National Renewable Energy Laboratory
*Innovation for Our Energy Future*

# 10 FAQ's (Frequently Asked Questions) About Wind Energy Integration …and Answers

## Great Lakes Regional Wind Energy Institute

**Feb 24, 2009**

**Columbus, OH**

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NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

# 10 FAQ's about Wind

1) How much wind is currently installed in the US?
2) What are the benefits of wind energy to the power system?
3) How can wind's variability be incorporated into power system operations
4) Does wind plant output start/stop suddenly?
5) Can wind be predicted?

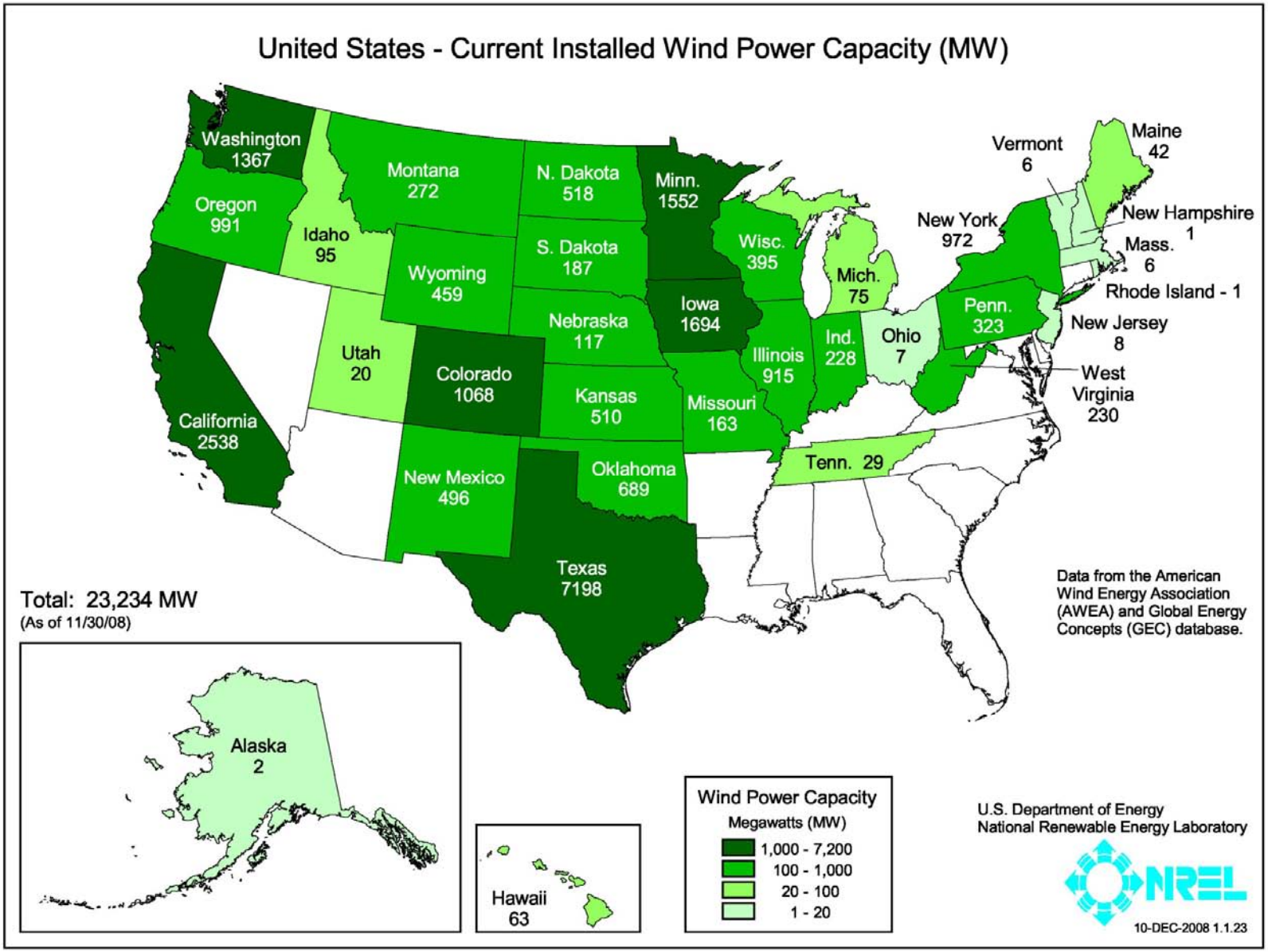
# 10 FAQ's about Wind

6) Can the power system be reliably operated with wind energy?
7) Does wind need backup or storage?
8) Is there a limit to how much wind can be accommodated on the grid?
9) Can wind power plants be controlled?
10) Can wind energy make effective use of transmission lines?
11) Bonus Question: How can more wind be accommodated on the grid?

# Where do the Answers Come From?

- Extensive analysis
  - Power system simulations that mimic real-time operations
  - Statistical analysis of wind and load data
  - Experience operating power systems with wind
- *International Energy Agency Task 25 Report: Design and operation of power systems with large amounts of wind power State of the art report*.
  - http://www.vtt.fi/inf/pdf/workingpapers/2007/W82.pdf
- Utility Wind Integration Group www.uwig.org
- NREL Systems Integration
  - http://www.nrel.gov/wind/systemsintegration/
  - http://www.nrel.gov/publications

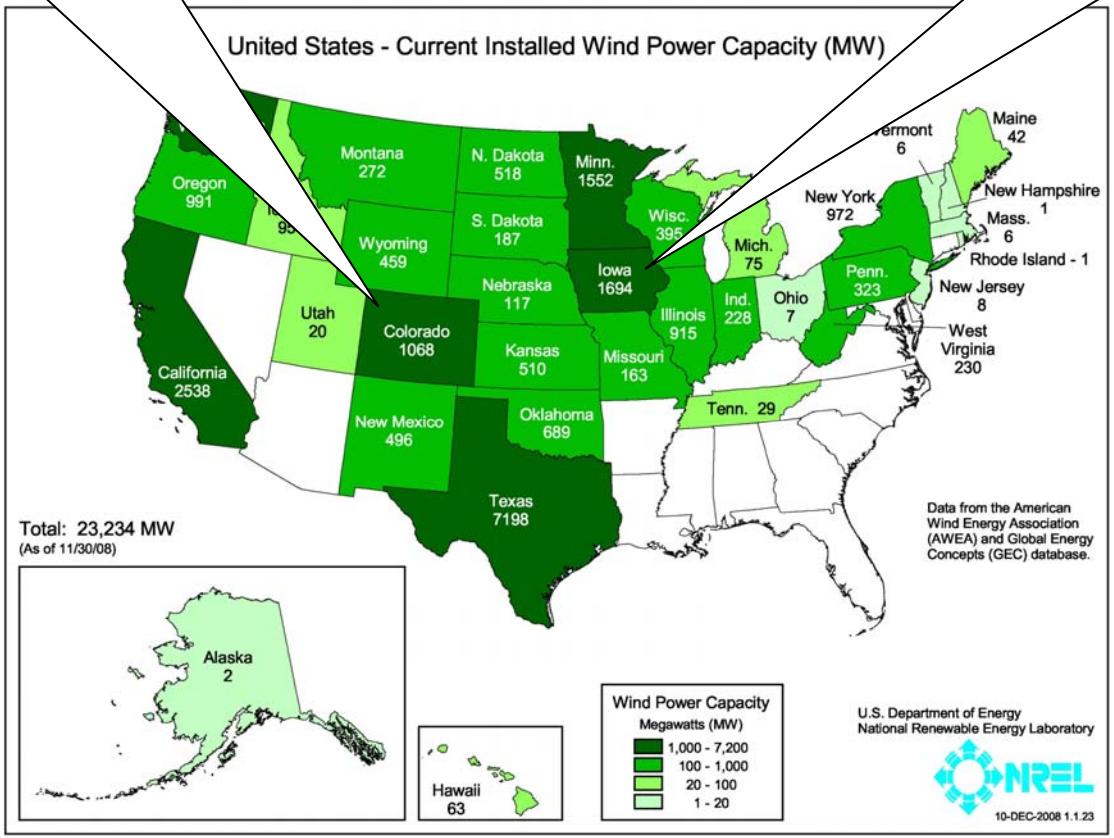
# 1) How much wind is currently installed in the US?



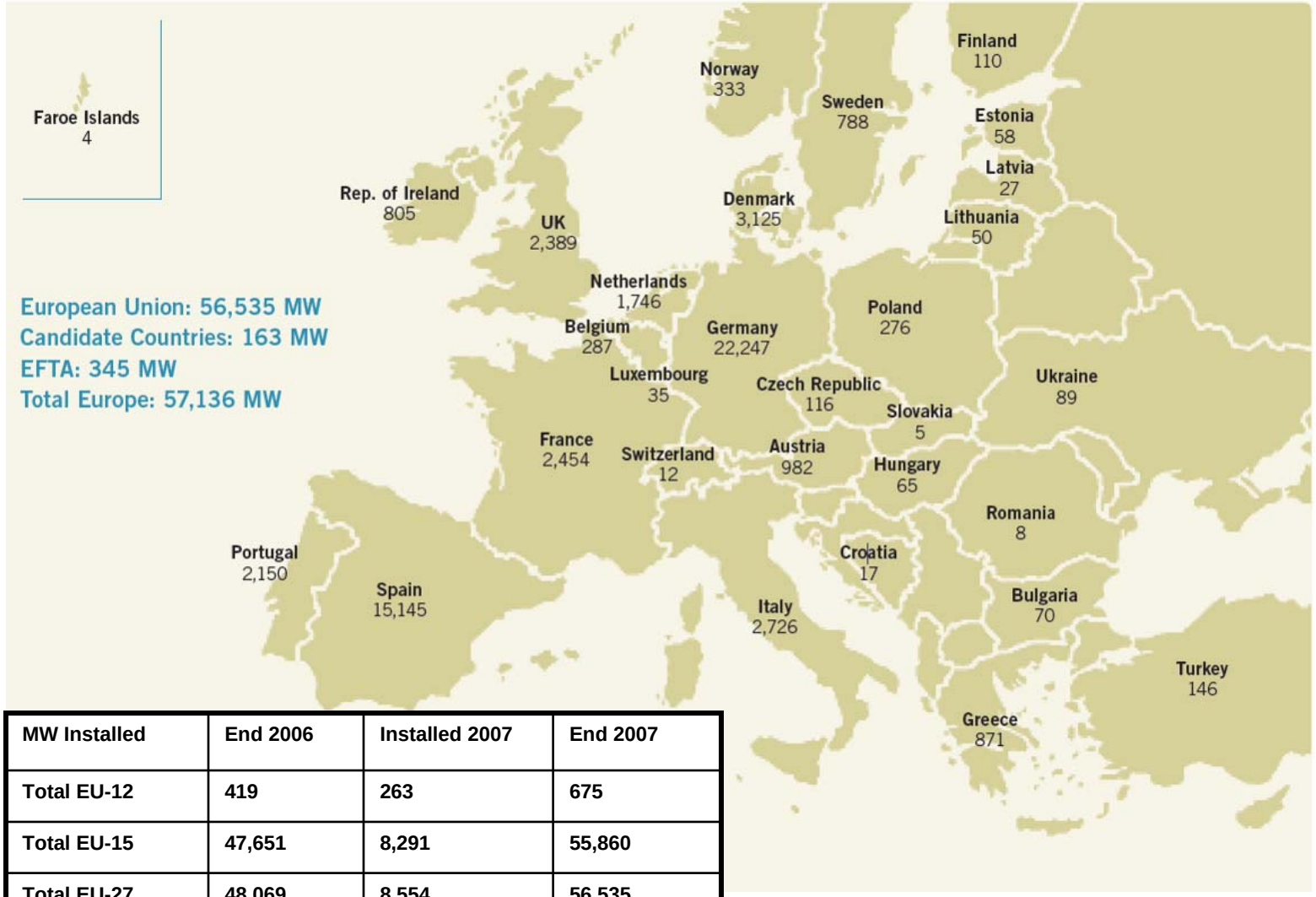
# 1) How much wind is currently installed in the US?

Colorado/Xcel: Approx 20% wind penetration (wind capacity/system peak)

Iowa: Approx 18% wind penetration (wind energy/annual demand, est. 2009)



# 1b) How much wind is currently installed in Europe?

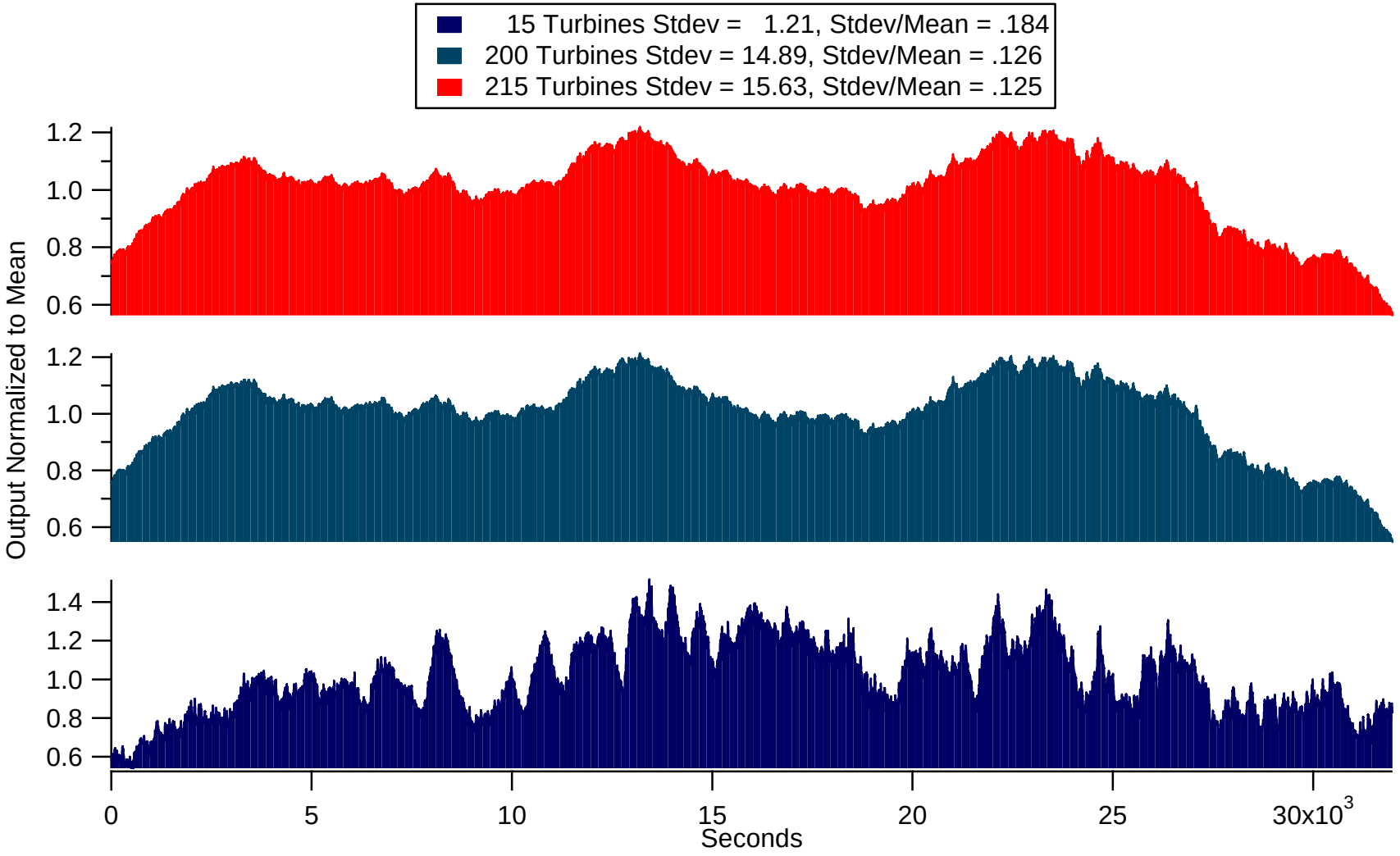



| MW Installed | End 2006 | Installed 2007 | End 2007 |
|---|---|---|---|
| Total EU-12 | 419 | 263 | 675 |
| Total EU-15 | 47,651 | 8,291 | 55,860 |
| Total EU-27 | 48,069 | 8,554 | 56,535 |

# 2) What are the benefits of wind energy to the power system?

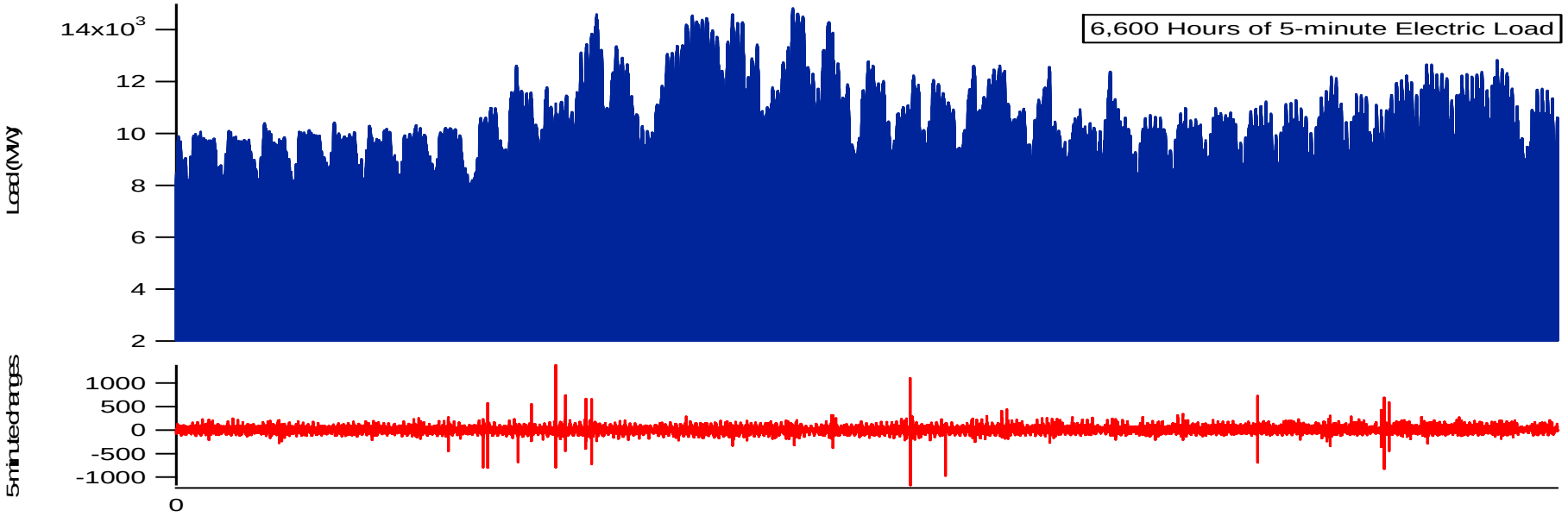
- Wind energy displaces
  - Fuel
  - Emissions; carbon
- Wind provides a hedge against rising fuel prices (natural gas, coal)
- Wind is an energy source with limited capacity contribution → other generation is also required
- Wind can be cost-competitive with other forms of generation and may reduce electricity cost

# 3) How can wind's variability be incorporated into power system operations?



# 3) How can wind's variability be incorporated into power system operations?

- Electric load (without wind) varies considerably
- Power system operating practices are built around meeting the variable load with dispatchable generators that can change their output level
- Wind adds more variability to the system
- Existing operating practice can be used/expanded upon with wind



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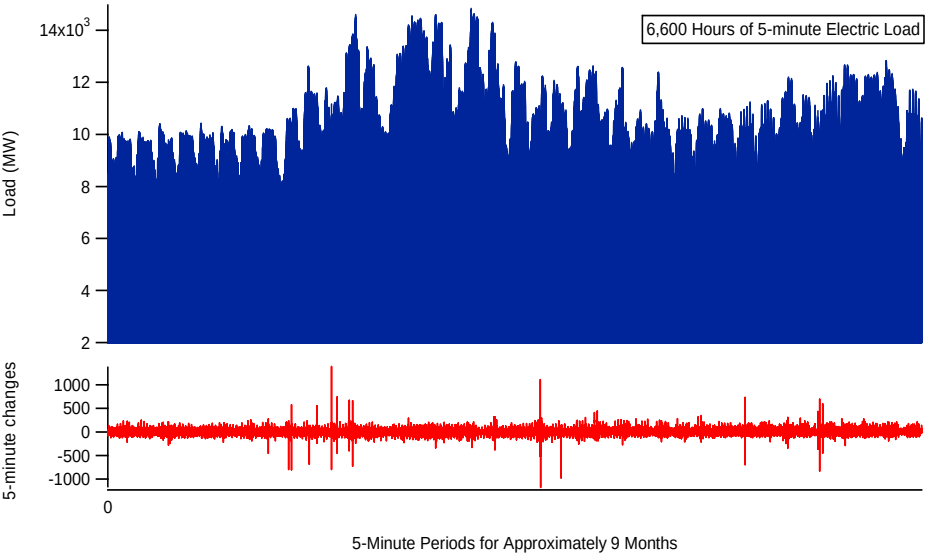
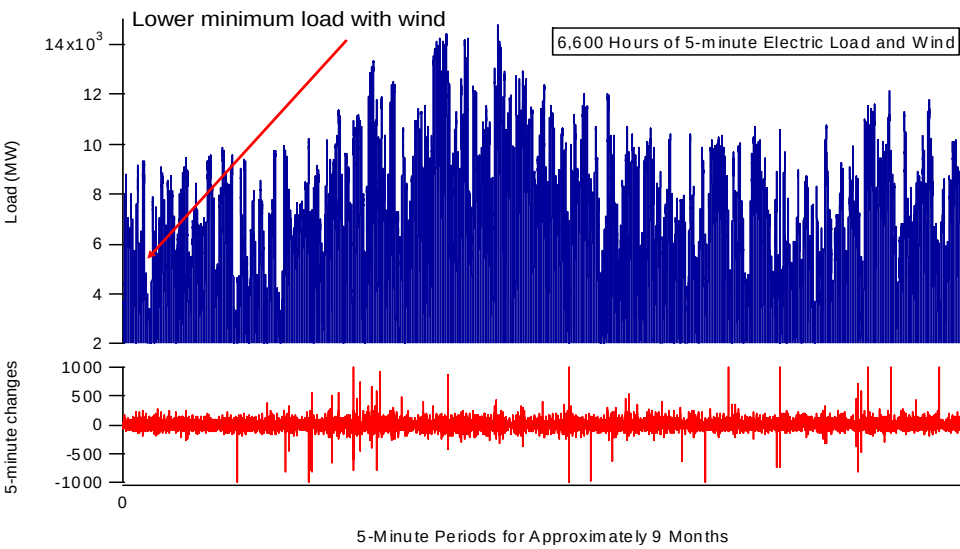



- Minnesota 25% wind energy penetration (by energy) causes an increase in variability that must be met by power system operators and the non-wind generation fleet

# Comparison of Cost-Based Integration Studies

| Date | Study | Wind Capacity Penetra-tion (%) | Regula-tion Cost ($/MWh) | Load Following Cost ($/MWh) | Unit Commit-ment Cost ($/MWh) | Gas Supply Cost ($/MWh) | Tot Oper. Cost Impact ($/MWh) |
|---|---|---|---|---|---|---|---|
| May '03 | Xcel-UWIG | 3.5 | 0 | 0.41 | 1.44 | na | 1.85 |
| Sep '04 | Xcel-MNDOC | 15 | 0.23 | na | 4.37 | na | 4.60 |
| June '06 | CA RPS | 4 | 0.45* | trace | na | na | 0.45 |
| Feb '07 | GE/Pier/CAIAP | 20 | 0-0.69 | trace | na*** | na | 0-0.69*** |
| June '03 | We Energies | 4 | 1.12 | 0.09 | 0.69 | na | 1.90 |
| June '03 | We Energies | 29 | 1.02 | 0.15 | 1.75 | na | 2.92 |
| 2005 | PacifiCorp | 20 | 0 | 1.6 | 3.0 | na | 4.60 |
| April '06 | Xcel-PSCo | 10 | 0.20 | na | 2.26 | 1.26 | 3.72 |
| April '06 | Xcel-PSCo | 15 | 0.20 | na | 3.32 | 1.45 | 4.97 |
| Dec '06 | MN 20% | 31** | | | | | 4.41** |
| Jul '07 | APS | 14.8 | 0.37 | 2.65 | 1.06 | na | 4.08 |

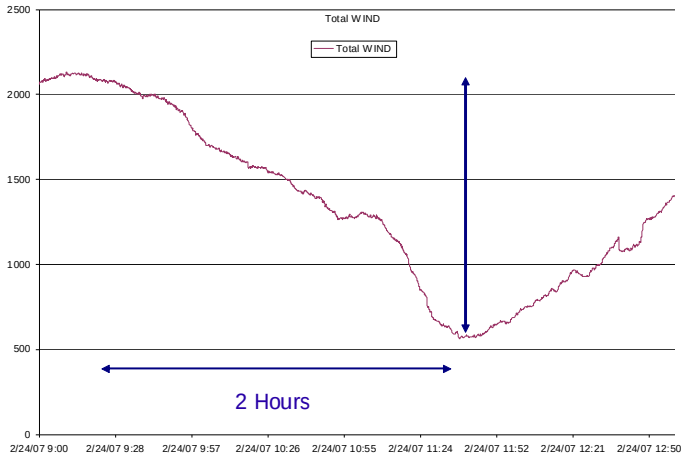
* 3-year average; total is non-market cost

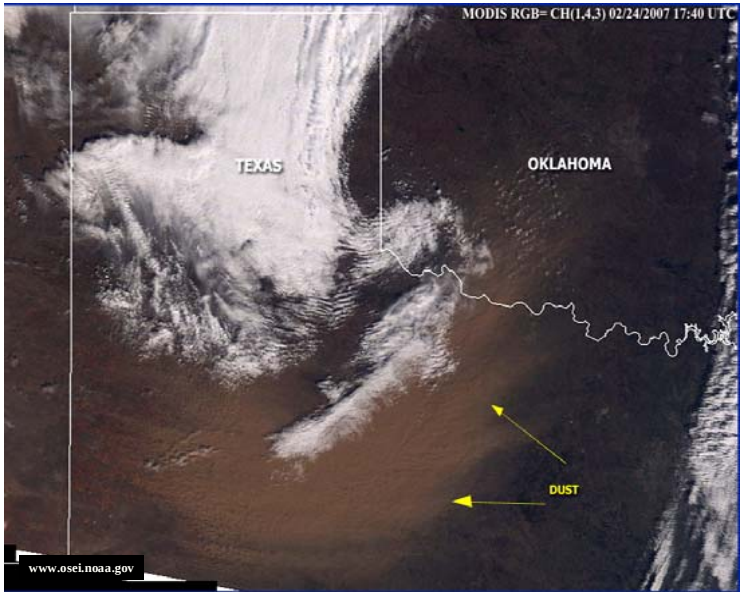
** highest integration cost of 3 years; 30.7% capacity penetration corresponding to 25% energy penetration; 24.7% capacity penetration at 20% energy penetration

*** found $4.37/MWh reduction in UC cost when wind forecasting is used in UC decision

# 4) Can wind power start and stop suddenly?

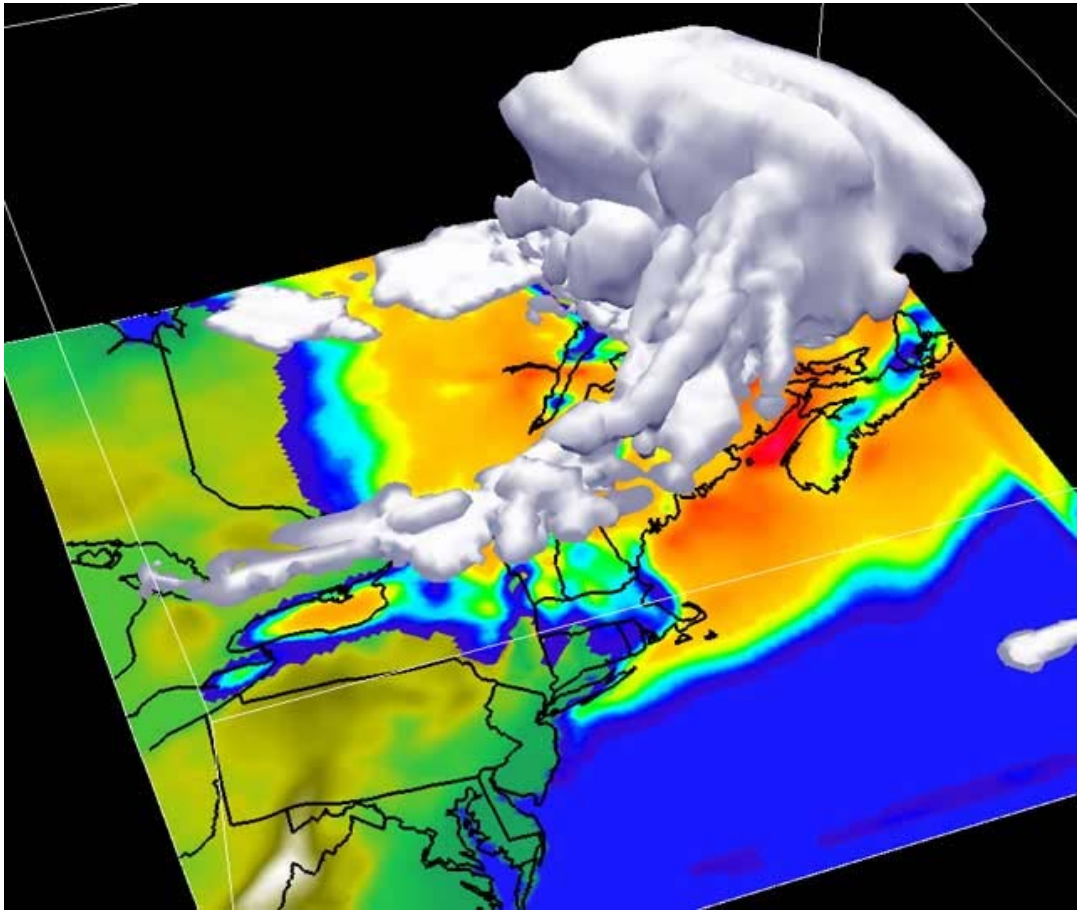
- Large wind farms have many individual wind turbines
- The turbines are spread over many miles and do not experience the same wind at the same time
- TX event Feb 24, 2007: drop of 1,500 MW over 2 hours is similar to behavior of load



# 5) Can wind be predicted?

- Wind forecasts are derived from weather prediction models
- Wind forecast accuracy is improving
- Several wind forecasting firms in U.S.



Courtesy: WindLogics, Inc. St. Paul, MN

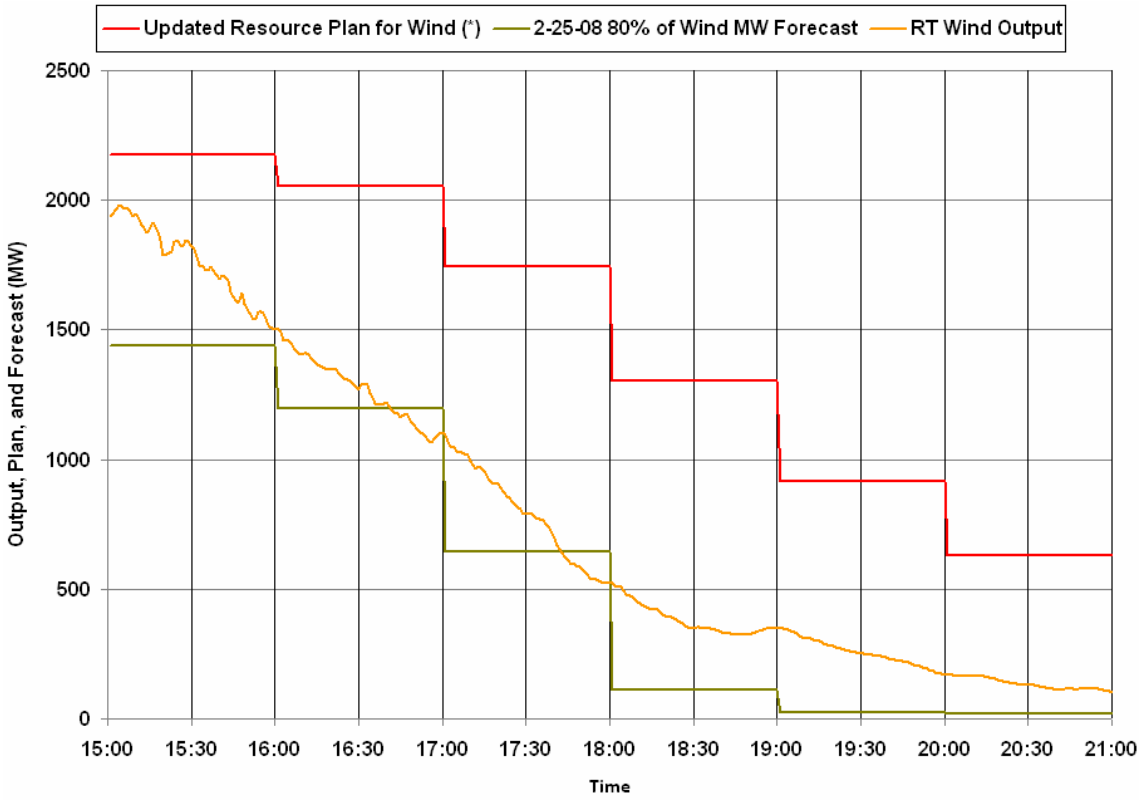
# Are wind forecasts being *used*?

- Forecasts must be tuned to the needs of the system operator and ***integrated in control room***
- Forecasts of potentially large ramp events?
- High-wind warning systems?
- Aggregate wind forecast error is reduced with large geographic aggregation
- Geographic dispersion can reduce forecast errors by 30-50% (WindLogics, UWIG Forecasting Workshop, Feb 2008)

| | **Mean Absolute Error (Percent)** |
|---|---|
| Next day hourly wind power forecast | 10-14% of rated capacity |
| Next day total energy forecast | 20% of energy delivered |
| Next 2-3 hour power schedule | 5-7% of rated capacity |

# Wind Forecasts in the Control Room

- UWIG/WindLogics RDF
- Xcel/CO




http://www.ercot.com/meetings/ros/keydocs/2008/0313/07._ERCOT_OPERATIONS_REPORT_EECP022608_public.doc

# 6) Can the power system be reliably operated with wind energy?

- Yes – additional flexible generation (operating reserves) may be necessary at higher wind penetrations
- This additional operating reserve has a modest cost, typically about 10% of the cost of the wind energy itself
- Graph shows this level of operating reserve (blue) is a relatively small, varying fraction of wind generation

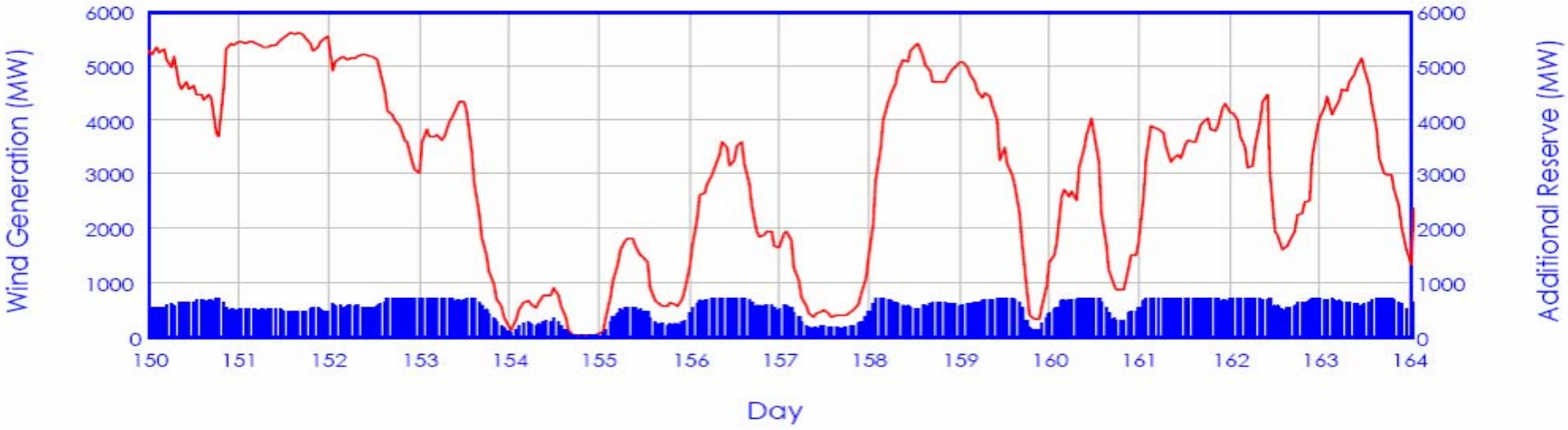
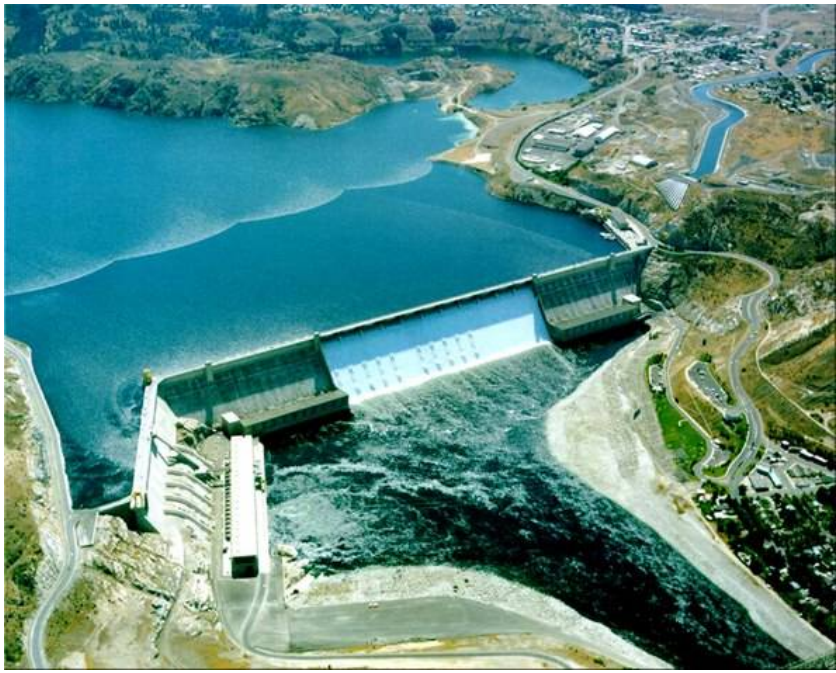



Figure 30: Illustration of time varying "operating reserve margin" developed from statistical analysis of hourly wind generation variations.

EnerNex: Minnesota 20% Wind study

# 7) Does wind need backup or storage?

- Increased operating reserves may be necessary, but not dedicated backup
- Although new storage has value, it may not be cost effective
- There is typically already storage on the system
  - Natural gas in the pipeline or storage facility
  - Controllable hydro
- A recent study by Xcel Energy in Colorado found
  - existing pumped storage provided $1.30/MWh offset to wind integration cost
  - Enlarging existing gas storage facility was economic at large wind penetration



EnerNex: Xcel Colorado Wind Integration Study

| Wind Penetration | 10% | 15% |
|---|---|---|
| $/ MWH Gas Impact No Storage Benefits | $2.17 | $2.52 |
| $ / MWH Gas Impact With Storage Benefits | $1.26 | $1.45 |

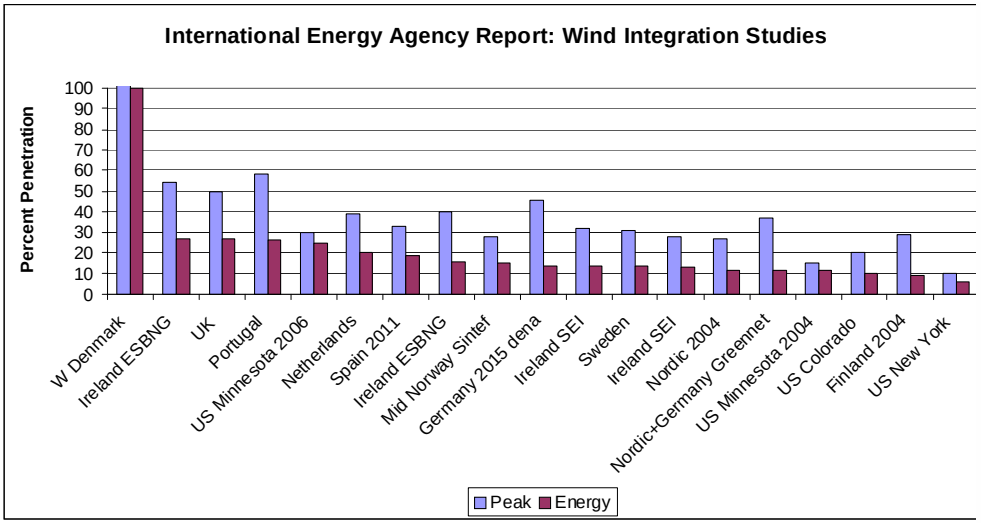
# 8) Is there a limit to how much wind can be accommodated on the grid?

- Current studies in the U.S. have analyzed *up to* 25% of all electric energy from wind
- Based on work done so far, the question is not *whether* wind can be accommodated at high penetrations, the question is *how* and at *what cost of integration*

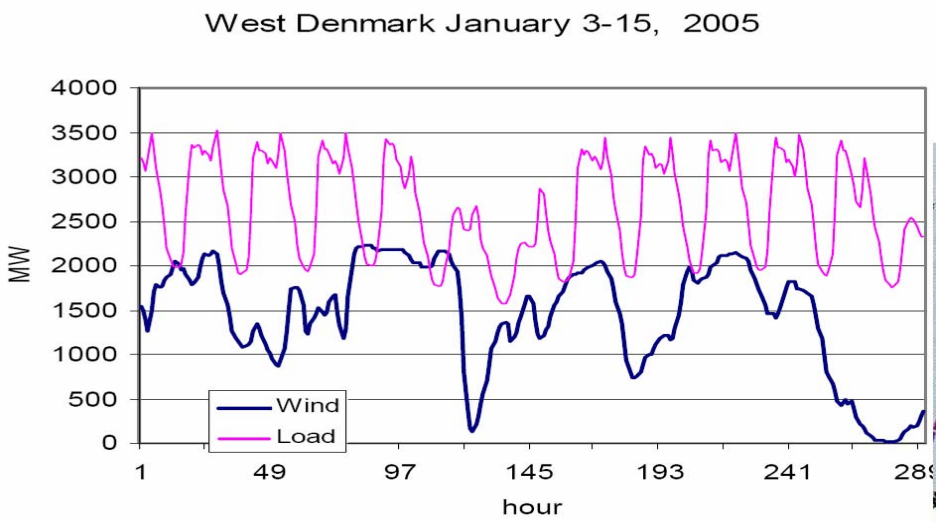
# 8) Is there a limit to how much wind can be accommodated on the grid?

Recent International Energy Agency Report:

*Design and operation of power systems with large amounts of wind power*




http://www.uwig.org/IEA_Annex25-State_of_the_Art_Report.pdf




Denmark has access to large export markets

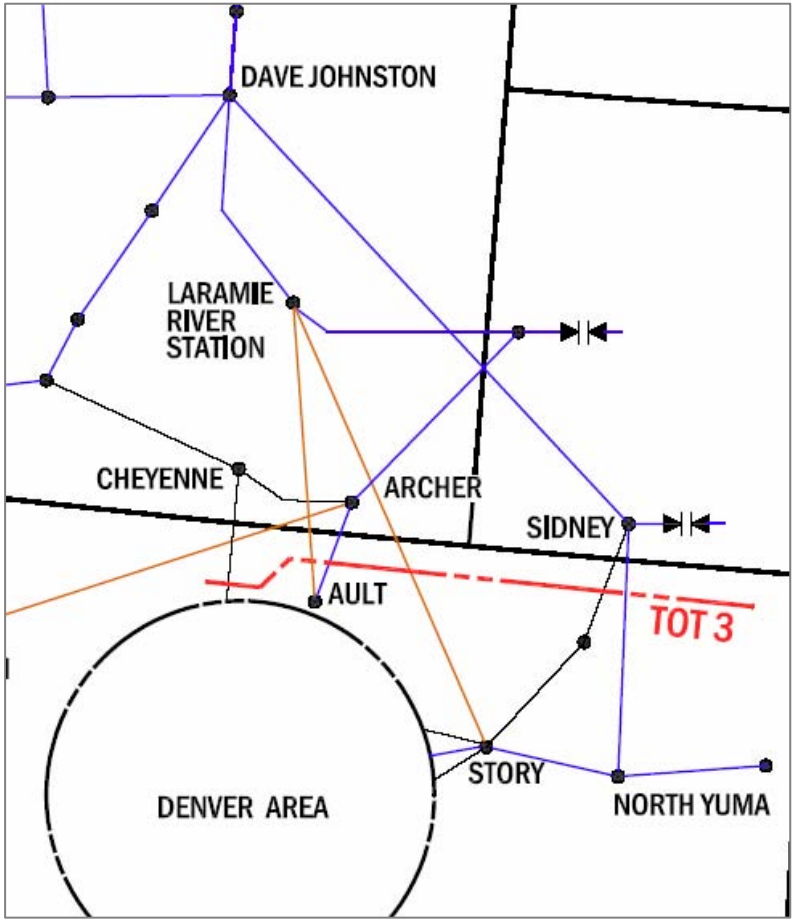
Lennart Söder,KTH, Sweden, presented at UWIG, Oct 23-25, 2006

# 9) Can wind power plants be controlled?

- New low-voltage ride-through (LVRT) grid codes in the U.S. will help wind turbines contribute to grid reliability
- Wind turbines can be controlled but not to the extent that conventional generation can be controlled
  - Ramp rate limits
  - Up-regulation (operate below potential so that wind output can be increased if needed)
  - Curtailment, if necessary and economic, at low-load/high-wind conditions

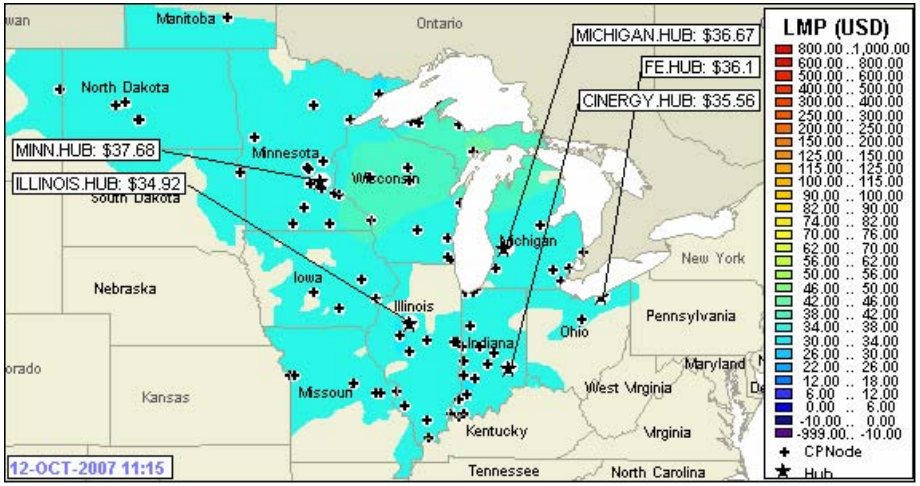
# 10) Can wind energy make effective use of transmission lines?

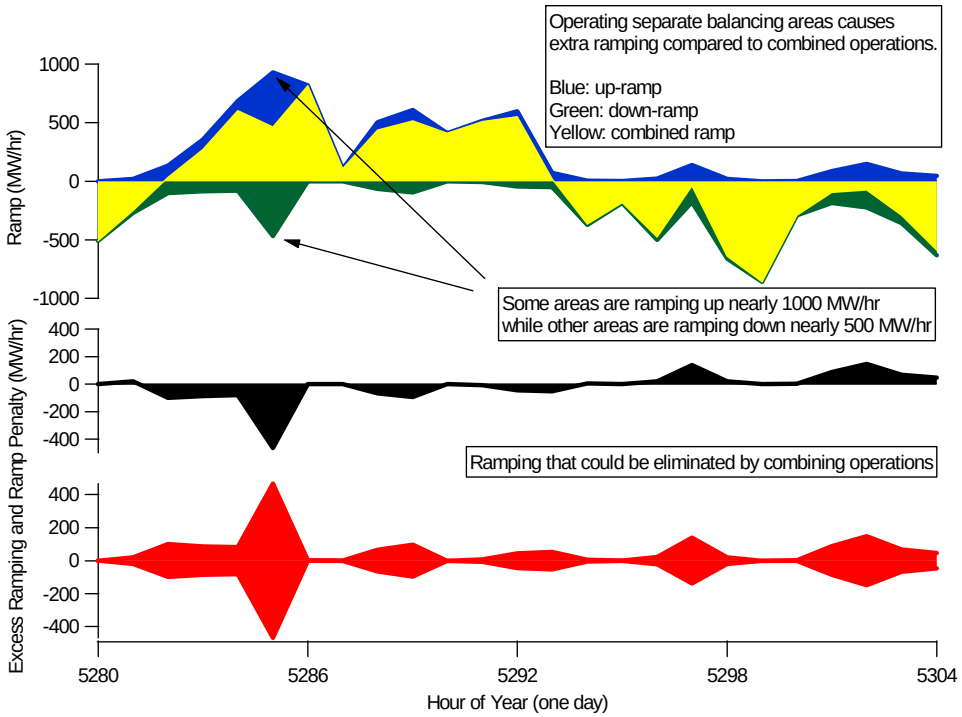
- Conditional-firm transmission tariff (recent FERC ruling)
- Wind does not need transmission all of the time
- Most transmission paths have some open capacity most of the time
- Adding wind can result in more efficient usage of existing transmission



# 11) Bonus: How can more wind be accommodated on the grid?

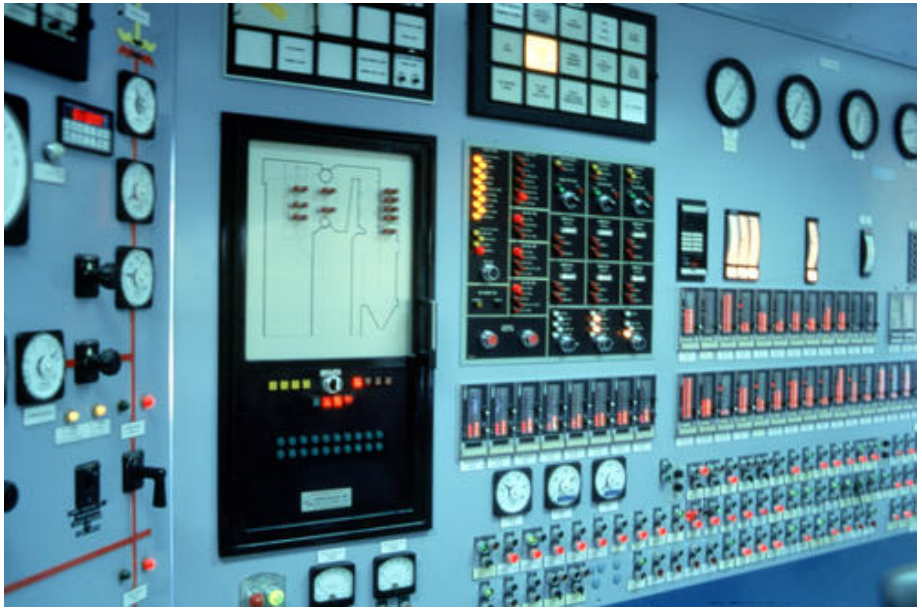
- Utility balancing areas can combine or cooperate – large electricity markets
- Example: *Ramping, or changing output of generators that can be eliminated with larger balancing areas* →



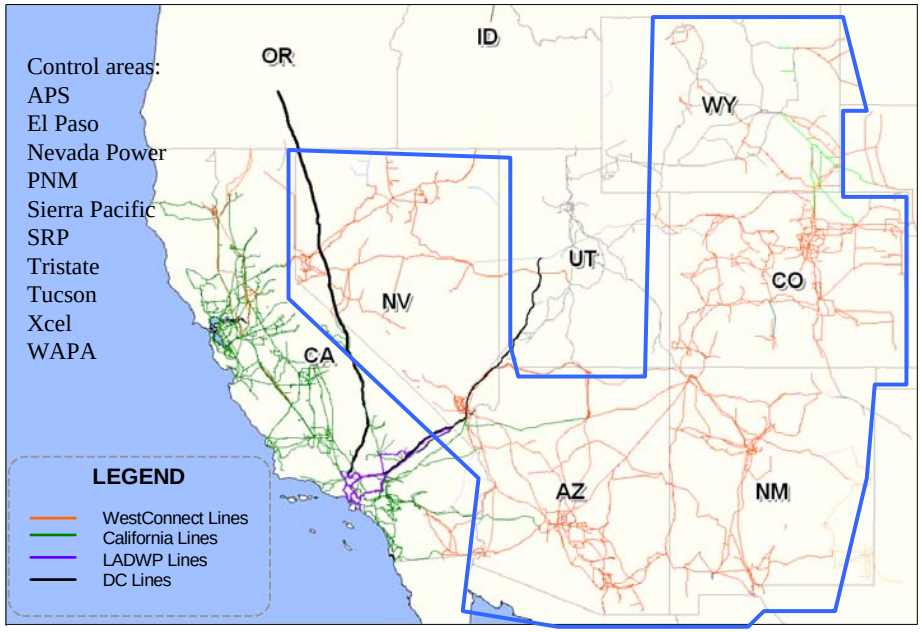
# 11) Bonus: How can more wind be accommodated on the grid?

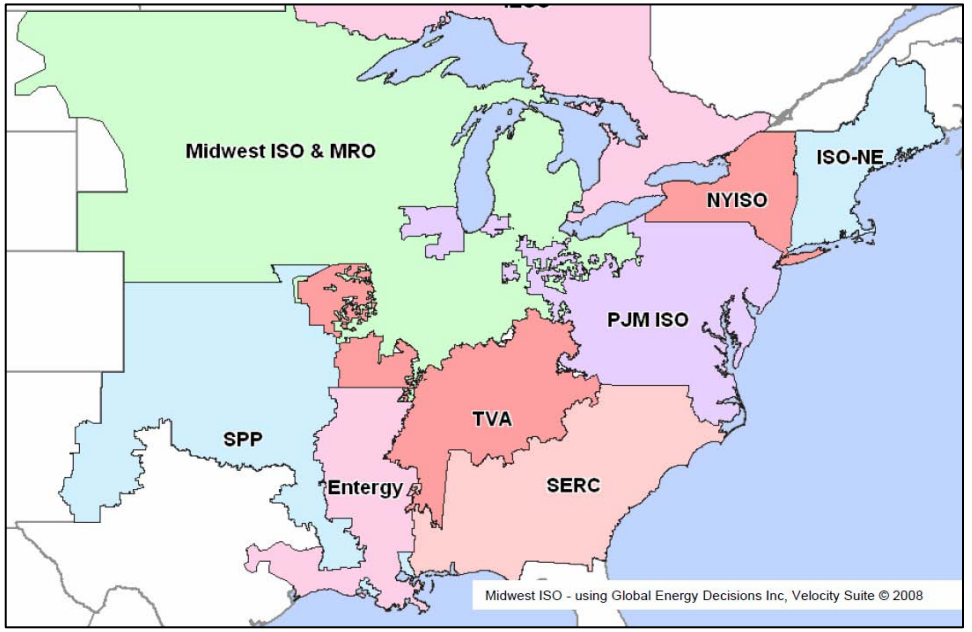
- Power system operations practices and wind farm control/curtailment
- Integration of wind forecasting and real time measurements into control room operations – ongoing work at ERCOT, AESO
- Hydro dispatch, pumped hydro
- Longer term: other storage and markets (plug-hybrid electric vehicles, hydrogen)



# Large-Scale Studies in Process

- Western Wind & Solar Integration Study
  - 30% Wind in footprint, 20% in WECC
- Eastern Wind Integration Study



# Increasing Attention in North America

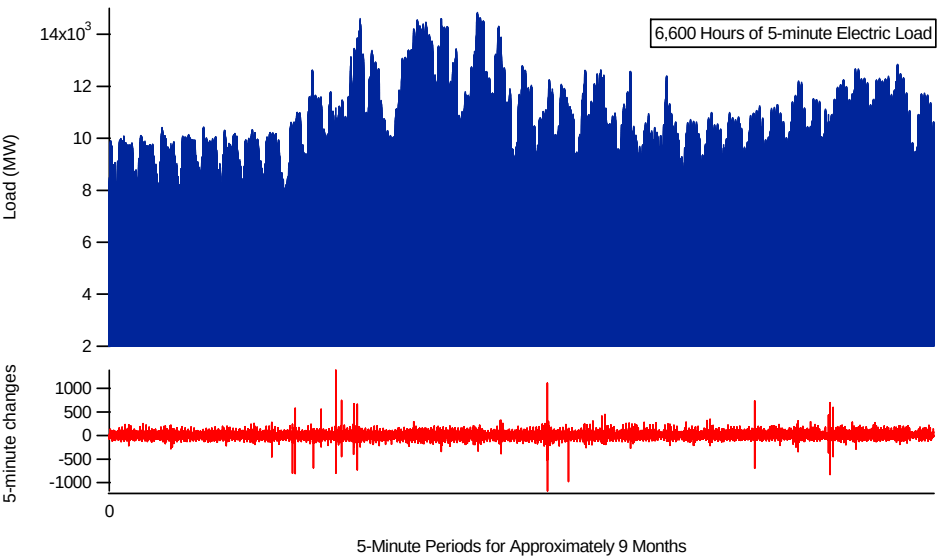

- IEEE Transactions on Power Systems (2007)
- IEEE Power Engineering Society Magazine, November/December 2005
- Updated in 2007 and planned update in 2009
- Wind Power Coordinating Committee Wind Super-Session, Summer 2008
- Utility Wind Integration Group (UWIG): Operating Impacts and Integration Studies User Group
- www.uwig.org

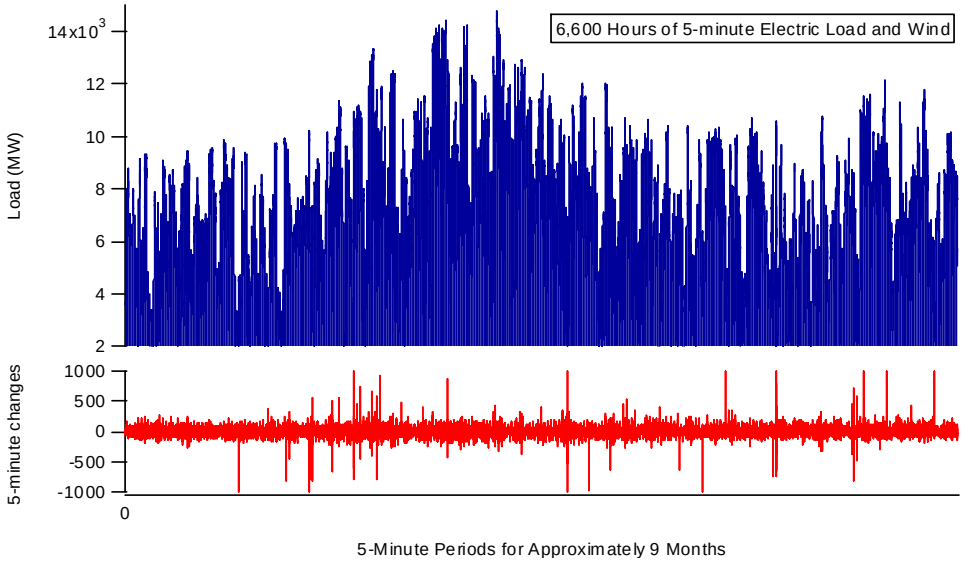
UWIG Utility Wind Integration Group

*Accelerating the Integration of Wind Generation into Utility Power Systems*

# Discussion (if time/interest)

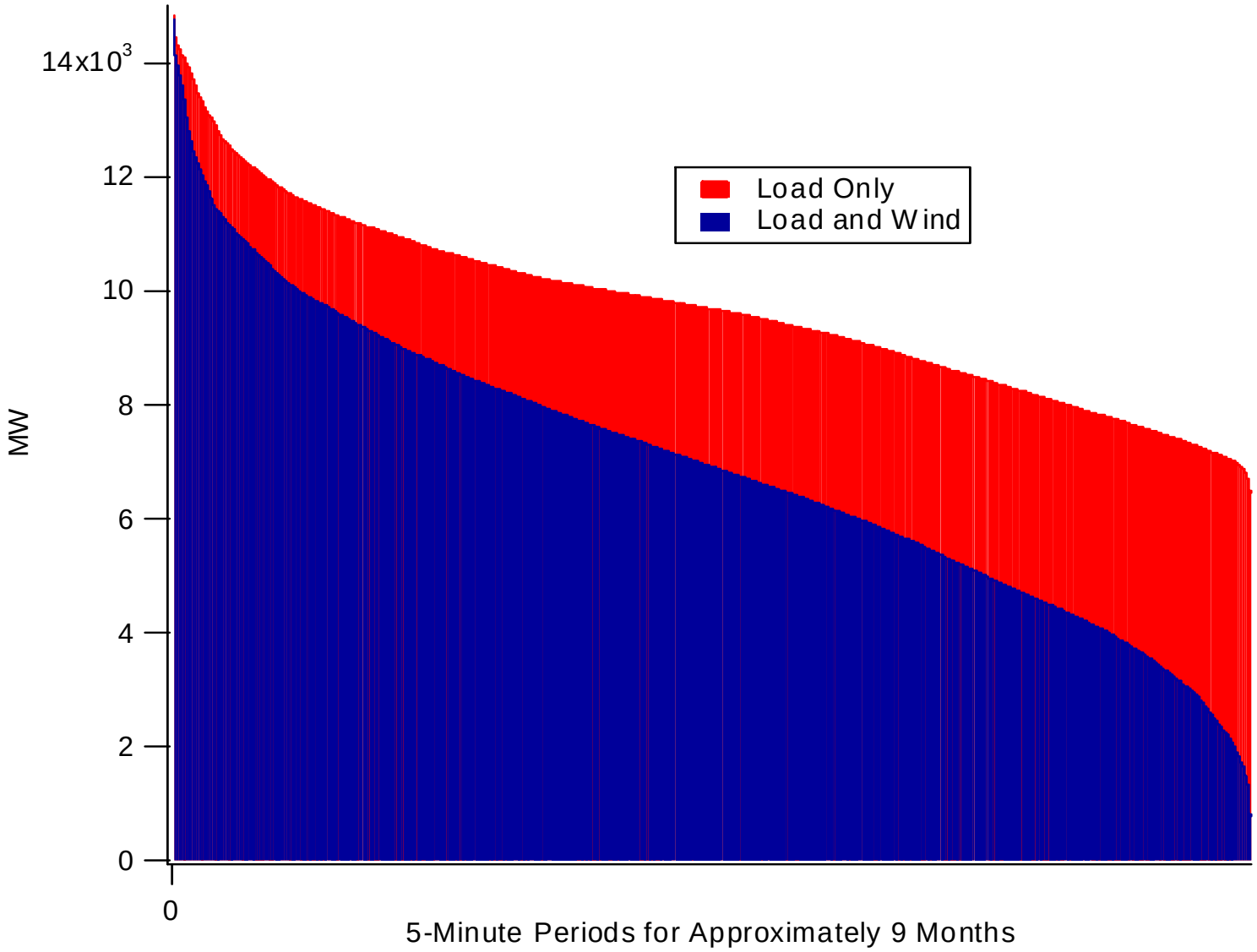
# Impact of 25% Wind Energy Penetration: 5-minute data



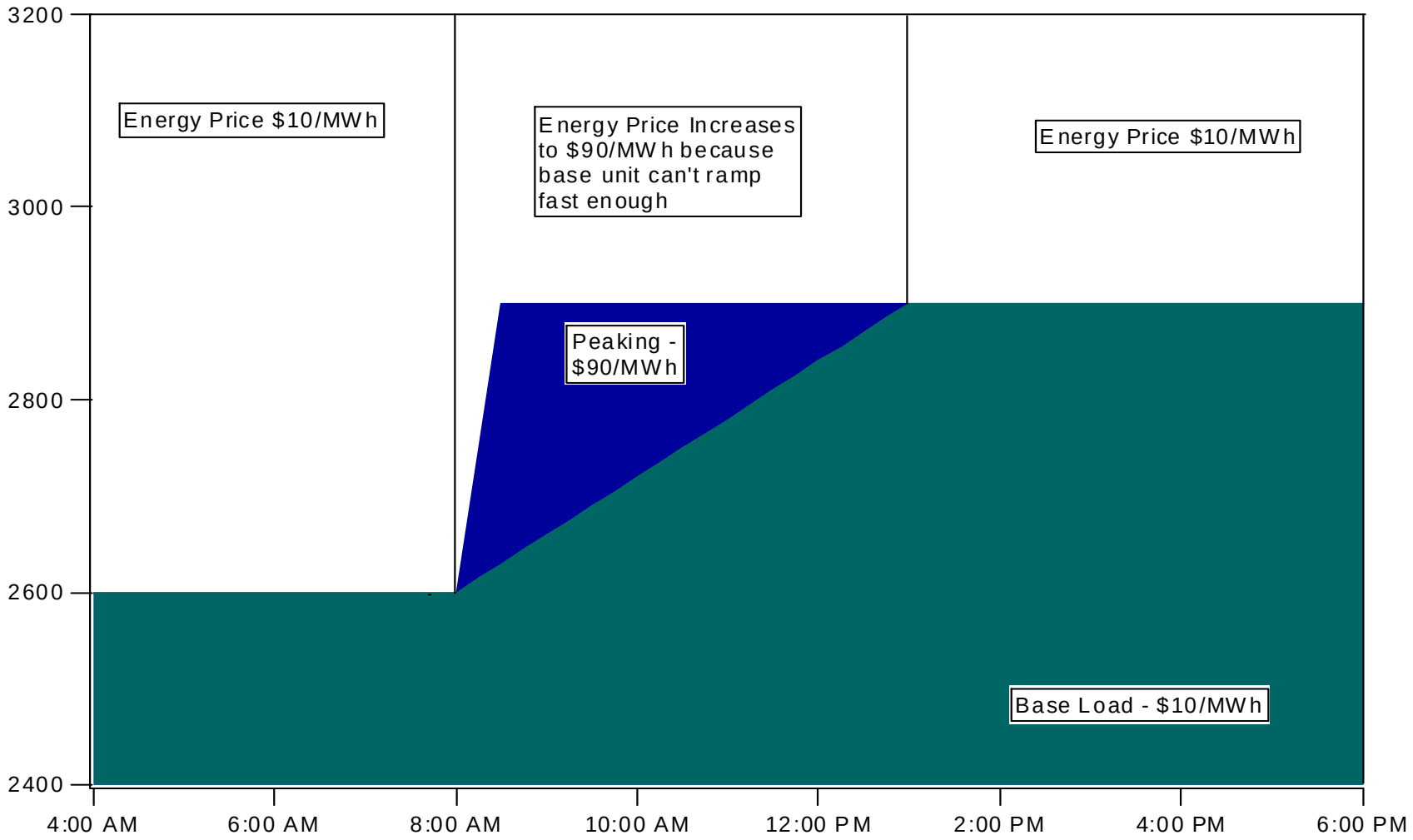




- Ramp requirements increase with 25% wind energy penetration. The upper panel also shows the importance of being able to achieve lower minimum loads by the conventional generation fleet.

# Lower Turn-down is required

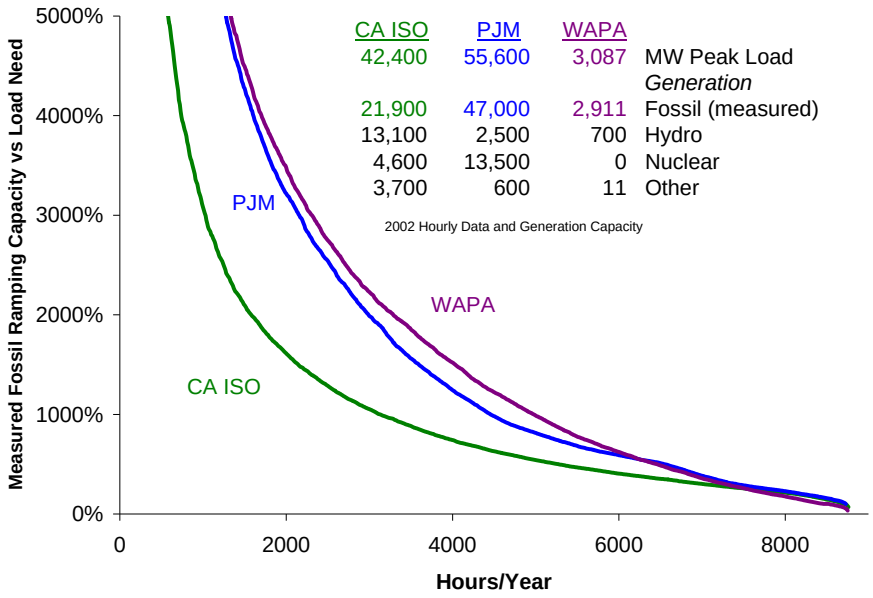


# Can the non-wind fleet ramp quickly enough?



# Better use of existing flexibility

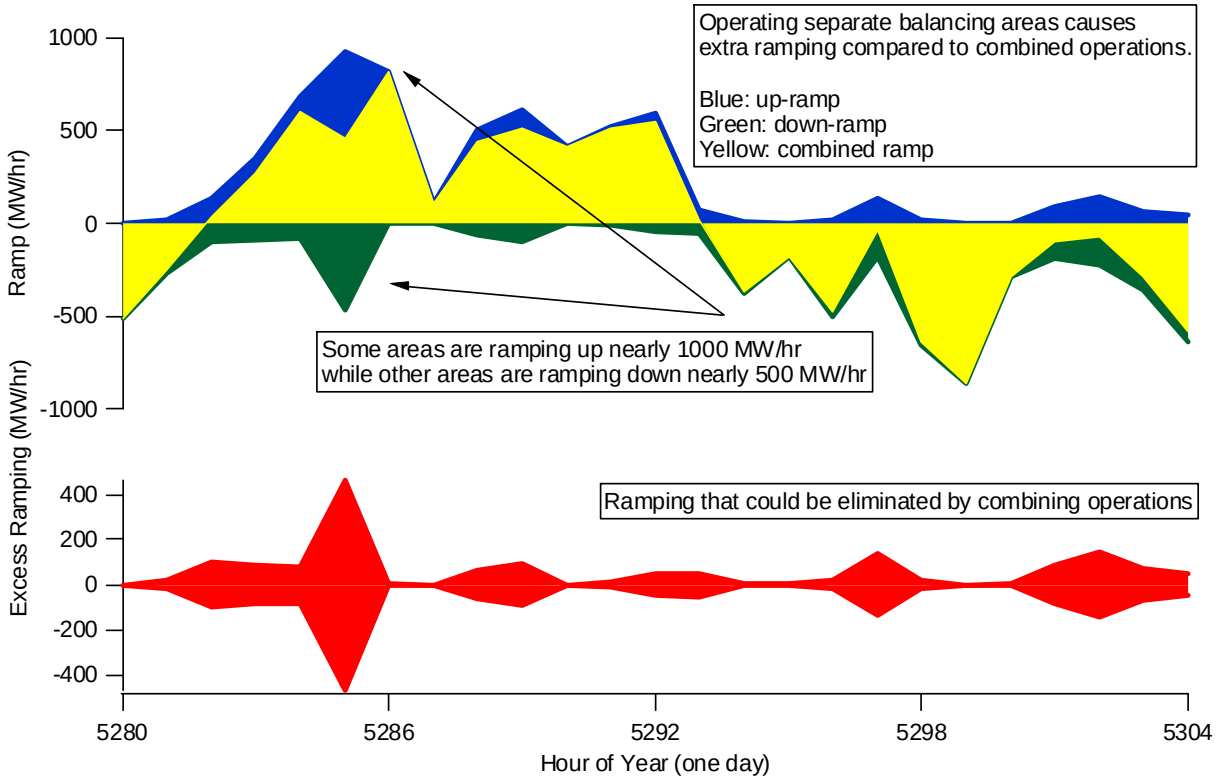
- Tap into maneuverable generation that may be "behind the wall"[1]
- Provide a mechanism (market, contract, other) that benefits system operator and generator
- Fast energy markets help provide needed flexibility[2] and can often supply load following flexibility at no cost[3]




[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

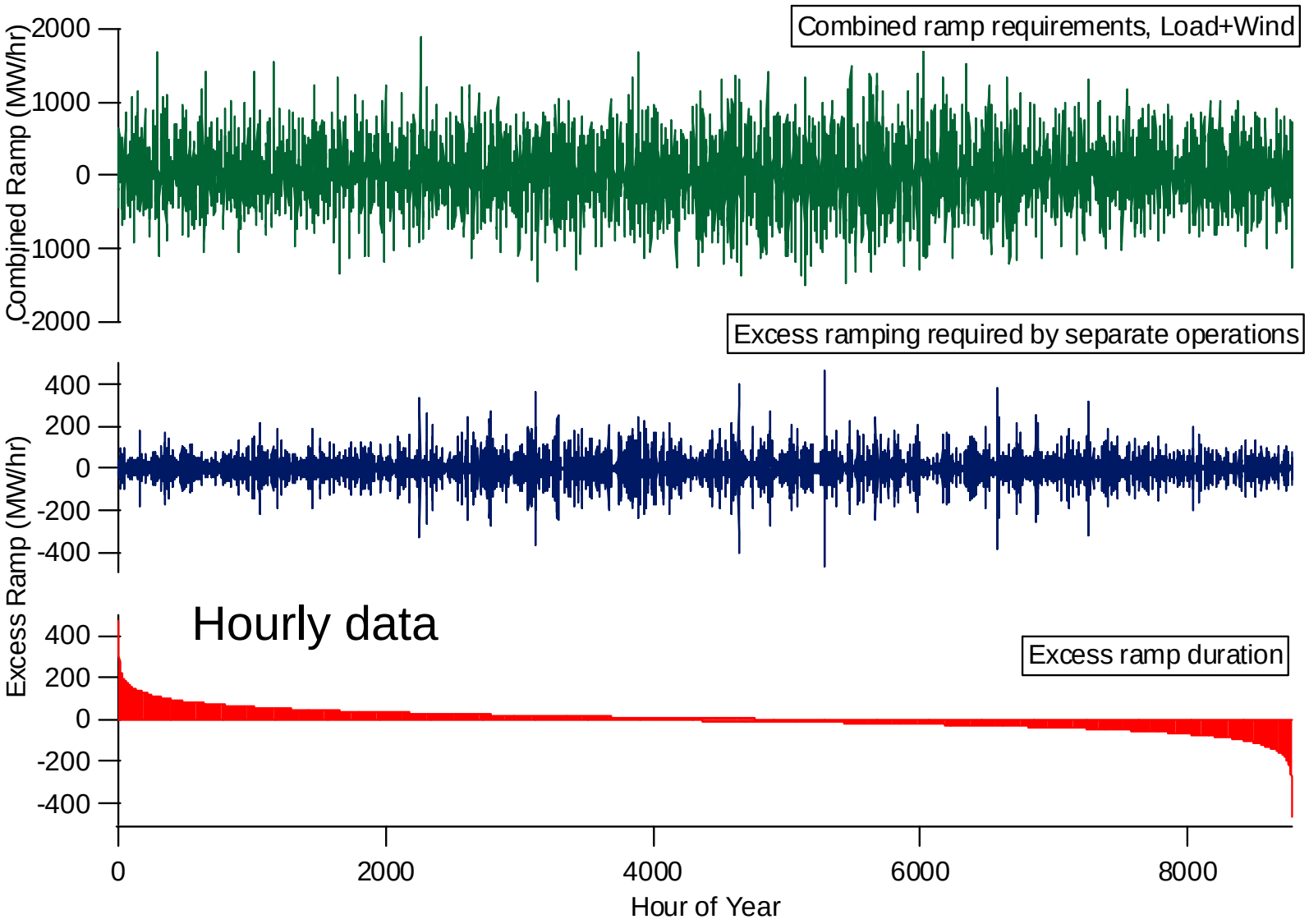
# Acquire additional flexibility across BAs

- Reduce the need for ramping by combined BAs (real or virtual)
  - Ramping *capability* adds linearly
  - Ramping *need* adds less than linearly

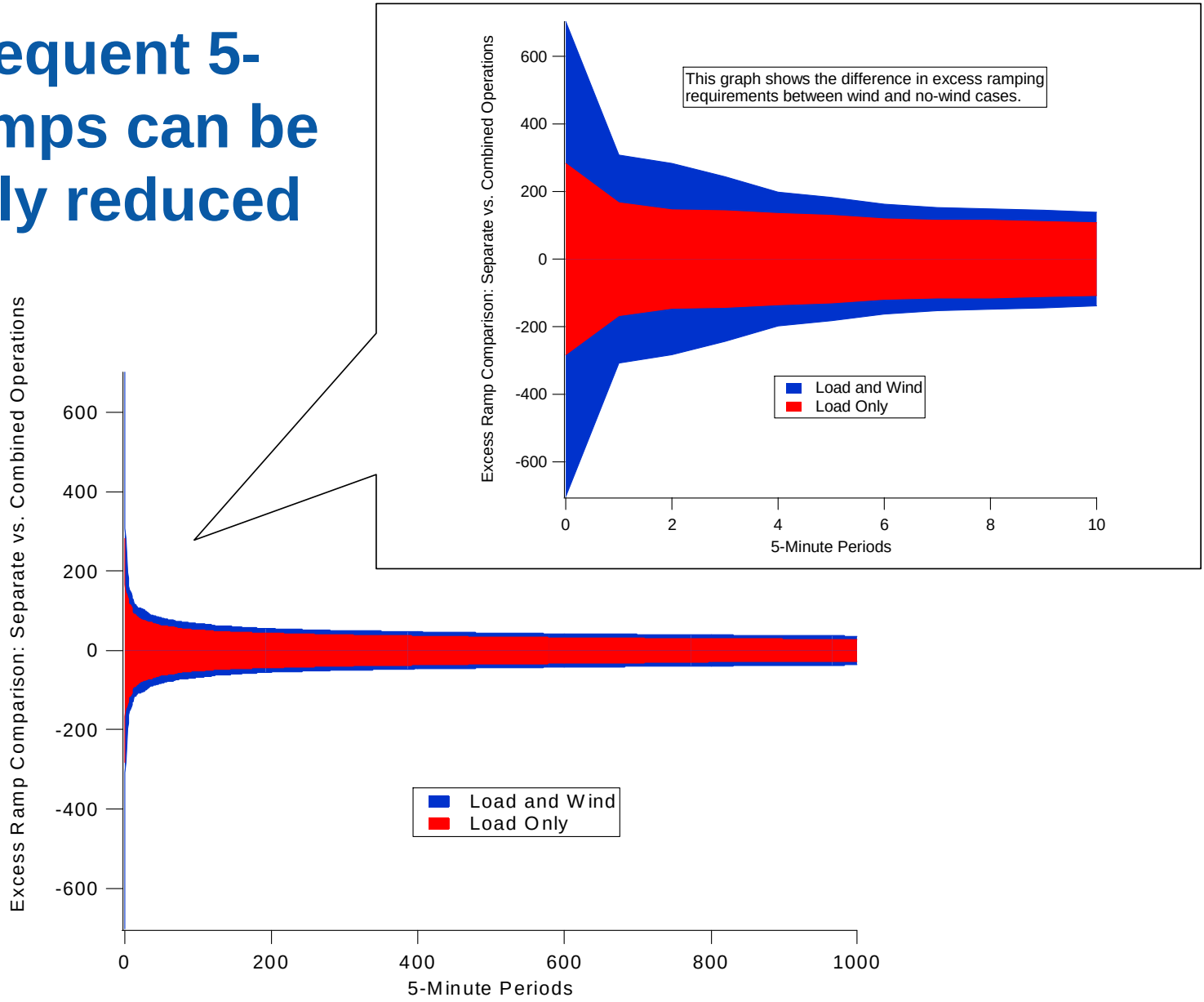



Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf

# BA Consolidation Reduces Ramp Requirements



# Large, infrequent 5-Minute Ramps can be significantly reduced




Milligan & Kirby 2008, An Analysis of Sub-Hourly Ramping Impacts of Wind Energy and Balancing Area Size .