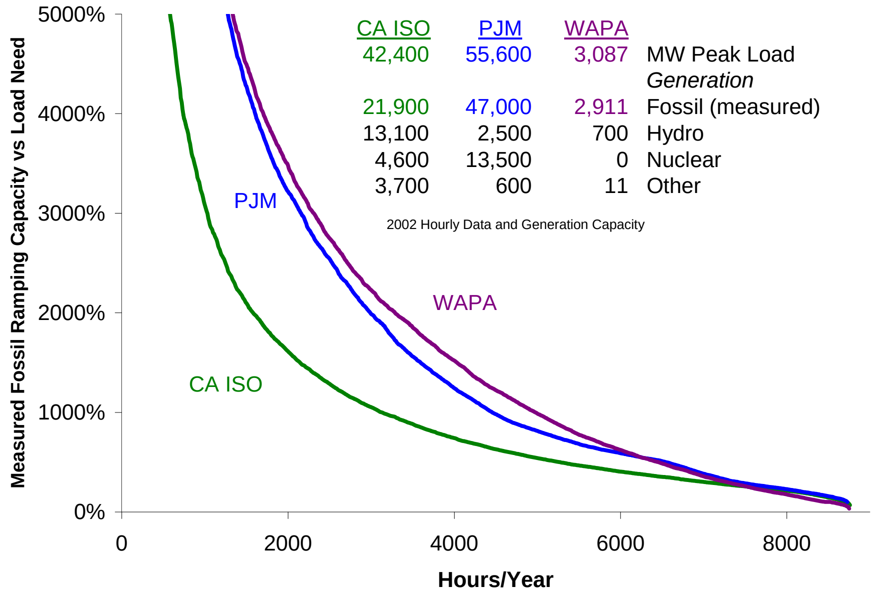
Inter-BA Scheduling and Communication



Milligan and Kirby (2009). Capacity Requirements to Support Inter-Balancing Area Wind Delivery. 29 pp.; NREL Report No. TP-550-46274, and An Examination of Capacity and Ramping Impacts of Wind Energy on Power Systems, Kirby & Milligan, ElecJ Aug./Sept. 2008, Vol. 21, Issue 7, pp 30-42

Better use of existing flexibility

- Tap into maneuverable generation that may be "behind the wall"[1]
- Provide a mechanism (market, contract, other) that benefits system operator and generator/loads
- Fast energy markets help provide needed flexibility[2] and can often supply load following flexibility at no cost[3]



Generators and loads should be able to participate in these markets equally

[1]Kirby & Milligan, 2005 Methodology for Examining Control Area Ramping Capabilities with Implications for Wind http://www.nrel.gov/docs/fy05osti/38153.pdf

[2]Kirby & Milligan, 2008 Facilitating Wind Development: The Importance of Electric Industry Structure. http://www.nrel.gov/docs/fy08osti/43251.pdf

[3]Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf

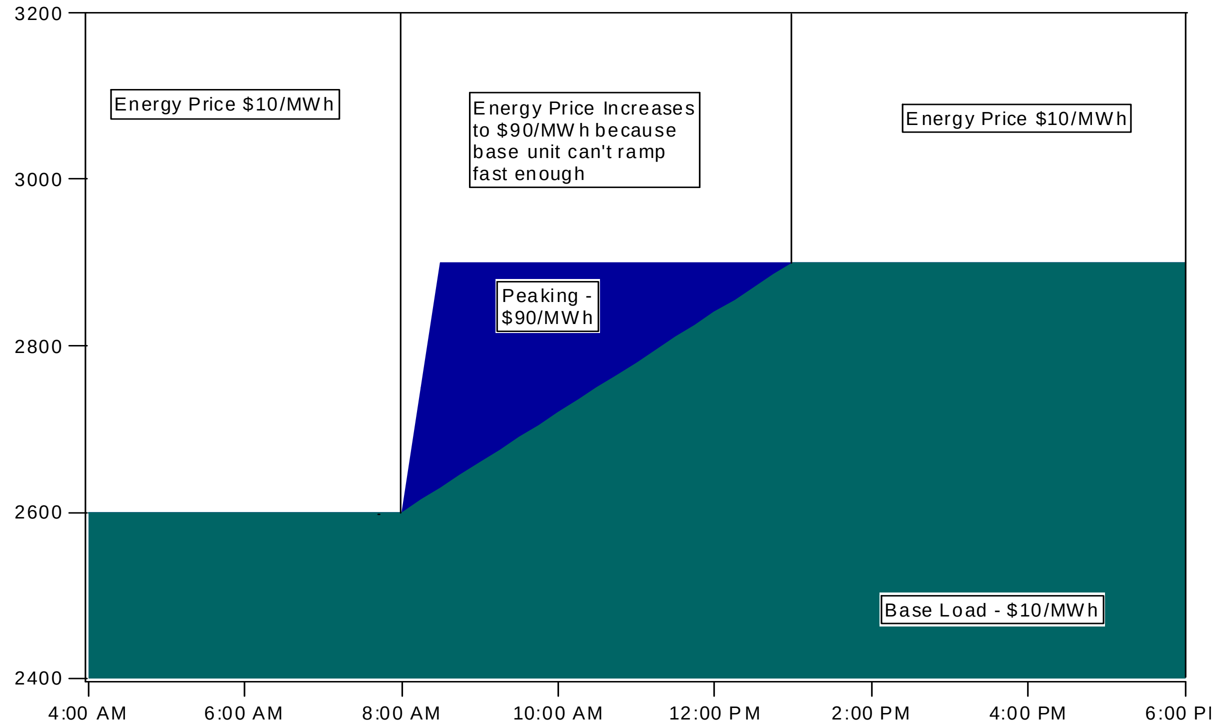
Do Markets Incent Flexibility?

Short-run

- Ramp products necessary to supplement energy markets?
- Low LMPs and capital cost recovery

Long-run

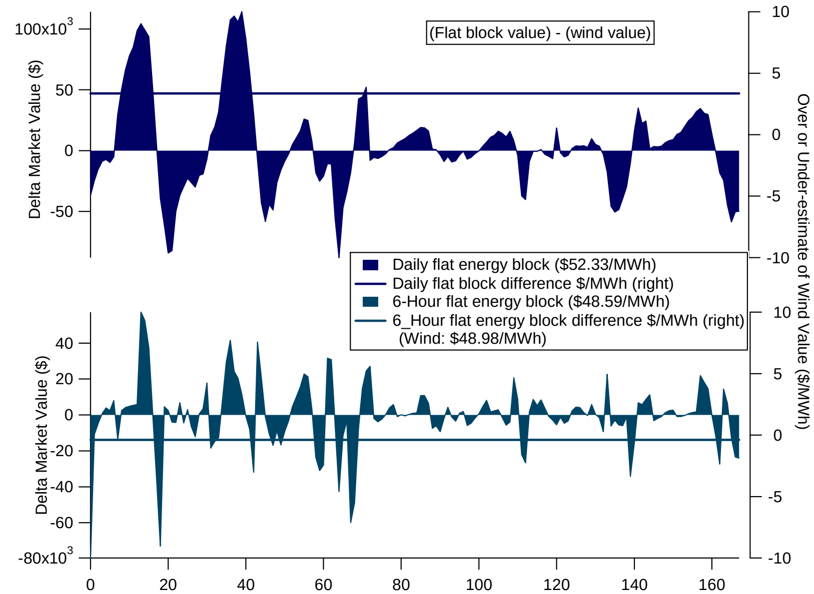
- Do prices induce long-term development of flexible supply/loads?



Integration Costs

Integration cost of wind and solar

- Can it be measured?
- If so, how is it defined?
- What is proper benchmark unit?
- How are cost and value untangled?
- What about units in one region that economically respond to needs in another region?
- Are there integration costs for other units?
  - Do all AGC units follow the signal?
  - Are there efficiency costs of adding conventional generators?



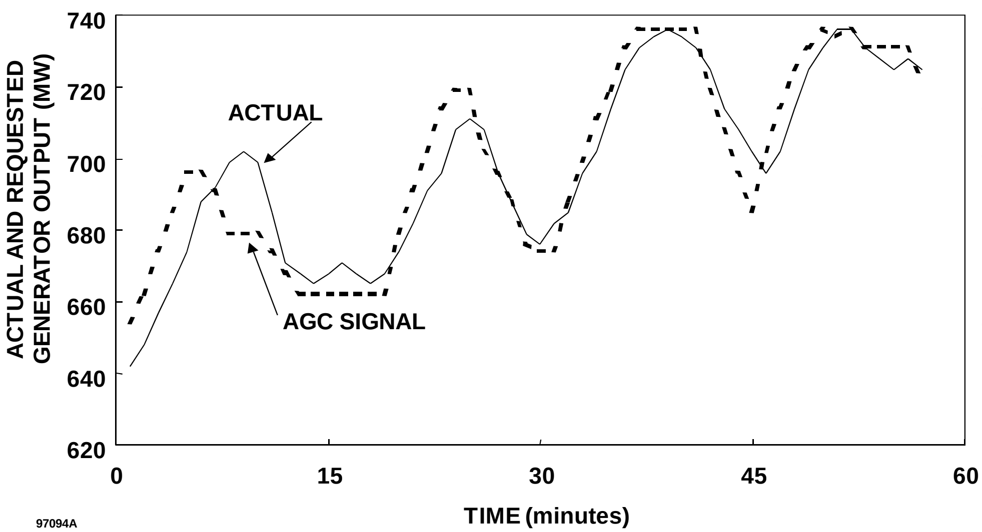
Milligan, M.; Kirby, B. (2009). Calculating Wind Integration Costs: Separating Wind Energy Value from Integration Cost Impacts. 28 pp.; NREL Report No. TP-550-46275. http://www.nrel.gov/docs/fy09osti/46275.pdf

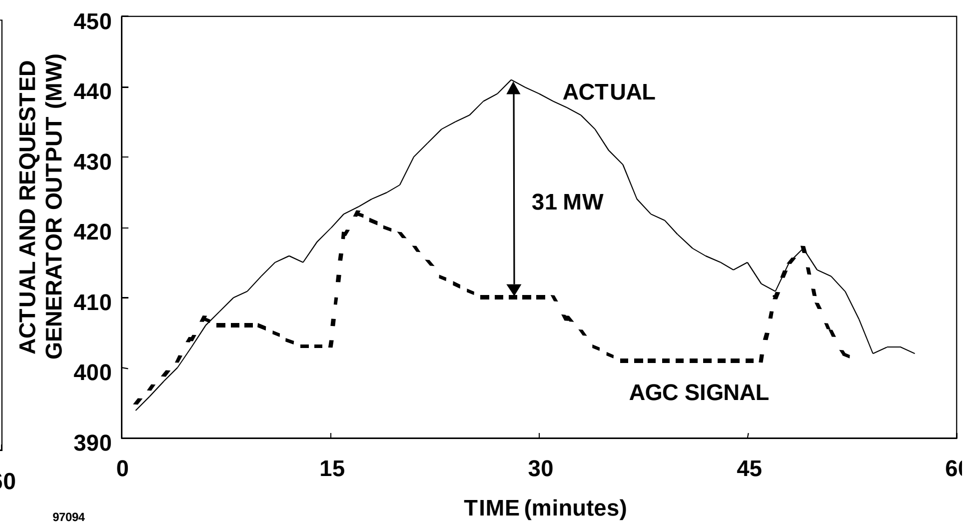
Milligan, M.; Ela, E.; Lew, D.; Corbus, D.; Wan, Y. H. (2010). Advancing Wind Integration Study Methodologies: Implications of Higher Levels of Wind. 50 pp.; NREL Report No. CP-550-48944. http://www.nrel.gov/docs/fy10osti/48944.pdf

Not all units can follow AGC

2 coal units show very different ability of following AGC.

Unit on the right *increases* the need for regulation on the system by 31 MW





Milligan, M.; Ela, E.; Lew, D.; Corbus, D.; Wan, Y. H. (2010). Advancing Wind Integration Study Methodologies: Implications of Higher Levels of Wind. 50 pp.; NREL Report No. CP-550-48944. http://www.nrel.gov/docs/fy10osti/48944.pdf

Integration cost of wind

- Large nuclear units set the contingency reserve obligation for power pools, resulting in real costs
- When any new generator is added to the generation mix, it potentially impacts *all* of the units that are above it in the dispatch stack
- Example: new cheap baseload
  - Units formerly run as base load are pushed up the stack: lower capacity factors, higher cycling
  - More cycling→higher O&M costs
  - Lower capacity factor→less revenue

Integration costs: wind and solar

Solar and wind integration issues are similar

- Wind is becoming reasonably well understood
- Solar
  - PV has high potential for short-term variability from cloud variations, but the impact of large PV plants is largely unknown
  - CSP without storage has some thermal inertia and is likely less variable than PV
  - CSP with storage is thought to be much less of an integration challenge but still unknown

Variability and uncertainty

Cycling efficiency

Are not unique to wind or solar

Accommodating Wind and Solar Integration

Example Utility Structures	Large BA	Geographically Dispersed Wind and Solar	Wind/Solar Forecasting Effectively Integrated Into System Operations	Sub-Hourly Energy Markets	Fast Access to Neighboring Markets	NonSpinning and 30 Minute Reserves for Wind/Solar Event Response	Regional Transmission Planning For Economics and Reliability	Robust Electrical Grid	More Flexible Transmission Service	Flexibility in Generation	Responsive Load	Overall
Large RTO with spot markets	10	8	7	10	7	2	7	6	7	7	3	7
Smaller ISO	6	6	6	3	3	2	6	4	7	2	2	4
Interior west & upper Midwest (non-MISO)	1	3	2	1	2	1	2	3	2	2	2	2
Large vertically integrated utility	7	6	6	2	2	2	5	4	2	5	2	4
Smaller Vertically Integrated Local Utility	1	3	2	1	2	1	2	4	2	2	2	2
Unconstrained hydro system										8		
Heavily fish constrained hydro system										3		
Weightings Factors	1	1	1	1	1	1	1	1	1	1	1	11

Adapted from Milligan, M.; Kirby, B.; Gramlich, R.; Goggin, M. (2009). Impact of Electric Industry Structure on High Wind Penetration Potential. 31 pp.; NREL Report No. TP-550-46273. http://www.nrel.gov/docs/fy09osti/46273.pdf

Selected NREL Integration Projects

- Wind → wind and solar
- Scoping EWITS 2, WWSIS 2
- Reserves analysis: UCD, MISO
- WECC's Efficient Dispatch Toolkit
- Development of variable time-step production simulation model (includes AGC)
- Coal cycling (GE, WECC)
- Wind Turbine Frequency control (EPRI, GE, others)
- Stochastic unit commitment and forecast error characterization

Questions?