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

National Renewable Energy Laboratory

Innovation for Our Energy Future

New Approaches to Deliver Wind Energy

Debbie Lew

Michael Milligan

National Renewable Energy Laboratory

Conference on Transmission Expansion in the Western U.S., May 21, 2007

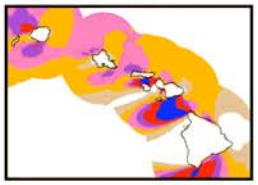
NREL is operated by Midwest Research Institute • Battelle

Transmission and Wind

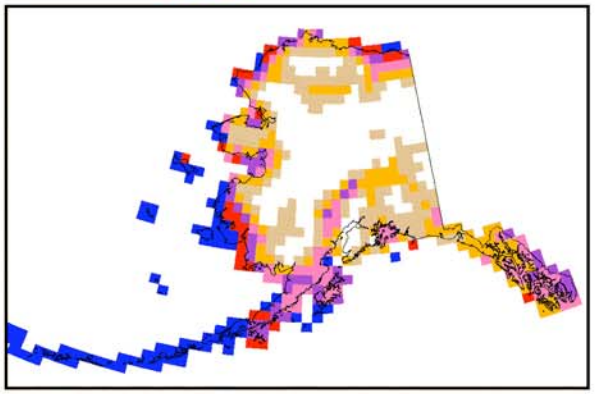
- Wind is geographically dependent (location constrained) – good wind not necessarily close to existing transmission

Composite Wind Resource Map

NREL Updated Maps:
Arizona (2003)
California (2002)
Colorado (2004)
Connecticut (2001)
Delaware (2002)
Hawaii (2004)
Idaho (2002)
Illinois (2001)
Indiana (2004)
Maine (2001)
Maryland (2002)
Massachusetts (2001)
Michigan (2004)
Missouri (2005)
Montana (2002)
Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
Texas mesas (2000)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)



The remaining states use data from the 1987 "Wind Energy Atlas of the United States".



Transmission Lines
Voltage (kV)
345 - 499
500 - 699
700 - 799
1000 (DC)

Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

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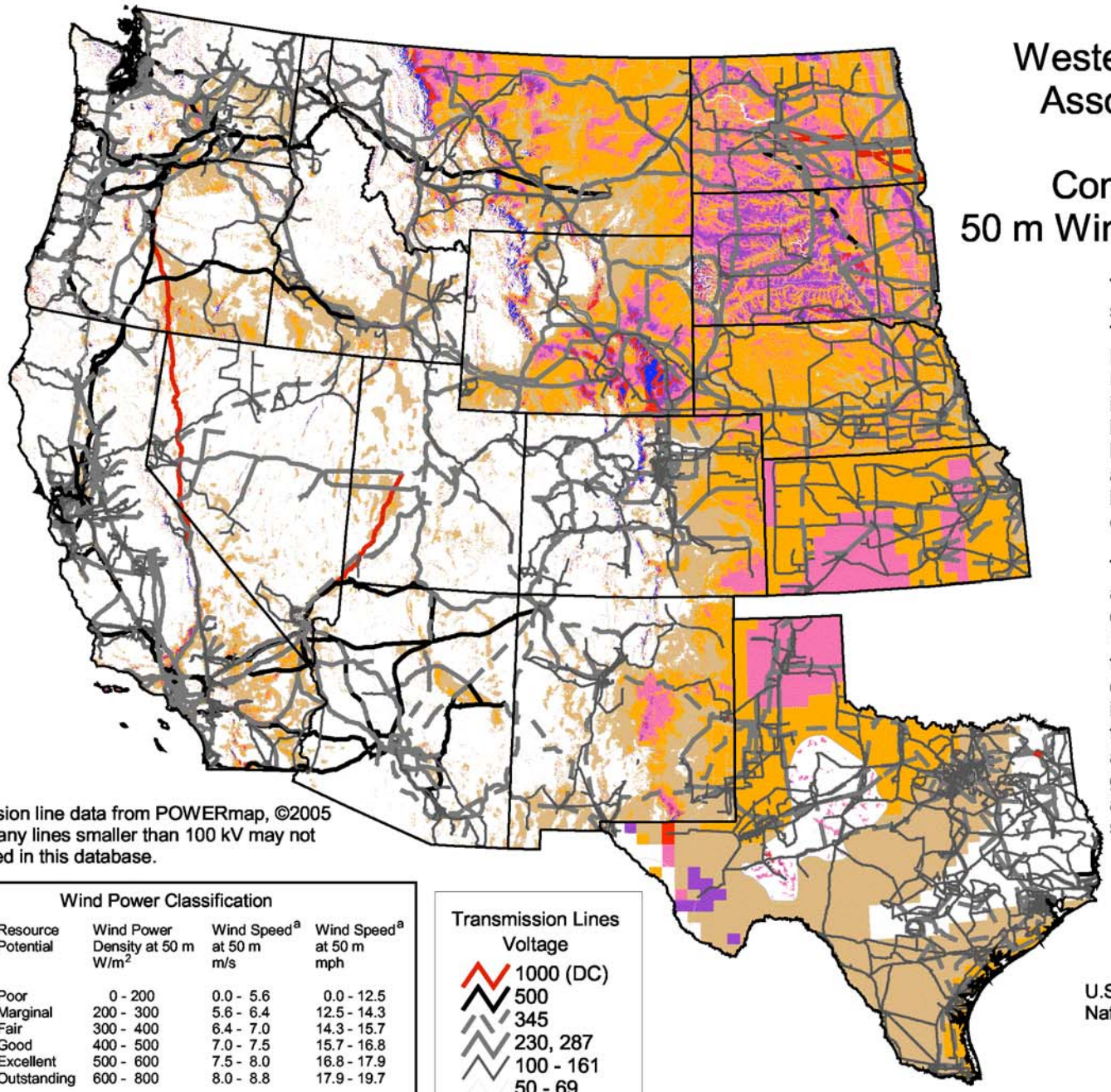
19-APR-2007 1.5.9

Transmission and Wind

- Wind is geographically dependent (location constrained) – good wind not necessarily close to existing transmission
- Issues:
  - Build transmission if generator requests, but wind can't get financing unless transmission exists
  - Wind build times shorter than transmission
  - Wind projects smaller than transmission
- Long-term wind buildout: single larger line more cost-effective than several smaller lines
- Transmission is a public good

Use More Grid



Western Governor's Association Area

Combined Data
50 m Wind Resource Data

The wind resource information shown for Kansas and most of Texas is from the 1987 "Wind Energy Resource Atlas of the United States". Wind resource is shown for every 1/3 degree of longitude by 1/4 degree of latitude. As little as 5% of the area shown in each area may be well-exposed to the power class displayed.

The remaining wind resource assessments were conducted on a state-by-state basis from 1999 to 2004. Over that time, the methodology and resolution of the data varied due to changes in the assessment process. Also, the fine resolution of these assessments may prevent many good resource areas from appearing when viewed at this scale.

Transmission line data from POWERmap, ©2005 Platts. Many lines smaller than 100 kV may not be included in this database.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

Transmission Lines Voltage

- 1000 (DC)
- 500
- 345
- 230, 287
- 100 - 161
- 50 - 69

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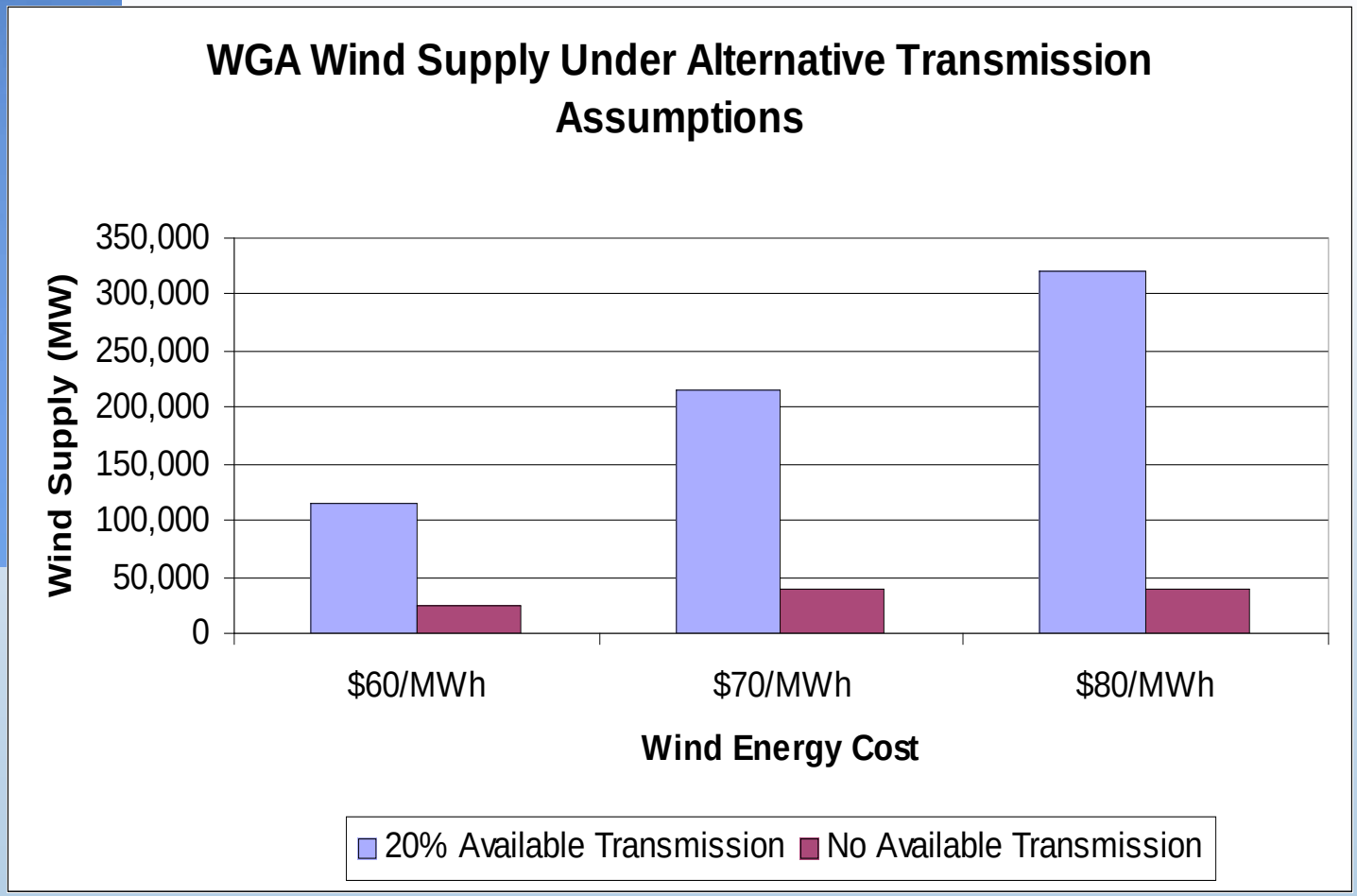
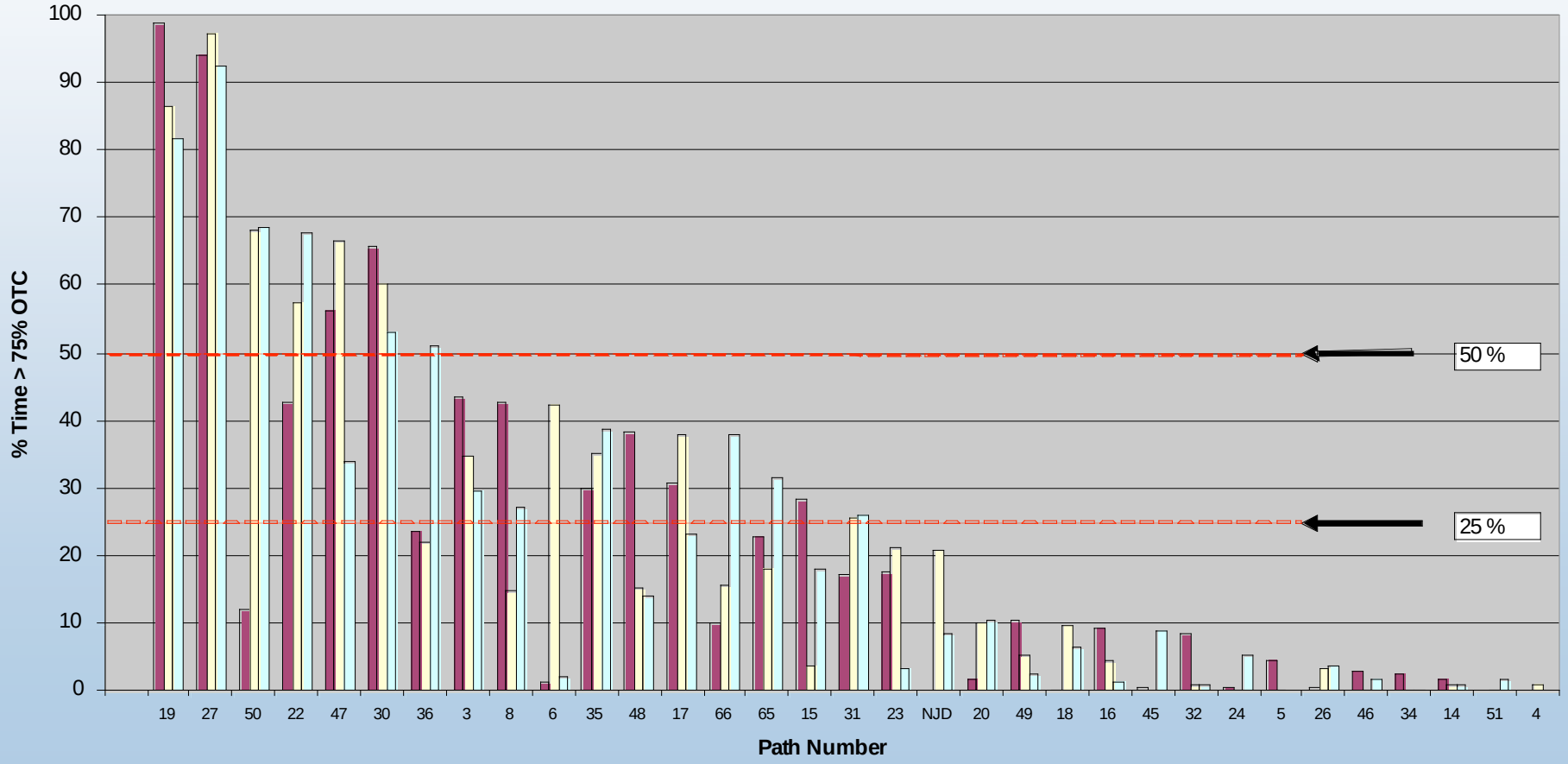


Production tax credit not included; costs do not reflect recent increases in turbine prices.

Use More Grid

- Firm transmission in the west is scarce—need a way to provide access to transmission “most” of the time wind needs it
- Need long-term contract to finance wind project
- Difficult to justify transmission expansion if there is unused capability
- ATC (Available Transfer Capability) is not generally available on key paths in the West
- ATC defined as available 8,760 hours
- Wind does not need all of this→ may be room for wind without ATC

Path Loading - % of Time > 75% of Path OTC during a Seasonal Period
Maximum Seasonal Loadings for each Path
Winter 98-99 thru Spring 2002



Source: Seams Steering Group-Western Interconnection report 2003

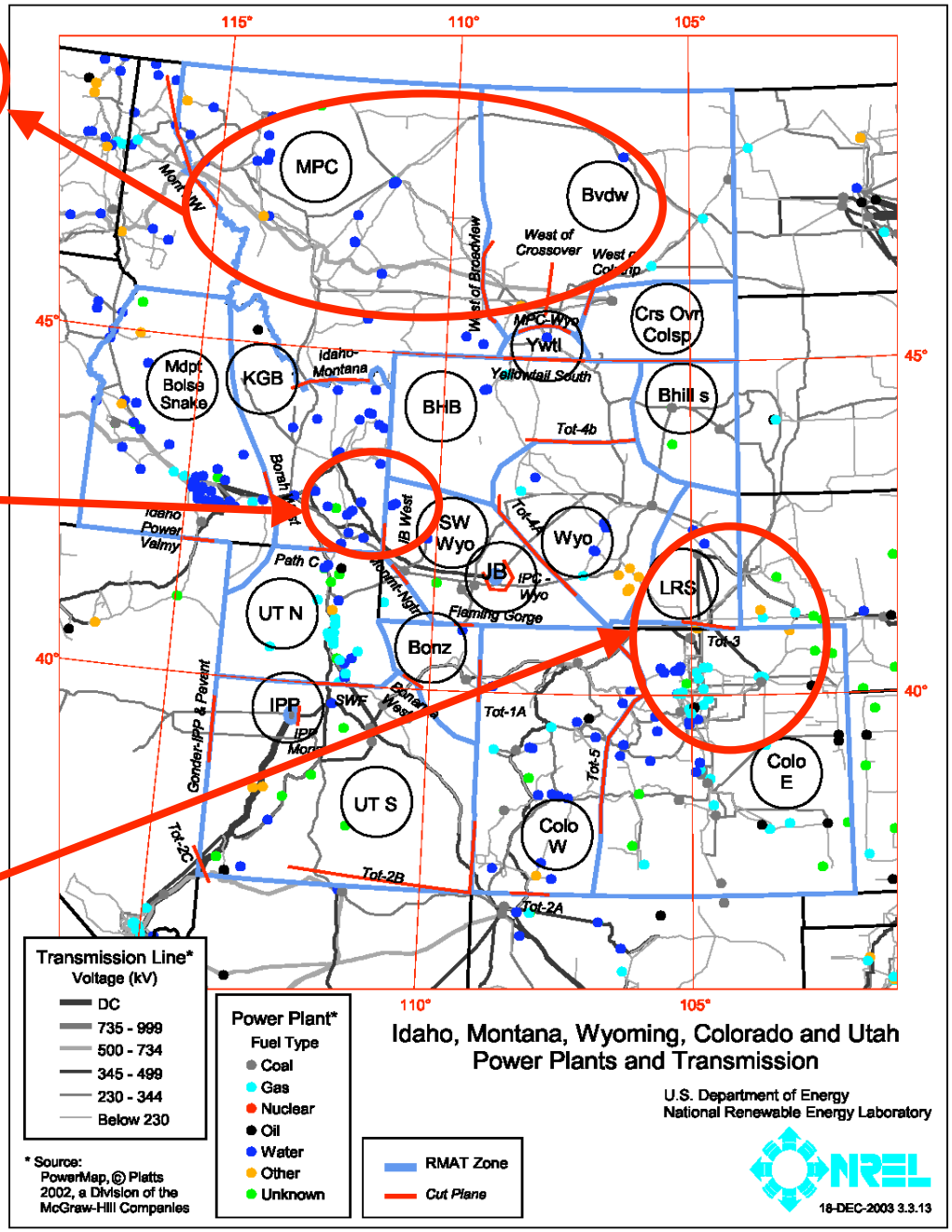
Analysis of Potential Impact of Conditional Firm: Rocky Mountain Area Transmission Study (RMATS)

- Analyze representative paths to
  - Quantify hourly profile of unused transmission capacity
  - determine feasibility to utilize this capacity thru flex-firm tariffs
- Paths chosen:
  - MT to Northwest
  - W of Naughton
  - TOT3

MT to NW Path: Incomplete data, serial path

W of Naughton: Incomplete data

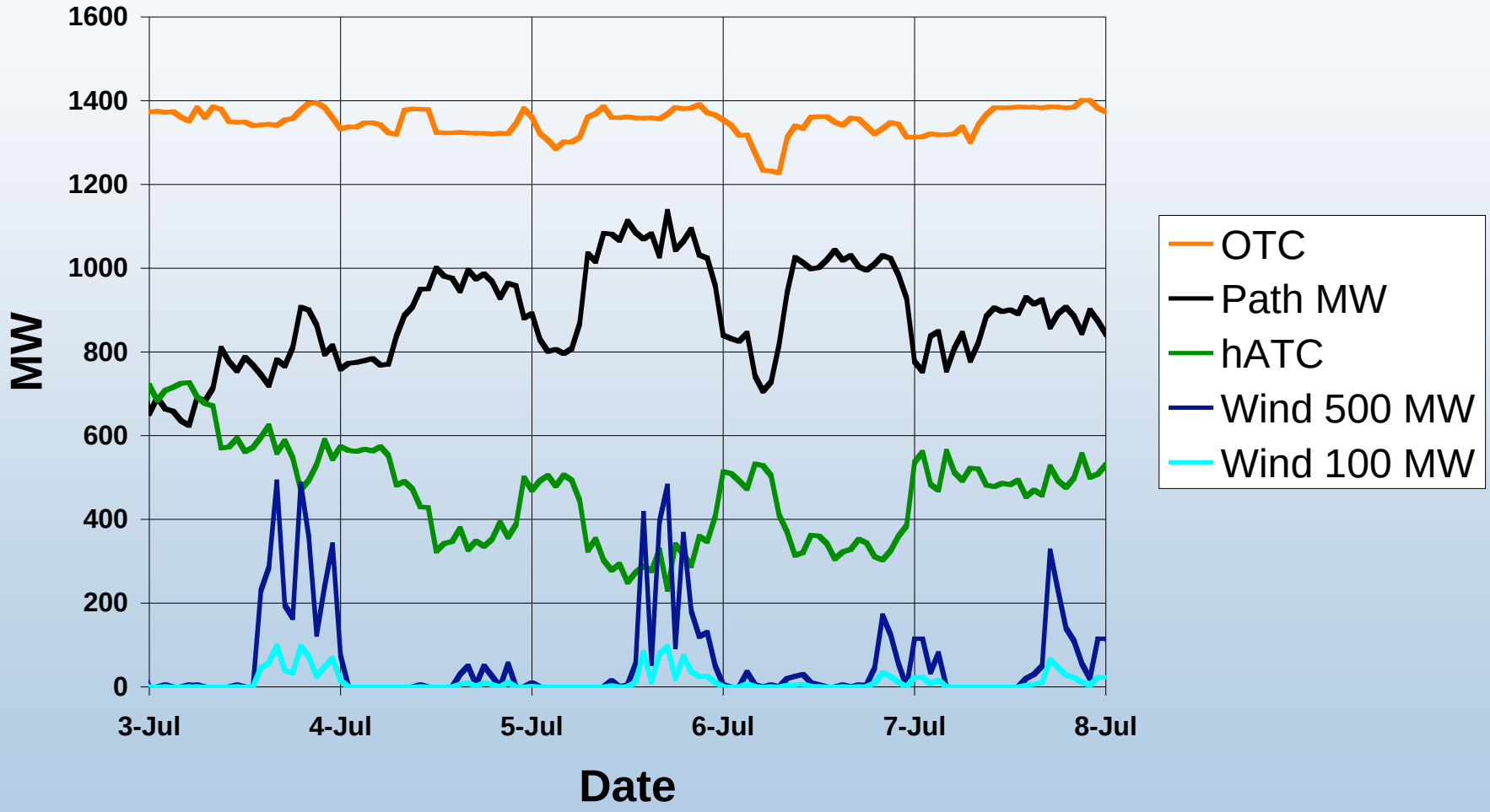
TOT3 Relative Location in RMATS Region – Load Bubbles and Cut-Planes



Approach

- Collect hourly path data for 3 years
  - Actual power flow
  - Schedule
  - Operating Transfer Capability (OTC)
  - Available Transfer Capability (ATC)
  - Estimate Unutilized Transfer Capability (UTC) that would potentially be available via a flex-firm tariff
- Hourly wind data for same period
- Compare chronological EHV data with wind production estimates
- Our analysis → potential for utilizing transmission capacity under new tariffs
- Unfortunately - data shortcomings for MT/NW and Naughton

TOT3 Daily Profiles
Summer 2002



Results from RMATS TOT3 Study

Average curtailment based on hourly ATC, in percentage of 100 MW wind plant total output

	100 MW Wind Farm				100 MW Constant Output			
	UTC Curtailed Wind	UTC Non-curtailed Wind	hATC Curtailed Wind	hATC Non-curtailed Wind	UTC Curtailed Constant Output	UTC Non-curtailed Constant Output	hATC Curtailed Constant Output	hATC Non-curtailed Constant Output
Winter	0.02%	99.98%	0.07%	99.93%	0.02%	99.98%	0.04%	99.96%
Spring	0.14%	99.86%	0.56%	99.44%	0.11%	99.89%	0.38%	99.62%
Summer	2.42%	97.58%	2.87%	97.13%	2.76%	97.24%	3.63%	96.37%
Year	0.76%	99.24%	0.99%	99.01%	1.18%	98.82%	1.60%	98.40%

Note: 100% of wind output is 372,593 MWh/year

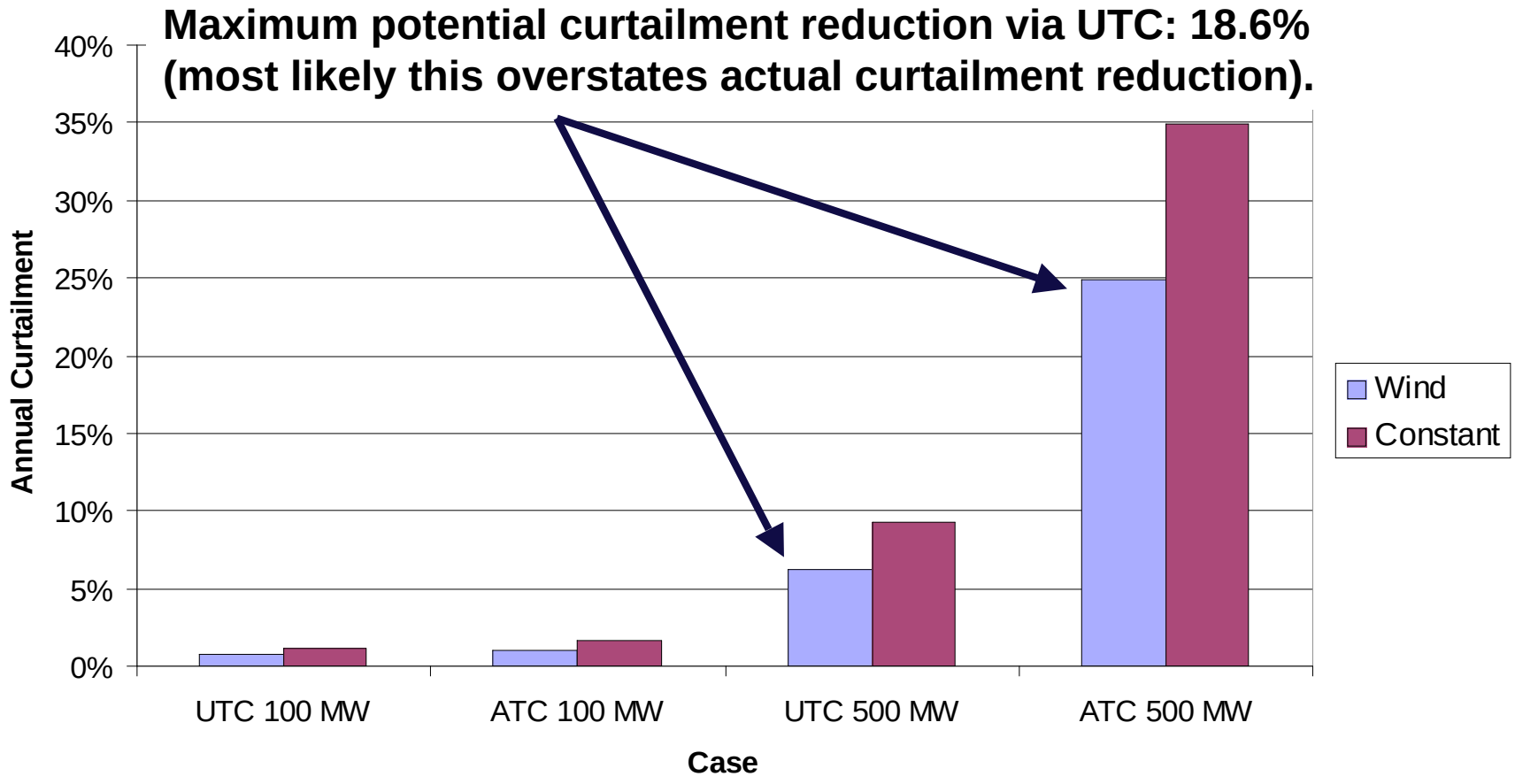
Results from RMATS TOT3 Study

Average curtailment based on hourly ATC, in percentage of 500 MW wind plant total output

	500 MW Wind Farm				500 MW Constant Output			
	UTC Curtailed Wind	UTC Non-curtailed Wind	hATC Curtailed Wind	hATC Non-curtailed Wind	UTC Curtailed Constant Output	UTC Non-curtailed Constant Output	hATC Curtailed Constant Output	hATC Non-curtailed Constant Output
Winter	3.05%	96.95%	22.23%	77.77%	3.99%	96.01%	30.03%	69.97%
Spring	4.42%	95.58%	16.04%	83.96%	5.89%	94.11%	25.26%	74.74%
Summer	11.83%	88.17%	31.95%	68.05%	15.75%	84.25%	43.59%	56.41%
Year	6.25%	93.75%	24.89%	75.11%	9.24%	90.76%	34.92%	65.08%

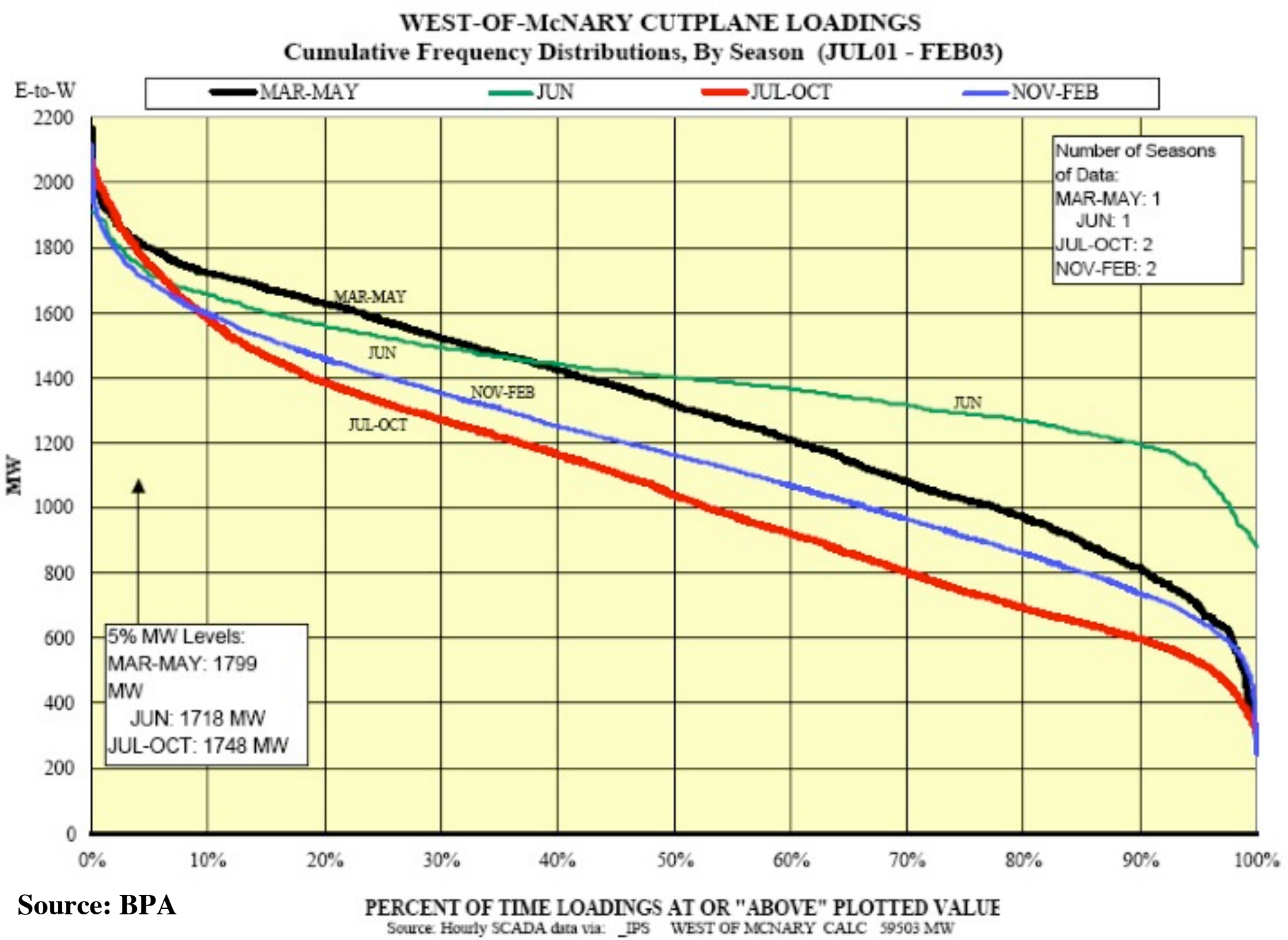
Note: 100% of wind output is 1,862,967 MWh/year

RMATS/TOT3 Results



UTC: Unutilized transmission capacity (physical)

ATC: Available Transmission Capacity (estimated)


WEST-OF-McNARY CUTPLANE LOADINGS
Cumulative Frequency Distributions, By Season (JUL01 - FEB03)
E-to-W
MAR-MAY
JUN
JUL-OCT
NOV-FEB
MW
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Number of Seasons of Data:
MAR-MAY: 1
JUN: 1
JUL-OCT: 2
NOV-FEB: 2
MAR-MAY
JUN
NOV-FEB
JUL-OCT
JUN
5% MW Levels:
MAR-MAY: 1799 MW
JUN: 1718 MW
JUL-OCT: 1748 MW
PERCENT OF TIME LOADINGS AT OR "ABOVE" PLOTTED VALUE
Source: Hourly SCADA data via: _IPS WEST OF MCNARY CALC 59503 MW

Source: BPA

Conclusions

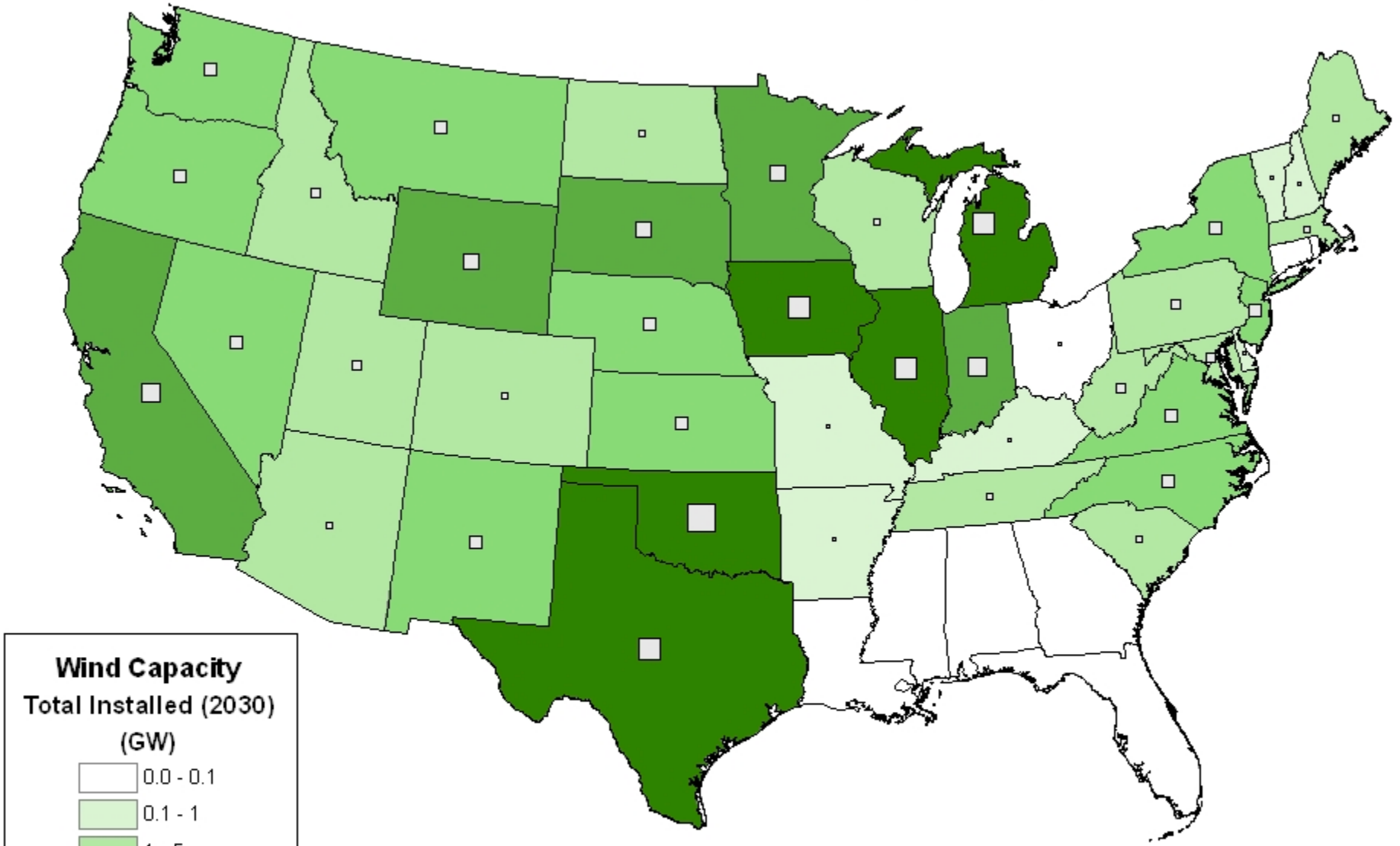
- Additional transmission capability could be utilized with conditional firm tariff
- Benefits
  - for wind
  - for other resources that may not be able to obtain firm transmission
  - Increase efficiency of transmission system

Current Status

- FERC Ruling 890 establishes conditional firm as part of the OATT and calls for consistency of ATC calculations
- Conditional Firm tariff - Transmission provider must define and quantify periods of potential curtailment
  - System conditions
  - Hours of month
- Requires consistency, standards, and transparency of ATC calculations
- BPA conditional firm product underway

Build more grid

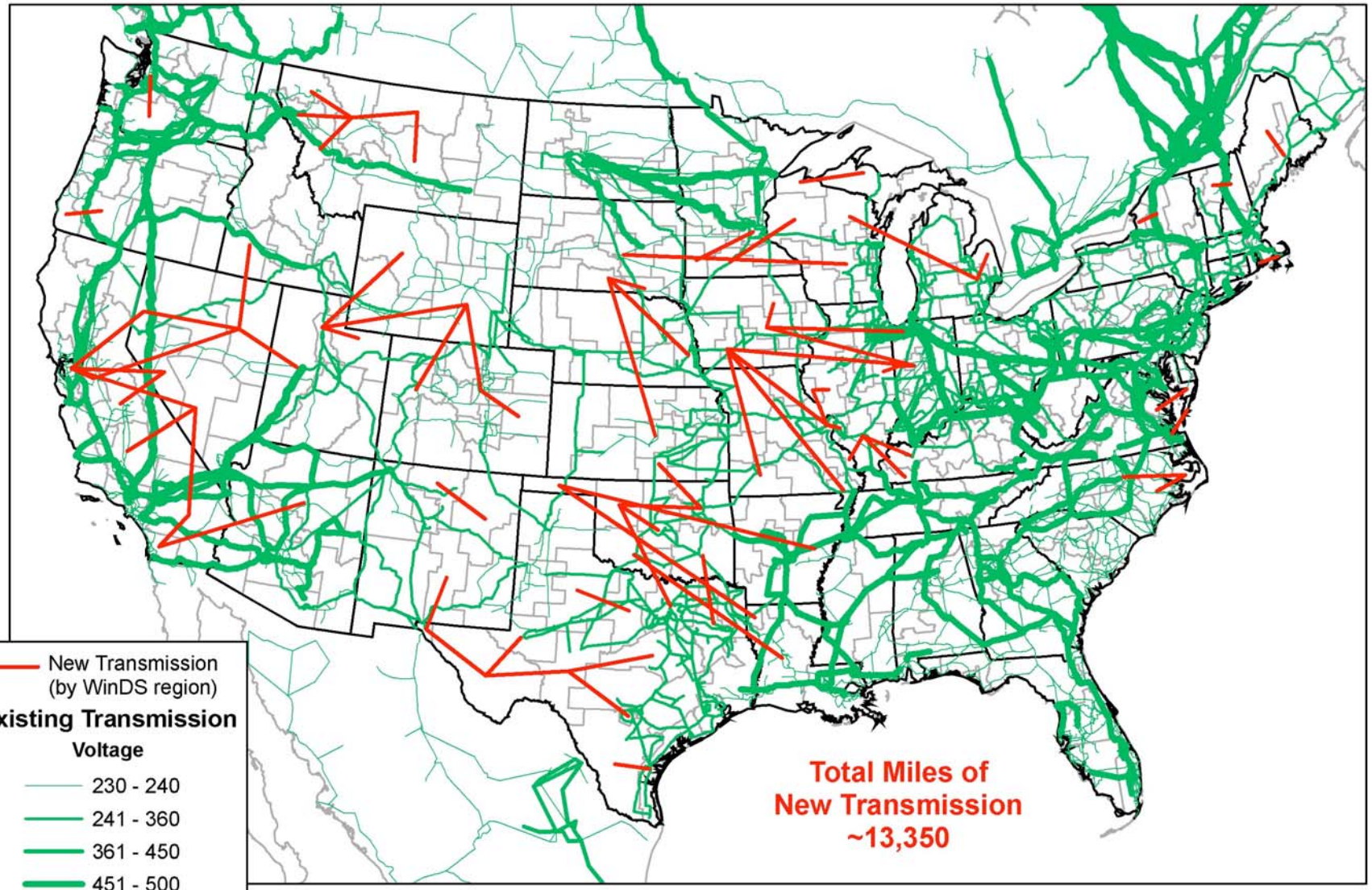
Installed Wind Nameplate Capacity by State (2030)



Optimistic_Case_20070515-DRAFT

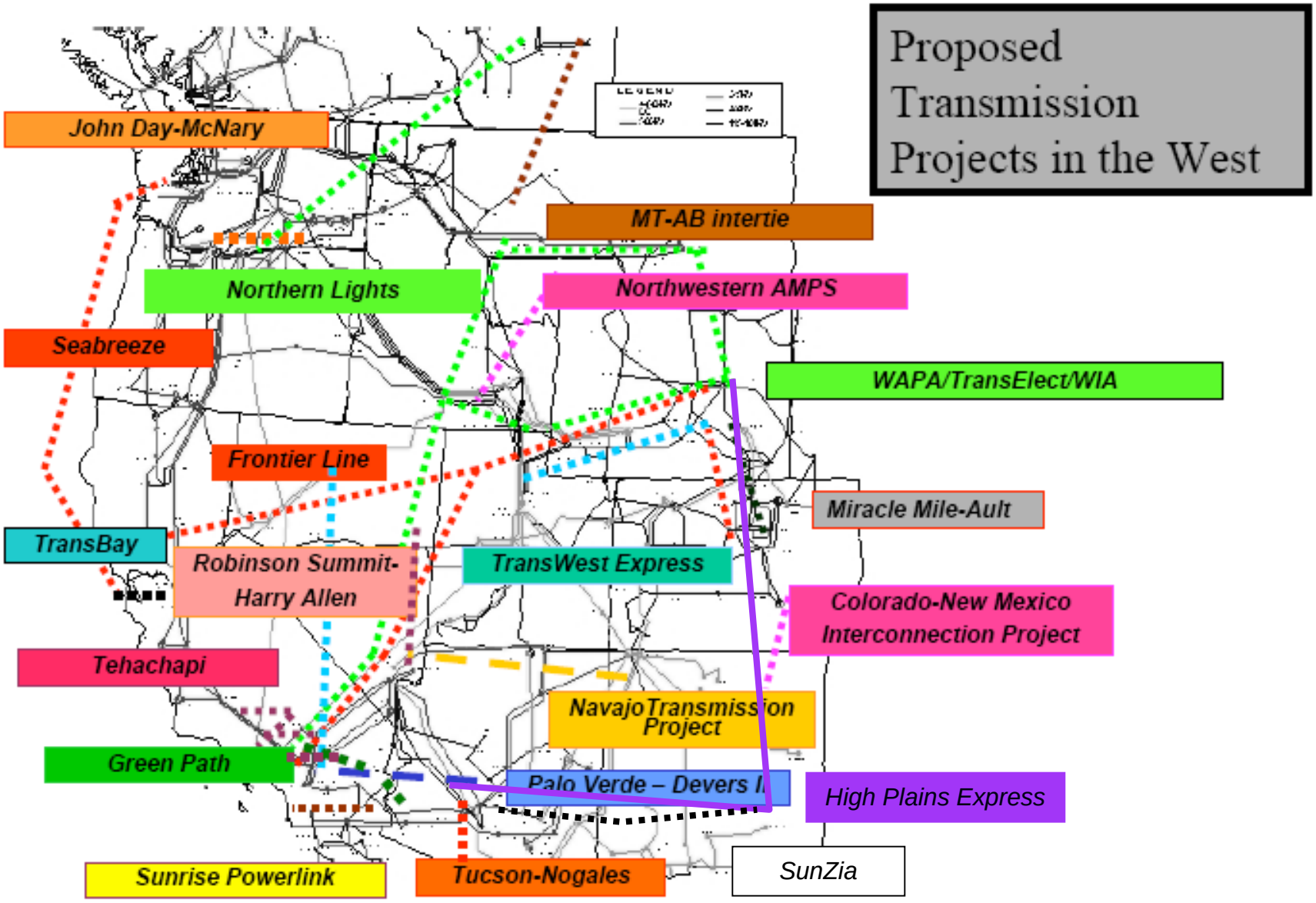
2030 - New Transmission Lines - WinDS Region Level - Simplified Corridors

Total Between Region Transfer >= 100 MW (all power classes, onshore and offshore), visually simplified to minimal paths
Arrows originate and terminate at the centroid of the region for visualization purposes; they do not represent physical locations of transmission lines.



Existing Transmission Data: POWERmap, powermap.platts.com

Optimistic_New Transmission Miles_03-12-2007 - DRAFT

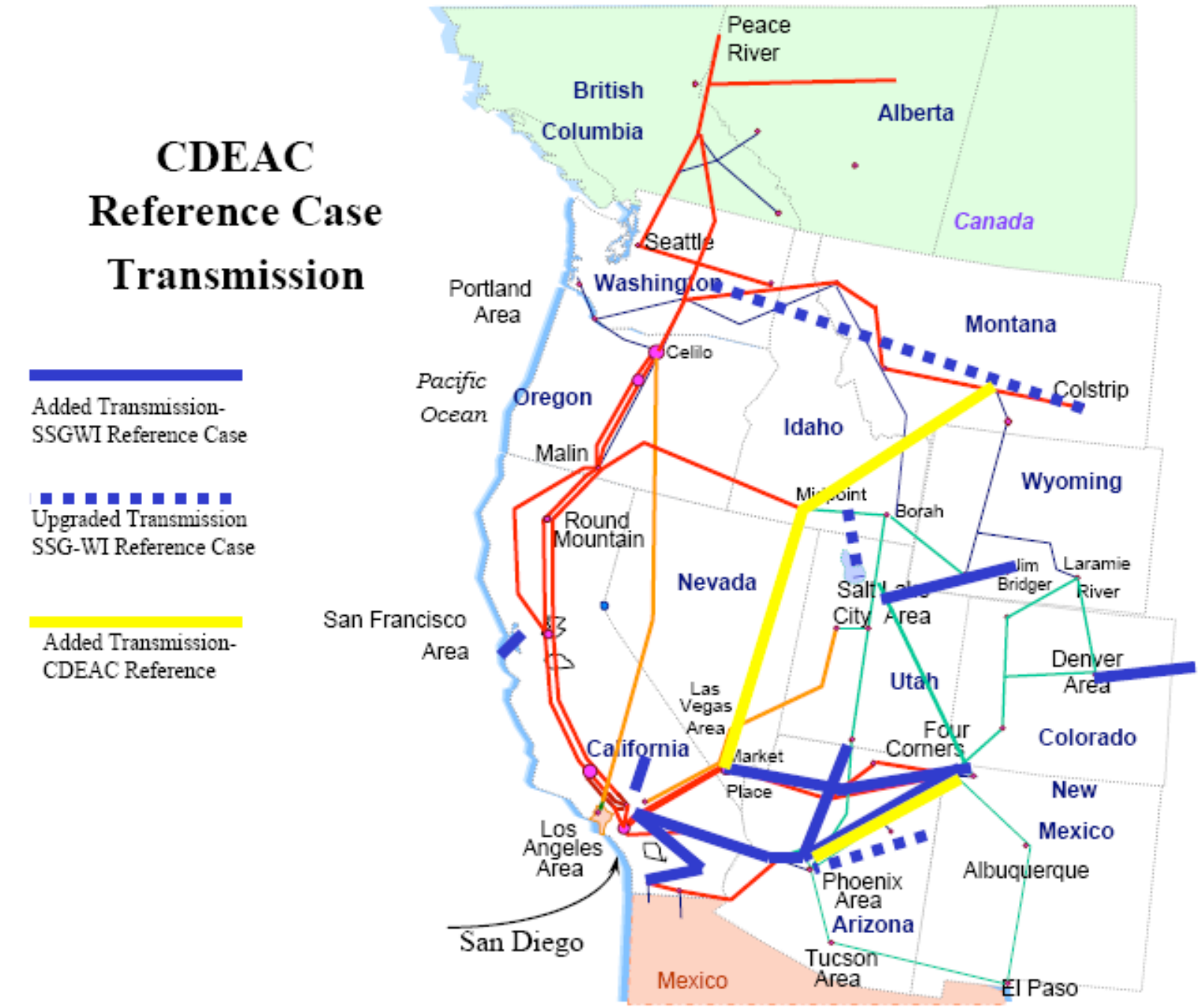


Modified from original of Western Interstate Energy Board/Western Governor's Association

Clean and Diverse Energy Advisory Committee

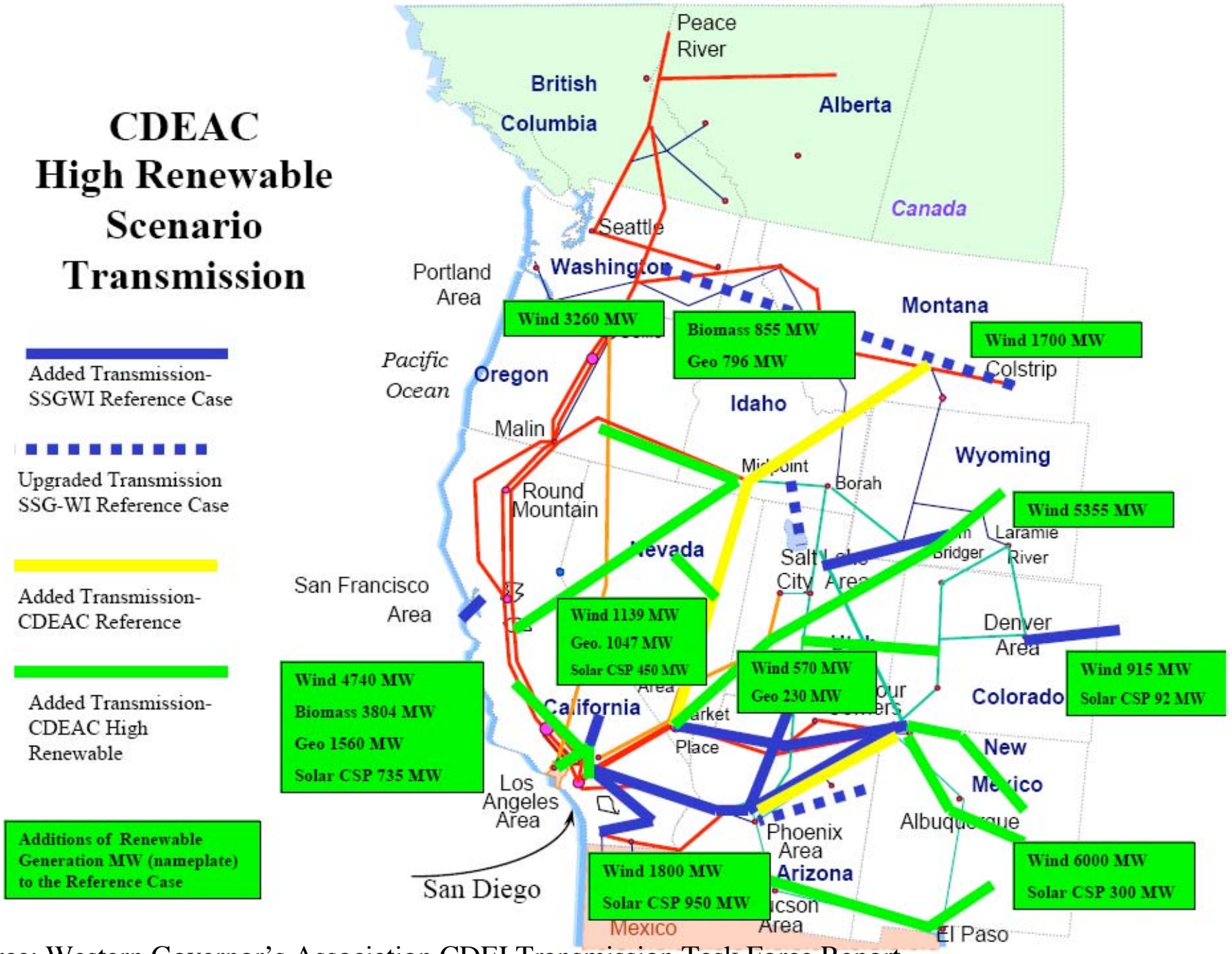
- Western Governors Association's Clean and Diverse Energy Advisory Committee (CDEAC)
- Goal: evaluate potential for 30 GW clean/diverse energy in the West by 2015

CDEAC Reference Case Transmission



Source: Western Governor's Association CDEI Transmission Task Force Report

CDEAC High Renewable Scenario Transmission



Source: Western Governor's Association CDEI Transmission Task Force Report

Policies Should Link Renewables Development with Transmission Development

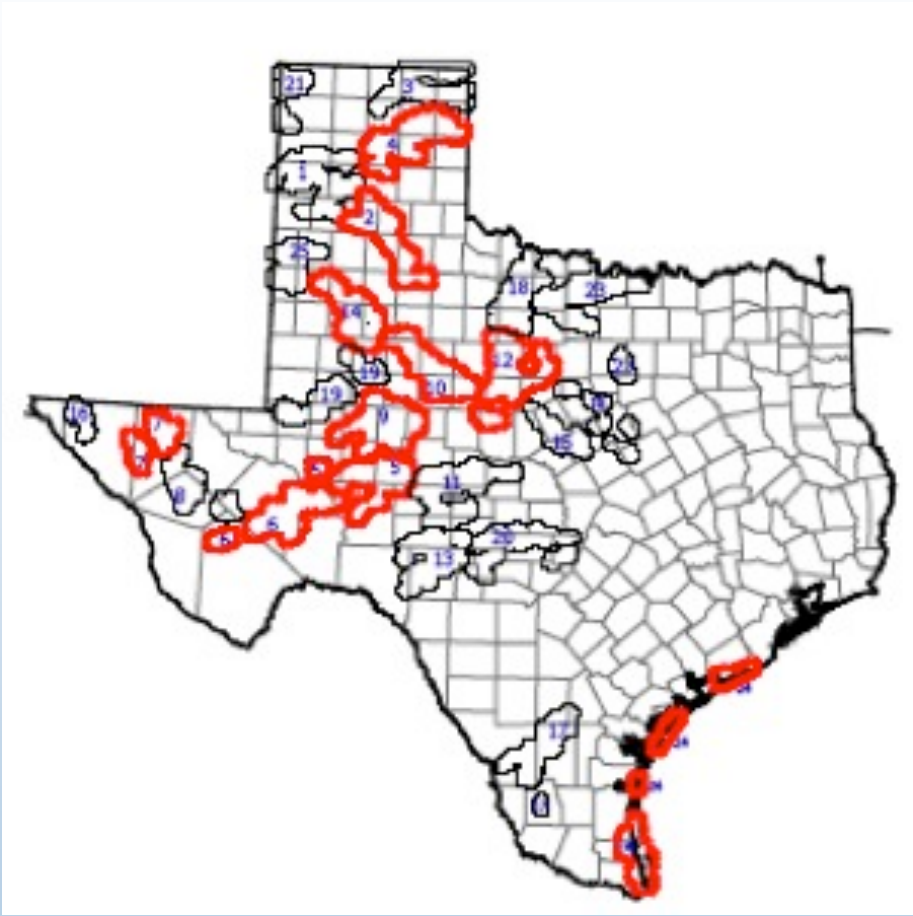
- Approximately half the states have renewables portfolio standards (RPS) or obligations
- Suggest states w/RPS put together a package that includes:
  - Resource area/zone transmission
  - Resource monitoring program to identify zones
  - Provide for confidential disclosure of wind developer data to inform locations
  - State authorities that facilitate transmission for renewables

The Resource Area/Zone Approach
Build Transmission First

- Texas - Competitive Renewable Energy Zone
- Colorado - Transmission to resource zones
- California - CAISO/FERC ruling on 3rd category of financing for Tehachapi Transmission Project
- New Mexico - Renewable Energy Transmission Authority
- Minnesota - CapX 2020

Texas - Competitive Renewable Energy Zones

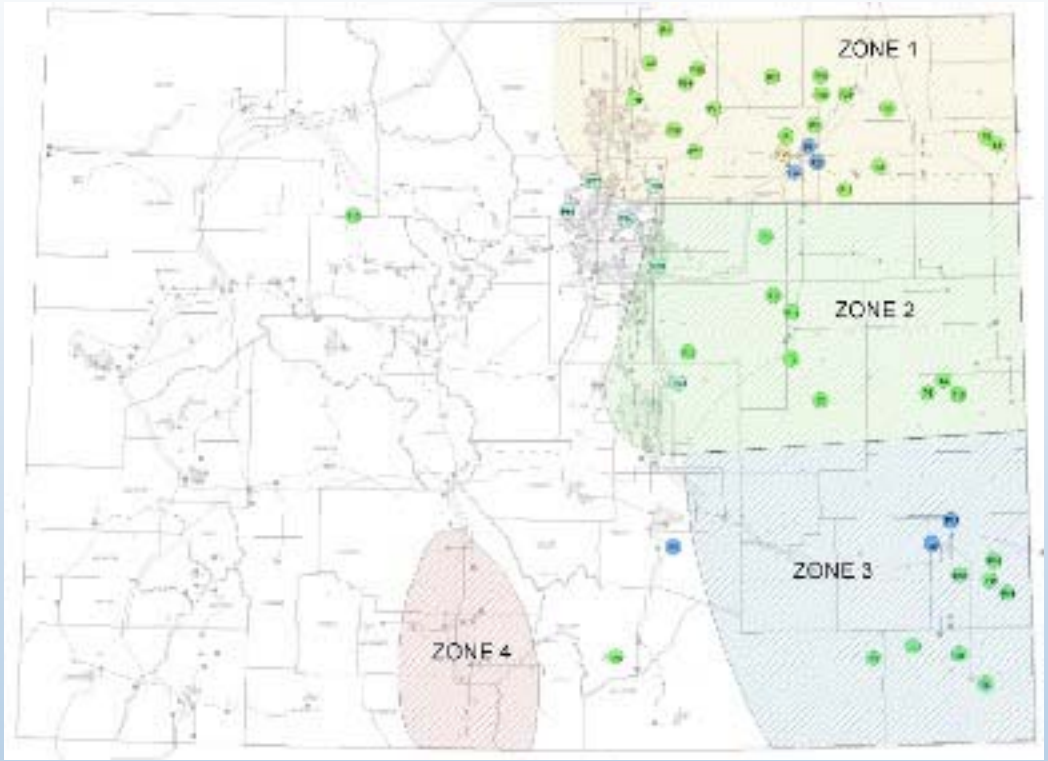
- 2005 - Senate Bill 20 increased Texas RPS to 5880 MW by 2015 and required creation of Competitive Renewable Energy Zones (CREZ)
- Build transmission from CREZs to loads
- CREZ - based on wind resource and transmission availability
  - Coastal
  - McCamey
  - Central Western Texas
  - Panhandle
- PUCT estimates transmission by 2010-2011



Source: ERCOT 12/06

Colorado Energy Resource Zones

- Senate Bill 100 requires utilities to designate energy resource zones and authorizes expedited cost recovery for transmission
- Not renewables-specific
- Starting 10/31/07, biennial plans:
  - Designate energy resource zones
  - Develop plan for transmission to zones
  - PUC decision within 180 days
  - Costs passed onto ratepayers



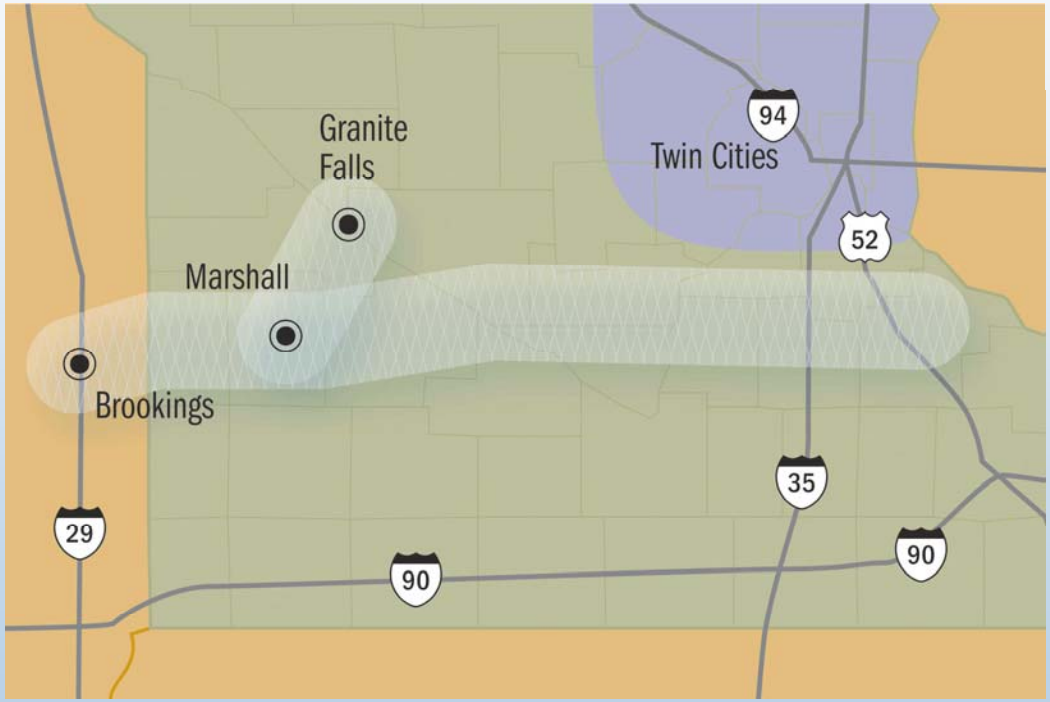
Source, Xcel, 4/24/07

California - 3rd category of transmission financing

- CAISO proposed mechanism for Tehchapi Transmission Project to FERC
- Remove barriers to location-constrained resources
- Utilities pay for transmission to renewable resource zones, with costs recovered in transmission tariff, and generators (incl non-renewables) pay going-forward costs when they connect
- Protect ratepayers
  - Rate impact cap - 5% for single project; total 15%
  - Requires minimum subscription (~25-30%) and further sufficient commercial interest (~25-35%)

Minnesota - CapX2020

- 2005 legislation encourages transmission and allows automatic rate adjustments for cost recovery of construction and investment in transmission
- CapX2020 - Joint initiative of transmission utilities for transmission expansion - collaborative planning by IOUs, coops, munis
- Project Group I
  - 600 miles of 345kV connecting MN, ND, SD, WI and 230 kV in Bemidji
  - $1.3B
  - Complete 2013-2014
- Developing applications to PUC
- Public process on corridors



Source: CAPX2020

State Authorities

- Wyoming Infrastructure Authority
- New Mexico Renewable Energy Transmission Authority
- Idaho Energy Resources Authority
- Kansas Electric Transmission Authority
- North Dakota
- South Dakota Energy Infrastructure Authority
- Colorado Clean Energy Development Authority proposed
- Utah proposed
- Montana proposed

Wyoming Infrastructure Authority

- Created June 2004
- Develop transmission infrastructure
  - Plan, finance, build, maintain, operate interstate transmission
- Finance and promote advanced coal power
- Issue bonds to finance transmission and coal
- Partner with public/private sector
- Own and operate transmission
- Investigate, plan, prioritize, establish transmission corridors
- $10M in loans for transmission studies and permitting
- TOT3, Wyoming-West, TransWest Express, Frontier

New Mexico Renewable Energy Transmission Authority

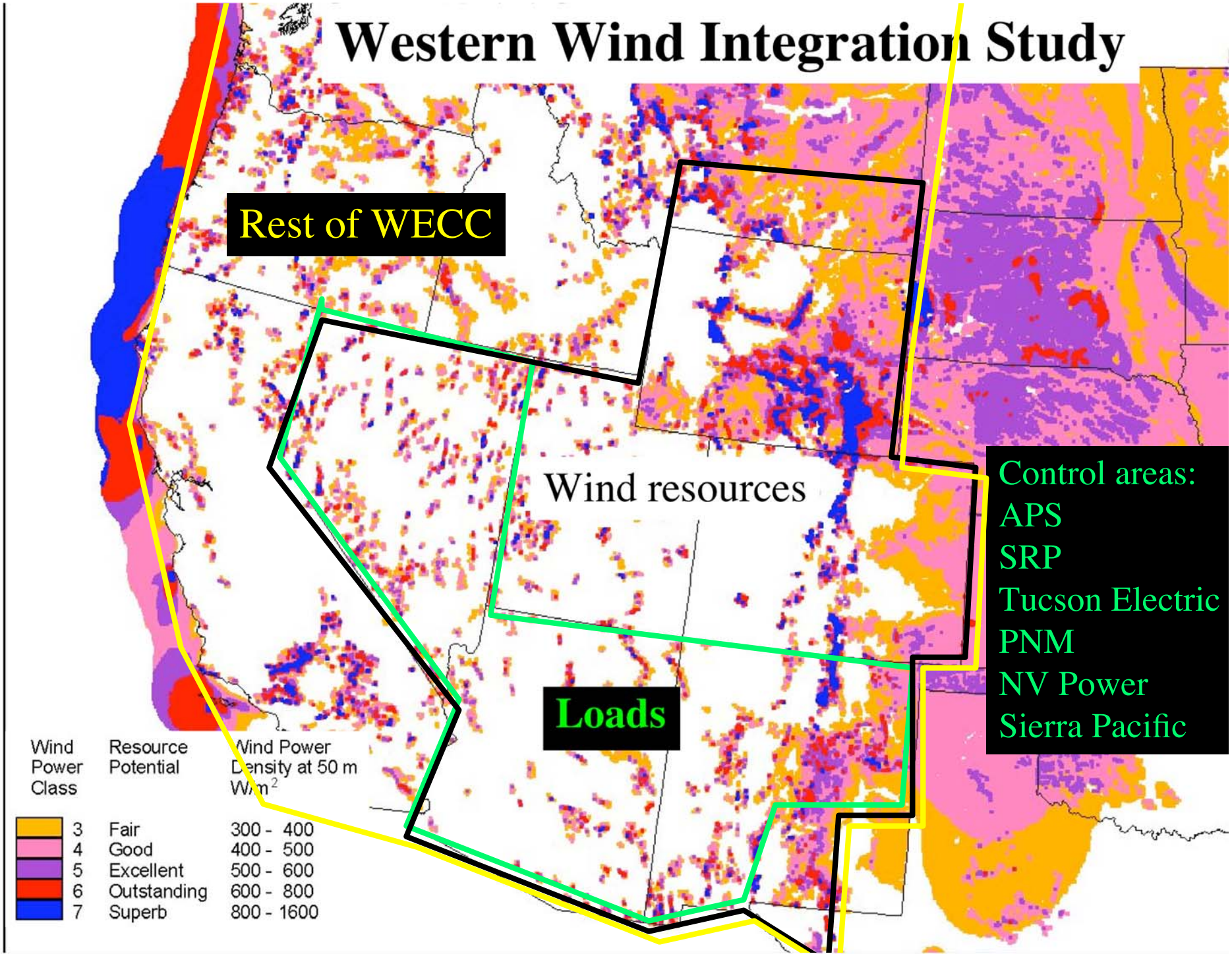
- First authority specifically for renewable energy transmission - At least 30% of energy in transmission project must be from renewables
- Finance, plan, acquire, maintain, and operate transmission
- Revenue bonding authority to finance projects, could include owning or leasing facilities
- Charge participating entities to recover debt and administrative costs
- Partner with public/private sector
- Identify and prioritize transmission corridors

National Interest Electric Transmission Corridors

- Congestion Study last August
- 2 Draft National Corridors
  - Southwest Area - Parts of CA, AZ, NV
  - Mid-Atlantic Area - Parts of OH, WV, PA, NY, MD, VA and all of NJ, DE, DC
- Transmission reviewed by FERC which would have backstop siting authority supplementing state authority

Western Wind Integration Study

- Determine cost of operating impacts of wind due to variability and uncertainty
- Examine
  - Long distance transmission of wind
  - Compare local to out-of-state wind resources
  - Geographical diversity of wind
  - Wind/load correlation
  - Wind forecasting role and value
  - Solar, especially concentrating solar power
  - Control area cooperation/consolidation
  - Hydro/wind interaction - Hoover
- Kick-off stakeholder meeting 5/23 at NREL in Boulder, CO
- To participate - Debbie at debra_lew@nrel.gov or (303) 384-7037


Western Wind Integration Study
Rest of WECC
Wind resources
Loads
Control areas:
APS
SRP
Tucson Electric
PNM
NV Power
Sierra Pacific
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m2
3 Fair 300 - 400
4 Good 400 - 500
5 Excellent 500 - 600
6 Outstanding 600 - 800
7 Superb 800 - 1600

Conclusions

- Transmission access is vital for wind power development
- More efficient use of the existing grid, especially long-term contracts for conditional firm is needed
- States that want to promote renewables should link renewables policies to transmission policies that include zone transmission, cost recovery, resource monitoring, and facilitation of transmission

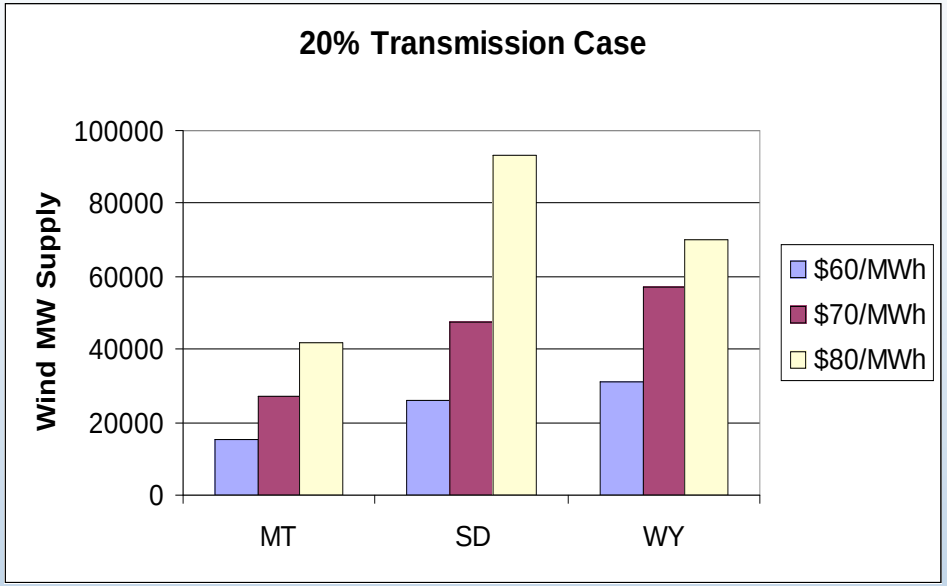
For more information

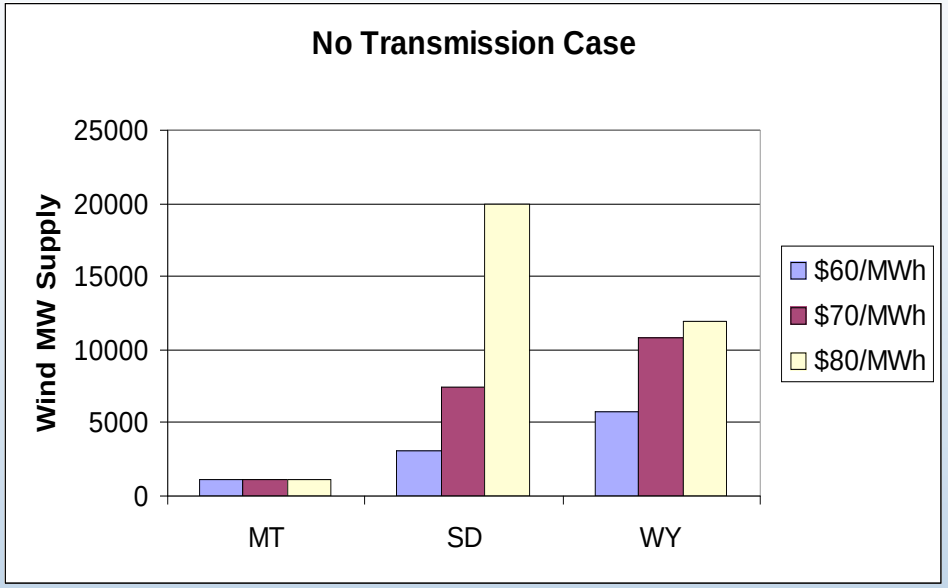
- Western Governor's Association CDEAC study
  - http://www.westgov.org/wga/initiatives/cdeac/cdeac-reports.htm
- RMATS Conditional Firm study
  - http://www.nrel.gov/docs/fy05osti/38152.pdf
  - http://www.nrel.gov/docs/fy04osti/35969.pdf
- FERC Order 890
  - http://www.ferc.gov/industries/electric/indus-act/oatt-reform.asp
- Texas CREZ
  - http://www.puc.state.tx.us/rules/rulemake/31852/31852adt.pdf
- CO energy zones
  - http://www.interwest.org/documents/documents/2007_co_sb100.pdf
  - http://www.rmao.com/wtpp/SB100.html
- CAISO/Tehachapi FERC ruling
  - http://www.ferc.gov/press-room/statements-speeches/kelliher/2007/04-19-07-kelliher-E-5.asp
- Minnesota CapX2020
  - http://www.capx2020.com/
- Wyoming Infrastructure Authority
  - http://www.wyia.org/
- New Mexico RETA
  - http://www.emnrd.state.nm.us/ecmd/factsheets.htm
- DOE National Interest Electric Transmission Corridors
  - http://nietc.anl.gov/
- Debbie Lew - debra_lew@nrel.gov
- Michael Milligan - michael_milligan@nrel.gov

Extra slides

Available transmission increases the supply of wind: some high-wind states

Note different scales





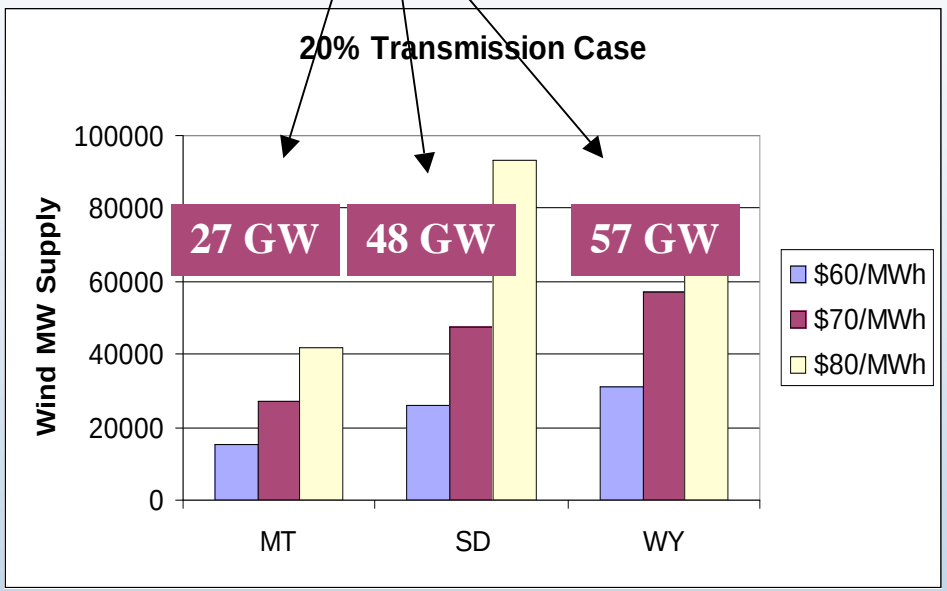
Assuming 20% of existing transmission is available for wind

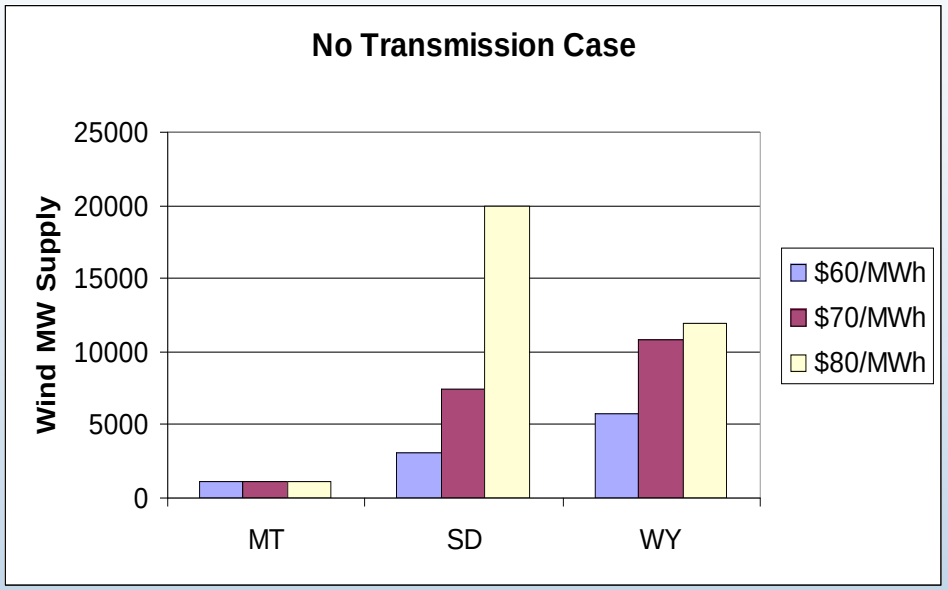
Assuming no existing transmission is available for wind, all new transmission is built by wind

Available transmission increases the supply of wind: some high-wind states

At $70/MWh: 132 GW from 3 key states at 20% transmission availability

Note different scales



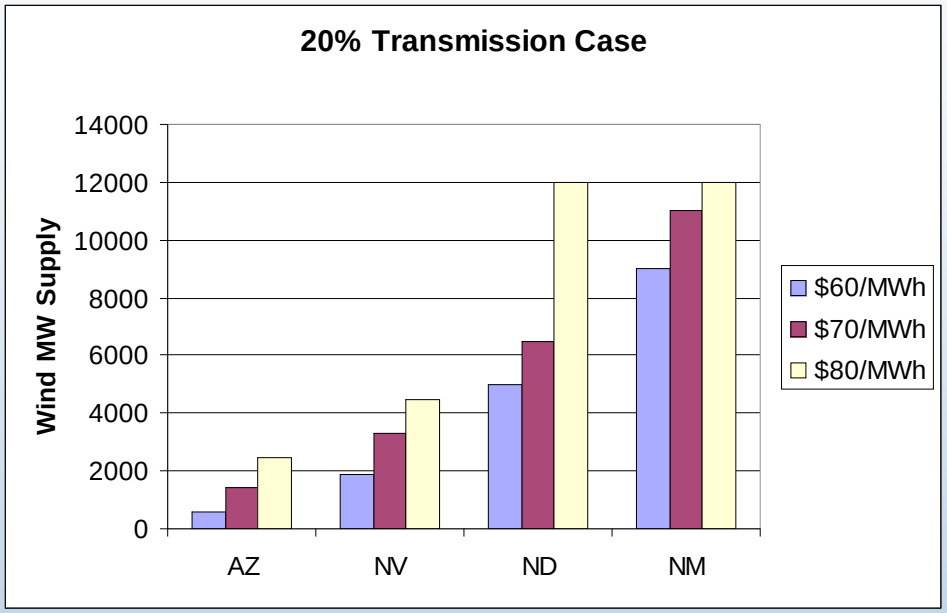


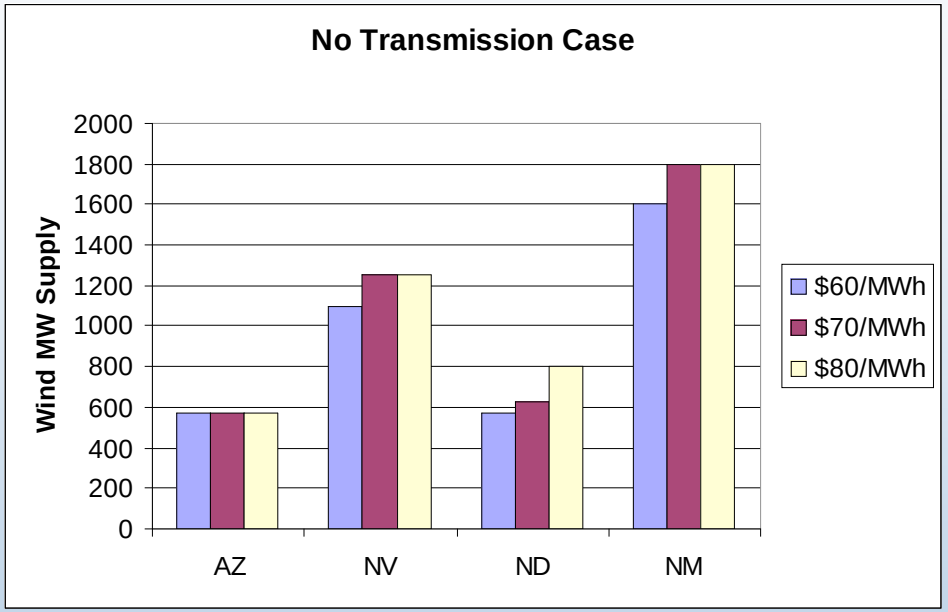
Assuming 20% of existing transmission is available for wind

Assuming no existing transmission is available for wind, all new transmission is built by wind

Some SW States (plus ND)

Note different scales

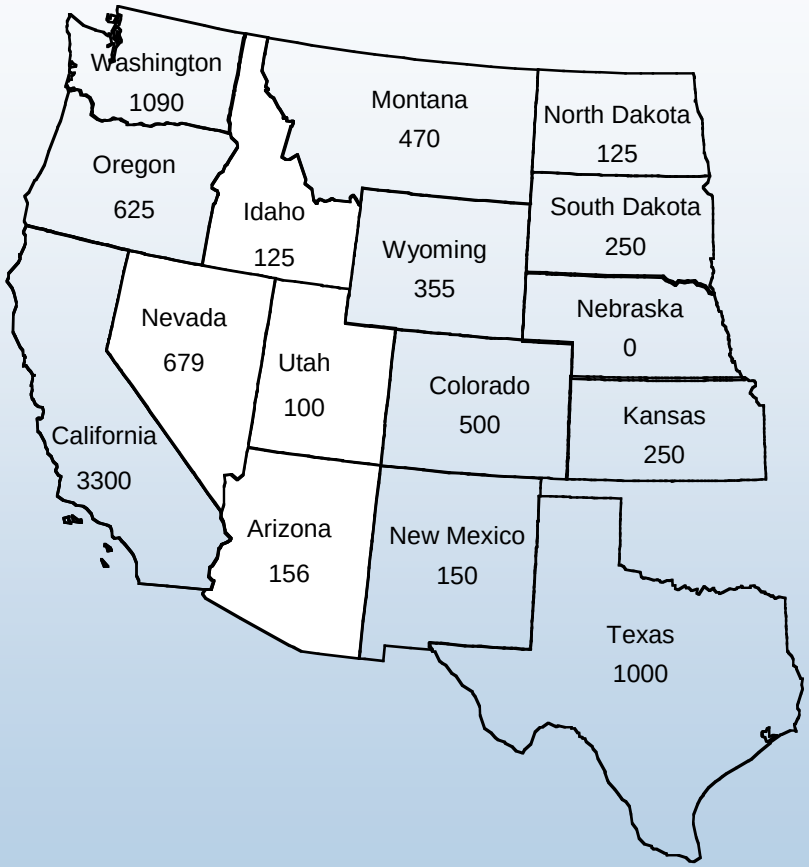




Assuming 20% of existing transmission is available for wind

Assuming no existing transmission is available for wind, all new transmission is built by wind

Western Governors' Association
Wind Additions: Scenario 1



No new transmission, limited flex-firm, low-range of build out

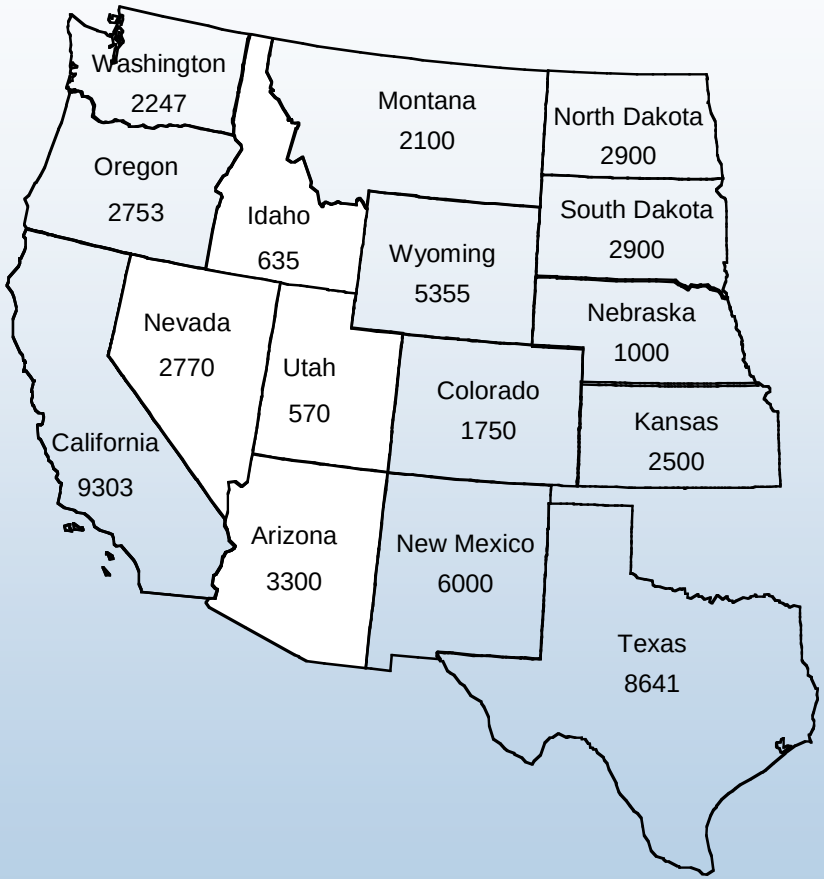
Total: 9,175 MW

Western Governors' Association
Wind Additions: Scenario 2

New flex-firm transmission, mid-range of build out

Total: 25,266 MW

Western Governors' Association
Wind Additions: Scenario 3



Maximum build-out. NM and CA cases may not be consistent

Total: 54,724 MW

Idaho Energy Resources Authority

- Created in 2005
- Improve generation and transmission infrastructure to allow additional generation or imports
- Bonding authority
- Debt finance renewable energy projects
- Plan, finance, construct, develop and acquire generation and transmission
- Can own transmission
- Partner with public/private sector

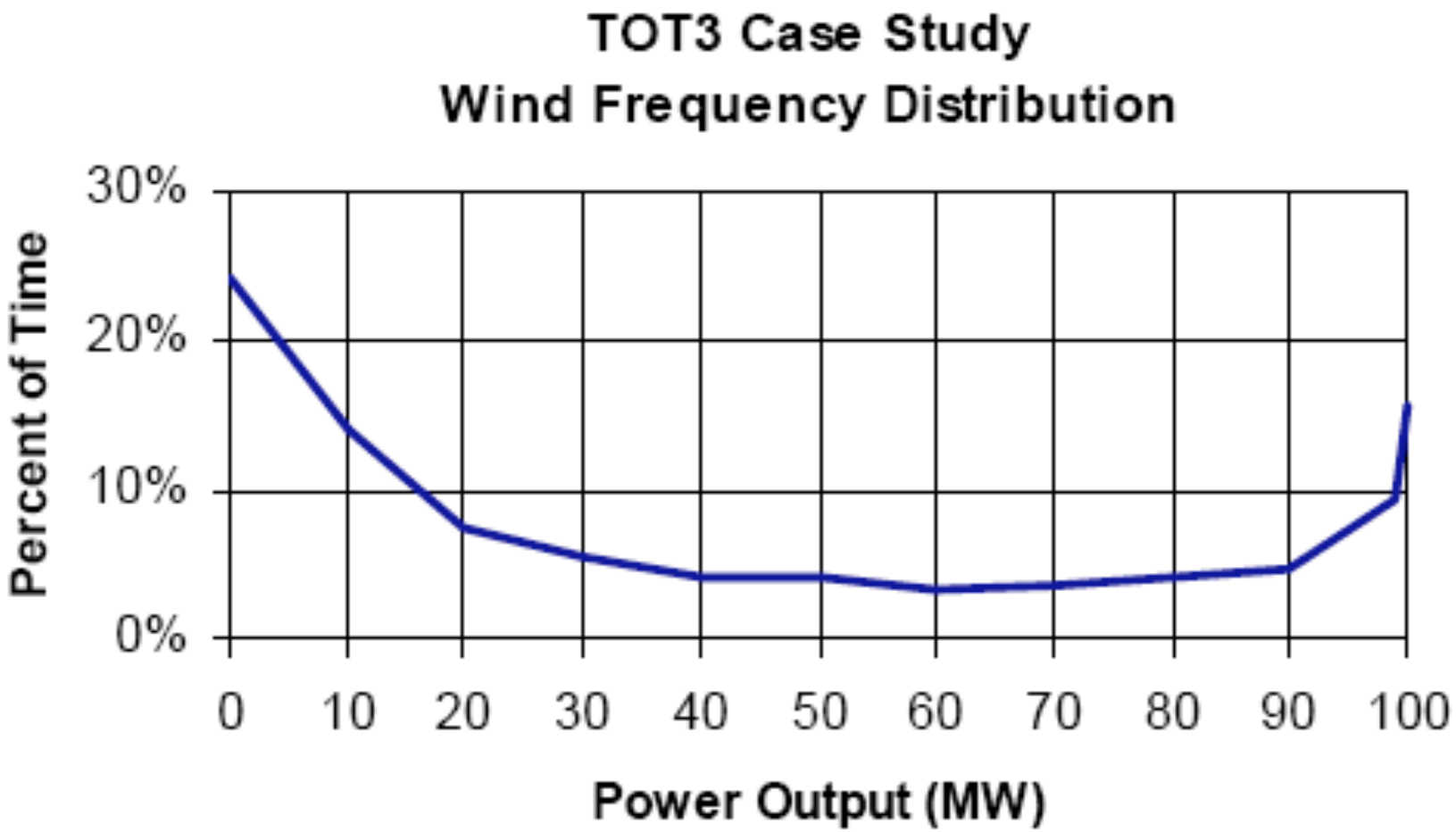
Comparison of Cost-Based U.S. Operational Impact Studies

Date	Study	Wind Capacity Penetra-tion (%)	Regula-tion Cost ($/MWh)	Load Following Cost ($/MWh)	Unit Commit-ment Cost ($/MWh)	Gas Supply Cost ($/MWh)	Total Operating 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 Multi-year	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**

* 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


TOT3 Case Study
Wind Frequency Distribution
Percent of Time
30%
20%
10%
0%
0
10
20
30
40
50
60
70
80
90
100
Power Output (MW)

TOT3 - Average Cumulative Distribution of ATC