A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

20% Wind Vision

York, Nebraska
May 13, 2008

Michael Milligan, Ph.D. (Consultant)
National Wind Technology Center
National Renewable Energy Laboratory
Golden, Colorado USA

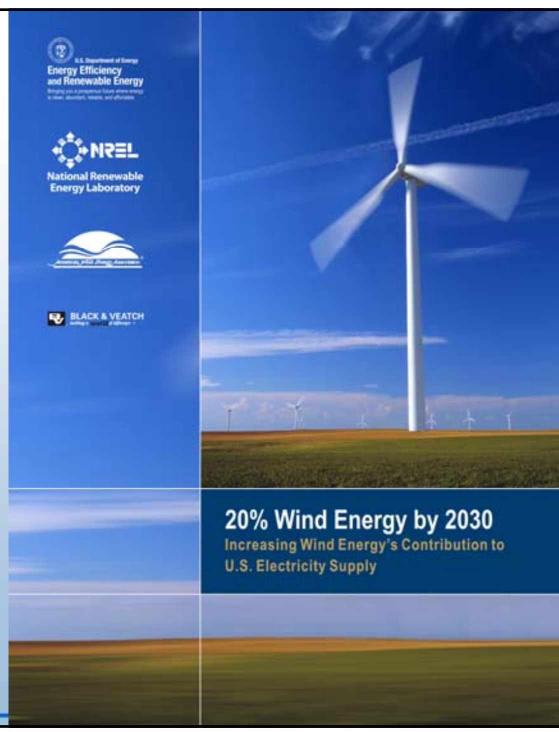
NREL is operated by Midwest Research Institute • Battelle

Outline

- Vision overview and intro
- Wind Supply and WinDS modeling
- Key results
- Can 20% wind be integrated?
  - What is needed? (Ramp, turn-down)
  - New large-scale studies: East and West
  - Transmission needs
- Implication for NB
  - Wind in the 20% scenario
  - Transmission authorities

Vision Overview and Intro

- Can the U.S. electricity supply include 20% contribution from wind?
- If so, what would it take?
- What are the issues?
- Report released May 12, 2008
- www.20percentwind.org
- This presentation covers some key items related to system integration and *my* view of some supporting evidence



A New Vision

For Wind Energy in the U.S.

White House photo by Eric Draper

State of the Union Address

"…We will invest more in … **revolutionary** and…**wind technologies**"

Advanced Energy Initiative

"Areas with good wind resources have the potential to **supply up to 20% of the electricity** consumption of the United States."

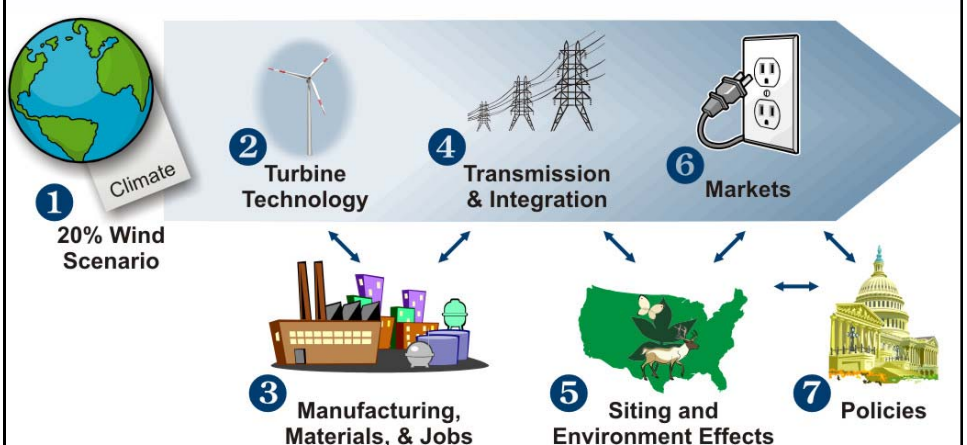
20% Wind Scenario:
Wind Energy Provides 20% of U.S. Electricity Needs by 2030

Key Issues to Examine:

- Does the nation have sufficient wind energy resources?
- What are the wind technology requirements?
- Does sufficient manufacturing capability exist?
- What are the economic costs and benefits?
- Can the electric network accommodate 20% wind?
- What are the environmental impacts and benefits?
- Is the scenario feasible?

Assessment Participants:

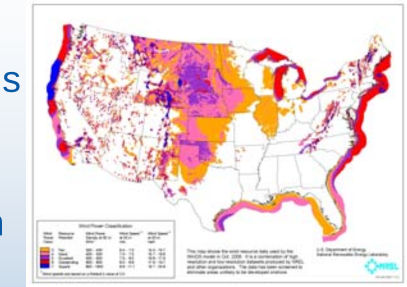
- American Wind Energy Association (AWEA)
  - Leading wind manufacturers and suppliers
  - Developers and electric utilities
  - Others in the wind industry
- U.S. Department of Energy (DOE)
  - Office of Energy Efficiency and Renewable Energy (EERE), Office of Electricity Delivery and Energy Reliability (OE), and Power Marketing Administrations (PMAs)
  - National Renewable Energy Laboratory (NREL)
  - Lawrence Berkeley National Laboratory (Berkeley Lab)
  - Sandia National Laboratories (SNL)
- Black & Veatch



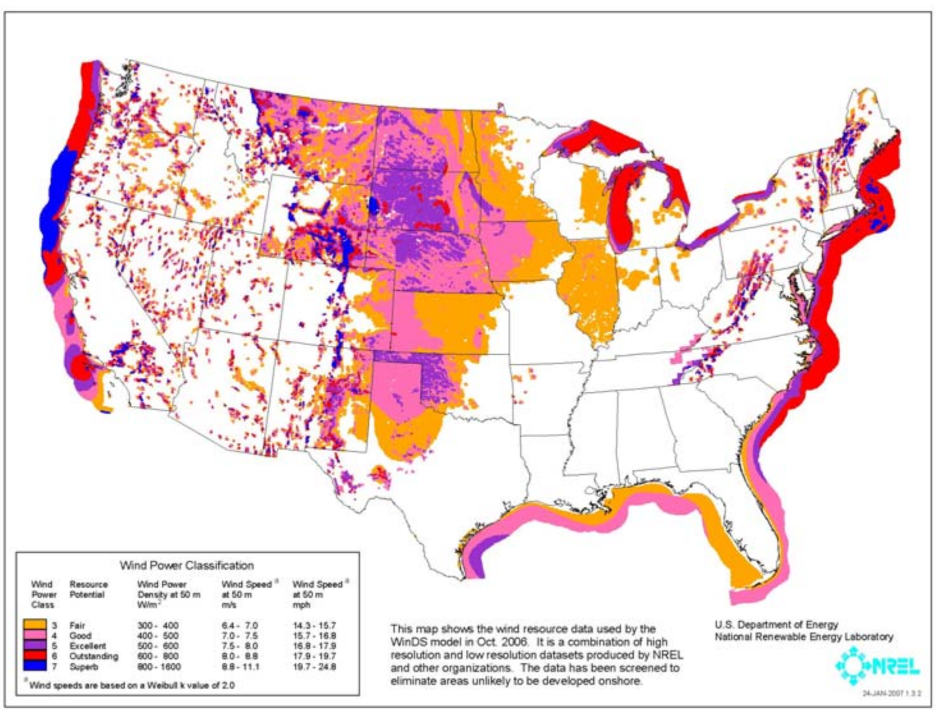
NREL National Renewable Energy Laboratory

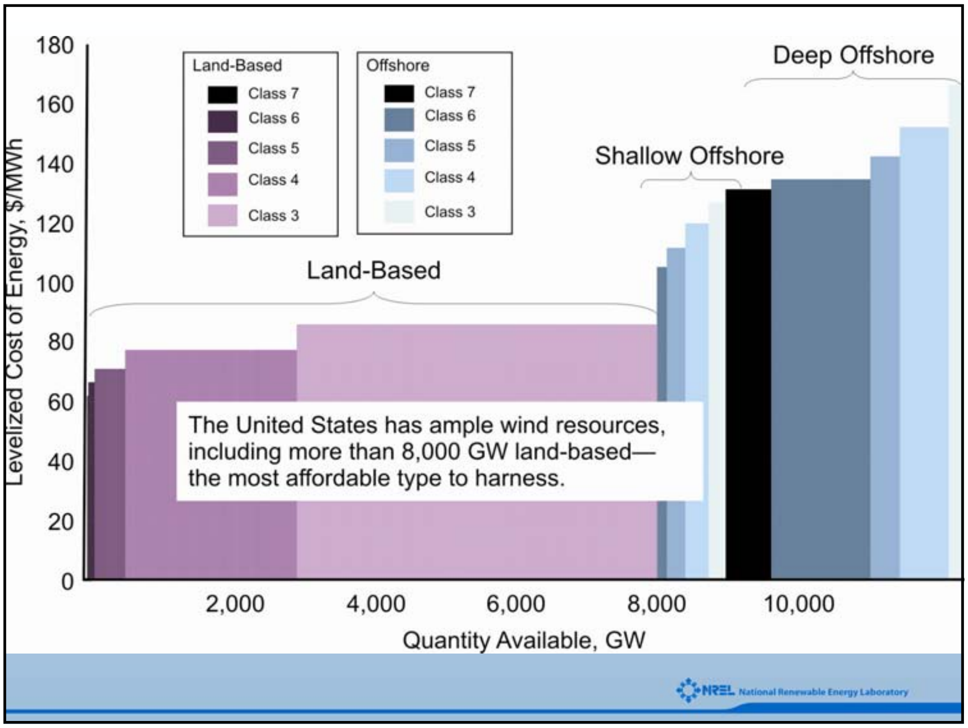
Wind Supply and Modeling

- National database of wind speeds, transmission locations and cost
- WinDS: Wind Deployment System generation expansion model for the United States
  - Utilized detailed wind data
  - Load data
  - Conventional generation characteristics
  - Transmission constraints, import limits are respected

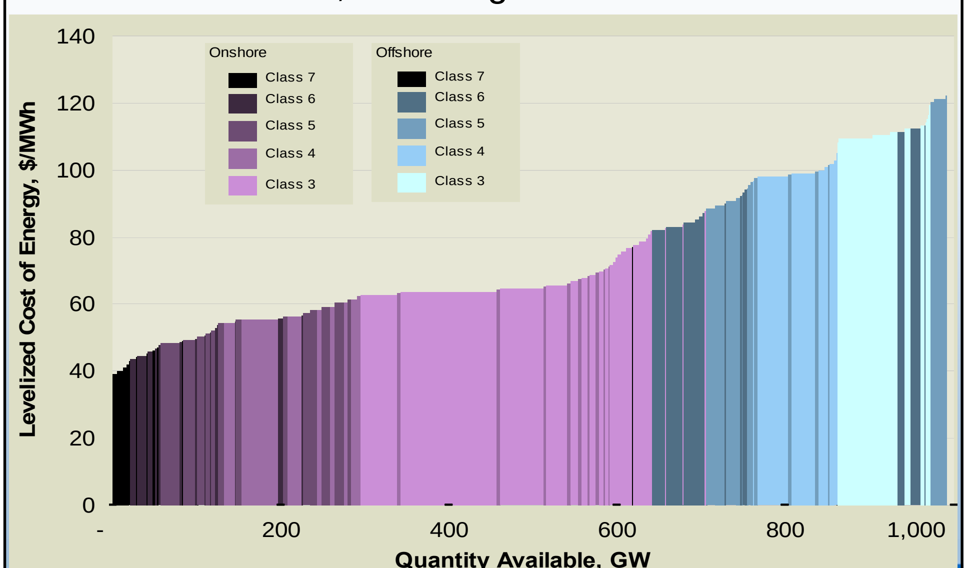


NREL National Renewable Energy Laboratory

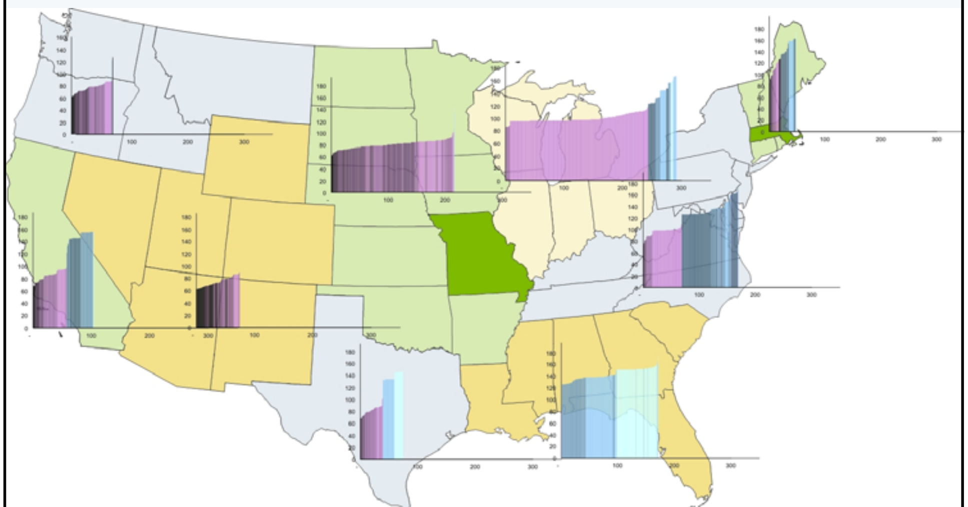




10% Available
Transmission 2010 Costs w/ PTC, $1,600/MW-mile, w/o Integration costs

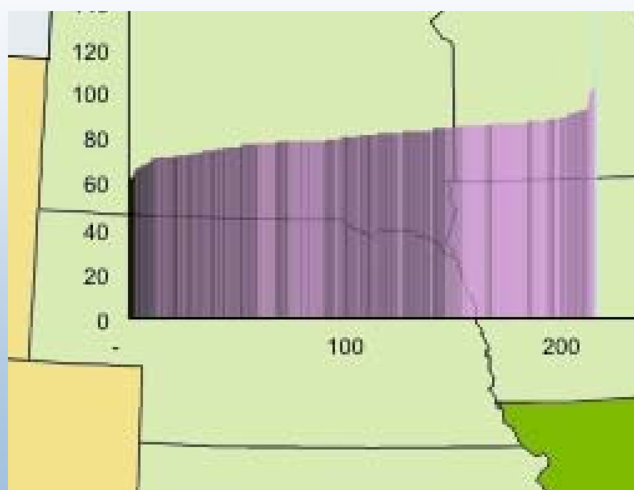


Regional supply curves for wind energy: energy costs including connection to 10% of existing transmission grid capacity in US$2006

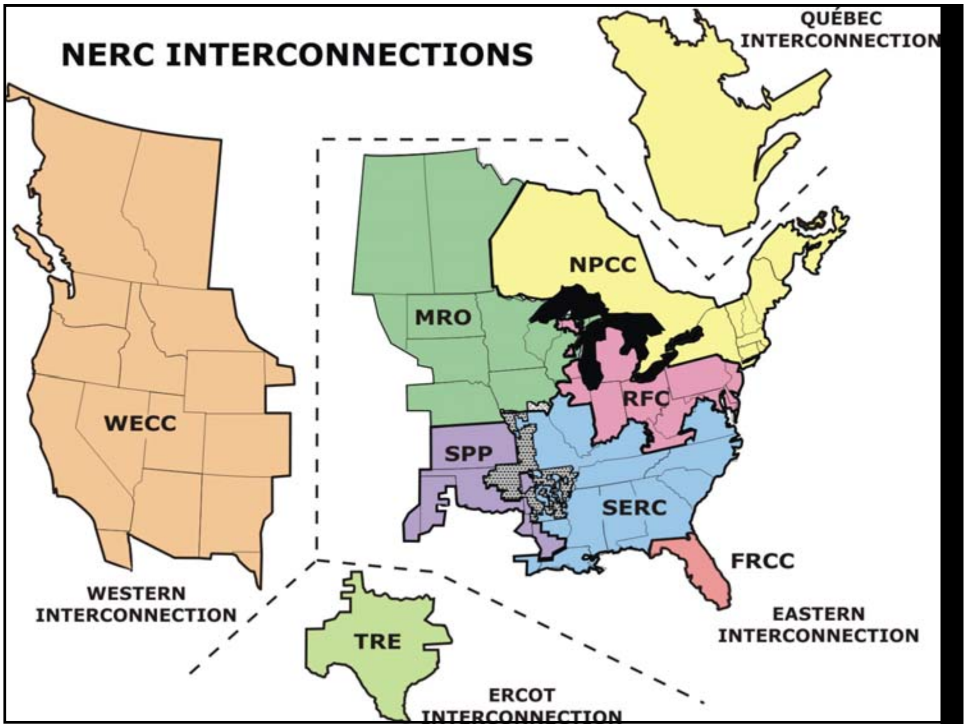


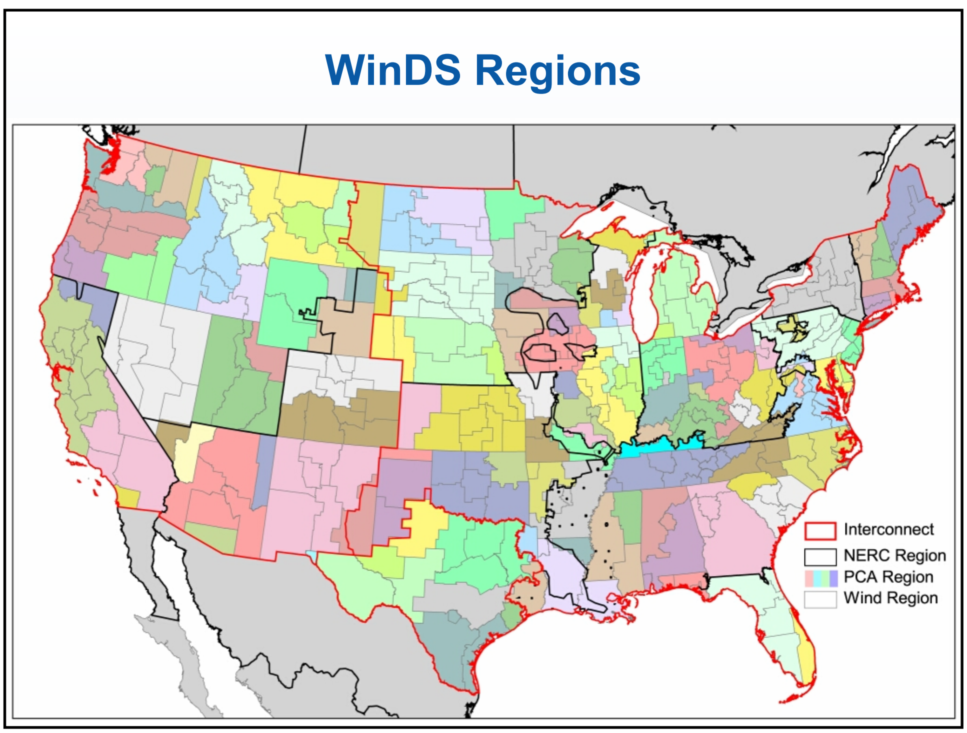
NREL National Renewable Energy Laboratory

Regional supply curves for wind energy: energy costs including connection to 10% of existing transmission grid capacity in US$2006

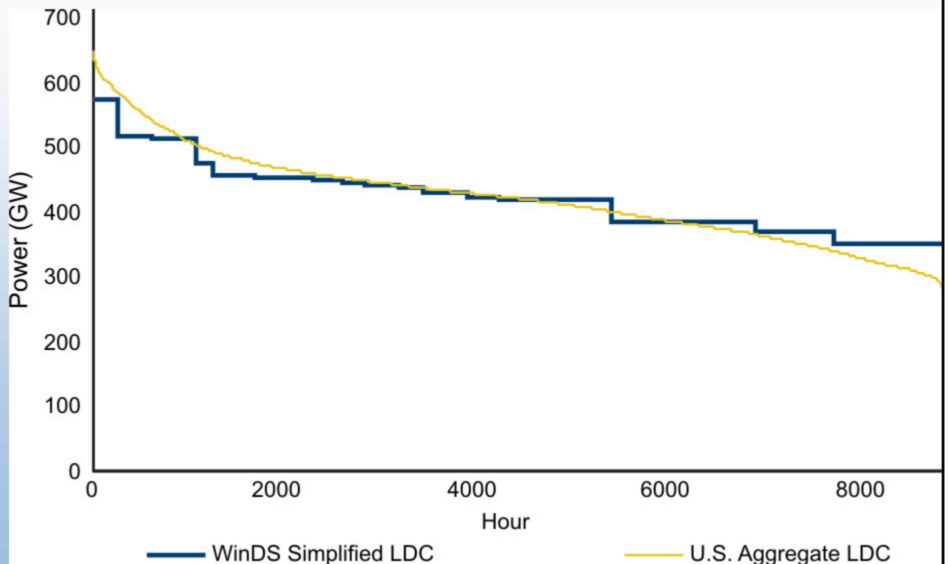


NREL National Renewable Energy Laboratory


NERC INTERCONNECTIONS
QUÉBEC INTERCONNECTION
NPCC
MRO
WECC
RFC
SPP
SERC
FRCC
WESTERN INTERCONNECTION
TRE
EASTERN INTERCONNECTION
ERCOT INTERCONNECTION

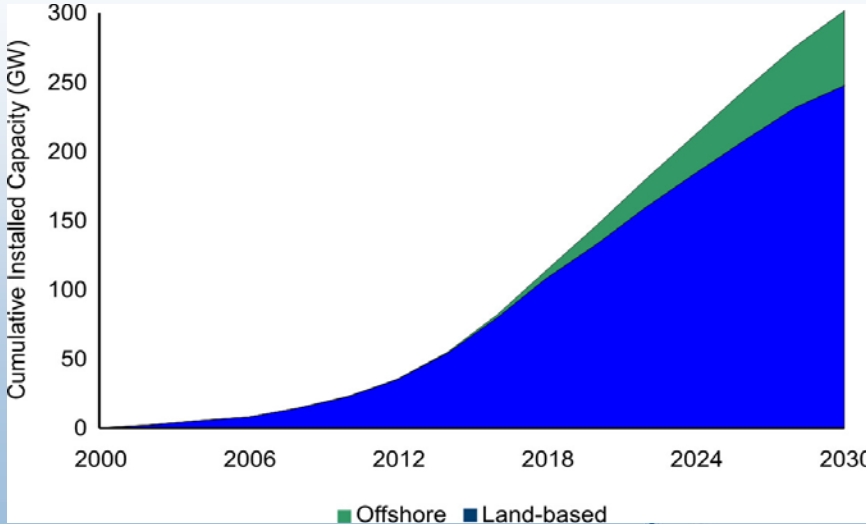

WinDS Regions
Interconnect
NERC Region
PCA Region
Wind Region

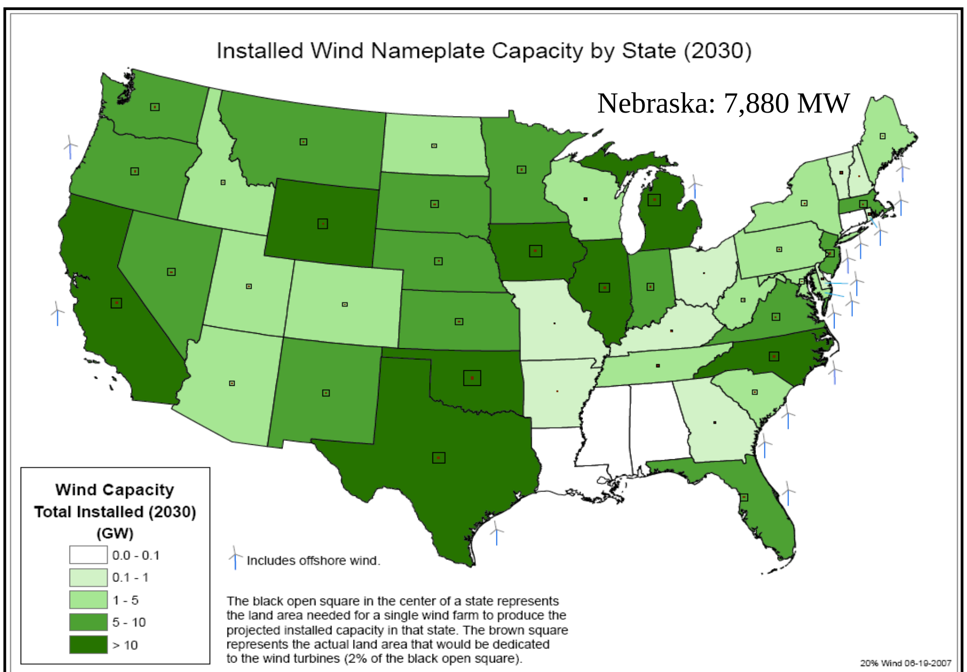
National load duration curve for base year in WinDS

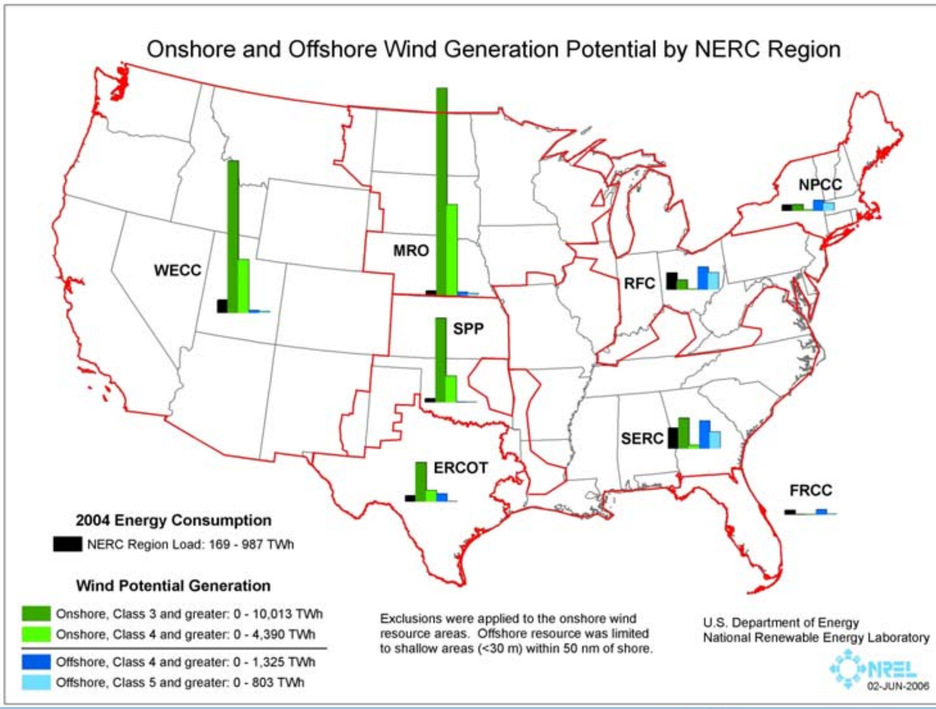


Key Vision Results

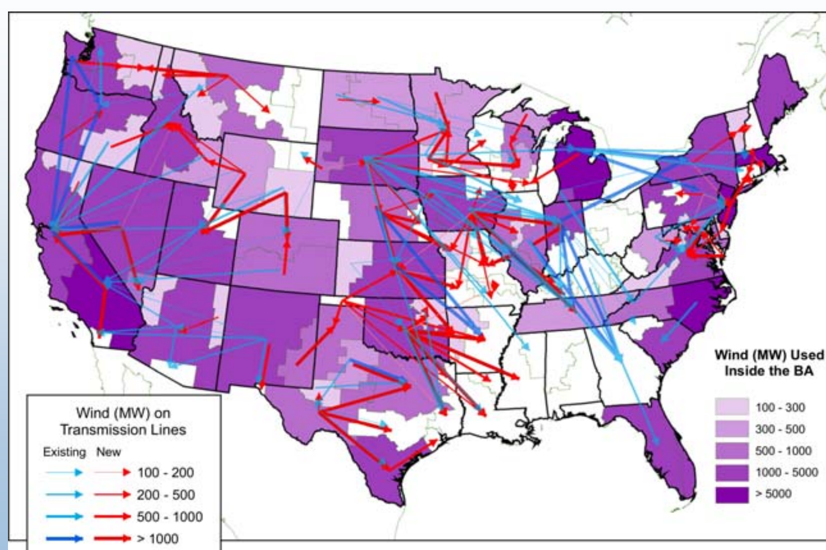
Cumulative installed wind power capacity required to produce 20% of projected electricity by 2030 (more than 16GW per year after 2018)



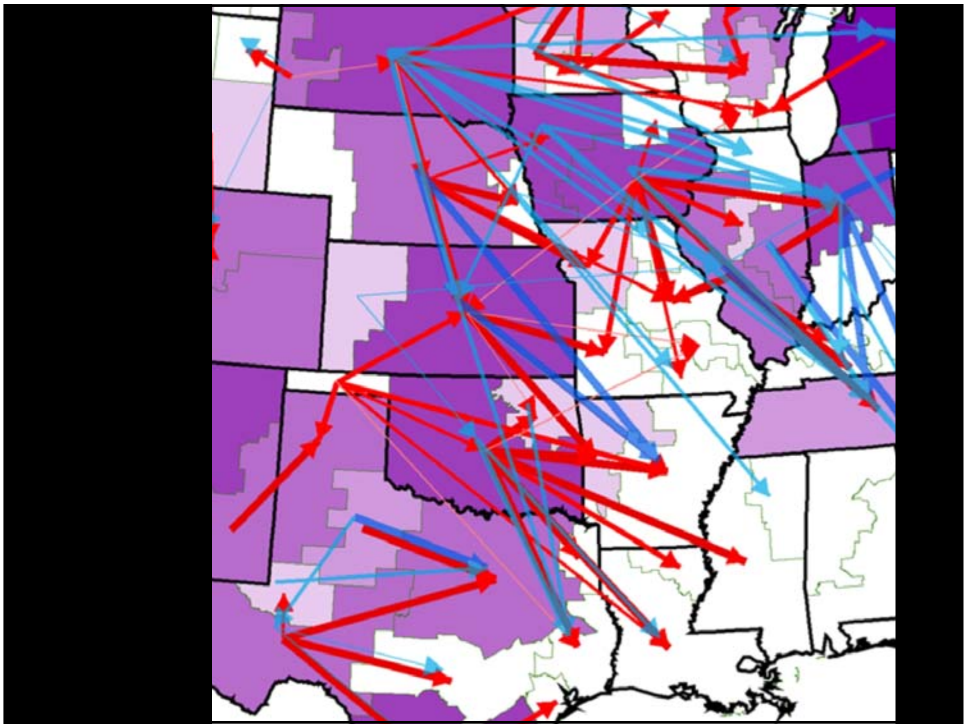




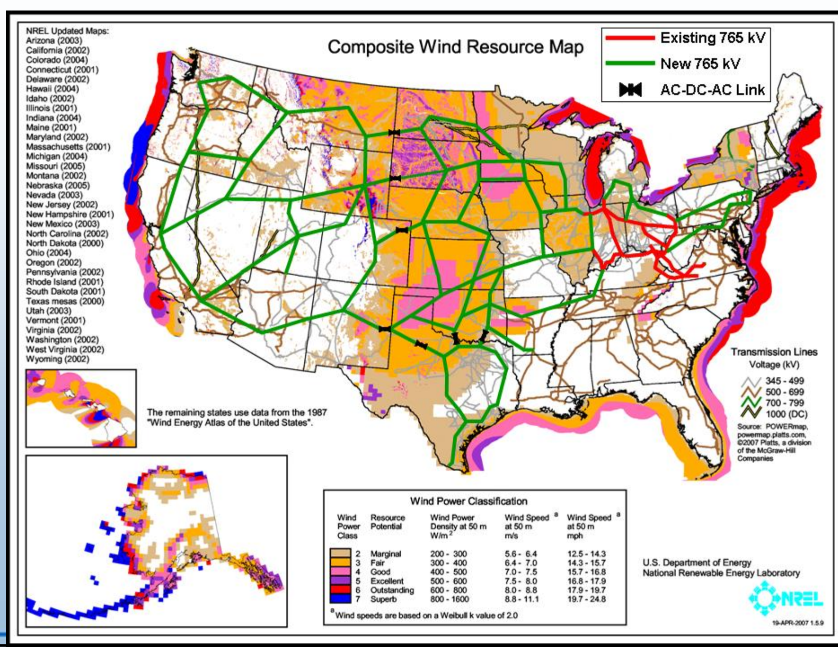
Estimated Transmission Links



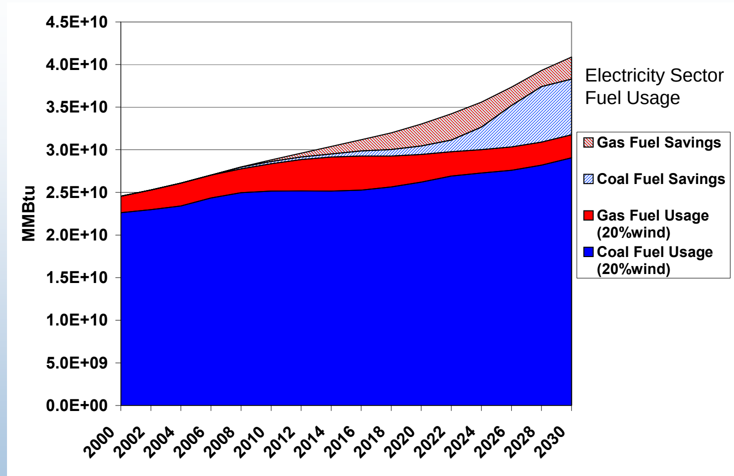
Total Between Balancing Areas Transfer >= 100 MW (all power classes, land-based and offshore) in 2030.
Wind power can be used locally within a Balancing Area (BA), represented by purple shading, or transferred out of the area on new or existing transmission lines, represented by red or blue arrows. Arrows originate and terminate at the centroid of the BA for visualization purposes; they do not represent physical locations of transmission lines.



AEP’s Conceptual 765kV Grid



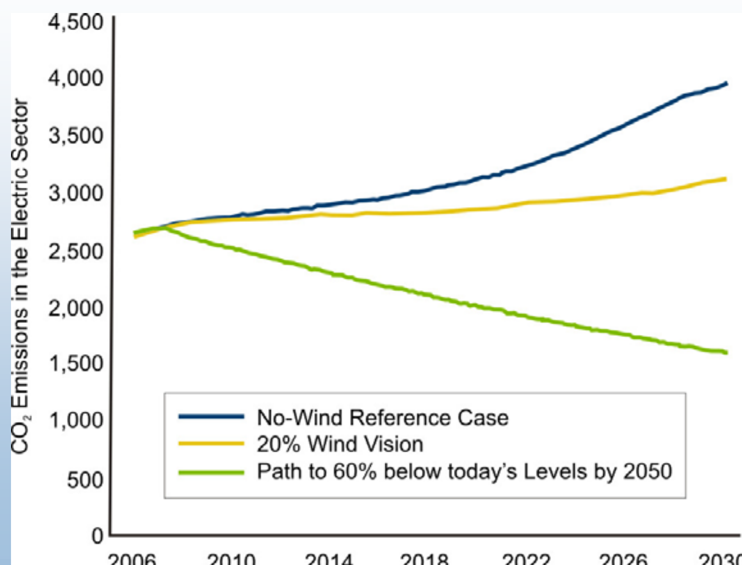
Fuel Savings From Wind



Reduction in National Gas Consumption in 2030 (%)	Natural Gas Price Reduction in 2030 (2006$/MMBtu)	Present Value Benefits (billion 2006$)	Levelized Benefit of Wind ($/MWh)
11%	0.6 -**1.1**- 1.5	86 - **150** - 214	16.6 - **29** - 41.6

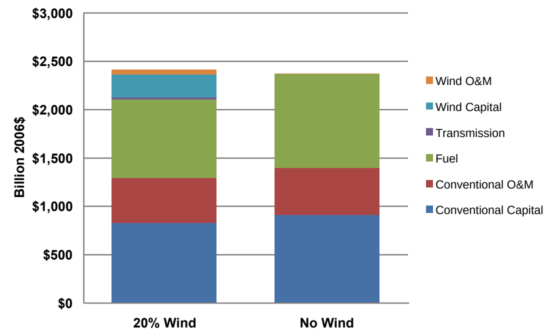
National Renewable Energy Laboratory

Electric Sector CO_2 Emissions



National Renewable Energy Laboratory

Incremental Cost of 20% Wind Vision



	Present Value Direct Costs (billion 2006$)*	Average Incremental Levelized Cost of Wind ($/MWh-Wind)*	Average Incremental Levelized Rate Impact ($/MWh-Total)*	Impact on Average Household Customer ($/month)**
Vision Scenario	$43 billion	$8.6/MWh	$0.6/MWh	$0.5/month

* 7% real discount rate is used, as per OMB guidance; the time period of analysis is 2007-2050, withWinDS modeling used through 2030, and extrapolations used for 2030-2050.
** Assumes 11,000 kWh/year average consumption

Results: Costs & Benefits

Incremental direct cost to society	**$43 billion**
Reductions in emissions of greenhouse gasses and other atmospheric pollutants	825 M tons (2030) **$98 billion**
Reductions in water consumption	8% total electric 17% in 2030
Jobs created and other economic benefits	140,000 direct $450 billion total
Reductions in natural gas use and price pressure	11% **$150 billion**
Net Benefits: $205B + Water savings	

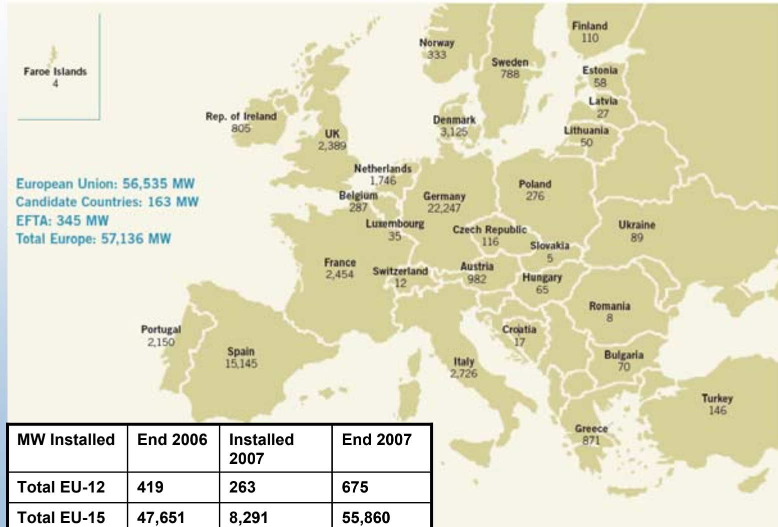
NREL National Renewable Energy Laboratory

Integrating 20% Wind

- Experience in Europe at higher penetration rates
- Large Balancing Areas and markets can reduce barriers and cost for all
- Key recommendations

http://www.vtt.fi/inf/pdf/workingpapers/2007/W82.pdf

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

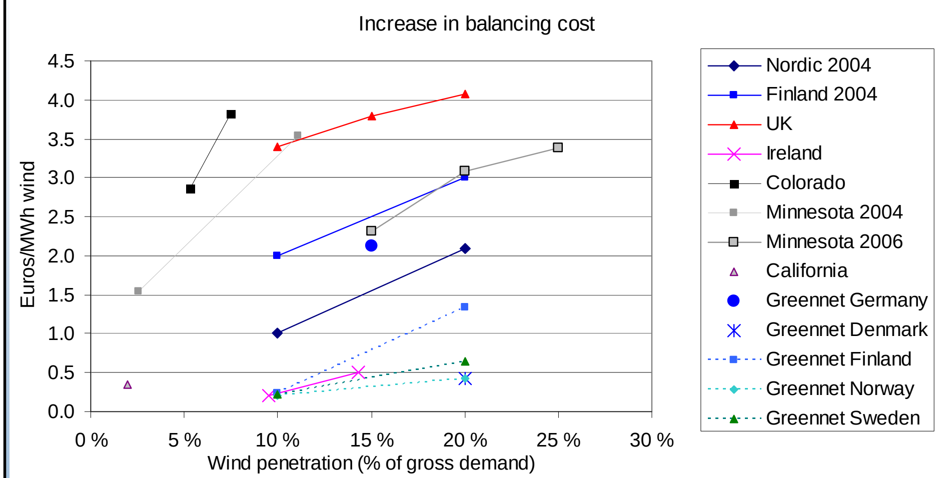
NREL National Renewable Energy Laboratory

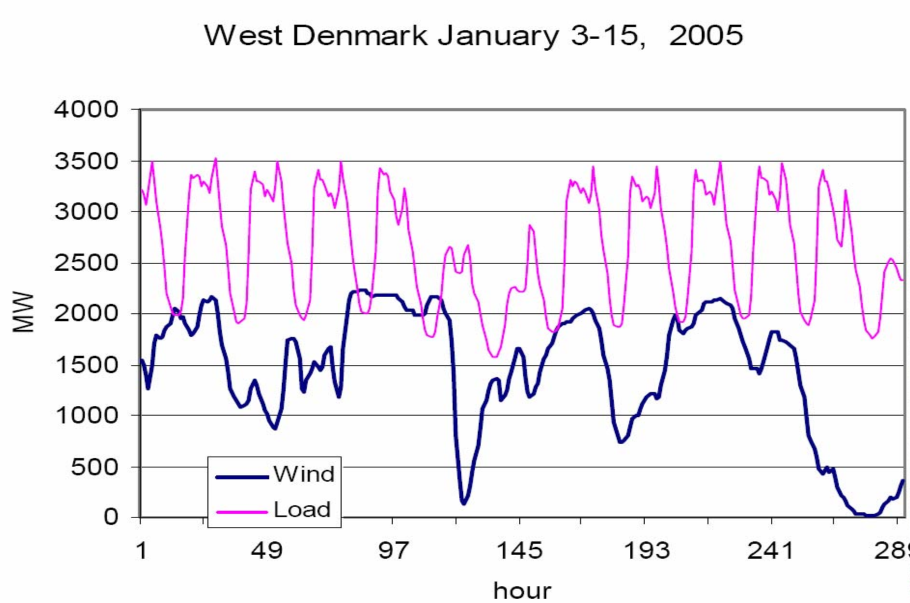
European Experience

(data for 2005-2006)	Denmark (W)	Spain	Germany	Ireland
Peak Load (MW)	3,700	44,000	78,000	4,800
Minimum Load (MW)	1,200	17,000	38,000	1,800
Wind Capacity (MW)	2,400	10,000	18,000	600
Wind, % Peak Load	65%	23%	23%	12%
Wind, % Minimum Load	200%	59%	50%	33%
Wind, % Total Energy	24%	7%	5.5%	6%
Capacity Goal by 2010 (MW)	3,600	20,000	25,000	1,200

NREL National Renewable Energy Laboratory

Comparison of International Results





Denmark has access to large export markets

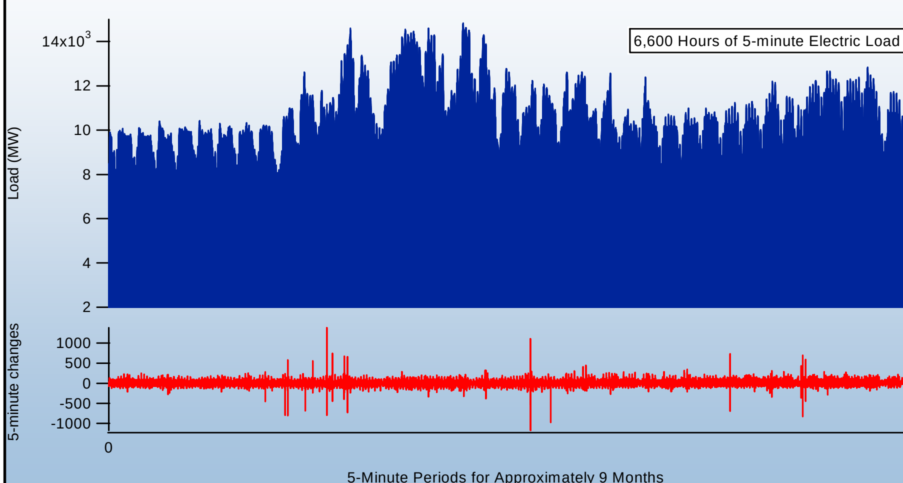
Lennart Söder,KTH, Sweden, presented at UWIG, Oct 23-25, 2006

Key Challenges for Wind Integration at High Penetration

- Can the increased variability be accommodated?
- Can the increased uncertainty be accommodated?
- Is there sufficient turn-down capacity?
- Is there sufficient transmission to ensure deliverability?

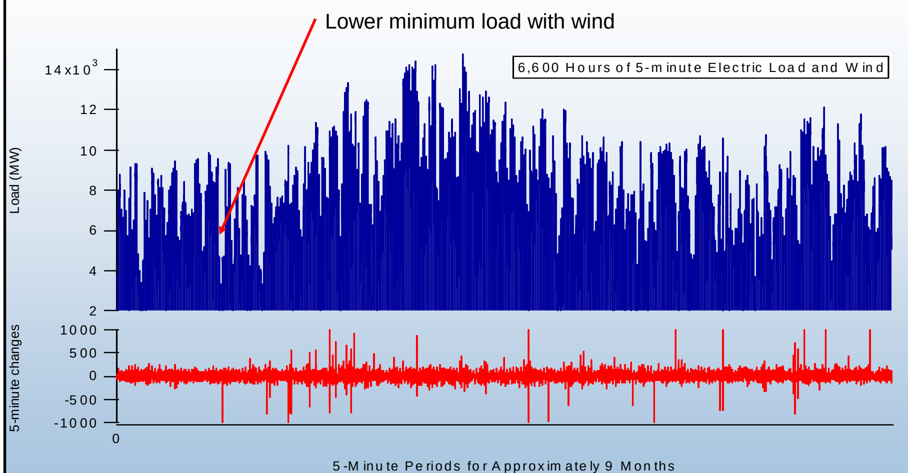
NREL National Renewable Energy Laboratory

Variability: Load Alone



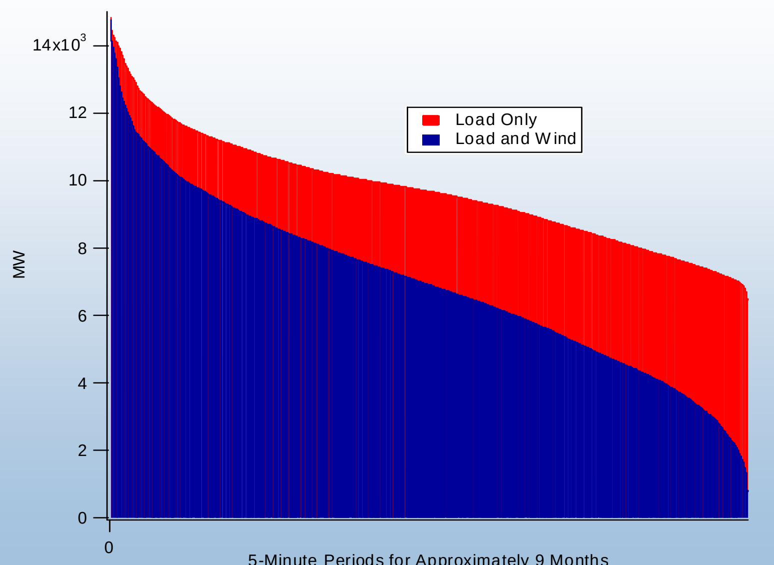
NREL National Renewable Energy Laboratory

Increased Variability: Load and Wind

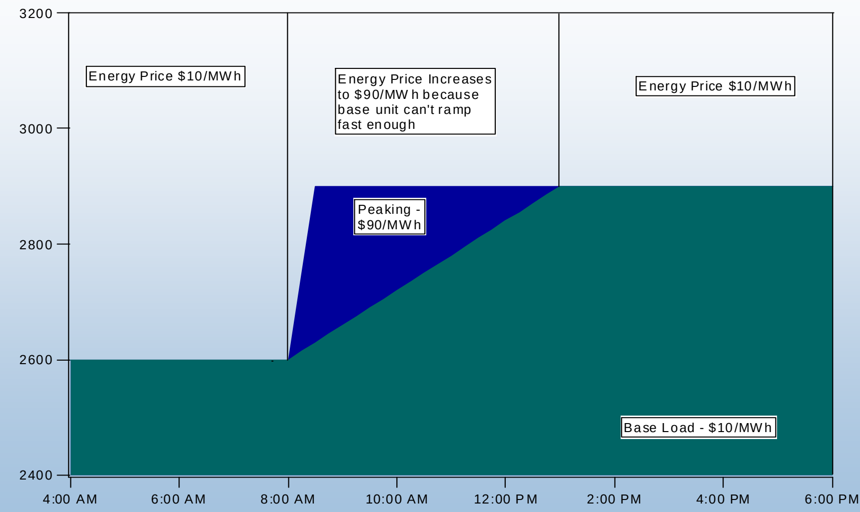


Ramp requirements increase with 25% wind energy penetration. The upper panel also shows the importance of being able to achieve lower minimum loads by the conventional generation fleet.

Lower Turn-down is required



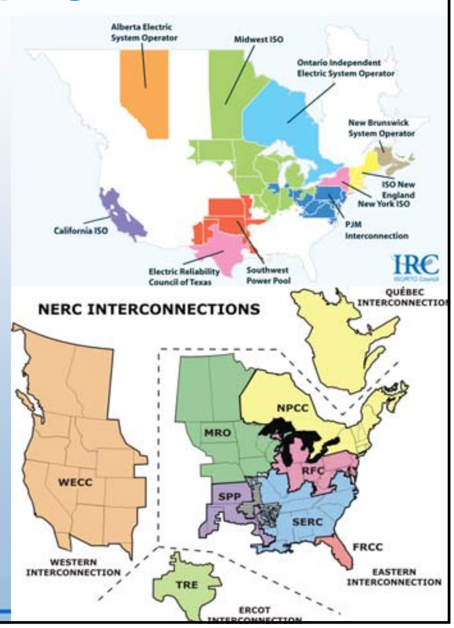
Can the non-wind fleet ramp quickly enough?



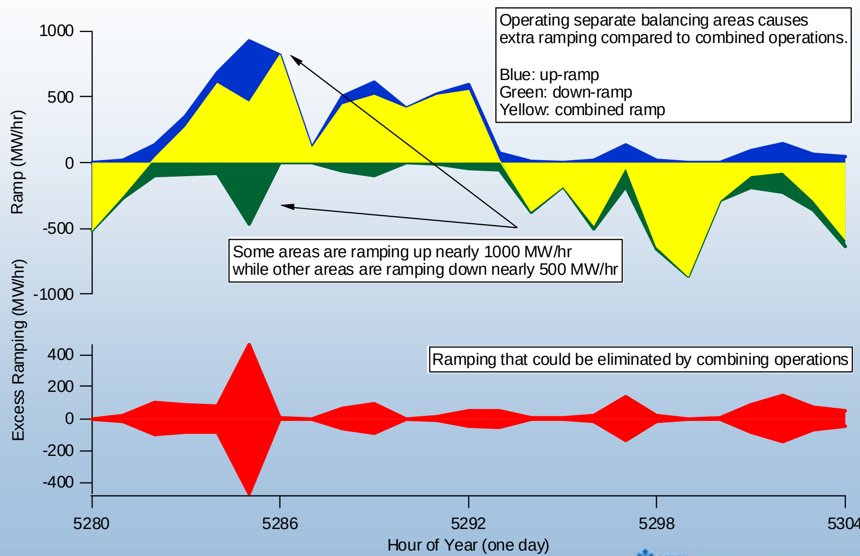
NREL National Renewable Energy Laboratory

Where can more ramping be obtained?

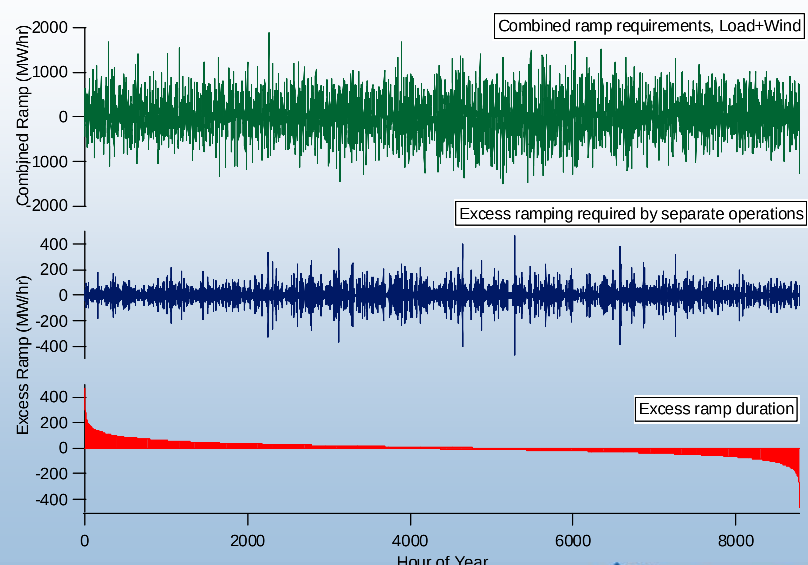
- More/different physical generation acquisition
- Virtual or real Balancing Area consolidation – or access to large markets
- Ramping constraints such as this are currently experienced in Alberta (AESO) and New Mexico (PNM)
- This constraint is a function of wind ***and*** non-wind generation characteristics



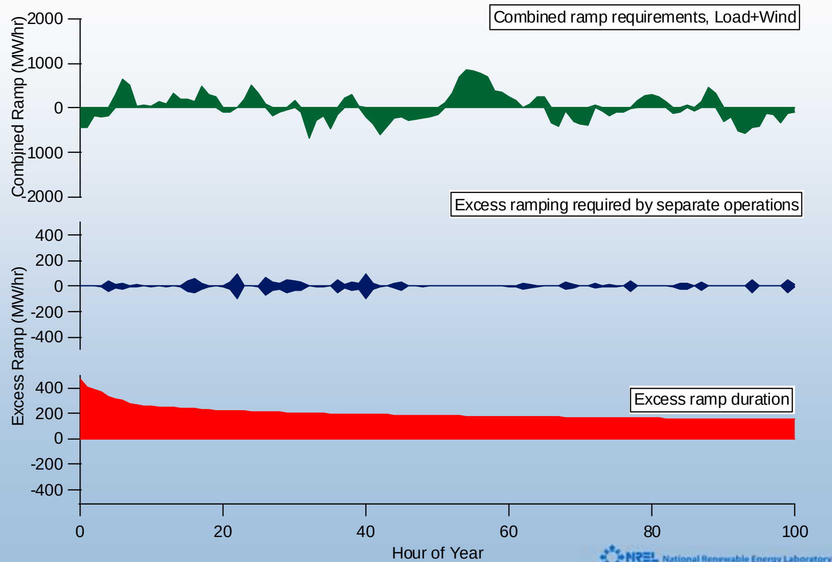
BA Consolidation Can Help (hourly)



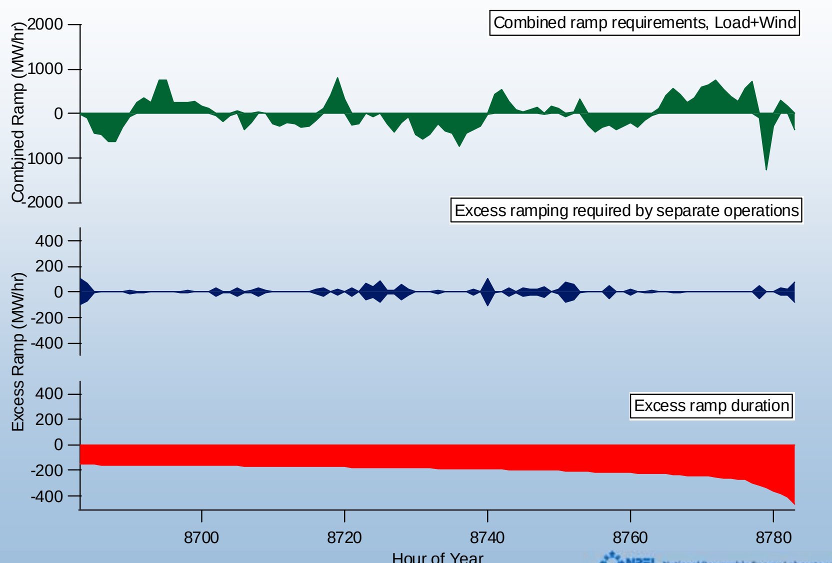
BA Consolidation Reduces Ramp Requirements (hourly)



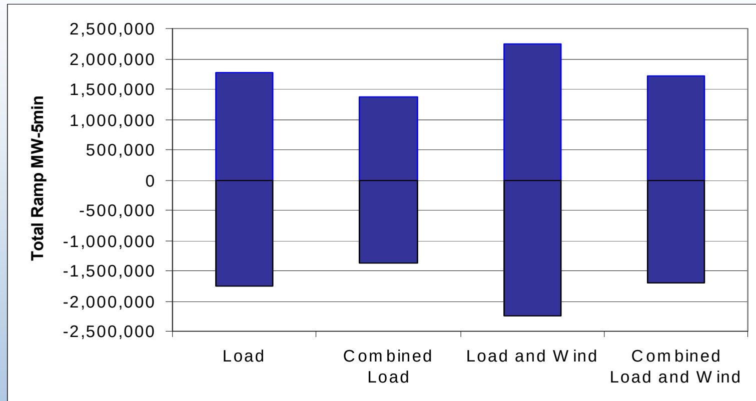
Large tail-events (infrequent, large ramps) can be eliminated (hourly)



Large tail-events (infrequent, large ramps) can be eliminated (hourly)

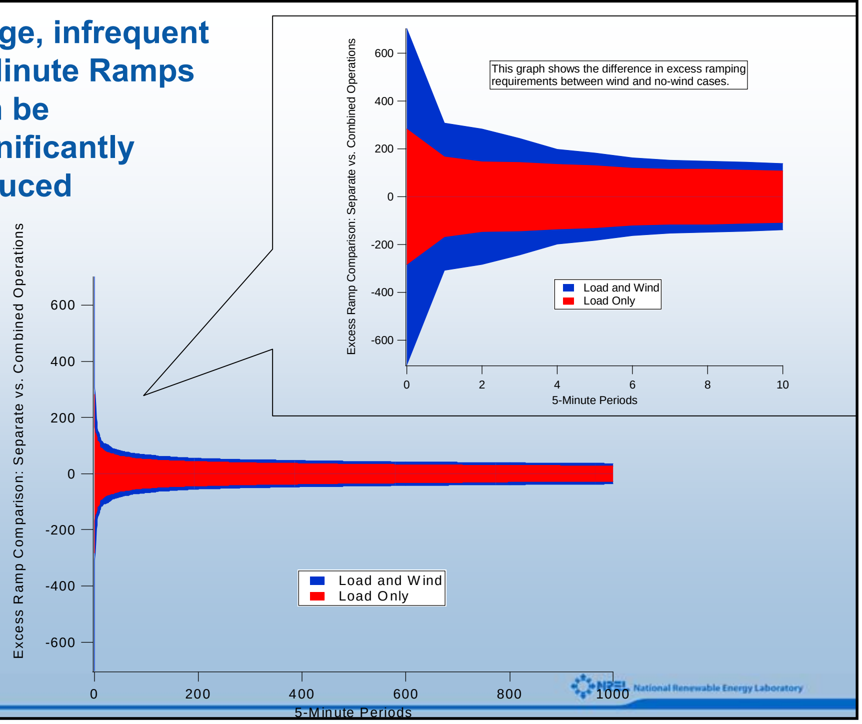


5-Minute Ramp Reductions

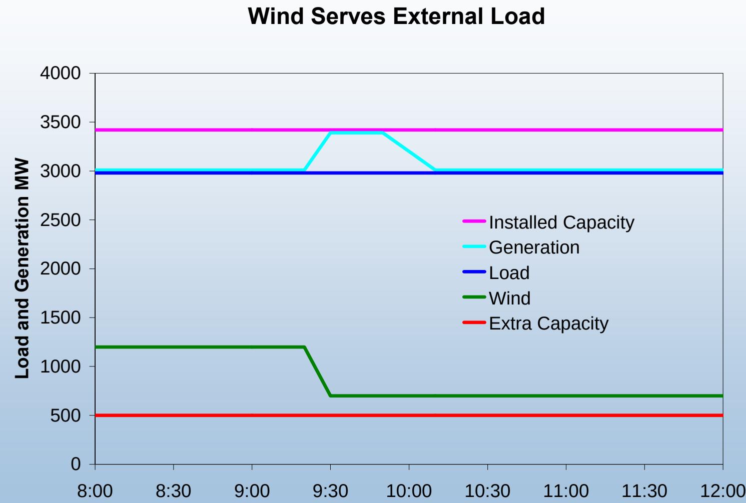


For load alone, there is a 22.4% reduction in ramping requirements when operations are combined. For load and wind together, this reduction is 23.8%.This graph shows the total ramping, measured in MW-5min (one MW ramp for 5 minutes)

Large, infrequent 5-Minute Ramps can be significantly reduced



More efficient use of existing capacity: larger BAs and faster markets



Due to hourly scheduling requirements the host CA covers delivery of wind until the end of the hour

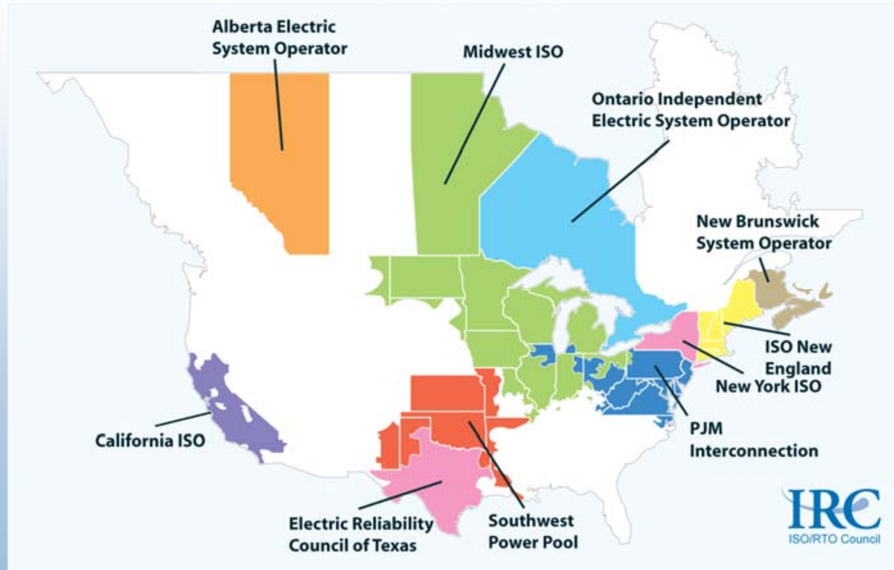
NREL National Renewable Energy Laboratory

How can lower turn-down be acquired?

- Less base-load/more flexible generation
- How to get there?
  - Transparent market signals that value turn-down (negative prices during low-load/high-wind periods
  - In regulated markets may need some form of targeted resource planning

NREL National Renewable Energy Laboratory

Power Markets in North America



Flexible Markets Reduce Energy Costs

- With or without wind
- Fast energy markets can extract ramping capacity from the energy market
- Ability to tap existing flexibility requires institutional solutions (Kirby & Milligan, 2005 *Methodology for Examining Control Area Ramping Capabilities with Implications for Wind* found substantial ramping capability often exists “behind the wall” and is not accessible to grid operators

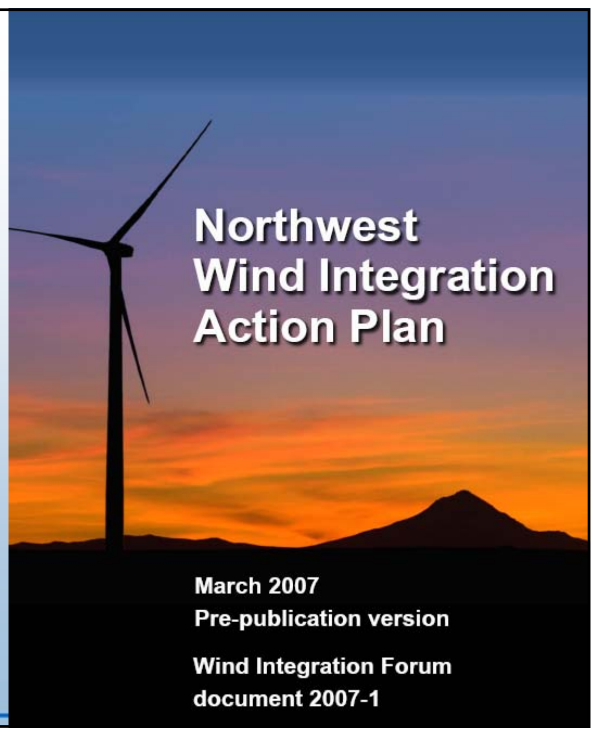
NREL National Renewable Energy Laboratory

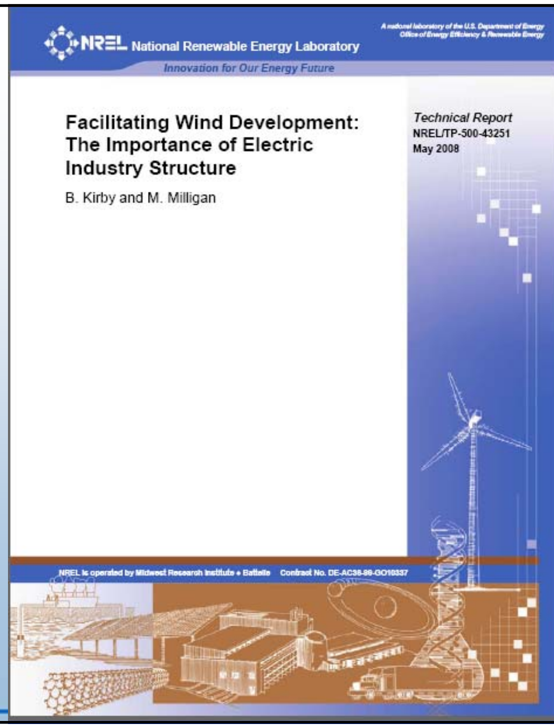
NYISO Load Following

- Energy markets provide a strong signal that motivates load following response
  - But only for currently marginal generators
- 5 minute energy market price averages $3.50/MWH *less* than the hourly market price
  - Customers do not appear to be paying a premium for load following

Kirby & Milligan, working paper. To appear.

Recognized Importance of Fast Energy Markets





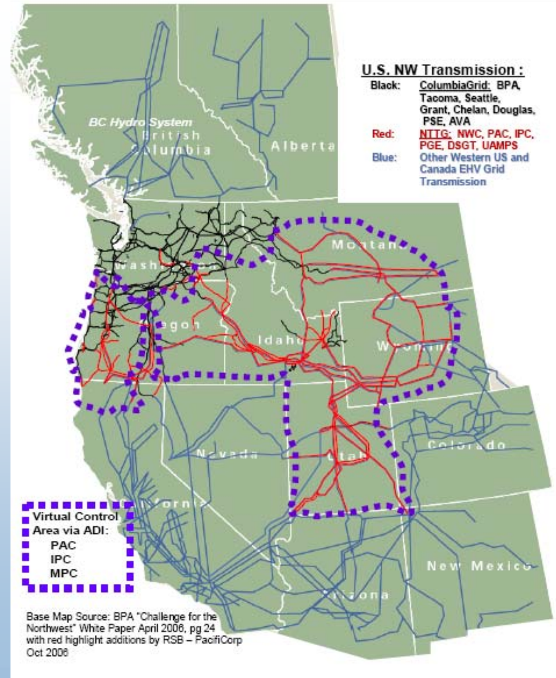
Balancing Area Consolidation: What Other Analyses/Experiments are Underway?

- Virtual consolidation
  - NTTG's ADI
- NREL's Large-scale studies
  - Western Wind and Solar Integration Study (WWSIS)
  - Eastern Wind and Transmission Study (EWITS) with JCSP

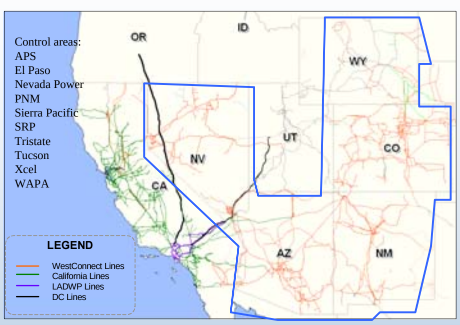
NREL National Renewable Energy Laboratory

Northern Tier Transmission Group

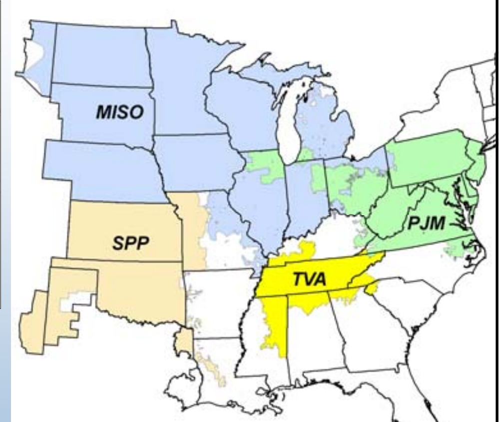
- ACE Diversity Interchange (ADI)
- Pooling of regulation signals
- Growing interest in the West
- BPA to join later in 2008



Large-scale integration studies



Western Wind and Solar Integration Study: 30% Wind penetration (energy)



Eastern Wind and Transmission Study (30% Wind penetration (energy)

Other Flexibility Options

- Fast-ramping generation with good heat rates, low turn-down, low start-up cost
- Bi-lateral pooling agreements (similar to ADI but longer time frames)
- Innovation in hydro scheduling
- Economic wind curtailment, ramp limitations during critical periods
  - Morning load pickup
  - Evening load drop off
- Storage has value, but not cost-effective

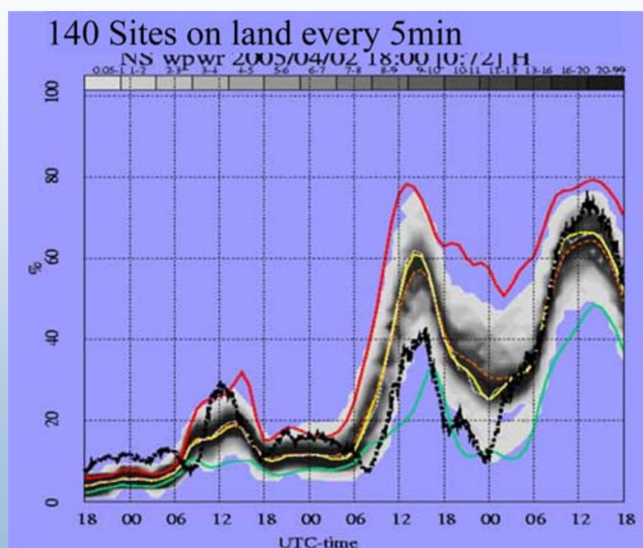
What about wind forecasts?

- Forecasts must be tuned to the needs of the system operator
- Forecasts of potentially large ramp events?
- High-wind warning systems?
- Aggregate wind forecast error is reduced with large geographic aggregation

Typical Wind Forecast Errors

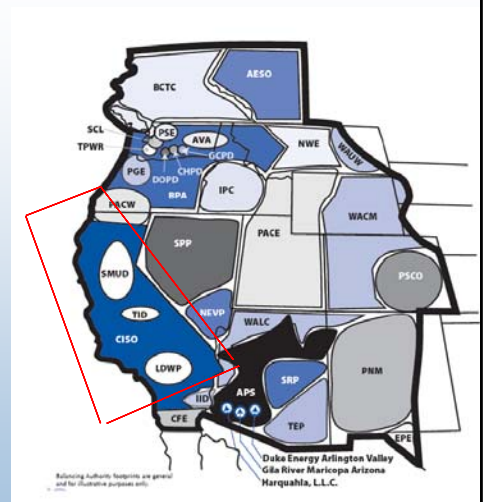
- Next day hourly power: 10-14% MAE of rated capacity
- Next day total energy: 20% MAE of energy delivered
- Next 2-3 hour power schedule: 5-7% MAE of rated capacity
- Improvements are likely

Forecasting and Balancing Markets Reduce Impacts



California Intermittency Analysis Project

- Consultant: GE Energy
- Up to 24% wind (rated capacity to peak)
- Savings
  - WECC nearly $2B
  - CA $760M
- Wind forecast benefit $4.37/MWh
- Regulation cost up to $0.67/MWh
- Unit commitment w/forecast results in sufficient load following capability (and no load following cost)



•http://www.uwig.org/CEC-500-2007-081-APB.pdf

NREL National Renewable Energy Laboratory

Geographic dispersion helps reduce wind forecast errors

- Geographic dispersion can reduce forecast errors by 30-50% (WindLogics, UWIG Forecasting Workshop, Feb 2008)

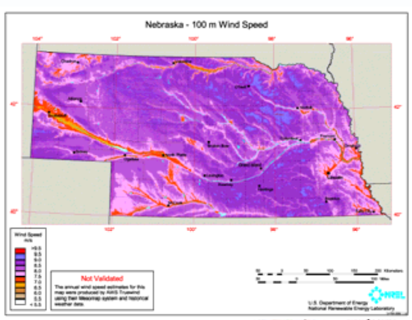
NRMSE Forecasting Error %	Germany (all 4 control zones) ~1000 km	1 German Control Zone ~350 km
Day ahead	5.7	6.8
4 hours ahead	3.6	4.7
2 hours ahead	2.6	3.5

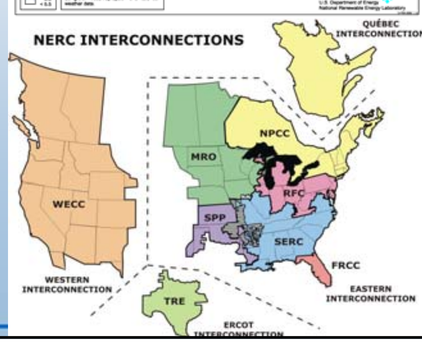
NREL National Renewable Energy Laboratory

NERC's IVGTF, Regional 15% Studies

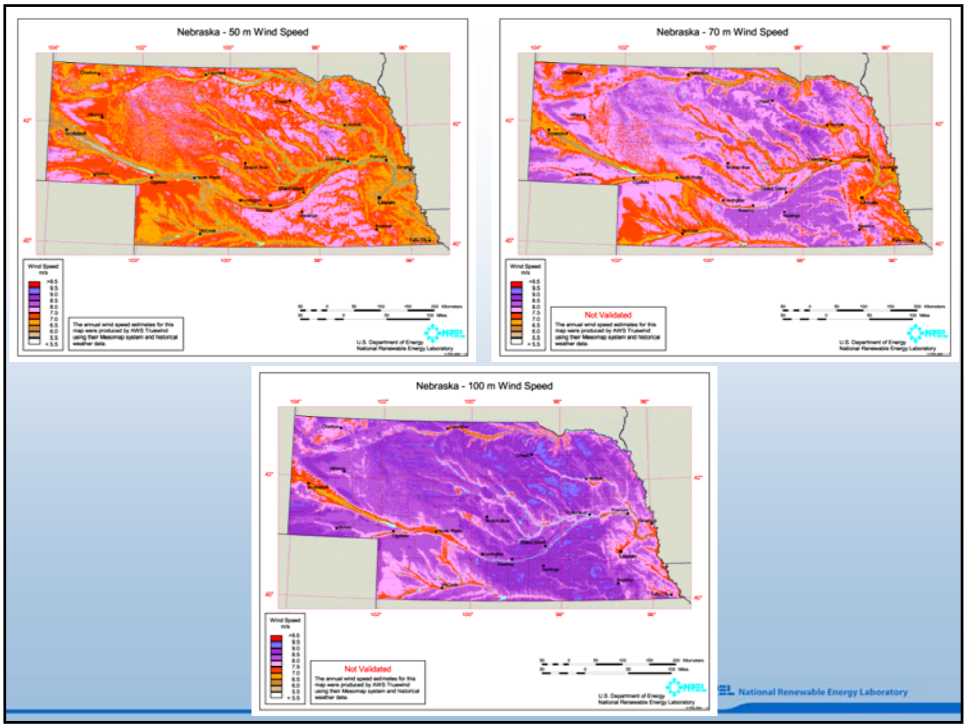
- White paper to be completed by end of 2008 (IVGTF)
- NERC Regional reliability councils to perform 15% renewable reliability study in 2009

Vision: Impacts on NE



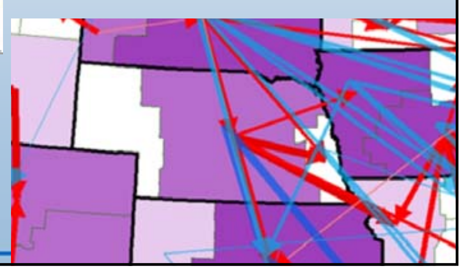


- Nebraska has a very robust wind resource: 7,880 MW of wind capacity in Vision scenario based on optimal location and economics
- Situated at the nexus of potential transmission
- → opportunities for significant wind energy export: Eastern or Western Interconnection
- → economic development impacts of wind and transmission



Vision Impacts on Nebraska

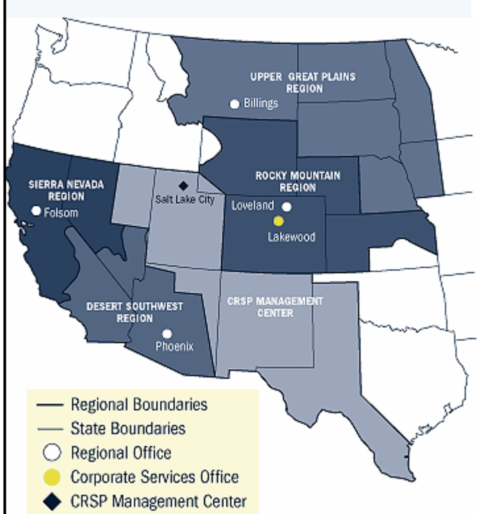
- Uniquely positioned at western edge of the Eastern Interconnection

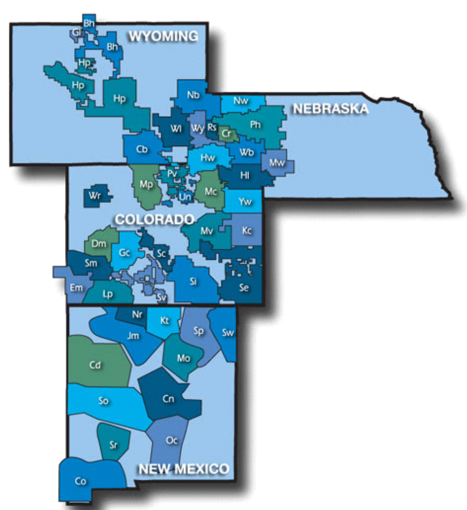


Integration of Large Wind In Nebraska: What would it take?

- Cooperation between balancing areas, utilities in the state
- Pooling of imbalance, generator response
- Innovative arrangements with WAPA, Tri-State, Basin
  - Participate in MISO or other large market
- Transmission planning
  - Coordination with MISO, possibly SPP
  - Transmission infrastructure authority? (more later)

Western Area Power Administration (WAPA) and Tri-State





Large-Scale Integration Summary

- Institutional constraints are often binding and limit physical response
- Power system was designed to handle variability, uncertainty
- Wind at high penetration rates can have significant impact on both
- Solutions are well-known
- Some challenges remain, technically and institutionally

NREL National Renewable Energy Laboratory

Nebraska – Economic Impacts

From the 20% Scenario
7,880 MW new development

Wind energy's economic "ripple effect"

Direct Impacts

Payments to Landowners:
- $20 Million/yr

Local Property Tax Revenue:
- $30 Million/yr

Construction Phase:
- 12,900 new jobs
- $1.5 B to local economies

Operational Phase:
- 2,000 new long-term jobs
- $165 M/yr to local economies

Indirect & Induced Impacts

Construction Phase:
- 13,100 new jobs
- $1.2 B to local economies

Operational Phase:
- 1,500 local jobs
- $145 M/yr to local economies

Totals
(construction + 20yrs)

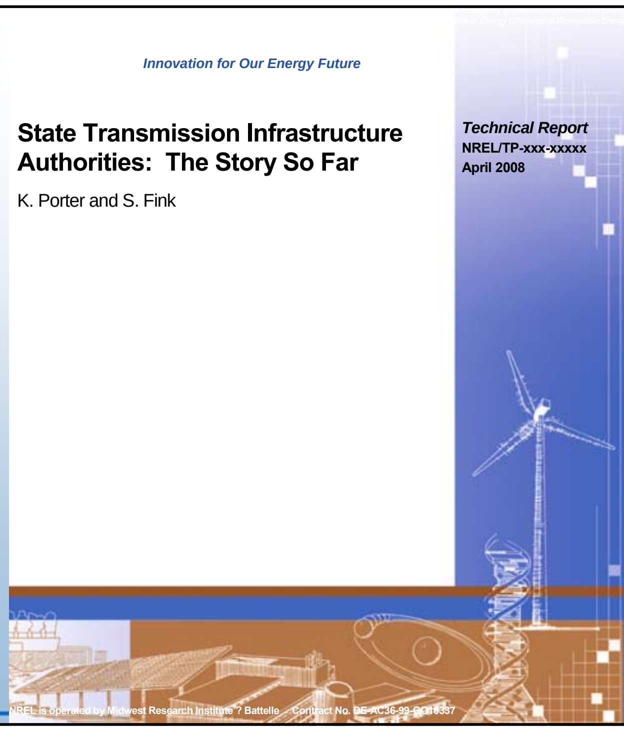
Total economic benefit = $8.9 B
New local jobs during construction = 26,000
New local long-term jobs = 3,600

Does not include impacts from transmission

All jobs rounded to the nearest hundred jobs; Millions of dollars greater than 10 million are rounded to the nearest five million

Construction Phase = 1-2 years
Operational Phase = 20+ years

Transmission: State Transmission Infrastructure Authorities


Innovation for Our Energy Future

State Transmission Infrastructure Authorities: The Story So Far

K. Porter and S. Fink

Technical Report
NREL/TP-xxx-xxxxx
April 2008

NREL is operated by Midwest Research Institute ? Battelle Contract No. DE-AC36-99-GO10337

Seven States Have State Transmission Infrastructure Authorities

- Wyoming Infrastructure Authority, 2004 (WIA)
- South Dakota Energy Infrastructure Authority, 2005 (SDEIA)
- North Dakota Transmission Authority, 2005 (NDTA)
- Idaho Energy Resources Authority, 2005 (IERA)
- Kansas Electric Transmission Authority, 2005 (KETA)
- New Mexico Renewable Energy Transmission Authority, 2007 (RETA)
- Colorado Clean Energy Development Authority, 2007 (CEDA)

Characteristics of State Transmission Infrastructure Authorities

- In large part, formed in large part to access in-state energy resources (particularly coal and wind)
- Located in states with high quality wind resources
  - North Dakota (1st)
  - Kansas (3rd)
  - South Dakota (4th)
  - Wyoming (7th)
  - Colorado (11th)
  - New Mexico (12th)
  - Idaho (13th)

Characteristics of State Transmission Infrastructure Authorities (2)

- Can issue revenue bonds to provide financial support for transmission (and in same cases generation and distribution) projects. Legislative approval may be required in some states.
- Do not rely on the full faith and credit of the state in issuing bonds.
- Most TIAs can build, own, and operate facilities.
- Most can adopt, amend, and repeal bylaws, and exercise eminent domain for project siting purposes.
- The most successful TIAs have received significant financial support from their respective states for start-up operations along with contingency funding for feasibility studies, project design, etc.

NREL National Renewable Energy Laboratory

Progress to Date

- Wyoming: provided $34.5 million through a private bond placement for Hughes Transmission Project; Wyoming-Colorado Intertie Project open season; 10% share in TransWest Express/Gateway South project; participating in High Plains Express project.
- Kansas: issued notices of intent to develop two 345-kV segments; resulted in ITC Great Plains taking the projects on.
- Transmission projects under development could add up to 8,500 MW of capacity; wind could amount to about 3,000 MW of that and perhaps more.

NREL National Renewable Energy Laboratory

TIA Recommendations

- Funding – provide adequate start-up and contingency funding .
- Independence – consider allowing TIA to issue bonds on its own authority instead of requiring legislative approval
- Start Small but Think Big – developing a small local project allows TIAs to gain valuable experience.
- Financial Partnerships – work at leveraging financial and technical expertise through partnerships with private developers.
- Ownership – most TIAs can own and/or operate facilities (with conditions) which seems to have stimulated transmission activity in some areas.

Questions?