Variable Renewable Generation Impact on Operating Reserves

Composite photo created by NREL

RMEL 2011 Spring Management, Engineering, and Operations Conference

May 17, 2011

Loveland, CO

Michael Milligan, Ph.D.

National Renewable Energy Laboratory

NREL/PR-5500-51497

Outline

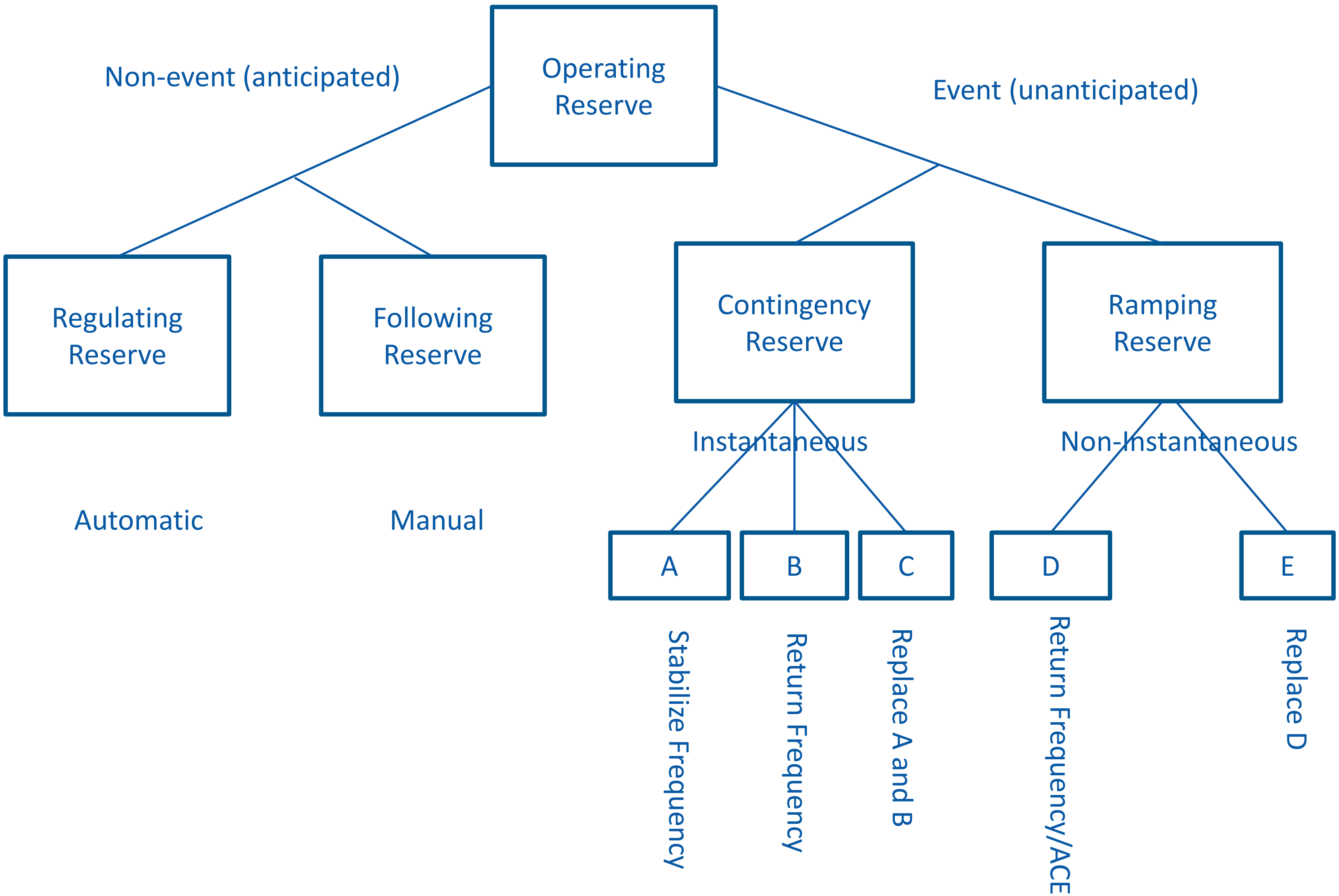
- Overview of reserves.
- Impact of wind/solar on reserves.
- What is needed for large-scale integration.

PIX 16562

NREL has Multiple Related Projects Underway

- Western Wind and Solar Integration Study (WWSIS) follow-on work:
  – Application of EWITS reserve methodology to estimate reserves impact of alternative EIM footprints (multi-phase analysis):
    - Reserve analysis;
    - Input to WECC/E3 Modeling;
    - GE-MAPS modeling;
    - PLEXOS modeling.
- Wilmington Project: collaboration with NREL, University College Dublin/Electricity Research Centre, Midwest Independent System Operator.
- International Energy Agency Collaboration.

Reserves

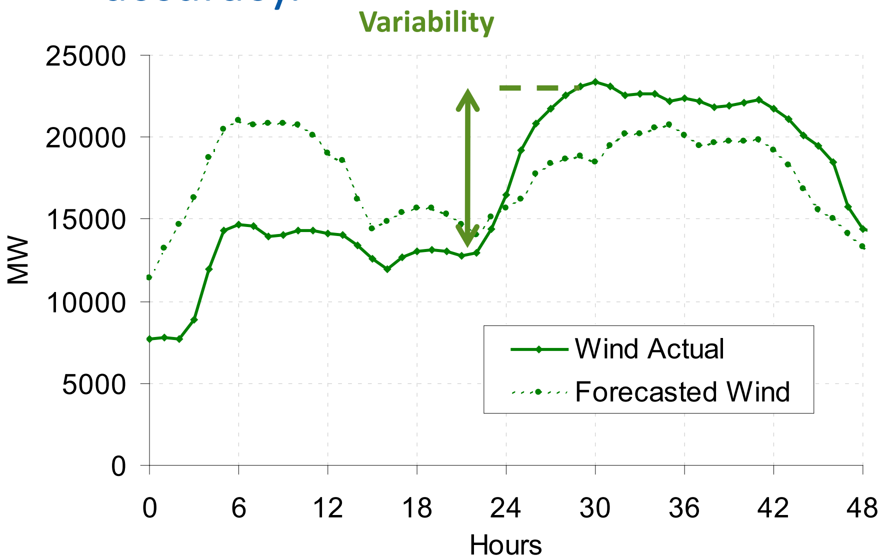


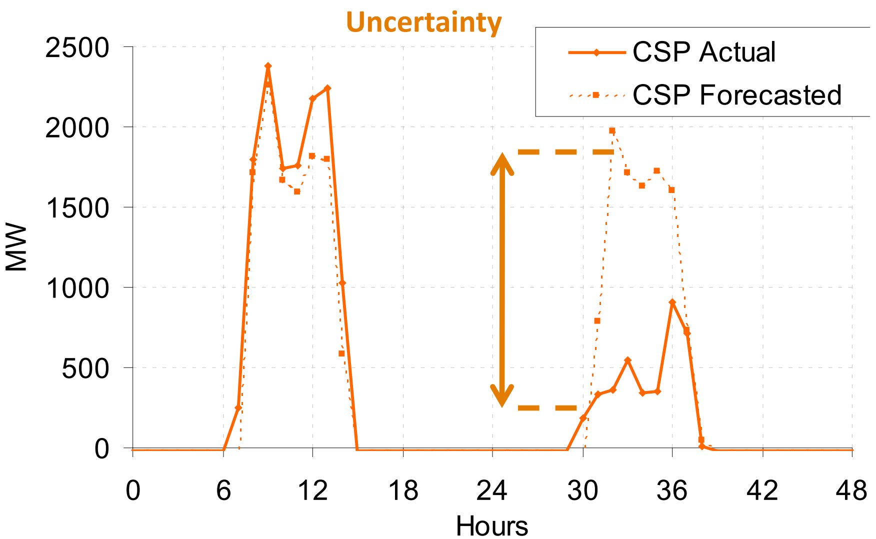
Operating Reserve
Non-event (anticipated)
Event (unanticipated)
Regulating Reserve
Following Reserve
Contingency Reserve
Ramping Reserve
Instantaneous
Non-Instantaneous
Automatic
Manual
A
B
C
D
E
Stabilize Frequency
Return Frequency
Replace A and B
Return Frequency/ACE
Replace D

Variability and Uncertainty

Variability: Wind and solar generator outputs vary on different time scales as the intensity of their energy sources (wind and sun).

Uncertainty: Wind and solar generation cannot be predicted with perfect accuracy.



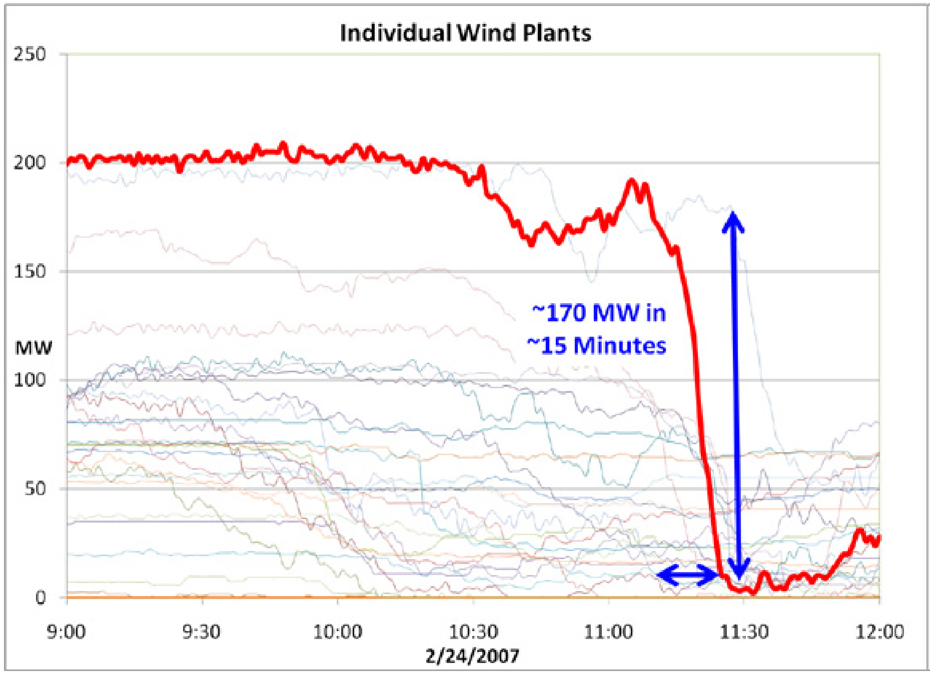


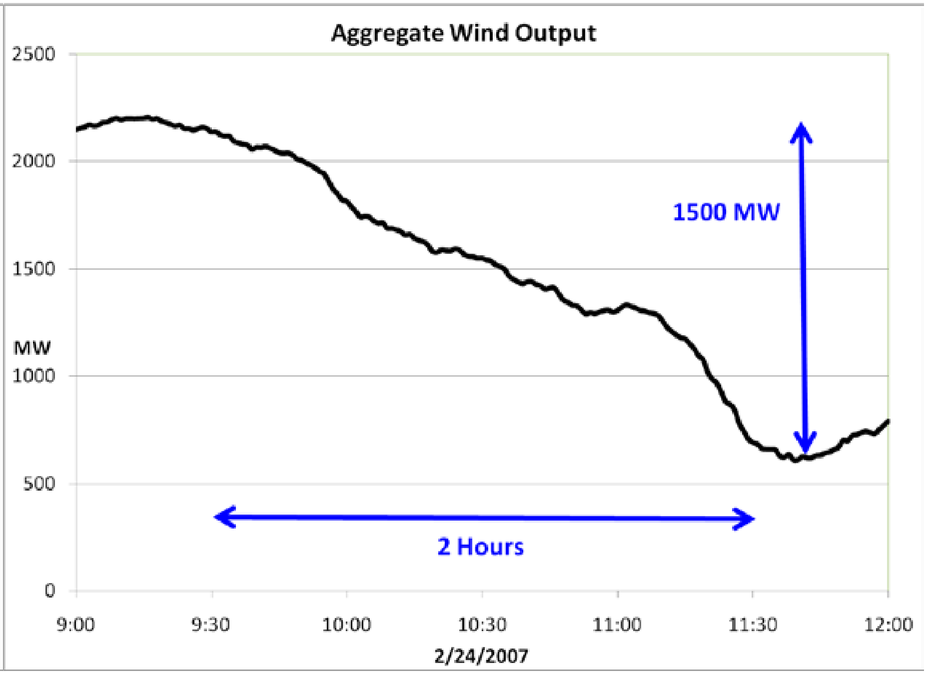
Variability: load varies throughout the day, conventional generation can often stray from schedules.

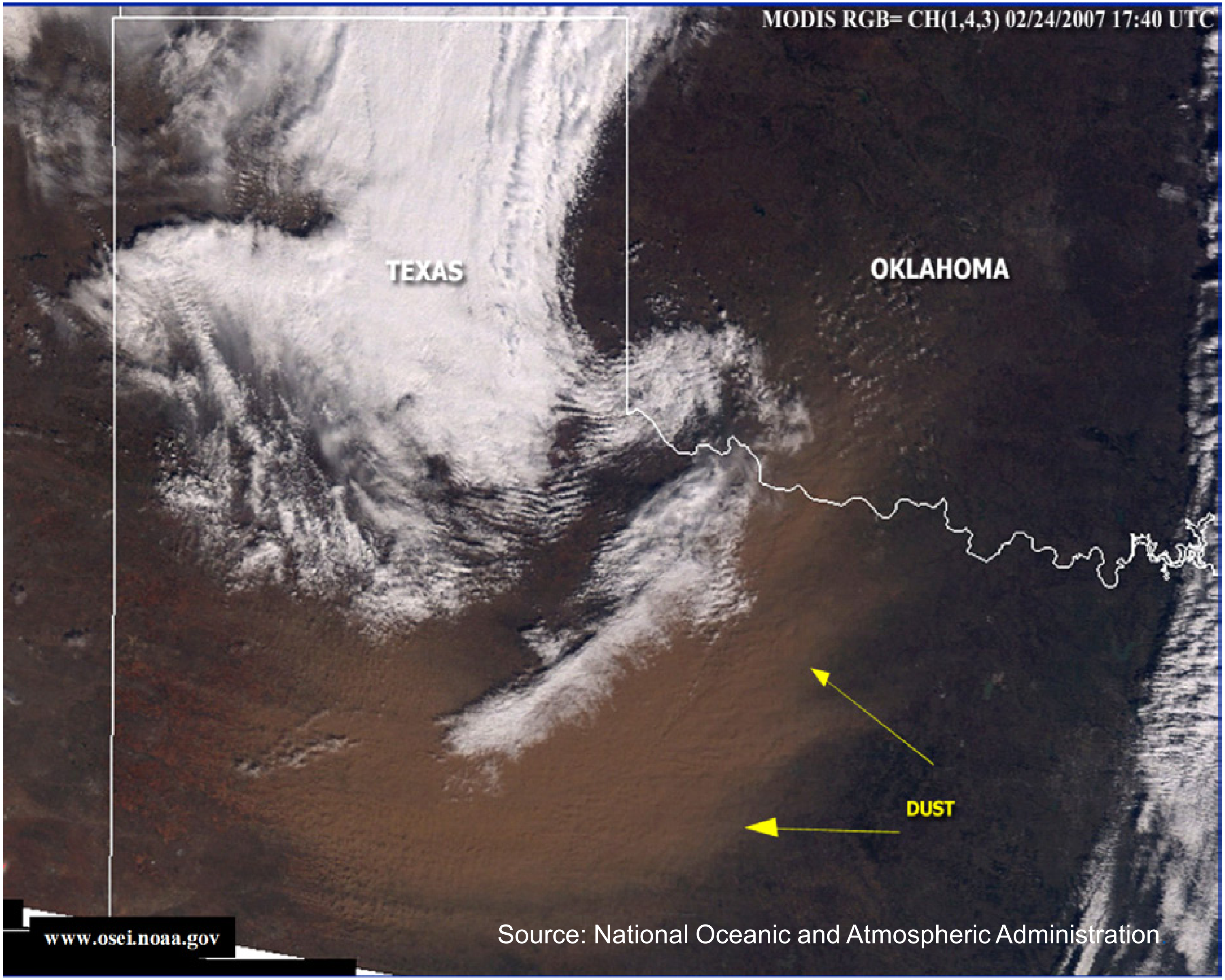
Uncertainty: Contingencies are unexpected, load forecast errors are unexpected.

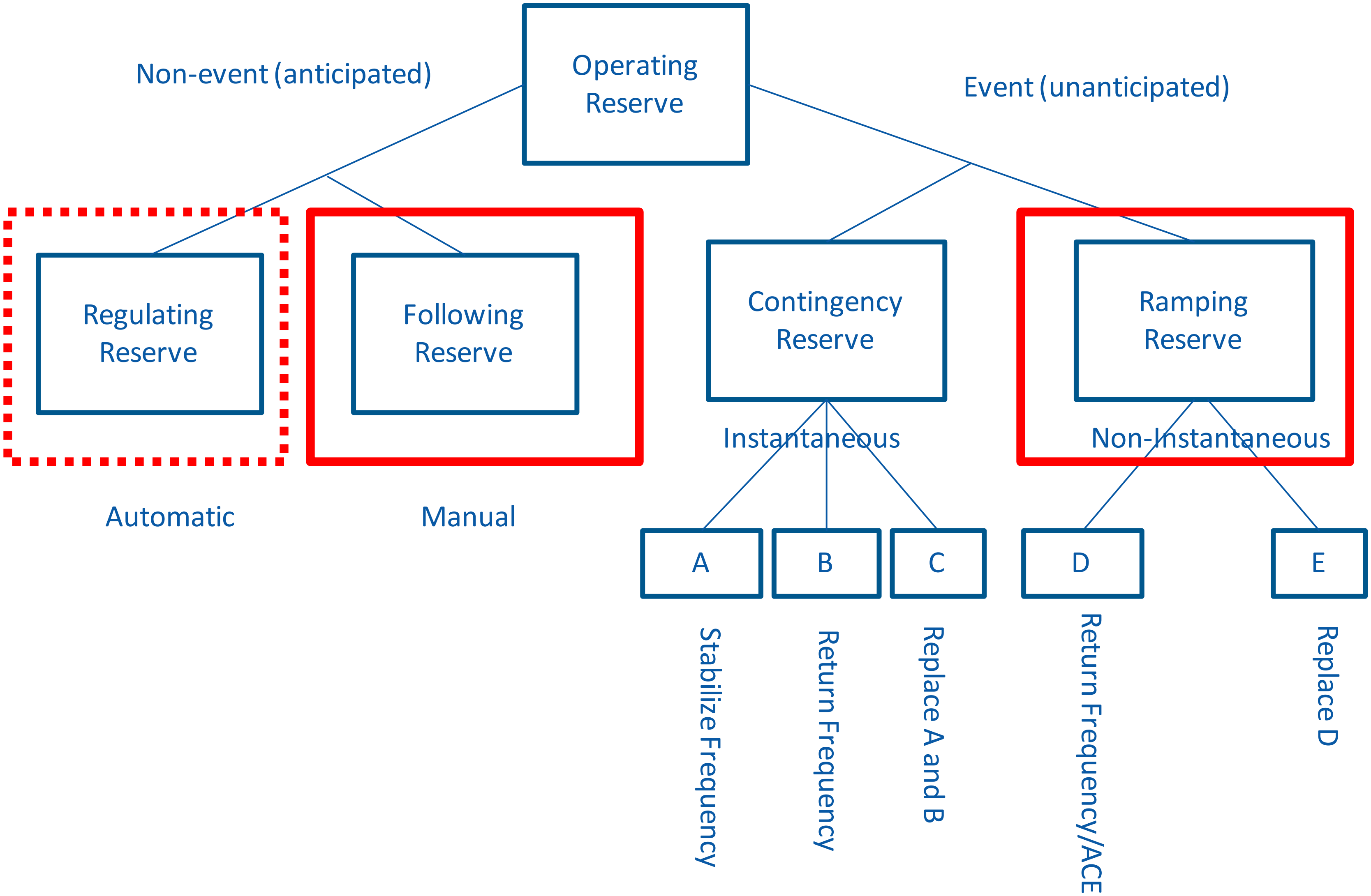
Wind and Solar Reserves

- Too slow to be contingency reserves…but large events are relatively rare and can often be forecast.



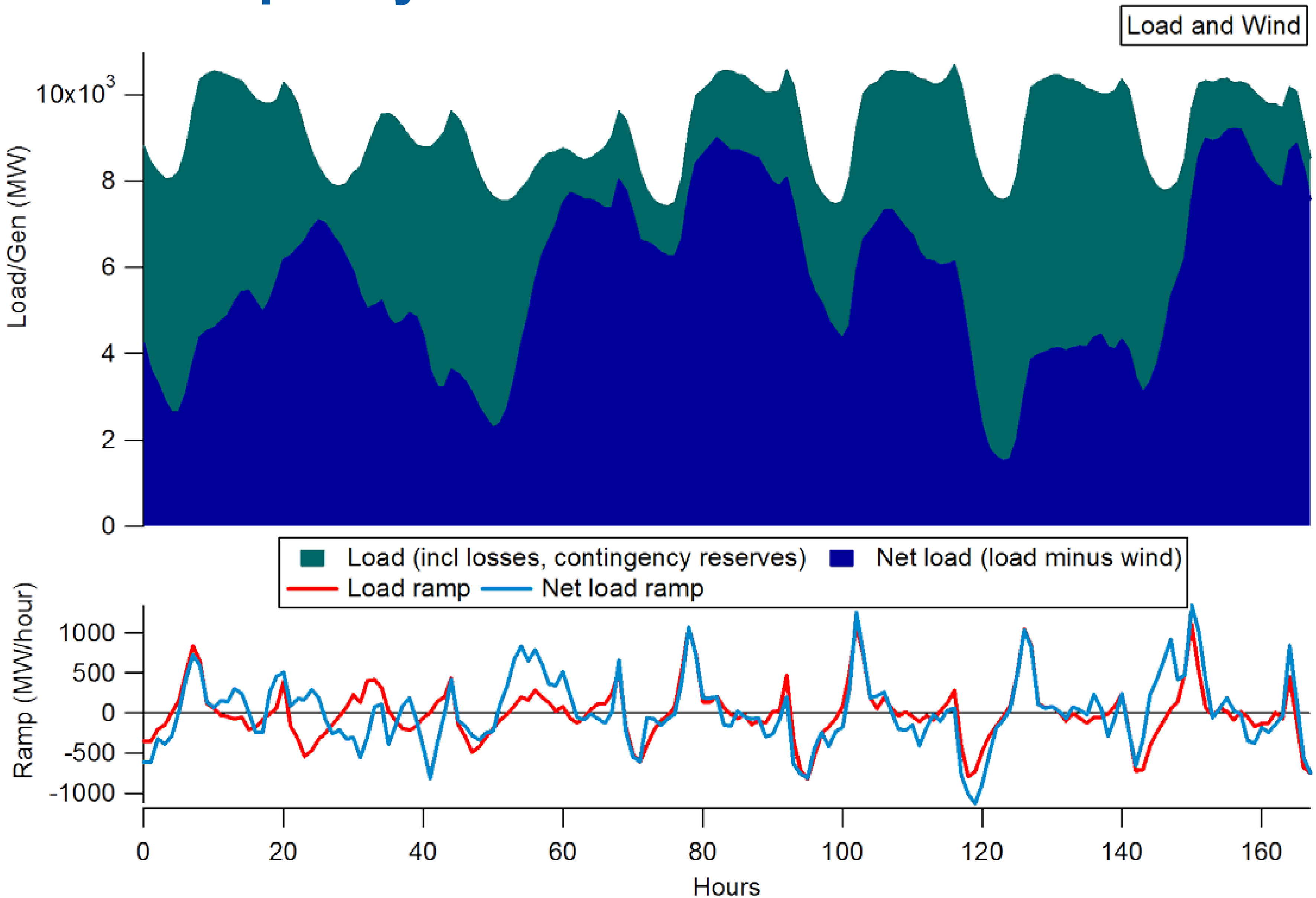



MODIS RGB= CH(1,4,3) 02/24/2007 17:40 UTC
TEXAS
OKLAHOMA
DUST
www.osei.noaa.gov
Source: National Oceanic and Atmospheric Administration

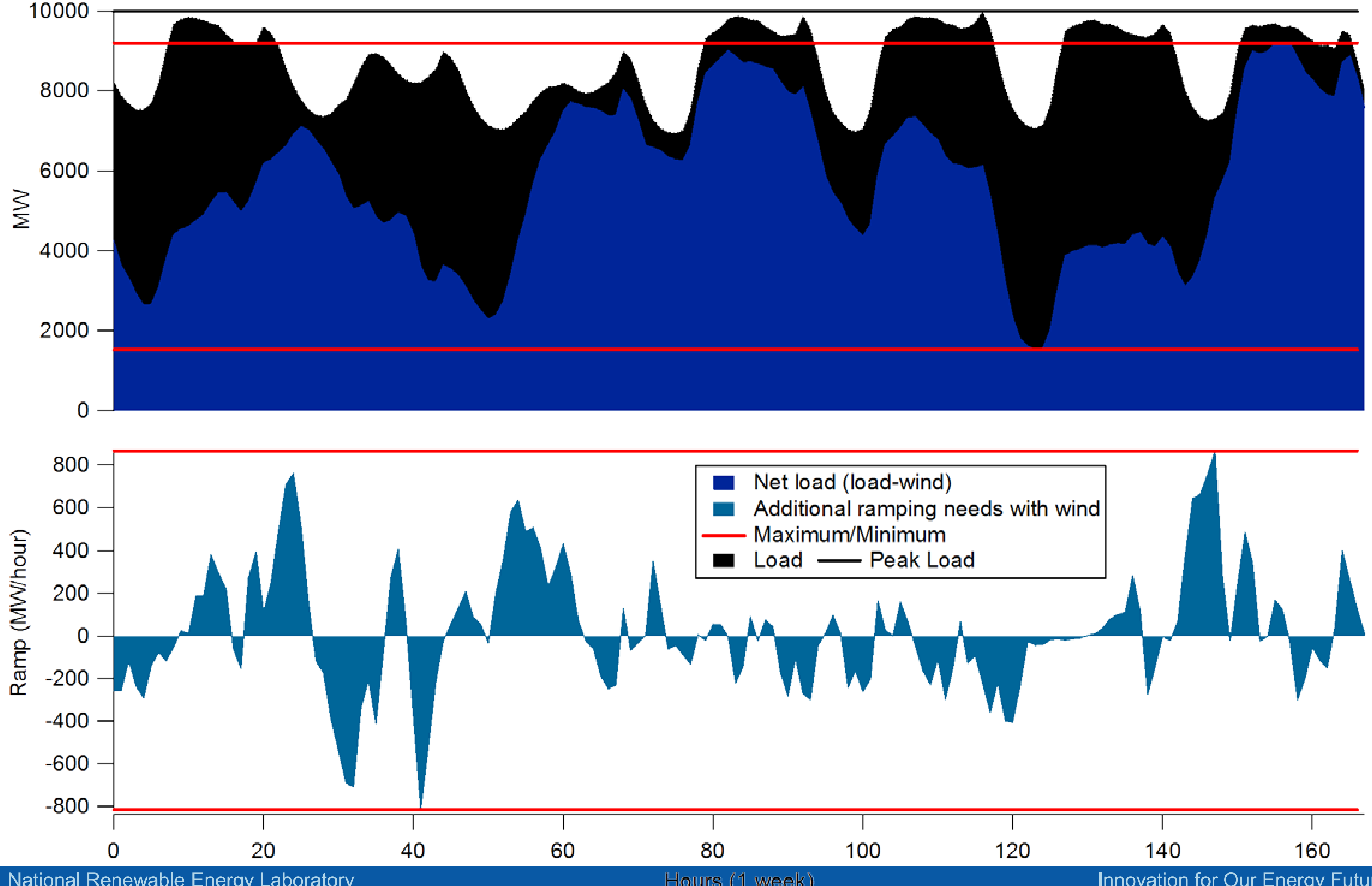


Operating Reserve
Non-event (anticipated)
Event (unanticipated)
Regulating Reserve
Following Reserve
Contingency Reserve
Ramping Reserve
Instantaneous
Non-Instantaneous
Automatic
Manual
A
B
C
D
E
Stabilize Frequency
Return Frequency
Replace A and B
Return Frequency/ACE
Replace D

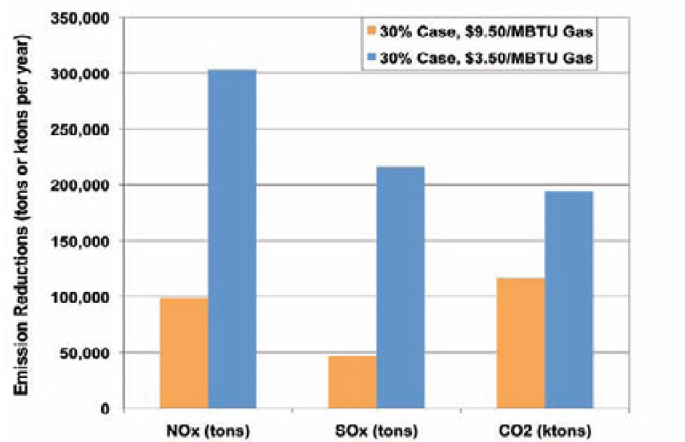
VG Requires More Operating Range But Not More Capacity



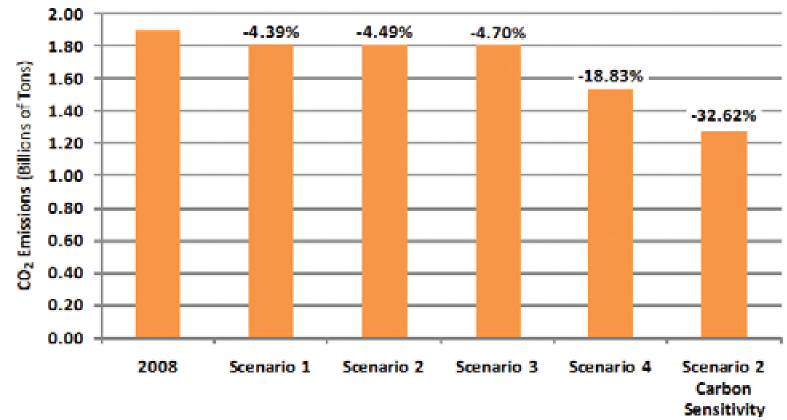
Additional Ramping/Range



Wind Reduces Emissions, Including Carbon



At high prices natural gas is displaced by renewable generation, leaving coal plants to handle variability at lower emissions reductions. When coal is displaced instead, greater emission reductions are observed.



Scenarios 1-3 are for 20% wind power penetration, with various combinations of new transmission and offshore wind farms, while Scenario 4 is for 30% wind power penetration. Scenario 2 Carbon Sensitivity includes the results if a $100/ metric ton carbon tax were imposed.

Western Wind and Solar Integration Study, www.nrel.gov/wwsis.
Every 3 wind-generated MW reduces thermal commitment by 2 MW.

Also see *Impact of Frequency Responsive Wind Plant Controls on Grid Performance*, Miller, Clark, and Shao. 9th International Workshop on Integration of Wind Power into Power Systems, Quebec, Canada, October 2010.

Results show decline from 2008, also eliminating any increase in carbon from 2008-2024. www.nrel.gov/ewits. Overall reduction in emissions in study year is estimated to be approximately 33-47%, depending on wind energy penetration scenario.

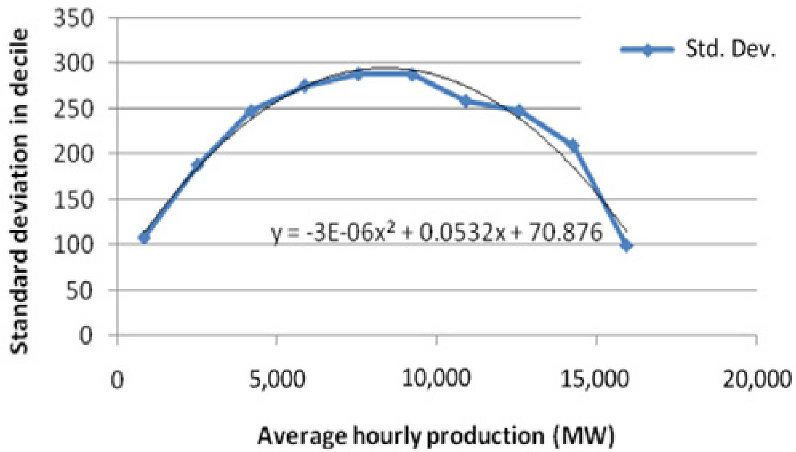
Trend in Analysis Towards Alternatives

Constant reserve

Things change with lots of Wind, Solar.

Variable reserve and moving away from traditional practice.

Base on expected variability.

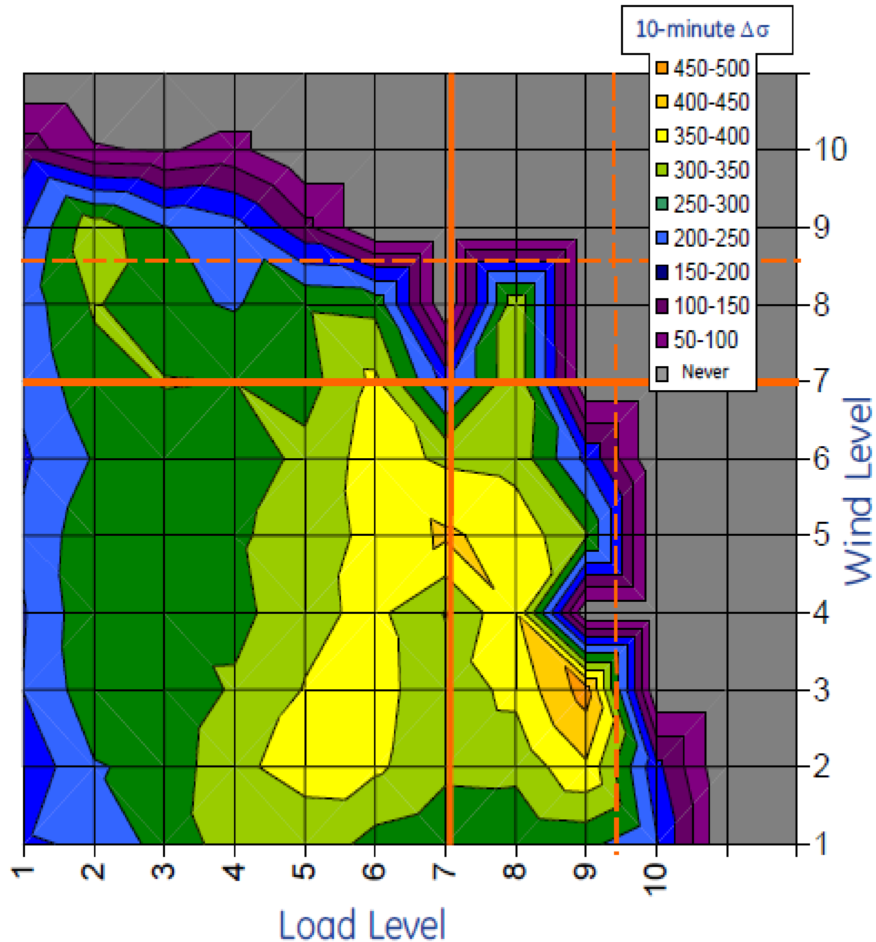


Ramp impacts.

Recognition that reserve products, markets may need to evolve further.

Analytic Approaches

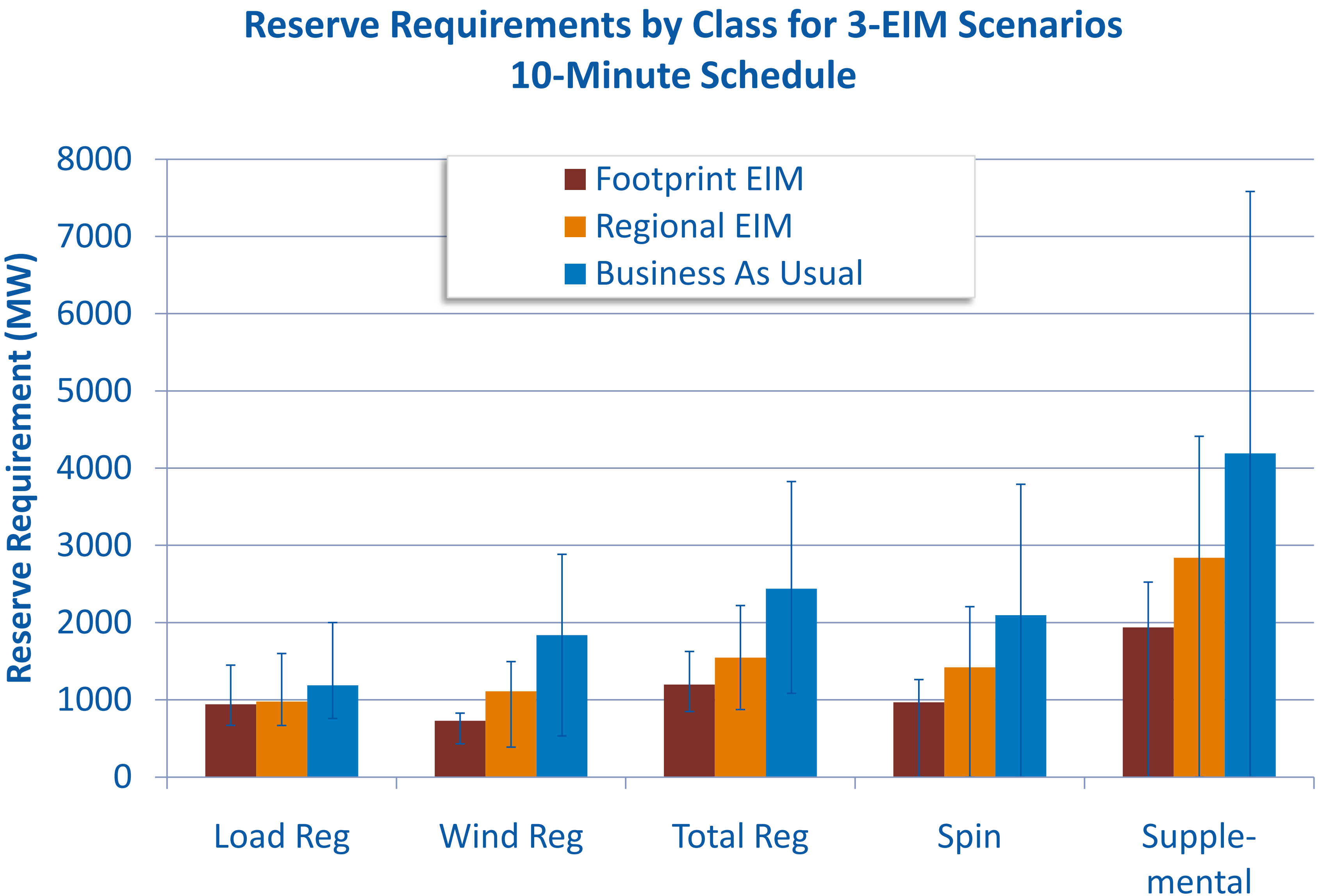
- Production cost modeling –
  - PLEXOS 5-minute modeling;
  - FESTIV high resolution modeling;
  - Stochastic scheduling programs.
- Statistical analysis.
- Hybrid.



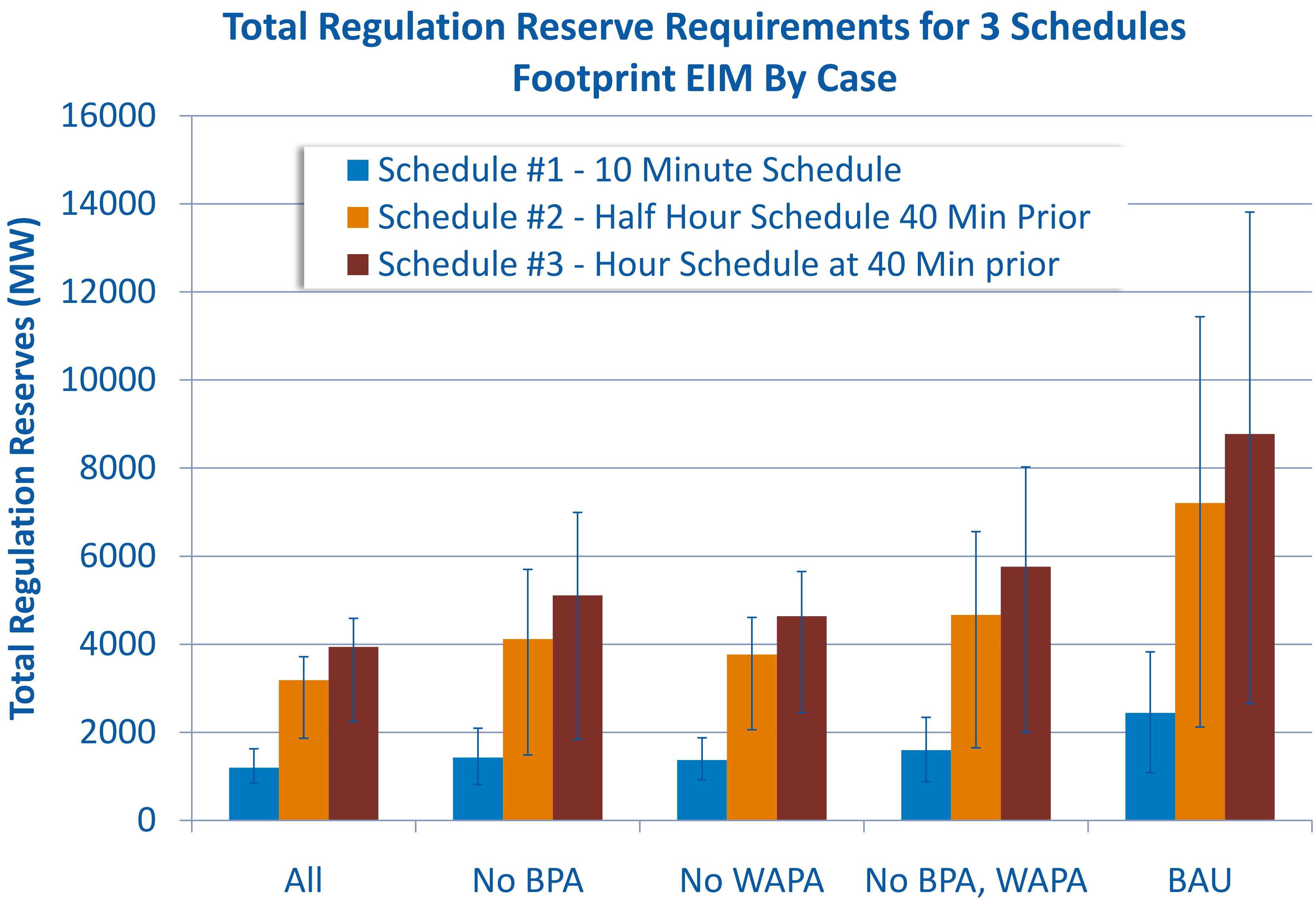
Reserves Depend Upon Many Factors

- Physical speed of response:
  - Needed.
  - Capability.
- Institutional:
  - Footprint size.
  - Scheduling practice.

Larger Footprints Reduce Reserve Requirements



Faster Scheduling Reduces Reserve Requirements



NREL-MISO-UCD Collaboration

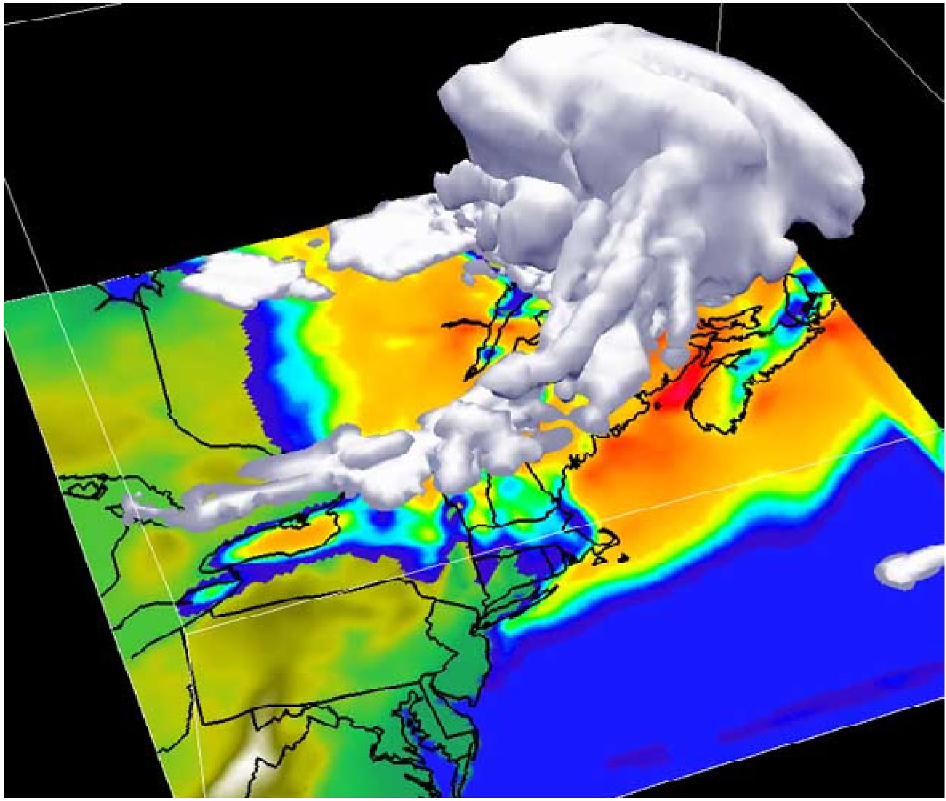
- Application of FESTIV and PLEXOS models.
- FESTIV:
  - SCUC, SCED, and AGC, all configurable;
  - Stochastic and deterministic;
  - Alternative AGC modes and time steps.
- Build off MISO system.
- Test the performance of alternative reserve approaches and simplified “rules.”

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.

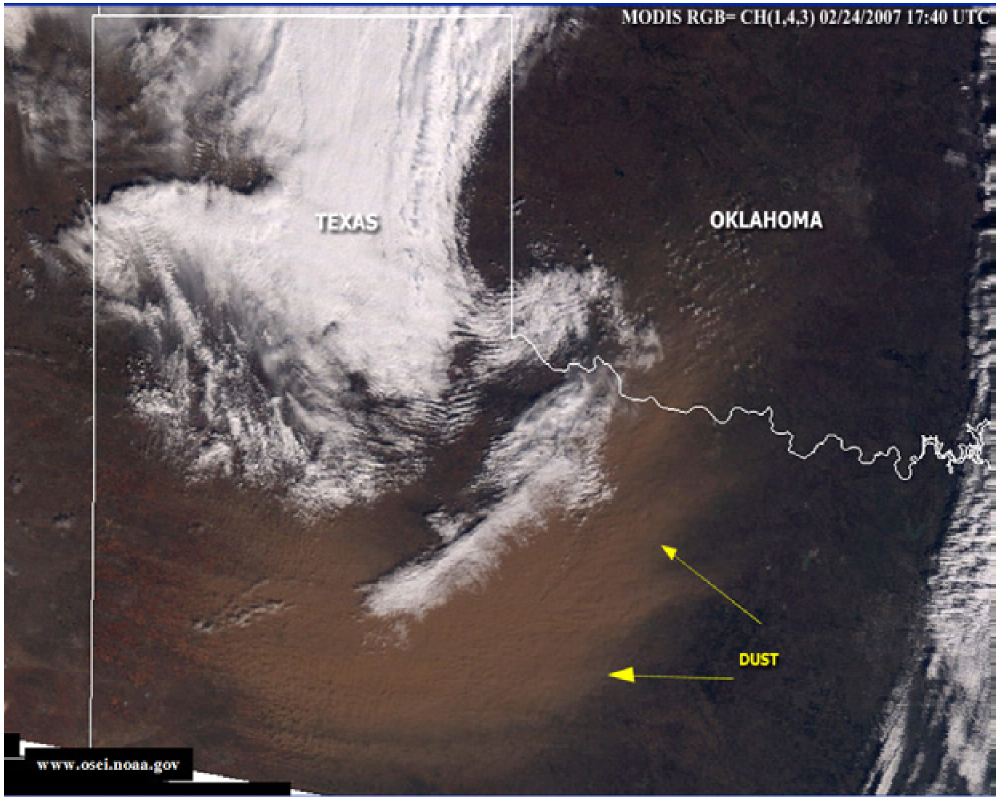


Courtesy: WindLogics, Inc. St. Paul, MN

Institutional

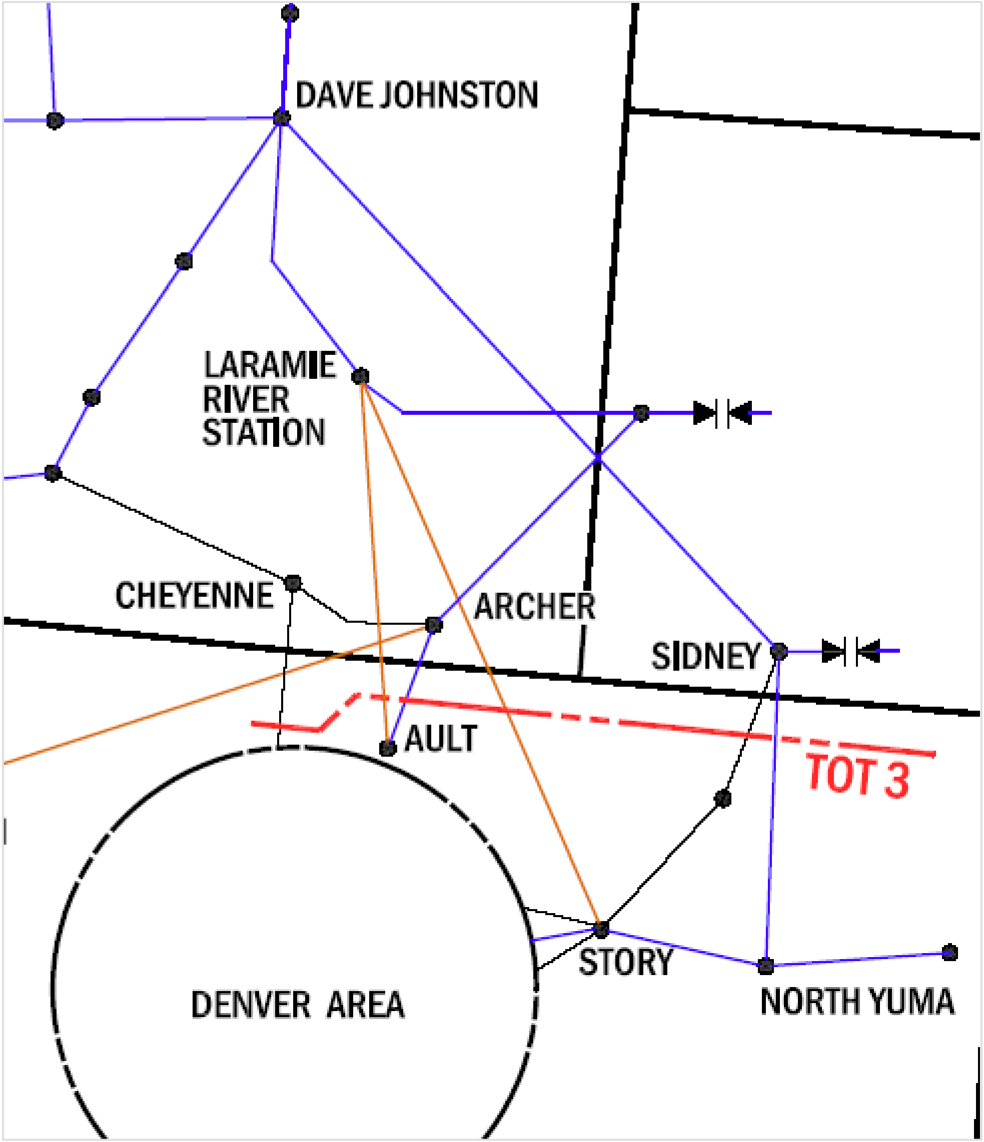
Energy Scheduling Rules and Other Institutional Factors

- 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.



Source: National Oceanic and Atmospheric Administration.

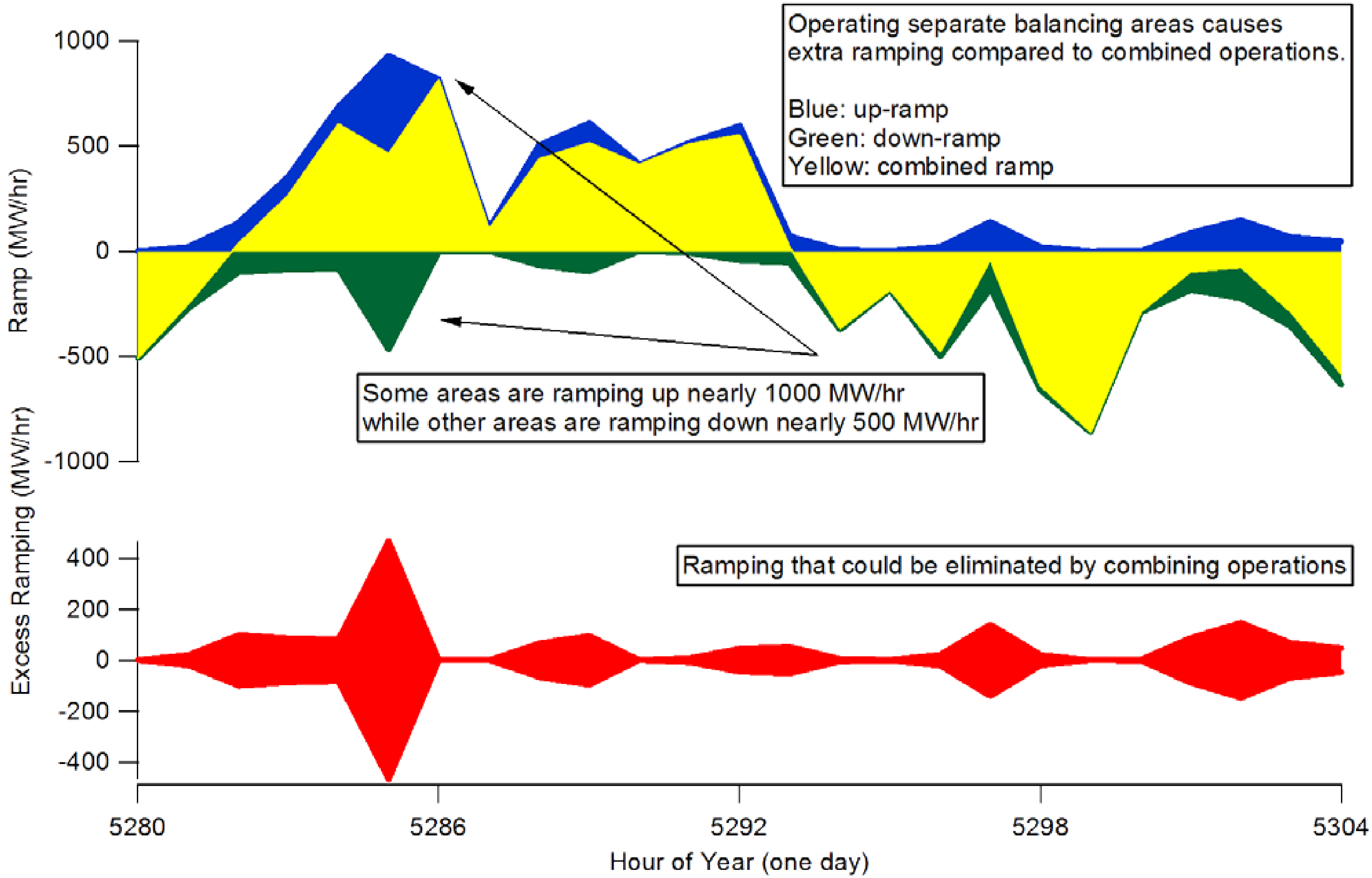
Smarter Transmission Usage



Non-Spin and Supplemental Reserves are 10 to 20 Times Cheaper than Regulation and Better Match Wind Ramping Characteristics

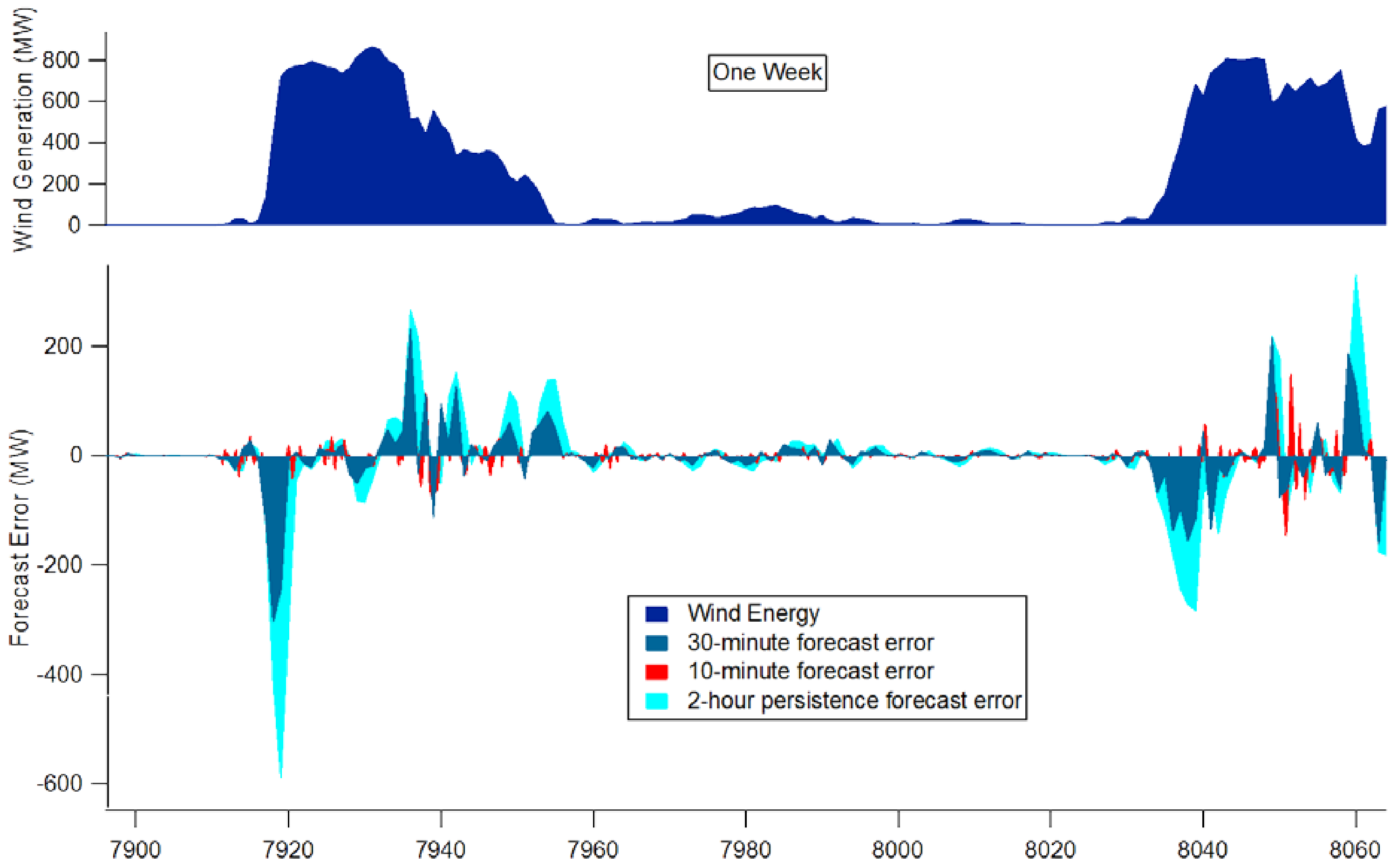
	2002	2003	2004	2005	2006	2007	2008
	Annual Average $/MW-hr						
California (Reg = up + dn)							
Regulation	26.9	35.5	28.7	35.2	38.5	26.1	33.4
Spin	4.3	6.4	7.9	9.9	8.4	4.5	6.0
Non-Spin	1.8	3.6	4.7	3.2	2.5	2.8	1.3
Replacement	0.90	2.9	2.5	1.9	1.5	2.0	1.4
ERCOT (Reg = up + dn)							
Regulation		16.9	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.

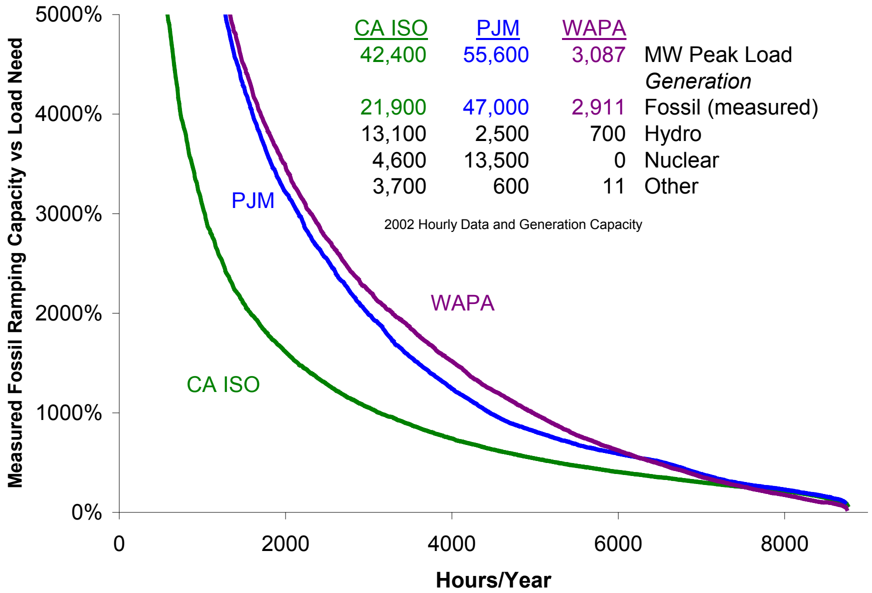
Inter-BA Scheduling and Communication



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, Elec. Journal 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.

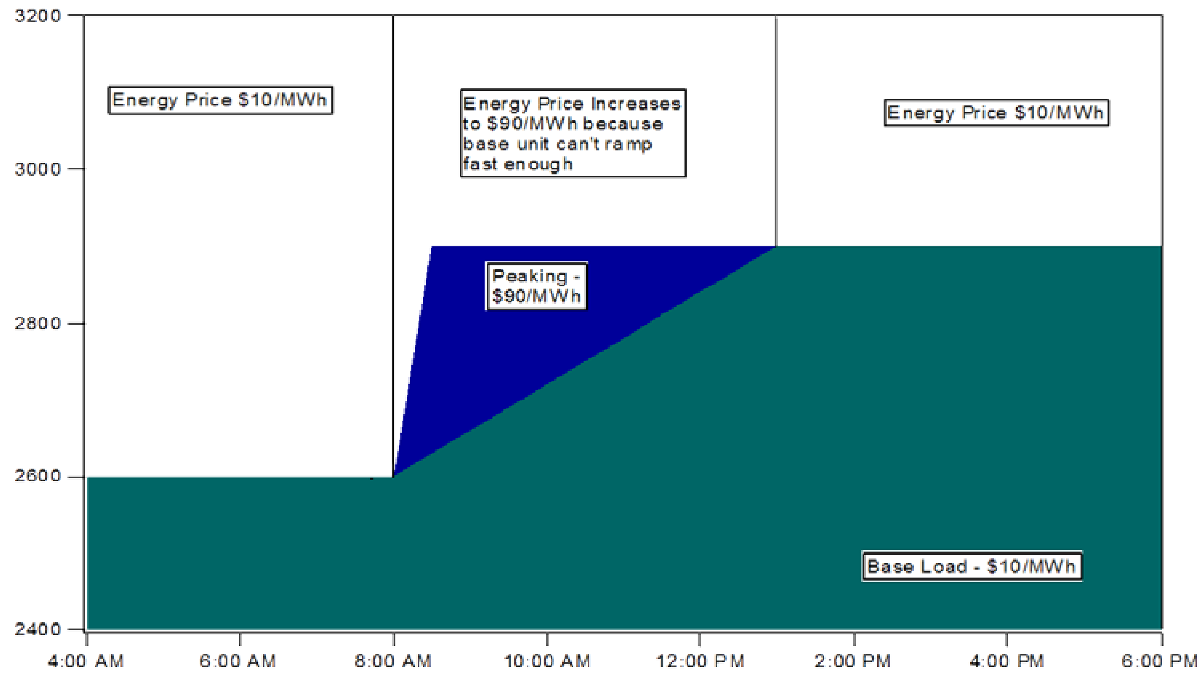
[1]Kirby & Milligan, 2005 Methodology for Examining Control Area Ramping Capabilities with Implications for Wind http://www.nrel.gov/docs/fy05osti/38153.pdf.

[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?

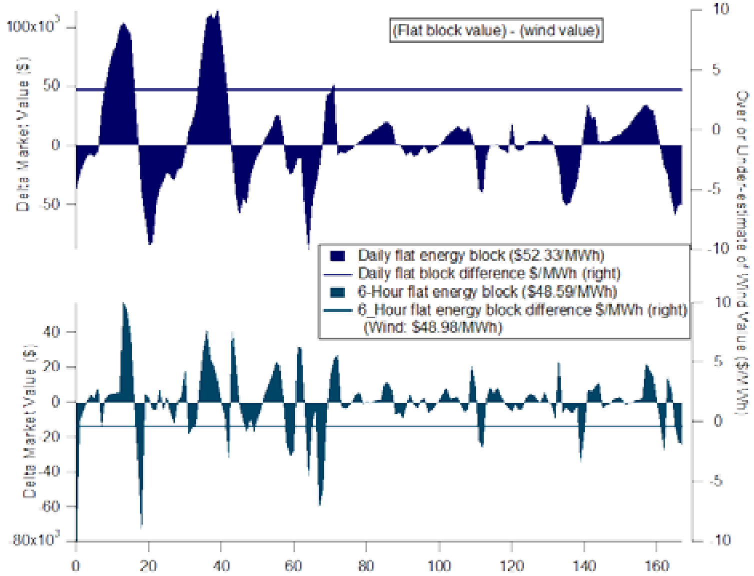
- Short-run:
  - Ramp products necessary to supplement energy markets?
  - Low LMPs and capital cost recovery.
- Long-run:
  - Do prices induce long-term development of flexible supply/loads?



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?

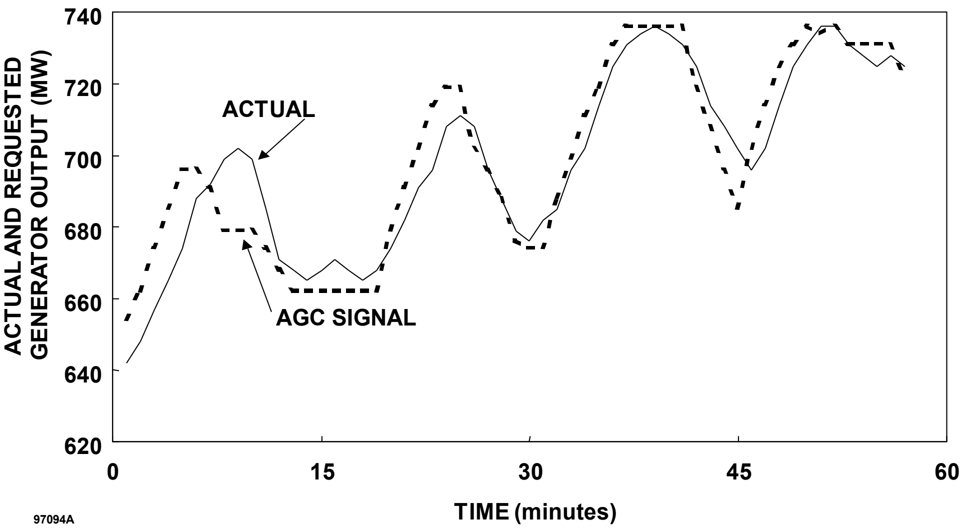


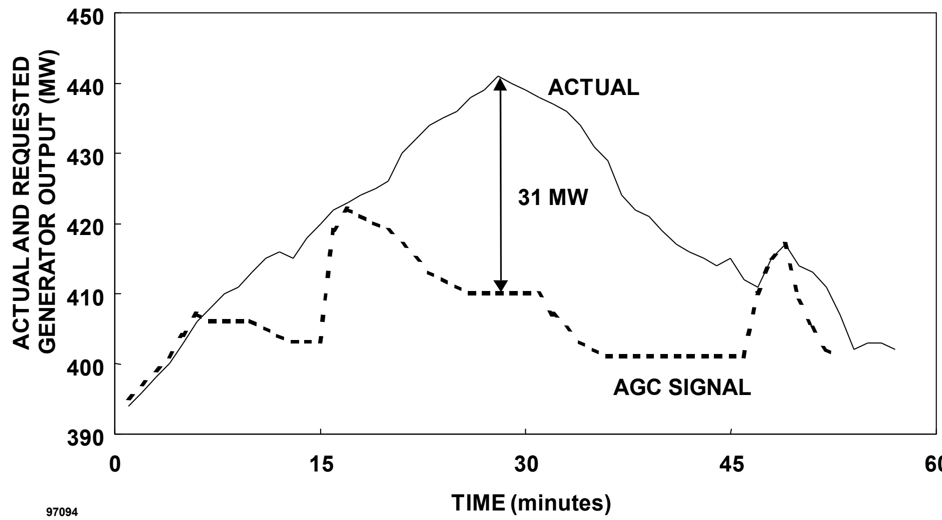
Milligan, M.; Kirby, B. (2009). Calculating Wind Integration Costs: Separating Wind Energy Value from Integration Cost Impacts. 28 pp.; NREL Report No. TP-550-46275. http://www.nrel.gov/docs/fy09osti/46275.pdf.

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 for others.
- 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 baseload 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

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	*Example Utility Structures*
10	8	7	10	7	2	7	6	7	7	3	7	Large RTO with spot markets
6	6	6	3	3	2	6	4	7	2	2	4	Smaller ISO
1	3	2	1	2	1	2	3	2	2	2	2	Interior west & upper Midwest (non-MISO)
7	6	6	2	2	2	5	4	2	5	2	4	Large vertically integrated utility
1	3	2	1	2	1	2	4	2	2	2	2	Smaller Vertically Integrated Local Utility
									8			Unconstrained hydro system
									3			Heavily fish constrained hydro system
1	1	1	1	1	1	1	1	1	1	1	11	*Weightings Factors*

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

Questions?

PIX 13367