Wind Energy 101: Fundamentals, Applications, and Markets

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Renewable Energy for Tribal Community Development
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Presentation Overview

- Wind Turbine Applications
- Wind Characteristics & Energy Potential
- Wind Turbine Topologies
- Estimating Turbine Energy Production
- Small Wind vs. Large Wind
- Large Wind Market & Policies
- Small Wind Market & Policies
- Executing a Large Wind Project

Wind Turbine Applications

Off-Grid Home with Wind/PV System

- West of Boulder, CO, at 9,000 ft
- Bergey 1500 wind turbine, 1.5 kW, 70 ft tower
- Solarex PV panels, 480 W
- 24 VDC battery, 375 Ah
- Onan generator, propane-fueled, 3 kW (at altitude)
- Trace inverter, 120 VAC, 1 phase
- Propane used for range, refrigeration, space heat, hot water (w/solar pre-heat)
- First wind turbine installed in 1978, fourth wind turbine now in service
- PV installed 1984 w/ tax credits
- System cost about $20,000

On-Grid Home with Wind System

- Tehachapi, CA, net metering for utility bill reduction
- Bergey Excel wind turbine, 23 ft rotor, 10 kW
- Total installed cost was $34,122 in October 1999
- California Buy-Down Program, $16,871 cash rebate
- Estimated payback: 8 years

On-Grid Farm with Wind System

- Southwestern Kansas
- Utility bill reduction
- Bergey Windpower Excel wind turbine
  10 kW, 23 ft rotor, 100 ft tower
- ~21,000 kWh/year generation, utility bill savings ~$2,800/year
- Installed in early 1980s, ~$20,000, received federal tax credit
- Maintenance costs $50/year
- One lightning strike, damage was covered by farm insurance

Medford, Massachusetts

- Turbine size: 100 kW
- Turbine manufacturer: Northern Power Systems
- Developer/owner: City of Medford, MA
- Application: net-metering for utility bill reduction at McGlynn Elementary & Middle School

Selawik, Alaska

- 4 x 50 kW wind turbines
- Turbine manufacturer: AOC
- Developer/owner: AVEC
- Capacity: 200 kW

Hull, Massachusetts

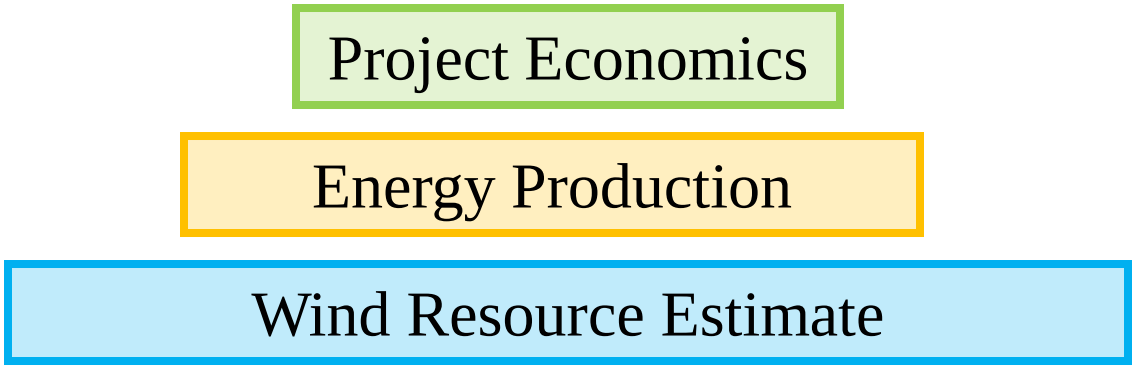
- Turbine size: 660 kW
- Turbine manufacturer: Vestas
- Developer/owner: Hull Municipal Lighting Plant
- Capacity: .66 MW

Ponnequin, Colorado

- Turbine manufacturer: Vestas, NEG Micon
- Developer/owner: DisGen/Xcel Energy
- Turbine size: 660–750 kW
- Capacity: 31.5 MW
- Commissioned: 1999

Wind Characteristics & Energy Potential

Why Care About Wind Resource Assessment?



An accurate wind resource estimate is the basis for estimating the performance and economics of a wind energy project

Energy and Power

ENERGY, ABILITY TO DO WORK

ENERGY = FORCE * DISTANCE

Electrical energy , kWh

POWER = ENERGY/TIME (rate at which energy is being created or used)

generator size, kW

Energy is a quantity

Power is a rate (quantity/time)

Power in the Wind

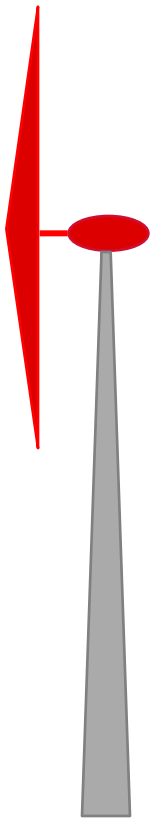
$$P = 0.5 \rho A v^3$$

P - power, watts

ρ - density of air, kg/m³

A - area, m² **(**$A = \pi D^2 / 4$)

v - wind speed, m/s



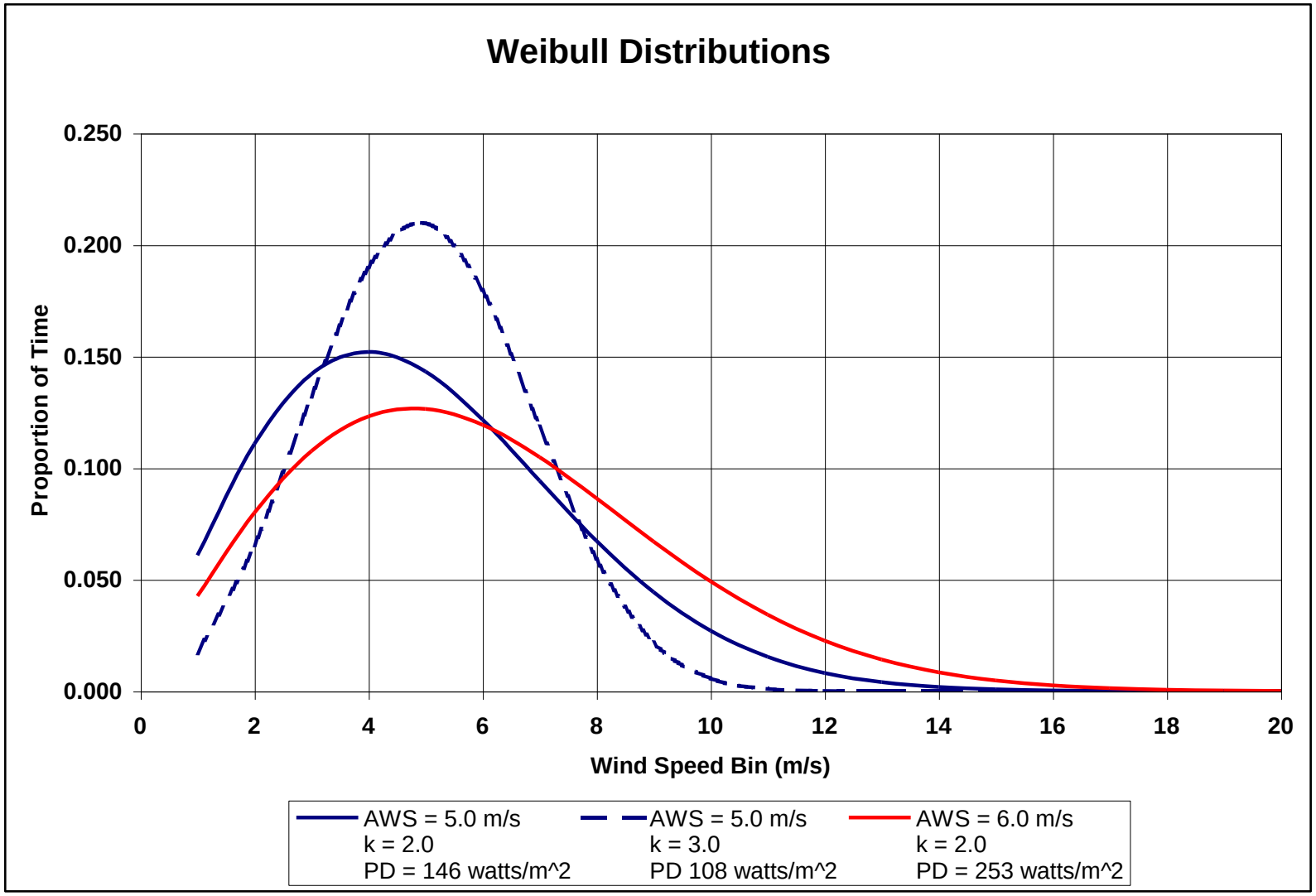
Courtesy: Alternative Energy Institute

Power Density

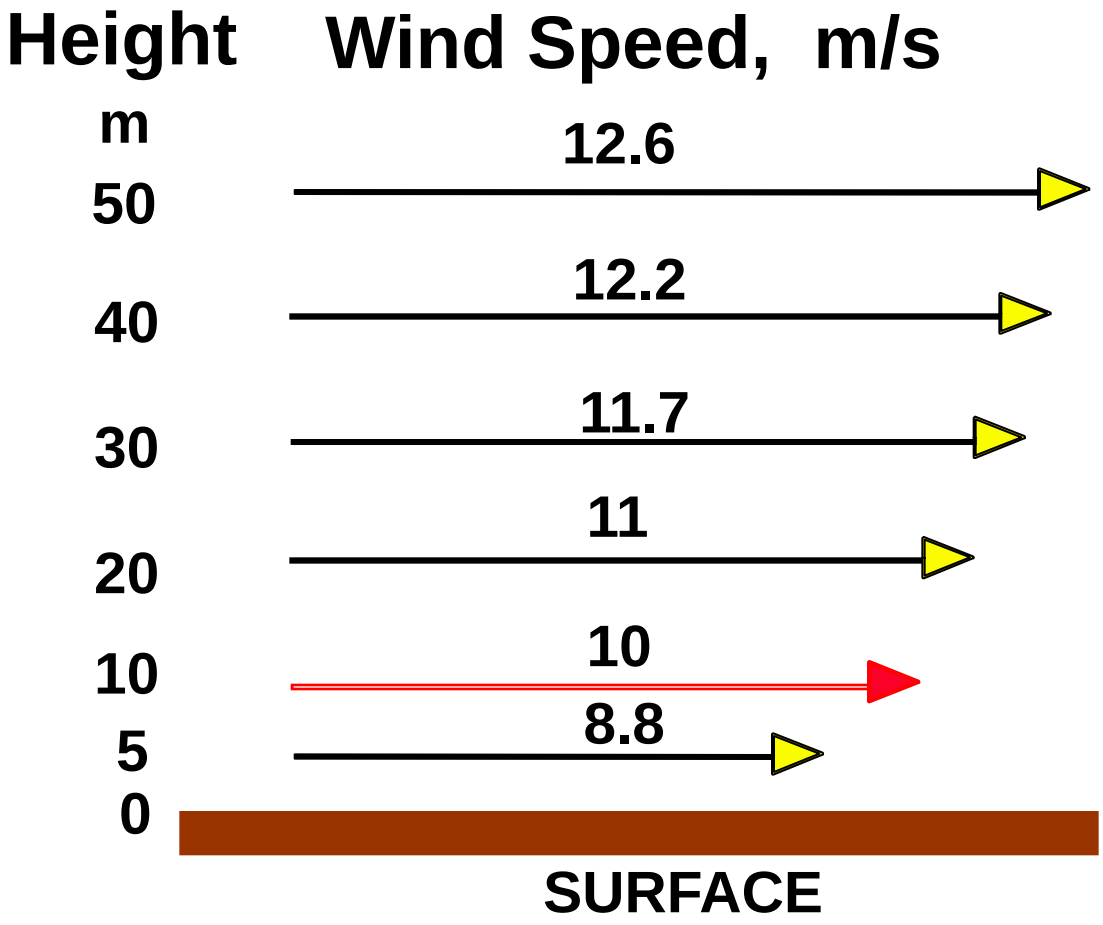
$$\text{Power Density} = P/A = 0.5\ \rho\ v^3$$

Wind Class	W/m^2 at 50 m	Wind speed at 50 m
1	0 - 199	0 - 5.9 m/s
2	200 - 299	5.9 - 6.7 m/s
3	300 - 399	6.7 - 7.4 m/s
4	400 - 499	7.4 - 7.9 m/s
5	500 - 599	7.9 - 8.4 m/s
6	600 - 800	8.4 - 9.3 m/s
7	> 800	> 9.3 m/s

Wind Speed Distribution



Wind Shear



Courtesy: Alternative Energy Institute

Wind Shear

Wind shear describes how the speed of the wind varies with height.

We can estimate the wind speed at height 2 based upon the wind speed at height 1

$$v_2 = v_1 * (h_2/h_1)^{\alpha}$$

h_1 - height 1

h_2 - height 2

v_1 - wind speed at height 1

v_2 - wind speed at height 2

$\alpha = 0.14$ (0.1 - 0.3) (wind shear exponent)

Using Wind Shear

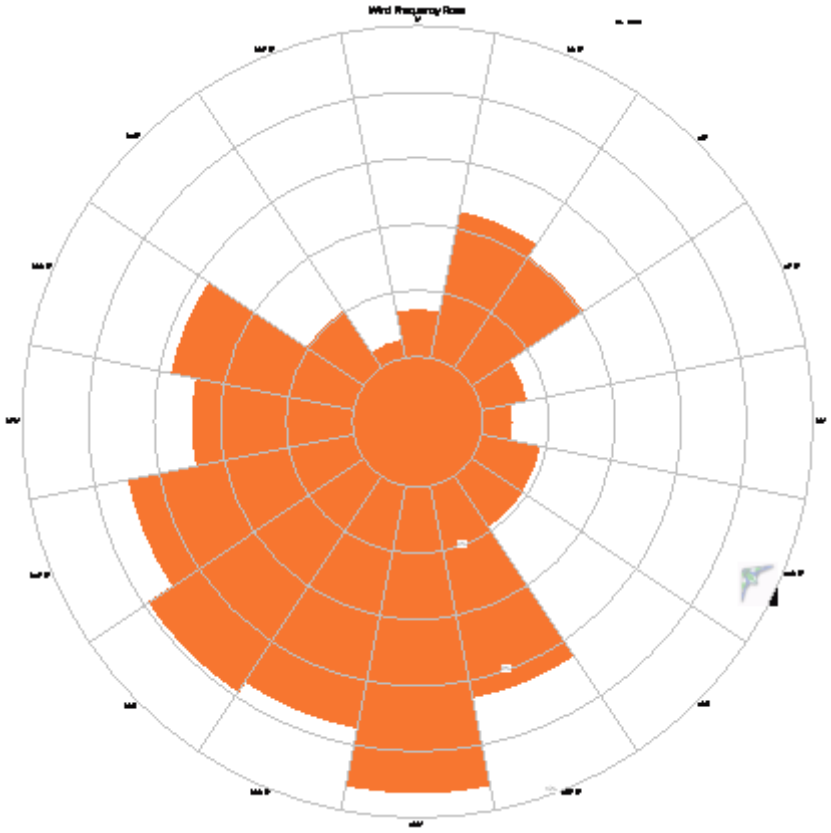
- Typically measurements from low levels are extrapolated upwards
- Range from 0.1 to 0.3 is common

Caveats

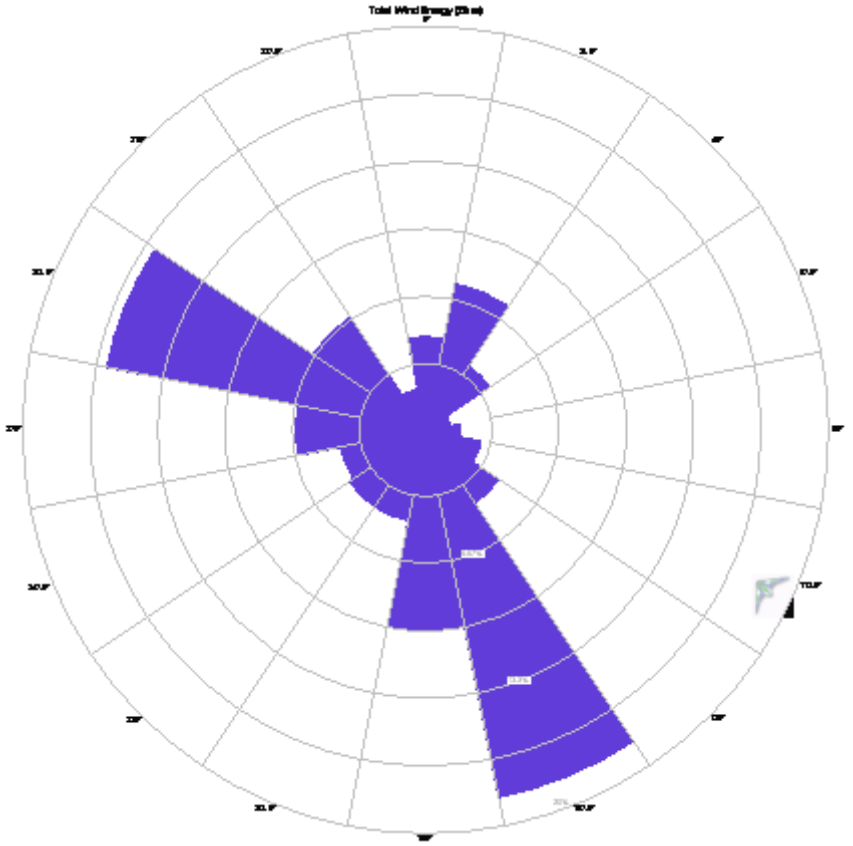
- Wind shear varies with location, time of day, season, direction, and height.
- The calculations break down at or below the line of ground clutter.

Wind Rose

Chadron, NE



Wind Rose



Energy Rose

Turbulence

Effect of turbulence

- Less energy production
- More turbine wear & tear ➔ Increased O&M expenses
- Turbulence effects are hard to quantify in advance

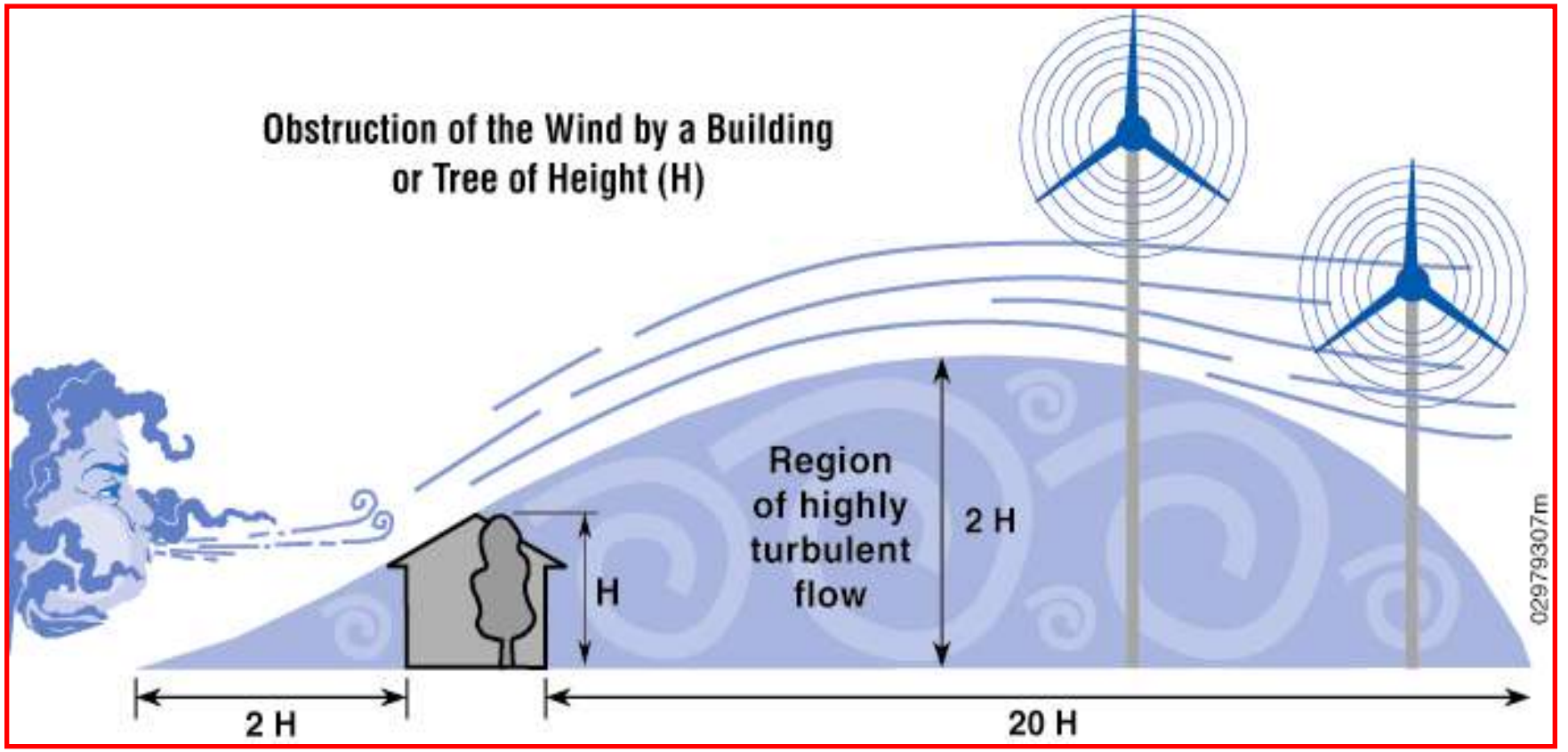
What causes turbulence?

- Terrain
- Ground clutter

How to minimize turbulence

• Ideally, the lowest portion of the turbine swept area should be ≥ 30 feet higher than anything else within ~ 300–500 meters.

Importance of “Micro-Siting”



Sources of Wind Data

Wind maps (static and interactive)

- State wind maps: http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
- *Renewable Energy Atlas of the West*: http://www.energyatlas.org/
- In My Back Yard (IMBY): http://mercator.nrel.gov/imby/
- Some states have additional data. Try searching the Web site of your state energy office.
- 3TIER First Look: http://firstlook.3tiergroup.com/
- AWS True Power Wind Navigator: https://www.windnavigator.com/cms/

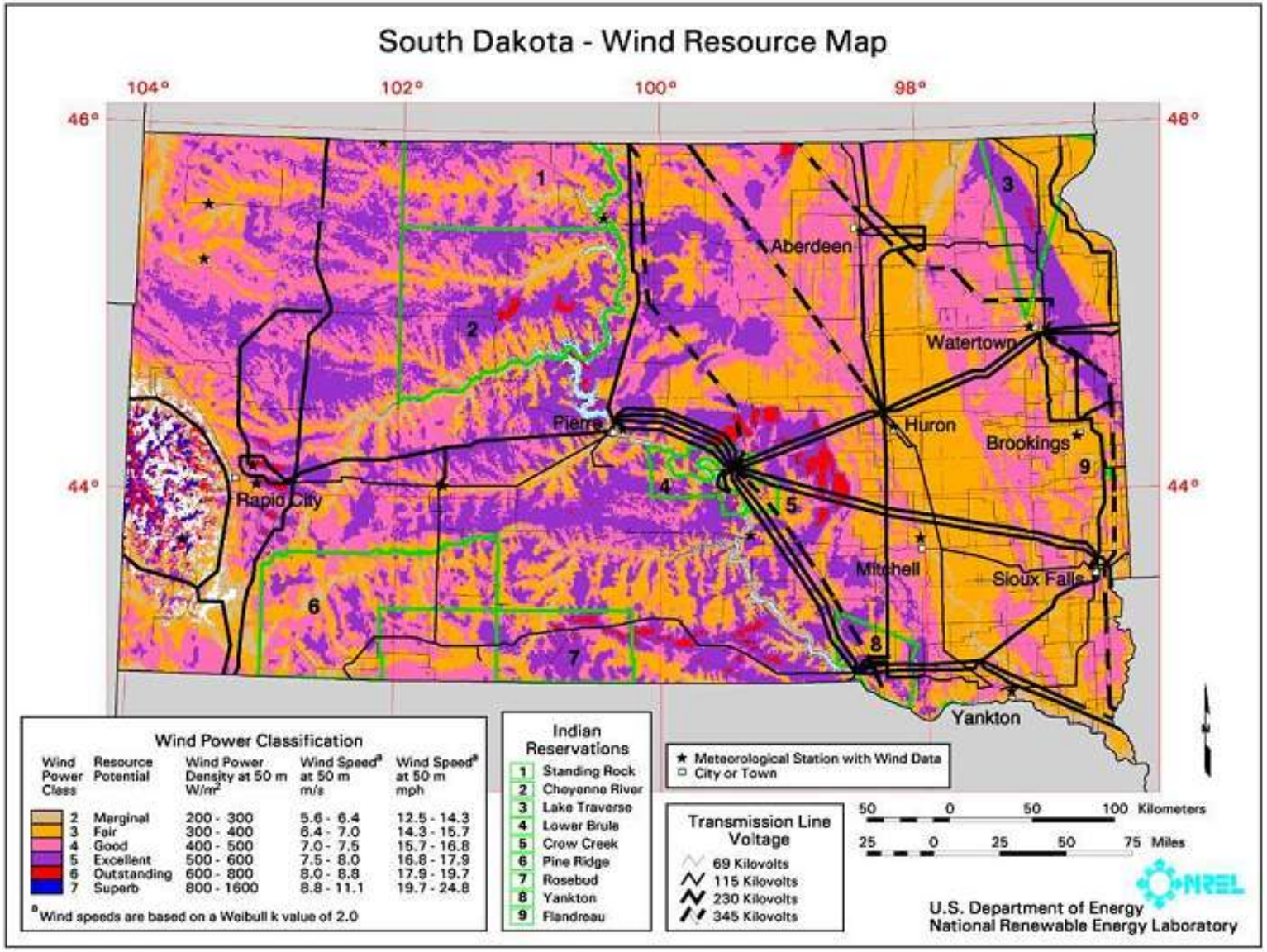
Sources of real data

- Real data from the area (airports, etc.). Data quality will vary.
- Consider on-site monitoring if your project is 50–100kW or larger

Cautions regarding wind maps

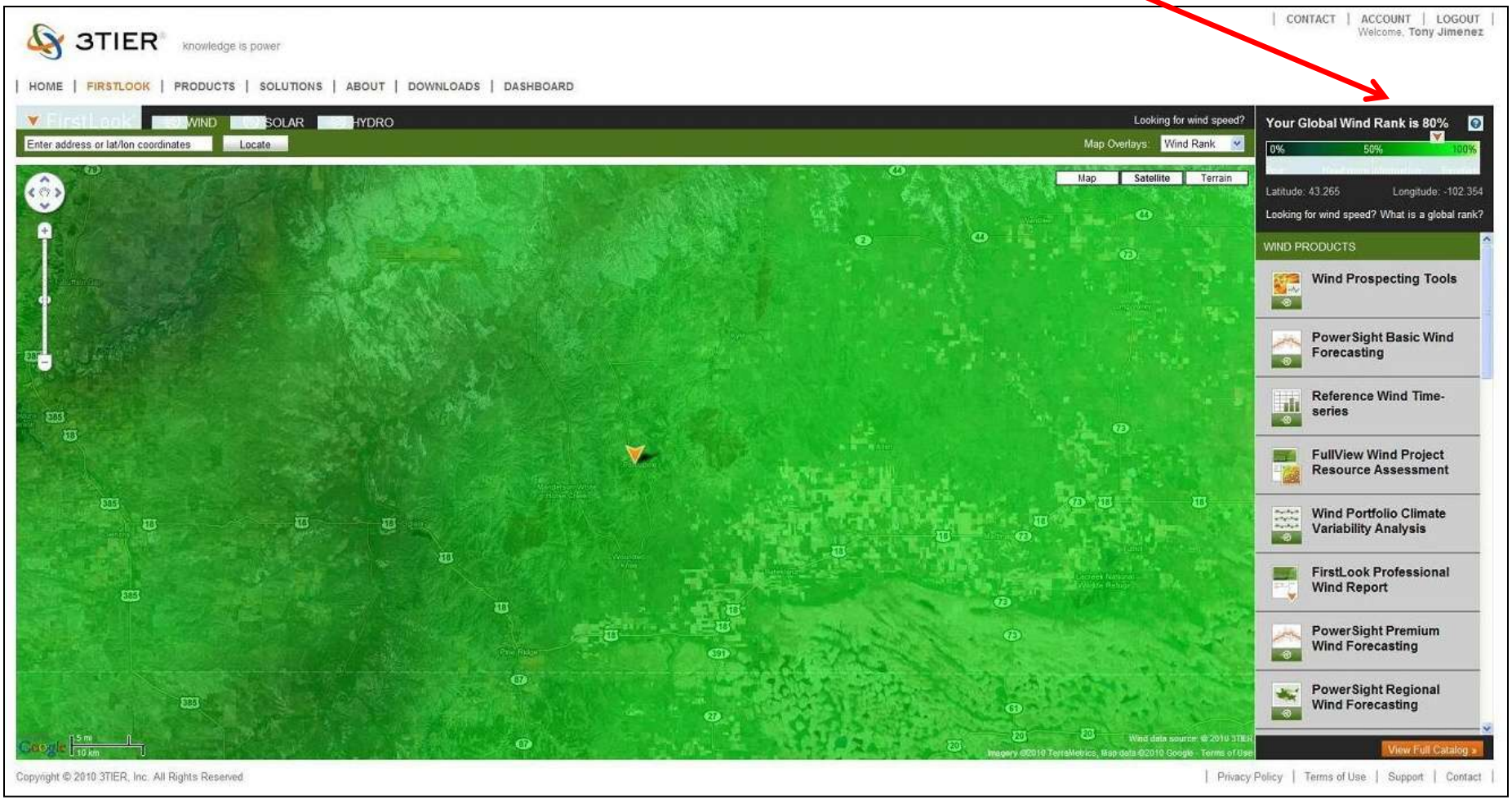
- The values assume good exposure to the wind

Sources of Wind Data
State Wind Map



Sources of Wind Data Firstlook Screen Shots

Average annual wind speed replaced with more generic “Global Wind Rank”

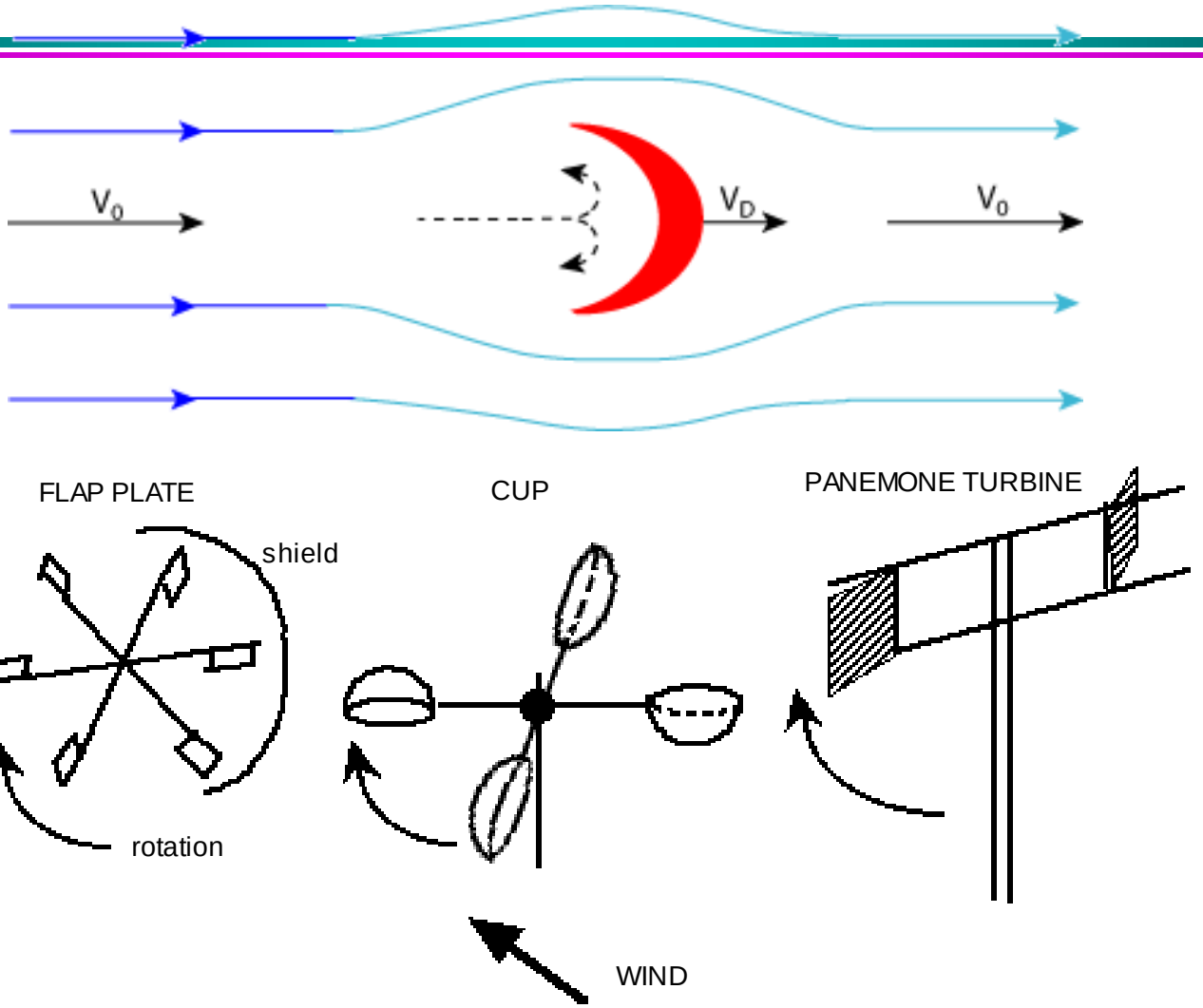


Wind Turbine Topologies

Wind Turbine Topologies

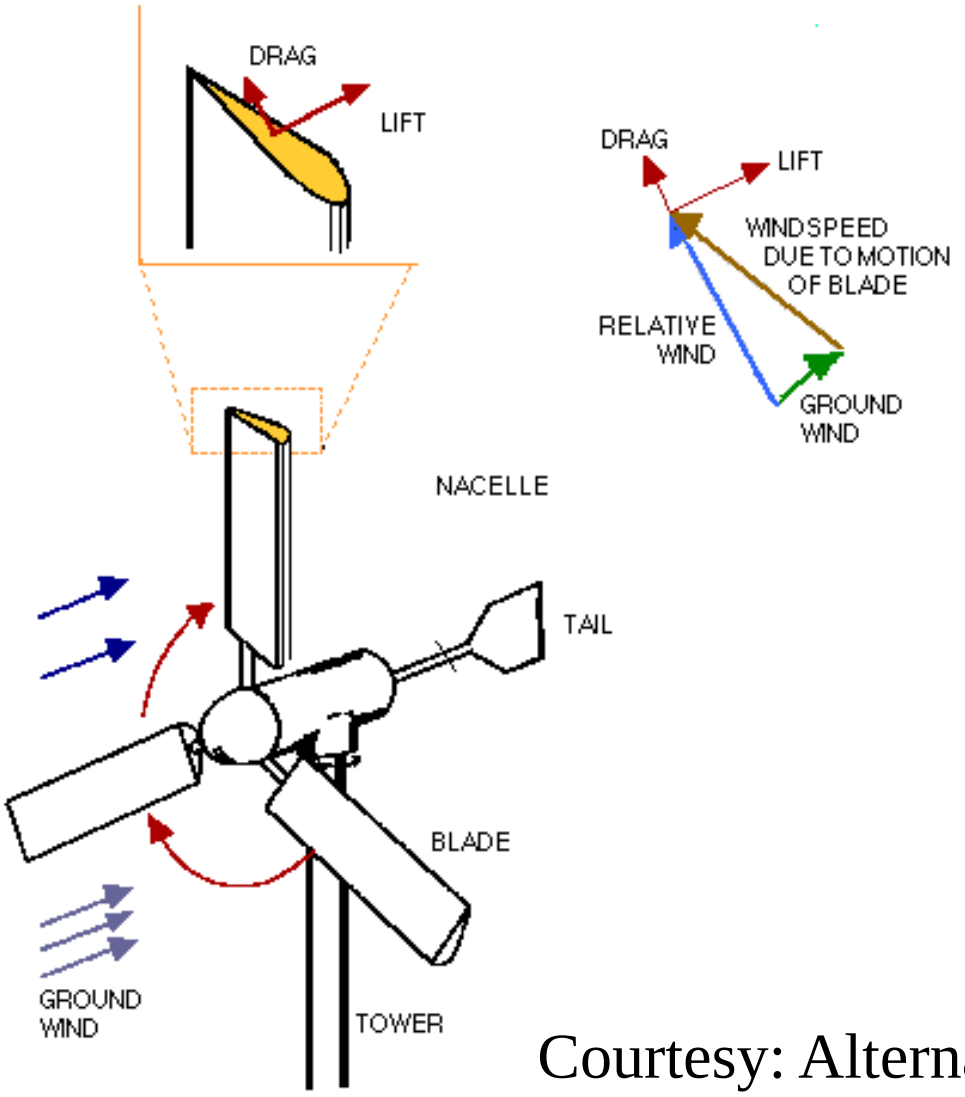
- Drag vs lift machines
- Horizontal axis vs vertical axis
- Upwind vs downwind
- Two vs three blades

Drag Machines



Courtesy: Alternative Energy Institute

Lift Machines



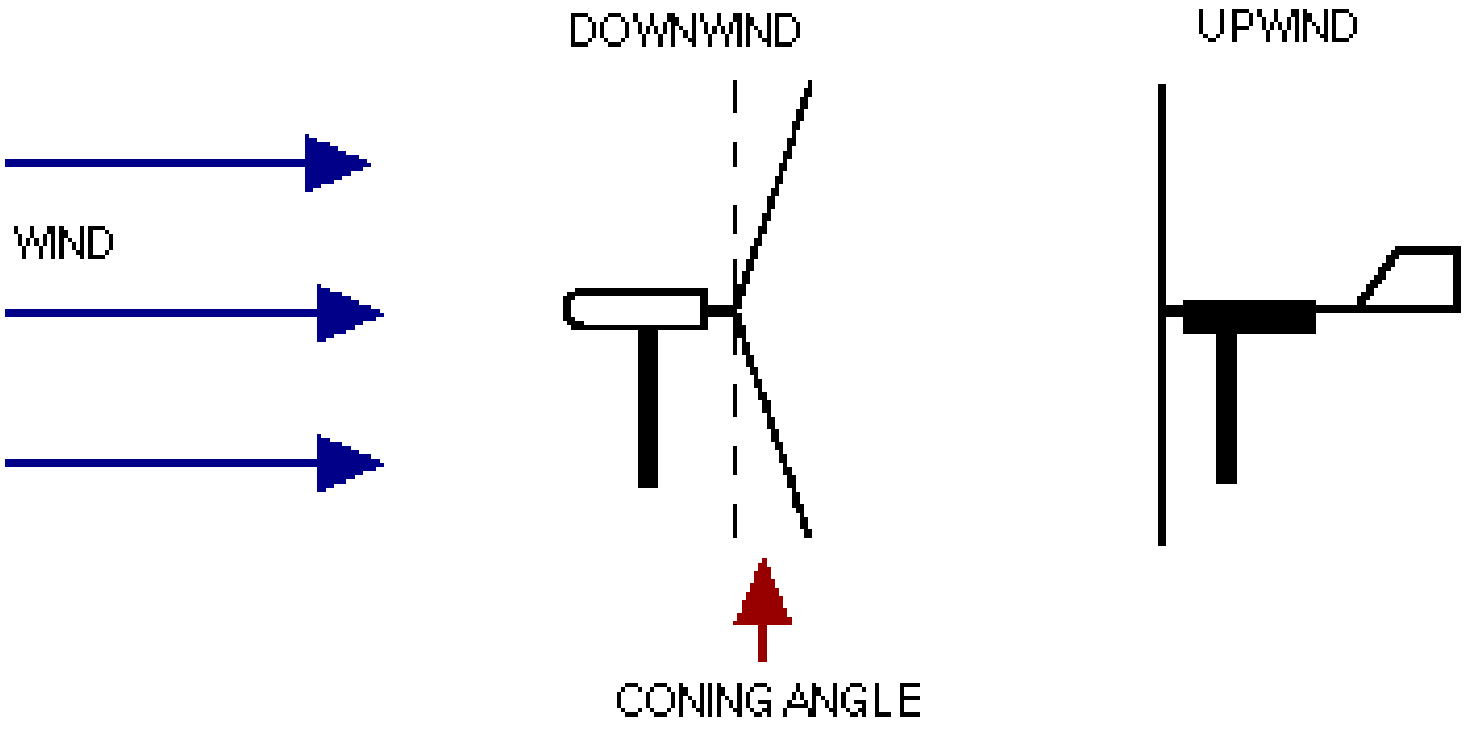
Courtesy: Alternative Energy Institute

Types

HAWT VAWT

Courtesy: Alternative Energy Institute

Downwind & Upwind



Courtesy: Alternative Energy Institute

Nacelle 1 MW

Courtesy: Alternative Energy Institute

Blade 27 m length

Rotor area = 2,460 m^2

Courtesy: Alternative Energy Institute

Small Wind vs. Large Wind

Sizes and Applications

Small (≤10 kW)

- Homes
- Farms
- Remote applications

(e.g., water pumping, telecom sites, ice making)

Intermediate (10 kW–1 MW)

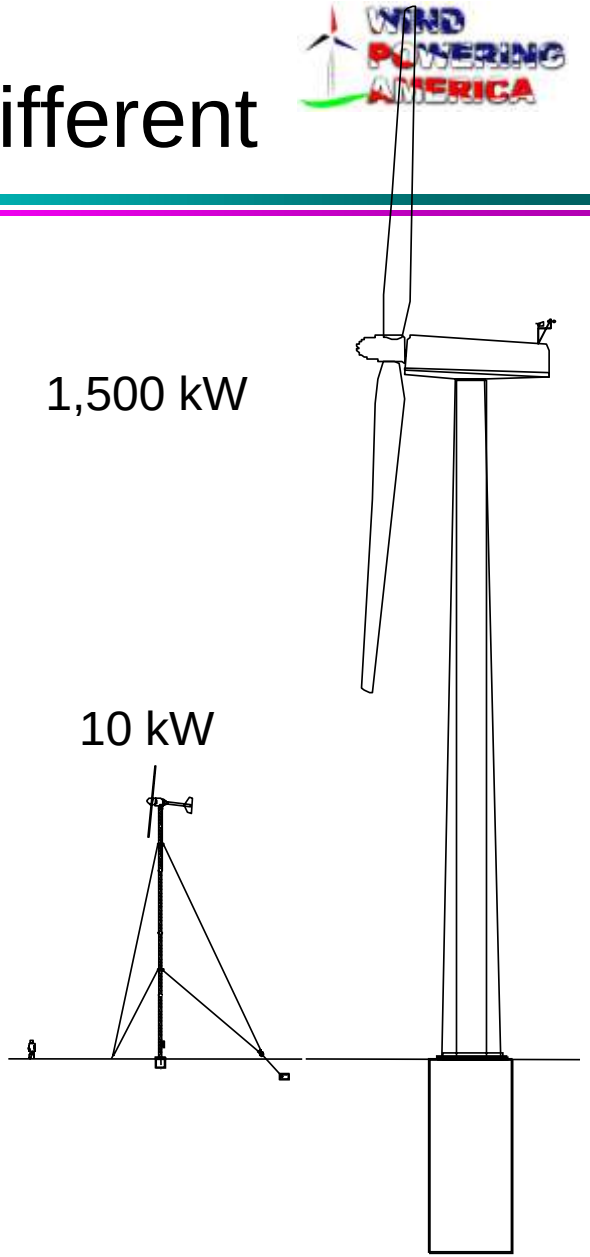
- Village power
- Hybrid systems
- Distributed power

Large (1 MW +)

- Central station wind farms
- Distributed power
- Community wind

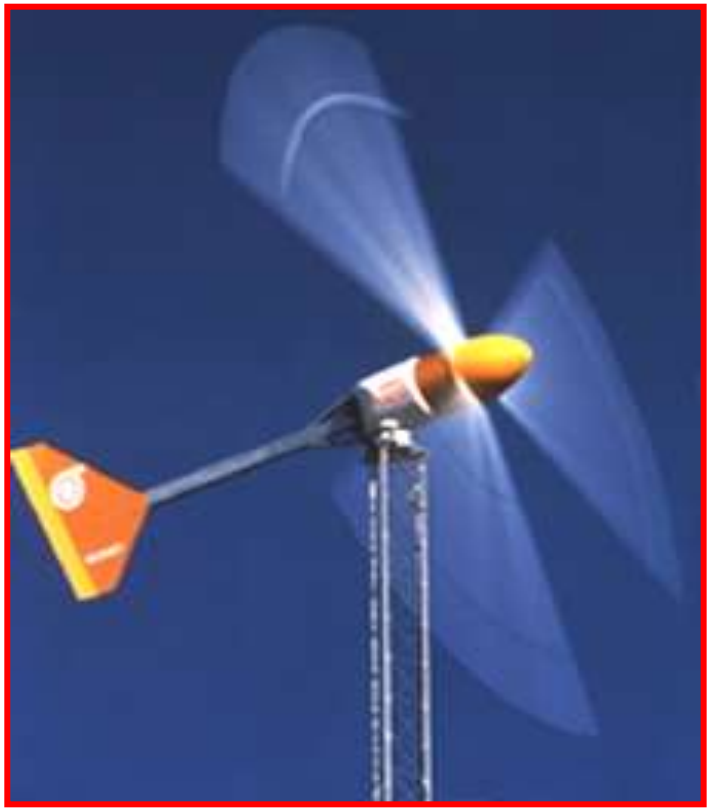
Small Wind Turbines Are Different

- Utility-scale wind power
  1,000–3,000 kW+ wind turbines
  - Installed on wind farms, 10–300 MW
  - Professional maintenance crews
  - 13 mph (6 m/s) average wind speed
- Small wind power
  300 W–100 kW wind turbines
  - Installed at individual homes, farms, businesses, schools, etc.
  - On the “customer side” of the meter, or off the utility grid entirely
  - High reliability, low maintenance
  - 9 mph (4 m/s) average wind speed



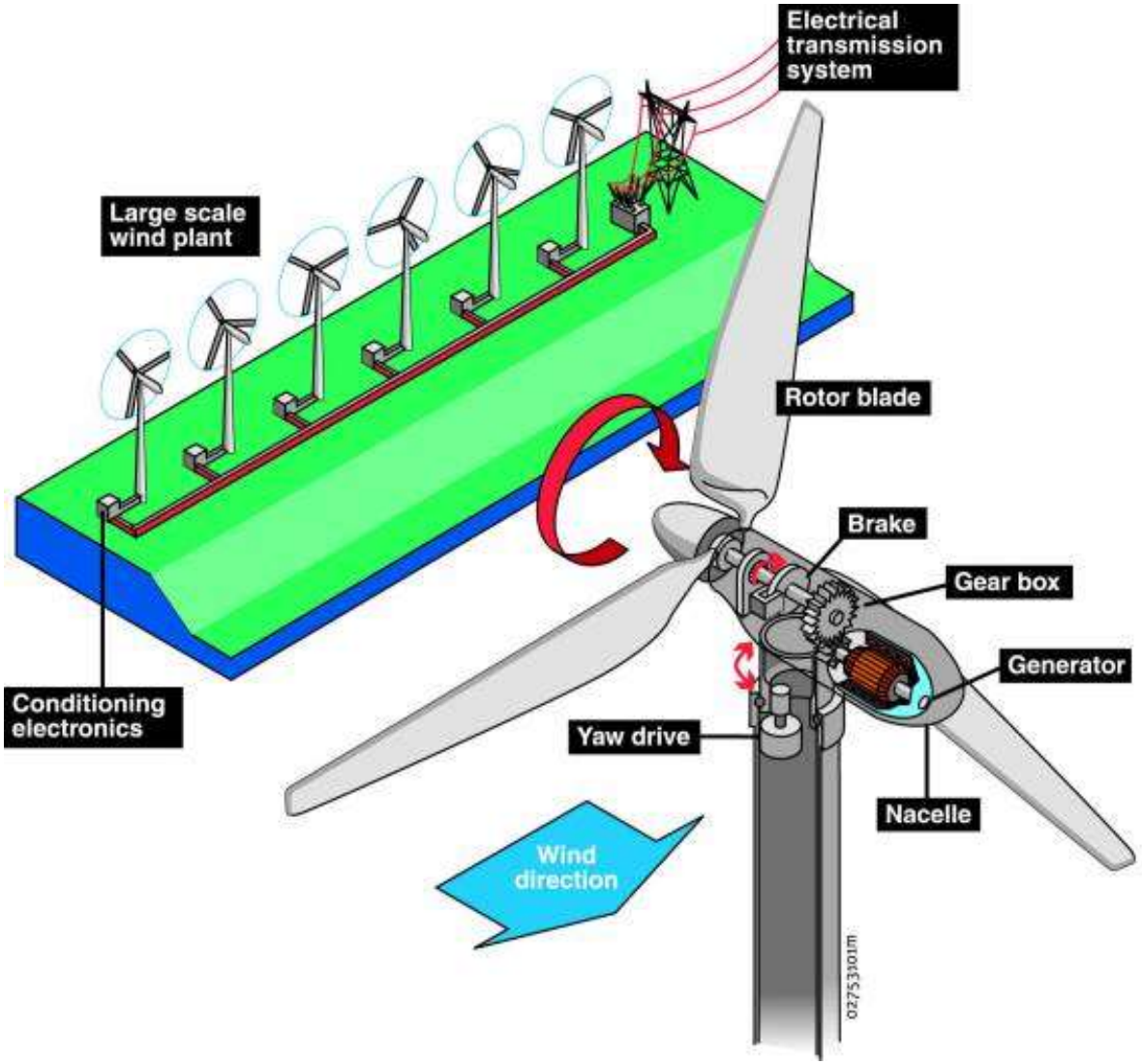
Small Wind Turbines

- Configuration: 2 or 3 blades aimed into the wind by the tail
- Blades: fiber-reinforced plastics
- Over-speed protection: furling (rotor turns out of the wind)
- Generator: direct-drive, permanent magnet alternator (no brushes), variable-speed operation
- Controller: electronic device that delivers
  - DC power for charging batteries
  - AC power for utility interconnection
- Result:
  – Simple, rugged design
  – Only 2–4 moving parts
  – Little regular maintenance required



Utility-Scale Wind Energy Technology

At its simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.



Estimating Turbine Energy Production

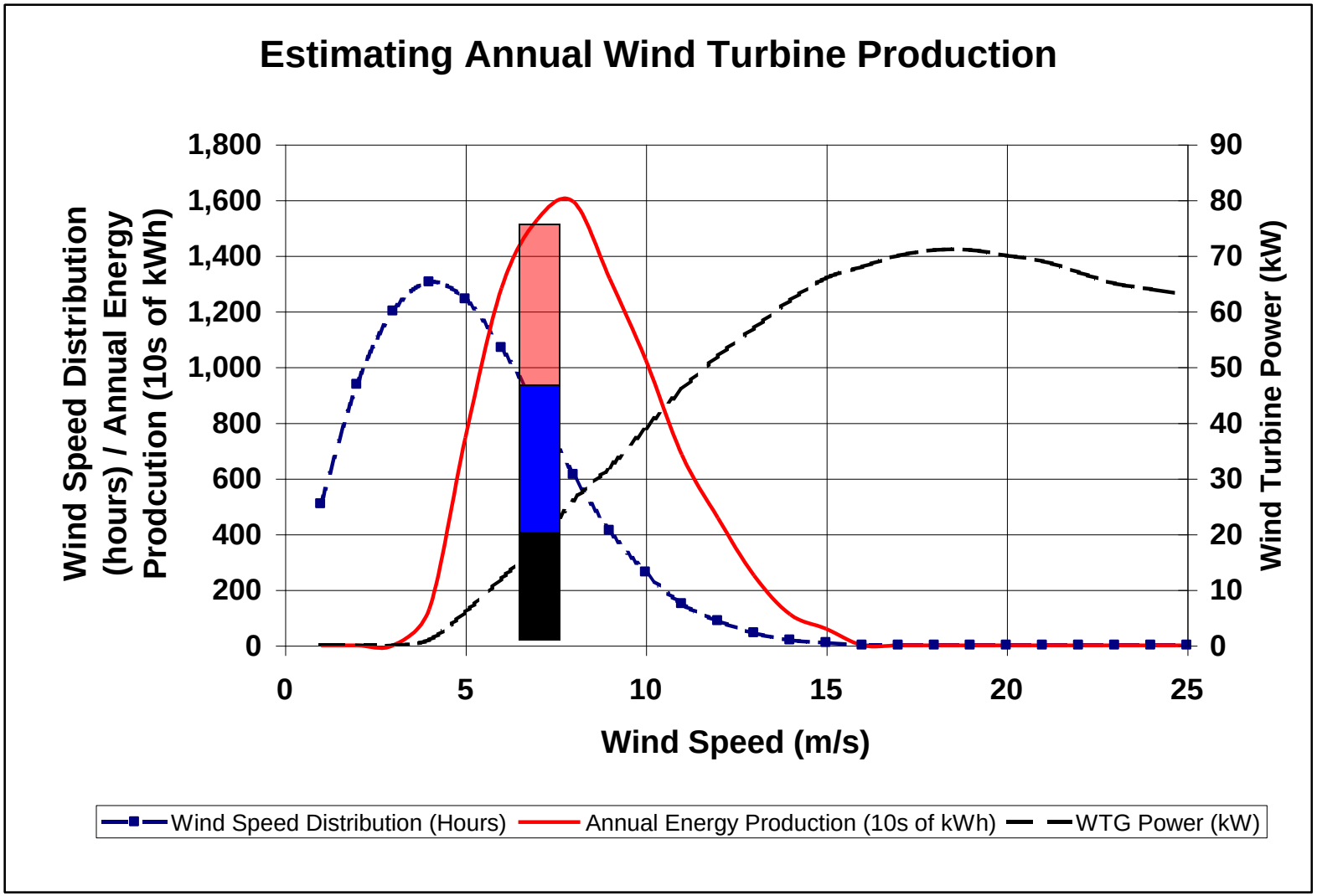
Calculation of Wind Turbine Power

Power from a wind turbine = C_p ½ ρ A V^3

- Effect of wind speed, V
- Effect of rotor diameter on swept area
  A = Pi D^2 / 4
- Effect of elevation and temperature
  on air density, ρ
- Limits on power coefficient (efficiency):
  C_p = 0.2 - 0.45 (theoretical max = 0.59)

Note: For a given turbine C_p varies with wind speed

Calculating Turbine Output



Calculating Turbine Output

Wind Speed (m/s)	WTG Power (kW)	Wind Speed Distribution	Wind Speed Distribution (Hours)	Annual Energy Production (kWh)
1	0	5.8%	508	0
2	0	10.7%	937	0
3	0	13.7%	1,200	0
4	1	14.9%	1,305	1,305
5	6	14.2%	1,244	7,464
6	12	12.2%	1,069	12,828
7	18	9.7%	850	15,300
8	26	7.0%	613	15,938
9	32	4.7%	412	13,184
10	39	3.0%	263	10,257
11	46	1.7%	149	6,854
12	52	1.0%	88	4,576
13	57	0.5%	44	2,508
14	62	0.2%	18	1,116
15	66	0.1%	9	594
16	68	0.0%	0	0
17	70	0.0%	0	0
18	71	0.0%	0	0
19	71	0.0%	0	0
20	70	0.0%	0	0
21	69	0.0%	0	0
22	67	0.0%	0	0
23	65	0.0%	0	0
24	64	0.0%	0	0
25	63	0.0%	0	0
Total		0.994	8,709	91,924

Wind Turbine Performance Examples

Small & medium wind turbines

- 10%–25% capacity factor
- 10 kW WTG @ 12% cap factor ==> 10,500 kWh/year

Large wind turbines

- 25%–45%
- 1.5 MW WTG @ 35% cap factor ==> 4,600,000 kWh/year

(Pause for Questions)

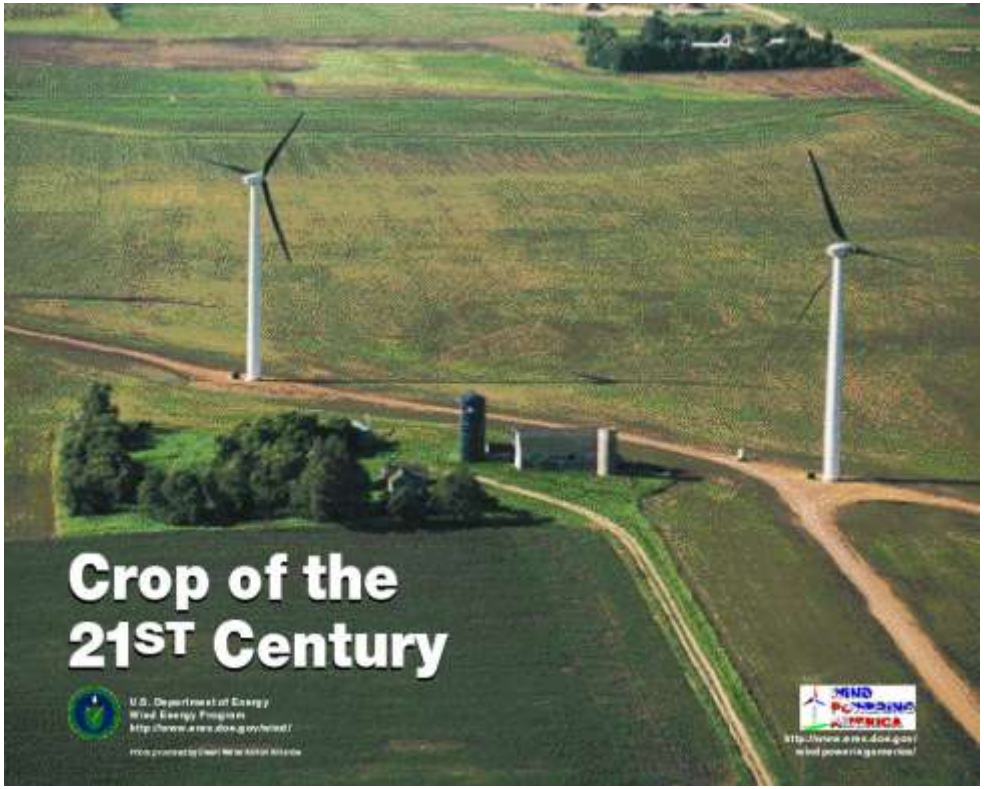
Large Wind Market & Policy Universe

Current Trends

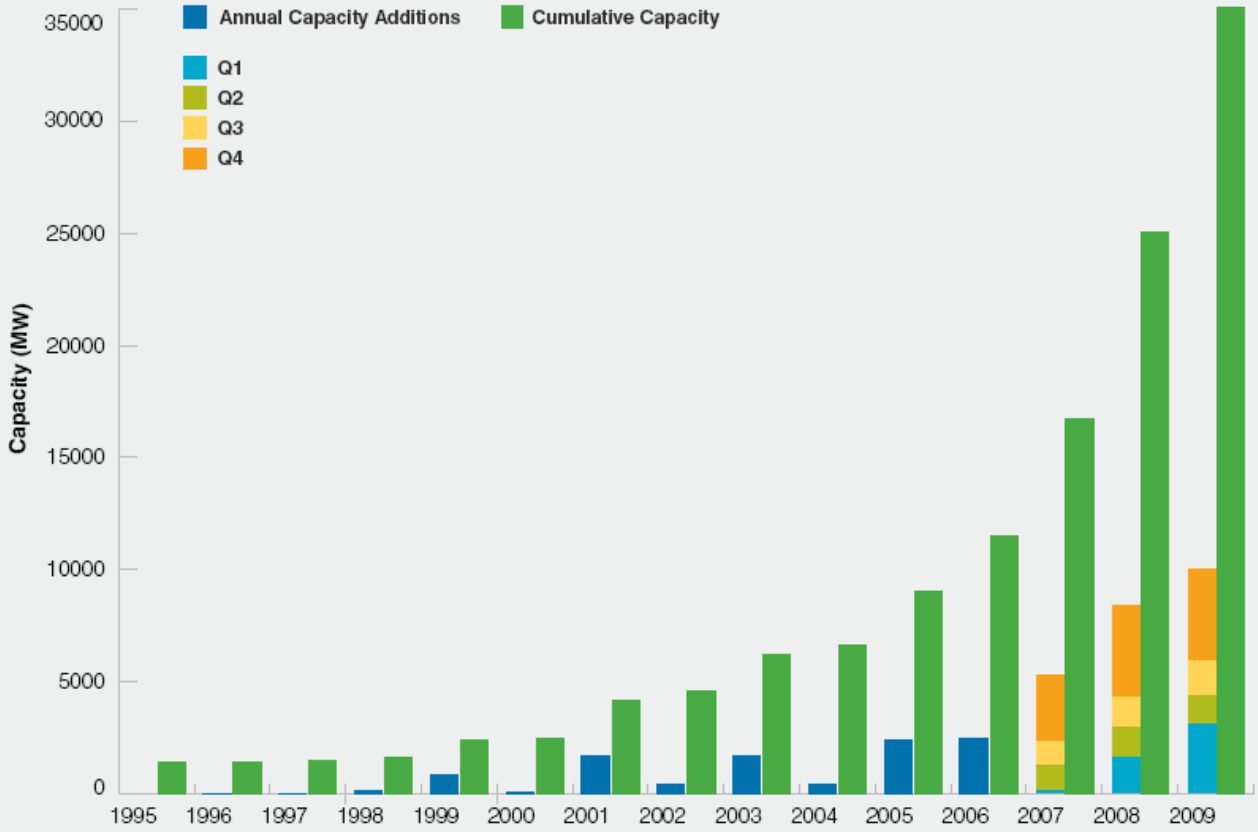
- Move toward ever larger machines
- More countries
- More financial players
- Industry consolidation
- Green energy and green tags
- Offshore
- Low wind speed turbines (U.S.)
- 20% report (U.S.)

Drivers for Wind Power

- Competitive wind costs
- Fuel price uncertainty
- Federal and state policies
- Economic development
- Environment/water
- Public support
- Green power
- Energy security
- Carbon risk



U.S. Annual & Cumulative Wind Power Growth



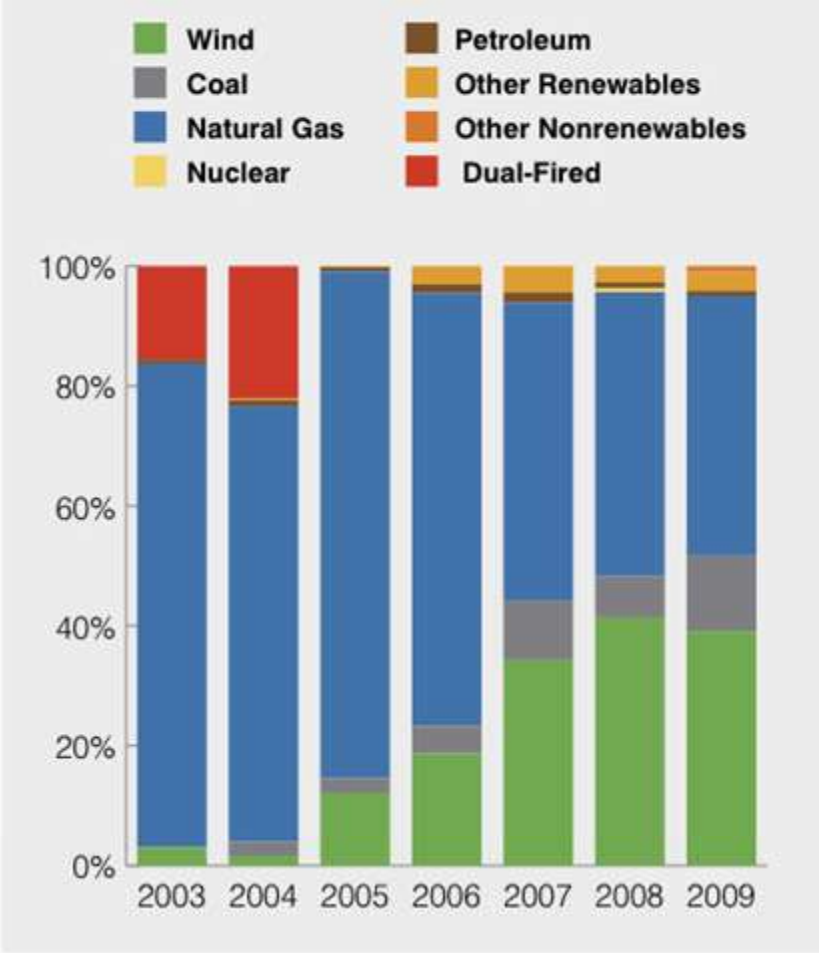
Year	Annual Capacity Additions (MW)	Cumulative Capacity (MW)
Through end 1995		1416
1996	1	1417
1997	17	1434
1998	140	1574
1999	819	2394
2000	67	2460
2001	1691	4151
2002	412	4563
2003	1670	6233
2004	397	6629
2005	2385	9014
2006	2462	11476
2007	5258	16725
2008	8366	25076
2009	10010	35086

Installation figures for years 2006 - 2009 (annual and cumulative) include capacity for installed turbines under 100 kW, whereas earlier years may not. The small wind report tracks sales of wind turbines 100-kW and below. The utility scale wind power projects database tracks turbine installations 100-kW and above. 100-kW turbine sales were subtracted from the small wind report total to avoid double counting. Data has changed slightly from the 2008 Wind Industry Report due to small decommissionings, changes in how the data was reported and other changes provided by companies.

Source: American Wind Energy Association U.S. Wind Industry Annual Market Report – Year Ending 2009

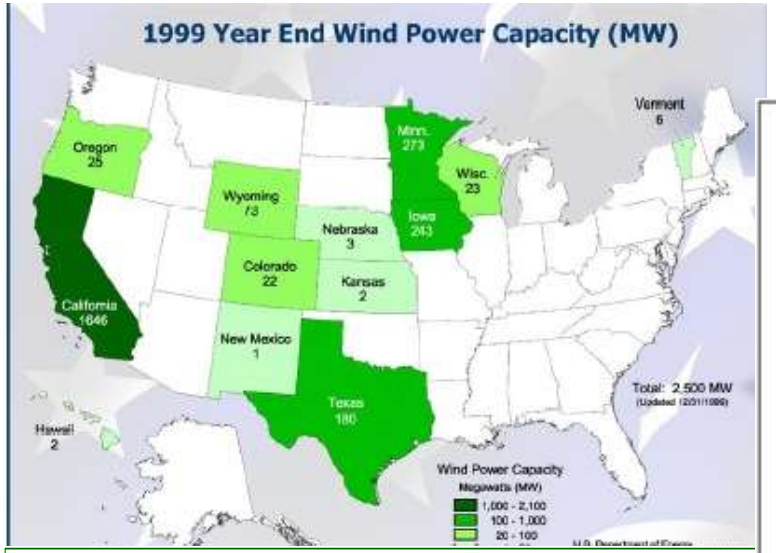
Percentage of New Capacity Additions

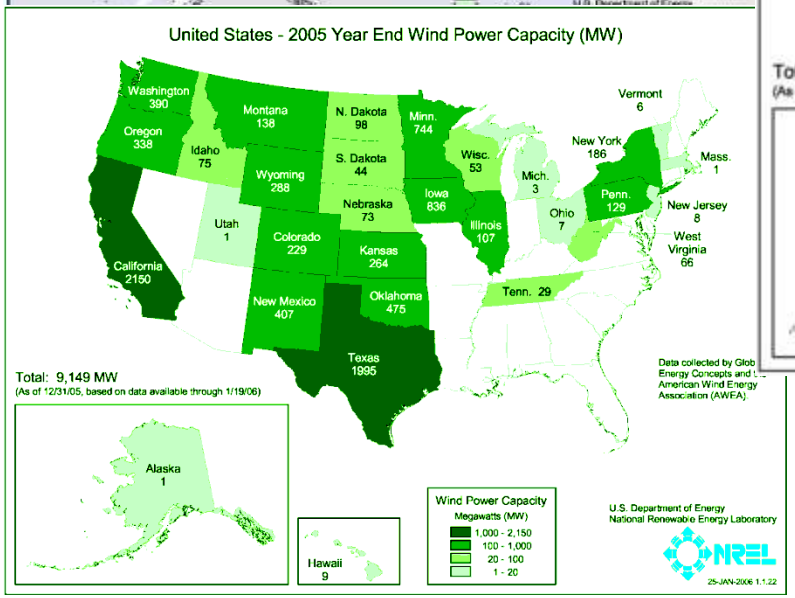
For the past five years, wind power has been one of the largest new sources for electricity generating capacity, second only to new natural gas units. In 2009, wind power provided 39% of all new generating capacity installed.

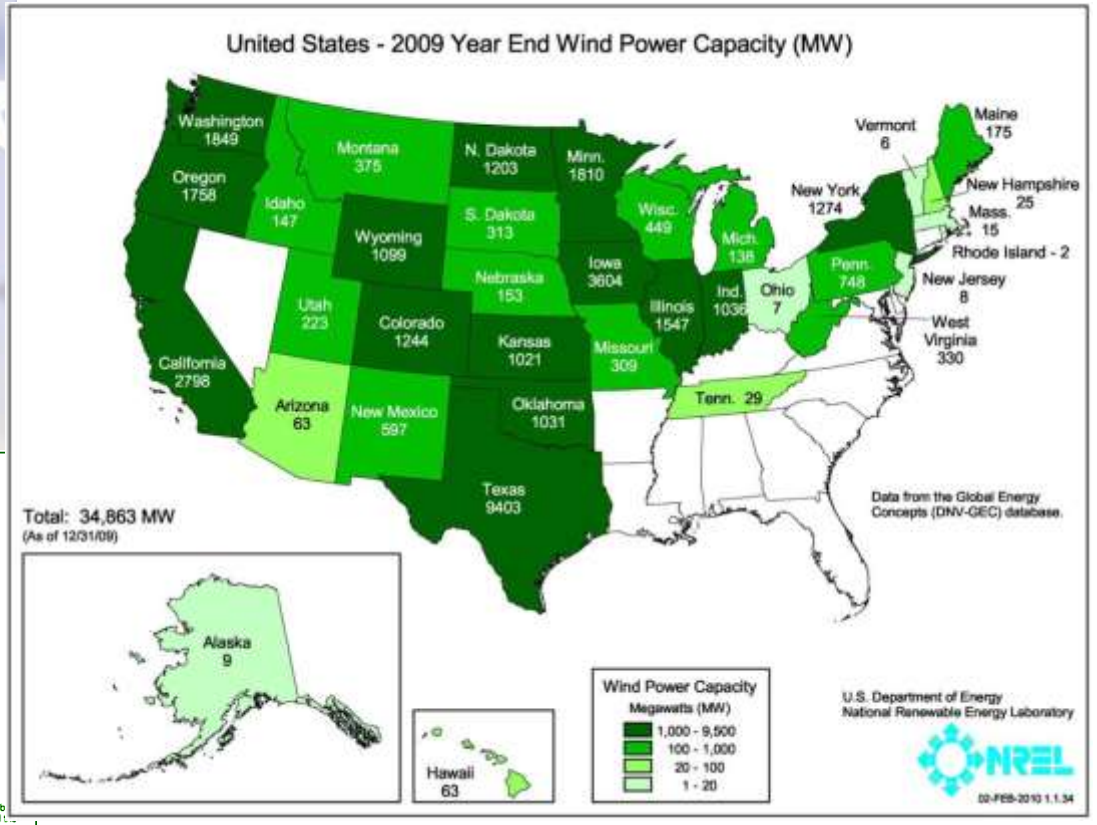


Source: American Wind Energy Association U.S. Wind Industry Annual Market Report – Year Ending 2009

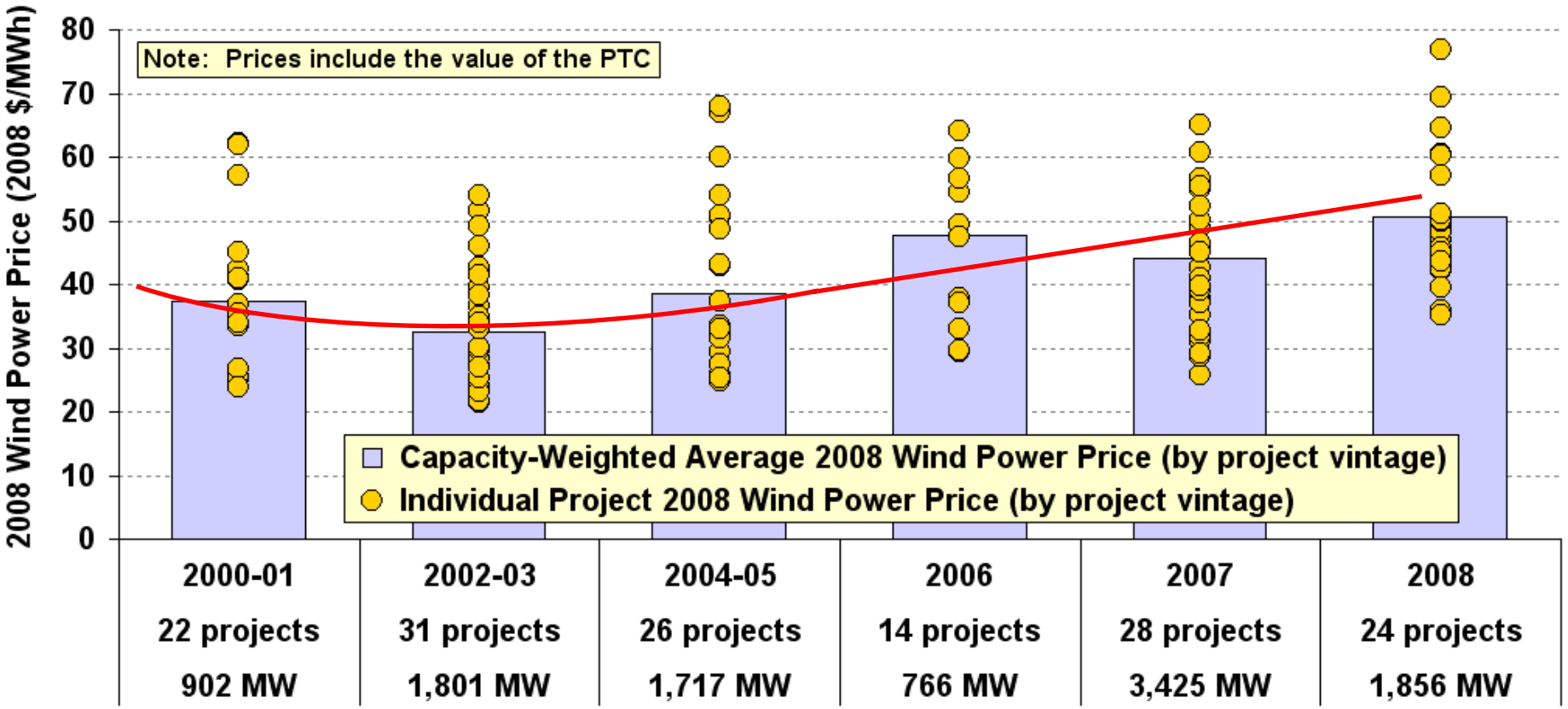
U.S. Installed Wind Capacities (99-10)







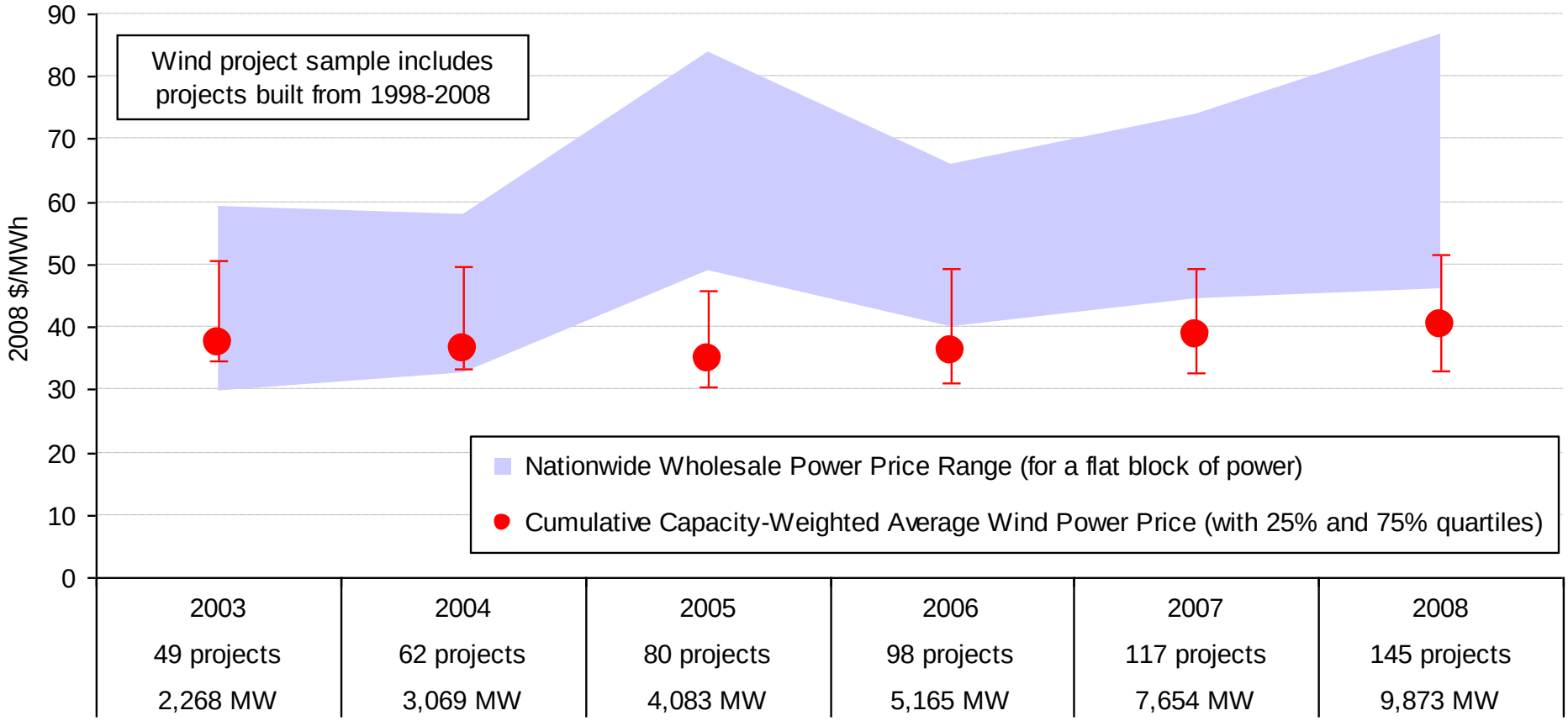
As a Result of Foregoing Trends, Wind Prices Have Been Rising Since 2002–03…



- Wind power prices bottomed out with projects built in 2002-03
- Projects built in 2008 are ~$15-20/MWh higher on average

2008 Wind Market Report; LBL

Wind Has Been Competitive with Wholesale Power Prices in Recent Years

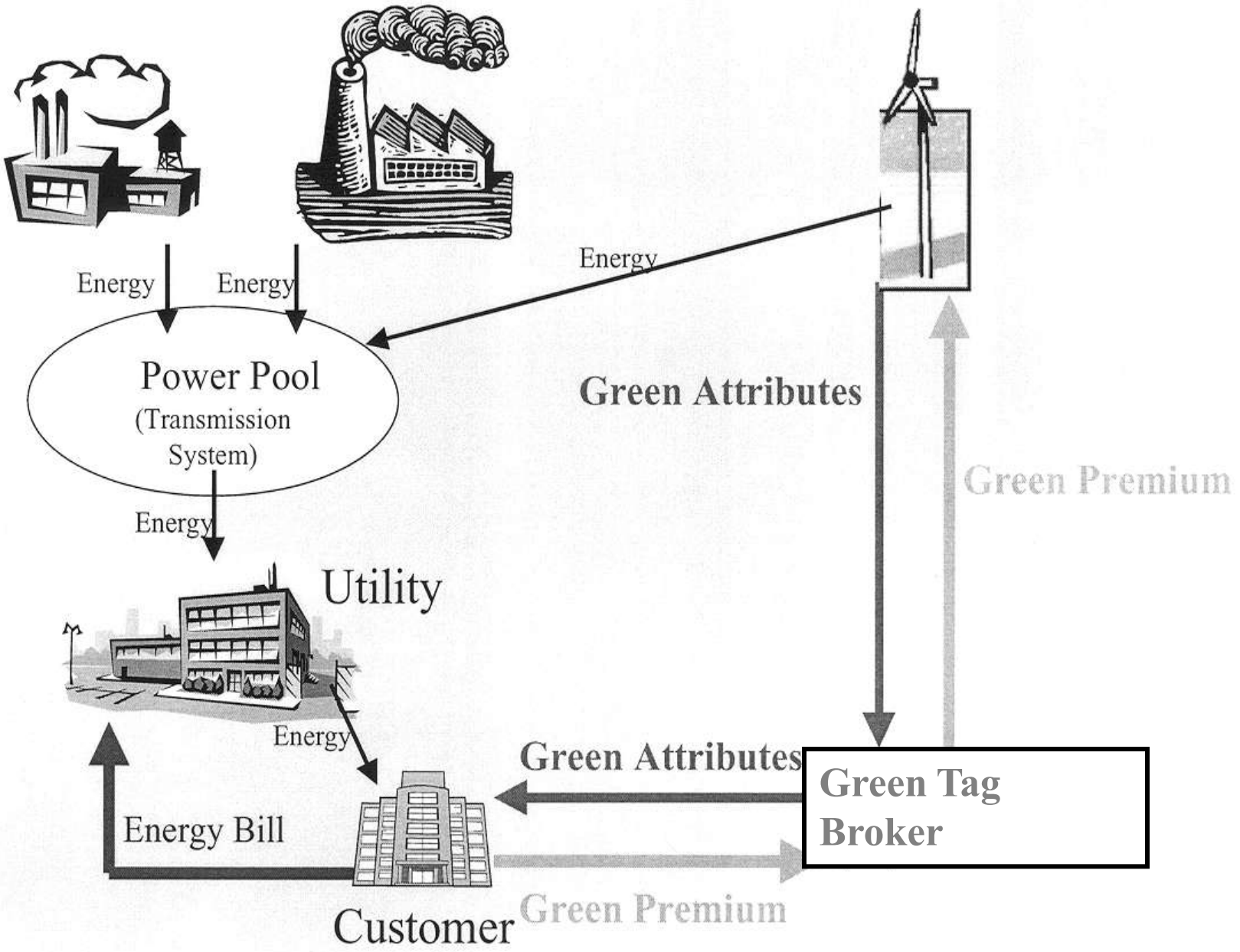


- Wholesale price range reflects flat block of power across 23 pricing nodes
- Wind power prices include sample of projects built from 1998-2008

Environmental Benefits

- No SOx or NOx
- No particulates
- No mercury
- No CO_2
- No water

Diagram 3 - Green Tag Transaction



Economic Development Opportunities

- **Land lease payments**: 3–5% of gross revenue $3,000–4,000/MW/year
- **Local property tax revenue:** 100 MW often brings in on the order of $500K–$1 million/yr
- 80–100 jobs/100 MW during **construction**
- 6–8 permanent **O&M jobs** per 100 MW
- **Local construction** and service industry: Foundations, roads—often done locally
- Investment as **Equity Owners**: production tax credit, accelerated depreciation, project revenues
- **Manufacturing** and assembly plants expanding in U.S.—single most significant economic development opportunity

Case Study: Prowers County, Colorado

- 162 MW Colorado Green Wind Farm (108 turbines)
- $200M+ investment
- 400 construction workers
- 14–20 full-time jobs
- Land lease payments $3,000–$6,000 per turbine
- **Prowers County 2002 assessed value $94M; 2004 assessed value +33% (+$32M)**
- **Local district will receive 12 mil tax reduction**
- Piggyback model

"Converting the wind into a much-needed commodity while providing good jobs, the Colorado Green Wind Farm is a boost to our local economy and tax base."

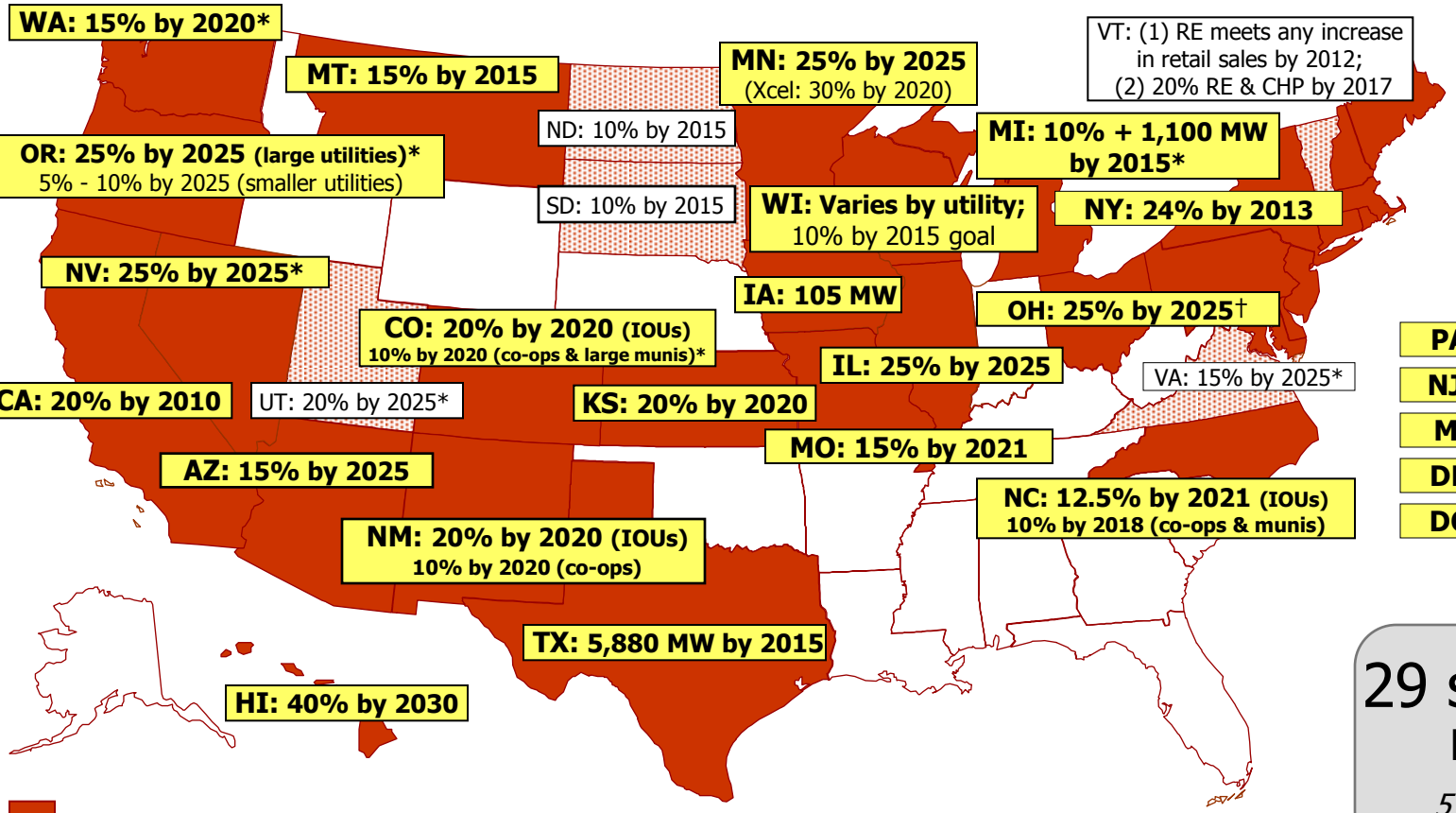
John Stulp, county commissioner, Prowers County, Colorado

Policy Is Now More Favorable to Wind Than at Any Other Time in the Past Decade

- ARRA 2009 established a number of federal policies to support wind
- Federal PTC currently in place through 2012 (longest extension in history)
- Wind projects can elect a 30% ITC or a 30% cash grant in lieu of the PTC
- New allocations of Clean Renewable Energy Bonds
- Expansion and enhancement of federal loan guarantee program
- Increased R&D funding
- Four new state RPS policies (MI, MO, OH, KS), and many revisions to existing state RPS policies (total is now 29 states plus Washington, D.C.)
- Efforts to pass an RPS and carbon regulation at the federal level continue

Renewable Portfolio Standards

www.dsireusa.org / August 2009



29 states & DC
have an RPS
5 states have goals

State renewable portfolio standard

State renewable portfolio goal

* Extra credit for solar or customer-sited renewables

† Includes separate tier of non-renewable alternative resources

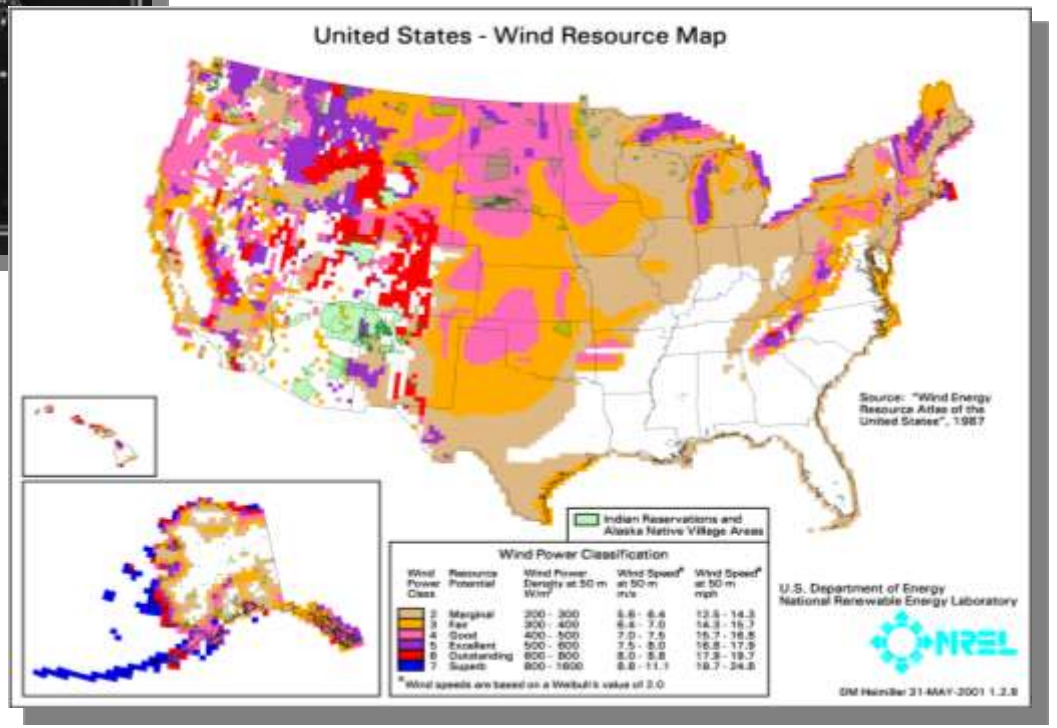
Studies Find that the Cost of Integrating Wind into Power Systems Is Manageable

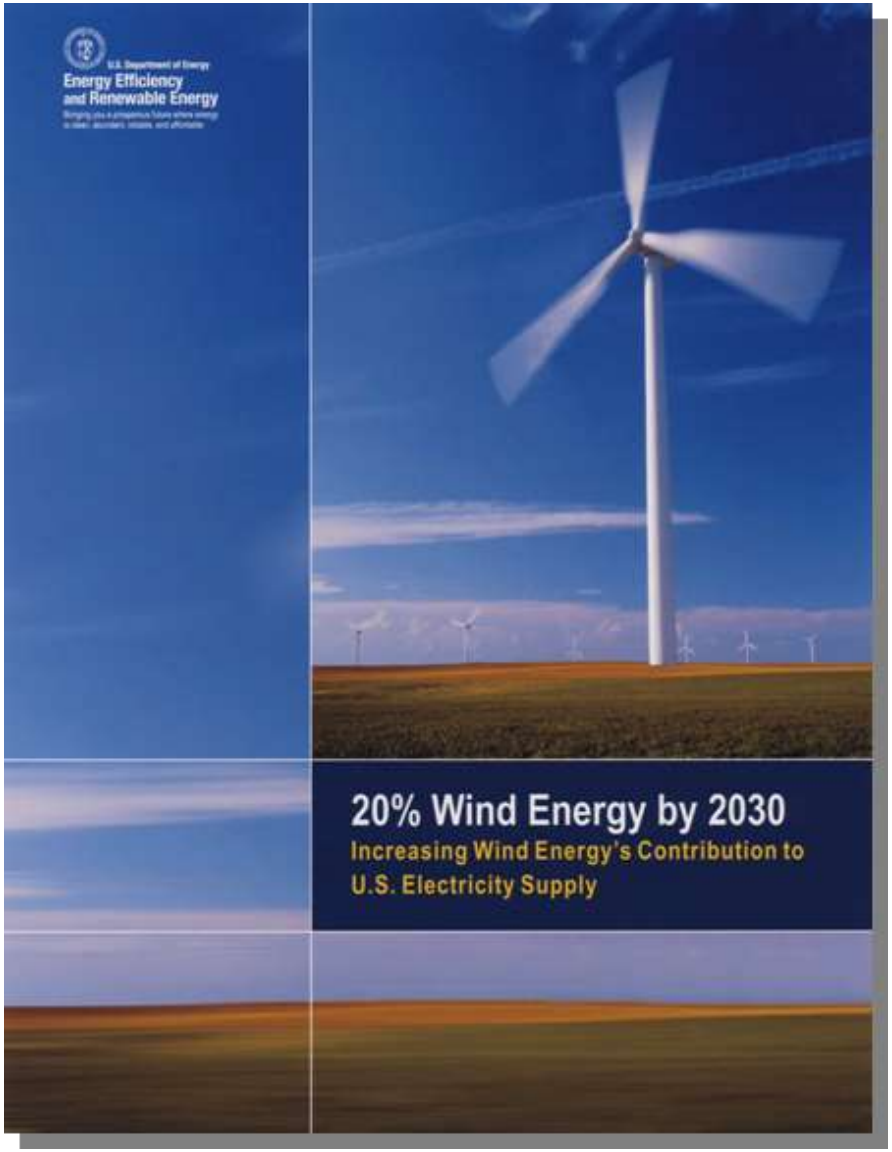
Date	Study	Wind Capacity Penetration	Integration Cost ($/MWh)				
			Regulation	Load Following	Unit Commit.	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp-2004	11%	0	1.48	3.16	na	4.64
2006	Calif. (multi-year)*	4%	0.45	trace	trace	na	0.45
2006	Xcel-PSCo	15%	0.20	na	3.32	1.45	4.97
2006	MN-MISO**	31%	na	na	na	na	4.41
2007	Puget Sound Energy	12%	na	na	na	na	6.94
2007	Arizona Pub. Service	15%	0.37	2.65	1.06	na	4.08
2007	Avista Utilities	30%	1.43	4.40	3.00	na	8.84
2007	Idaho Power	20%	na	na	na	na	7.92
2007	PacifiCorp-2007	18%	na	1.10	4.00	na	5.10
2008	Xcel-PSCo***	20%	na	na	na	na	8.56

* Regulation costs represent 3-year average.
** Highest over 3-year evaluation period.
*** This integration cost reflects a $10/MMBtu natural gas price scenario. This cost is much higher than the integration cost calculated for Xcel-PSCo in 2006, in large measure due to the higher natural gas price: had the gas price from the 2006 study been used in the 2008 study, the integration cost would drop to $5.13/MWh.

- Wind integration costs are < $10/MWh for capacity penetrations of up to ~30%
- Regulation impacts are small, load-following and unit commitment larger
- Larger balancing areas and use of wind forecasts ease integration challenges, and operators are increasingly relying on these strategies

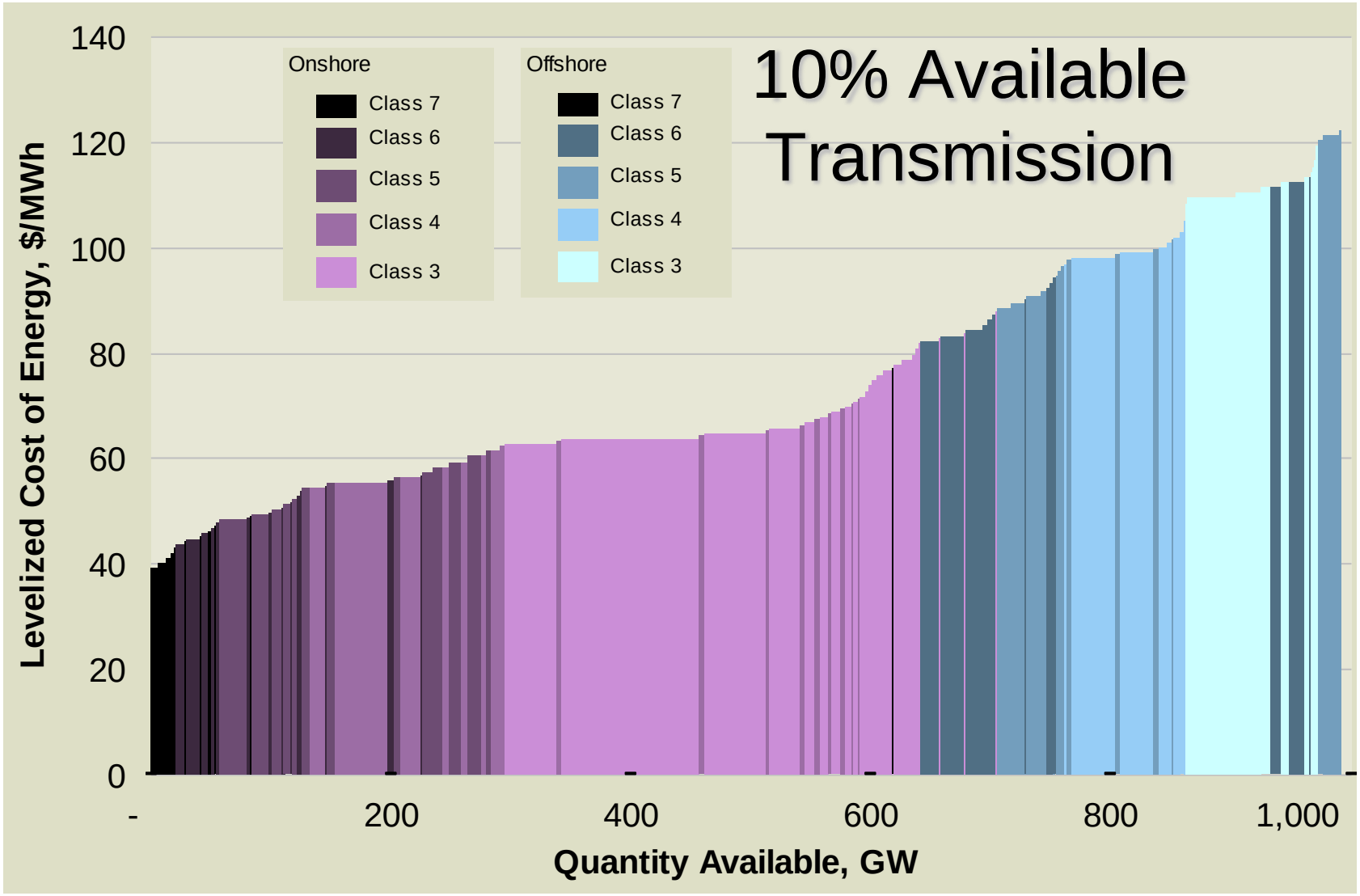
Transmission Constraints





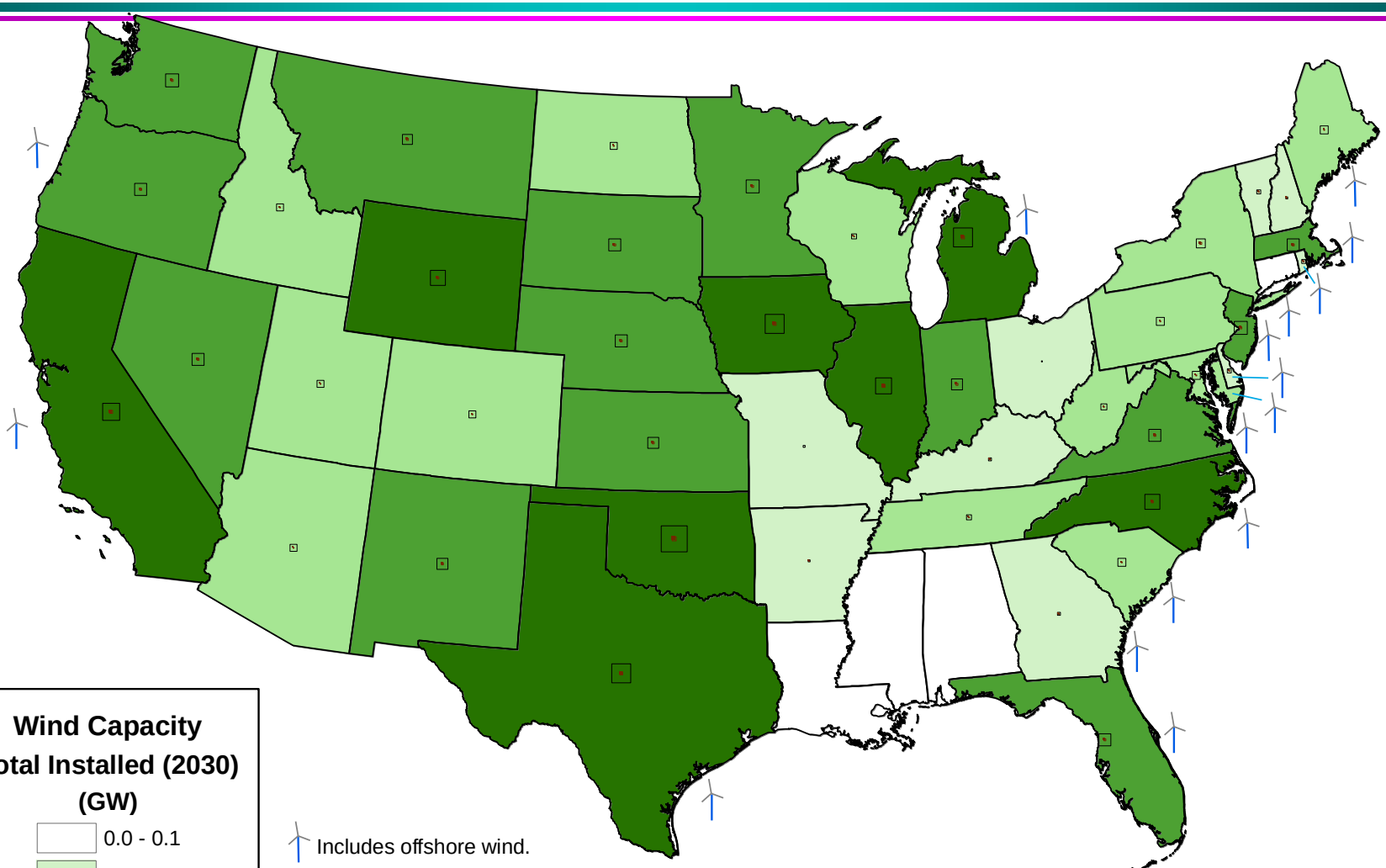
"The future ain't what it used to be."

—Yogi Berra

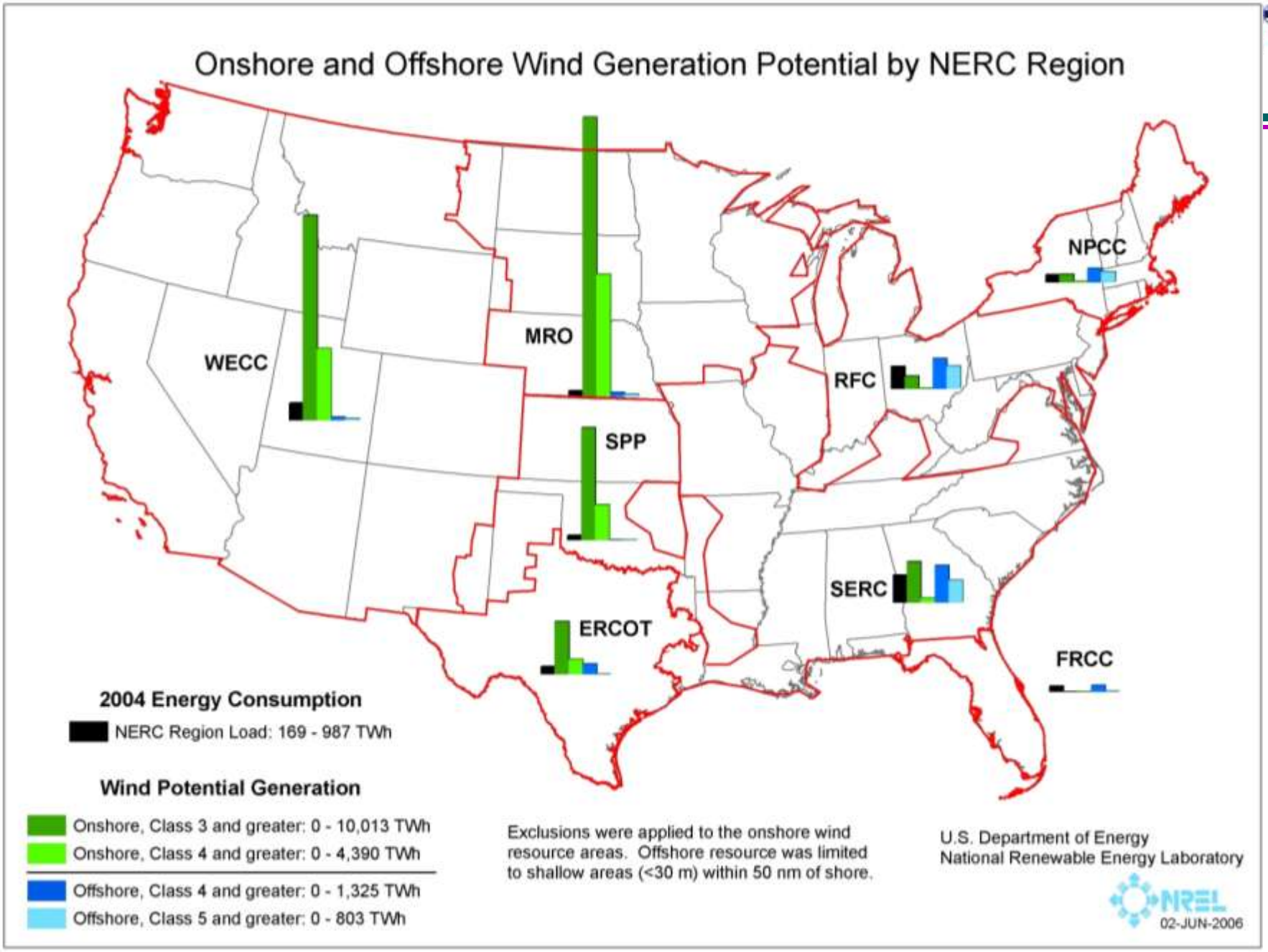


2010 costs w/ PTC, $1,600/MW-mile, w/o integration costs

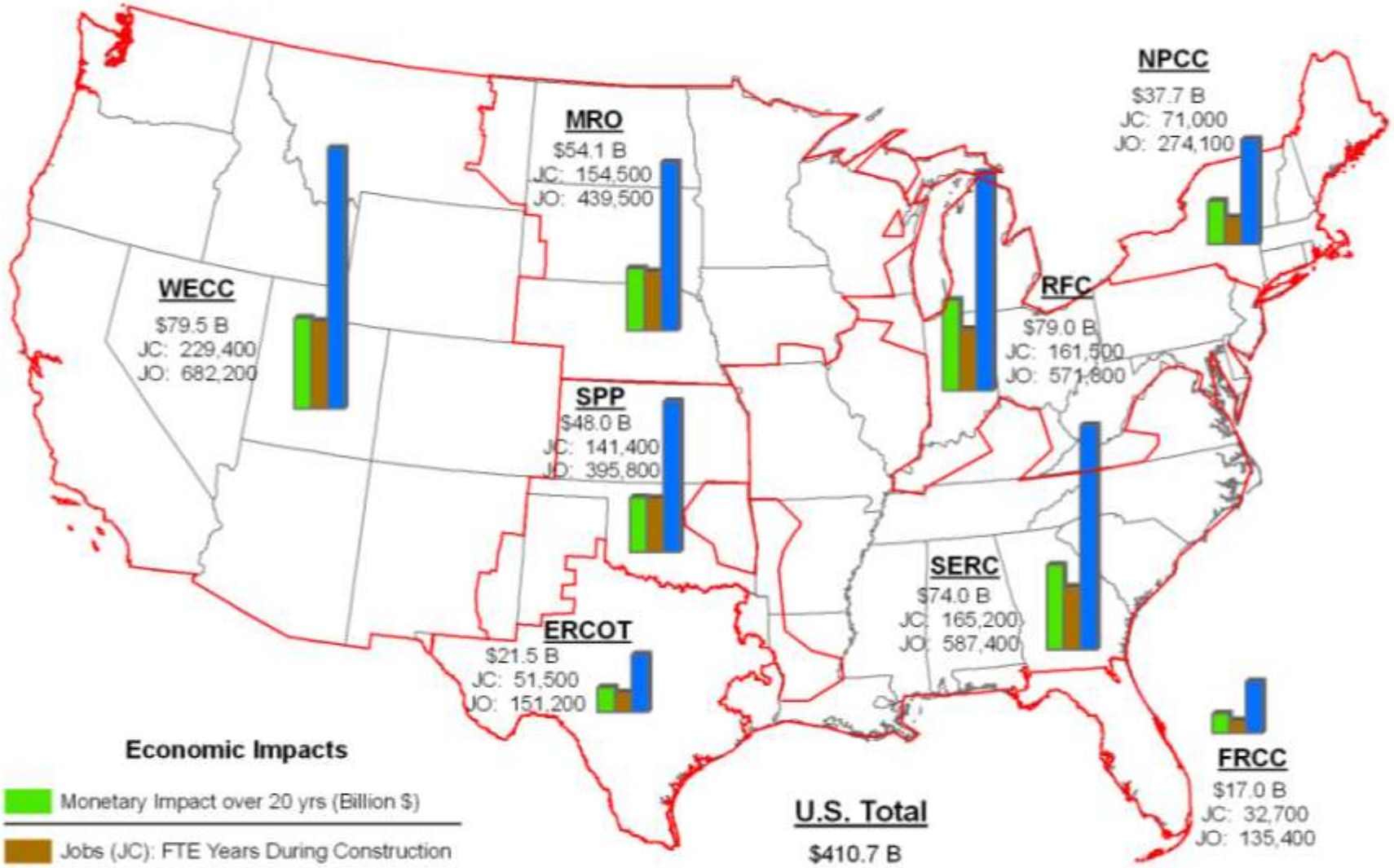
46 States Would Have Substantial Wind Development by 2030



The black open square in the center of a state represents the land area needed for a single wind farm to produce the projected installed capacity in that state. The brown square represents the actual land area that would be dedicated to the wind turbines (2% of the black open square).


Onshore and Offshore Wind Generation Potential by NERC Region
WECC
MRO
SPP
ERCOT
SERC
RFC
NPCC
FRCC
2004 Energy Consumption
NERC Region Load: 169 - 987 TWh
Wind Potential Generation
Onshore, Class 3 and greater: 0 - 10,013 TWh
Onshore, Class 4 and greater: 0 - 4,390 TWh
Offshore, Class 4 and greater: 0 - 1,325 TWh
Offshore, Class 5 and greater: 0 - 803 TWh
Exclusions were applied to the onshore wind resource areas. Offshore resource was limited to shallow areas (<30 m) within 50 nm of shore.
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
02-JUN-2006

20% Wind Electricity by 2030 - Economic Impacts by NERC Region



Economic Impacts

Monetary Impact over 20 yrs (Billion $)

Jobs (JC): FTE Years During Construction

Jobs (JO): FTE Years over 20 yrs Operation

Wind Vision case = 304 GW of wind capacity.
All job values rounded to the nearest 100.

U.S. Total

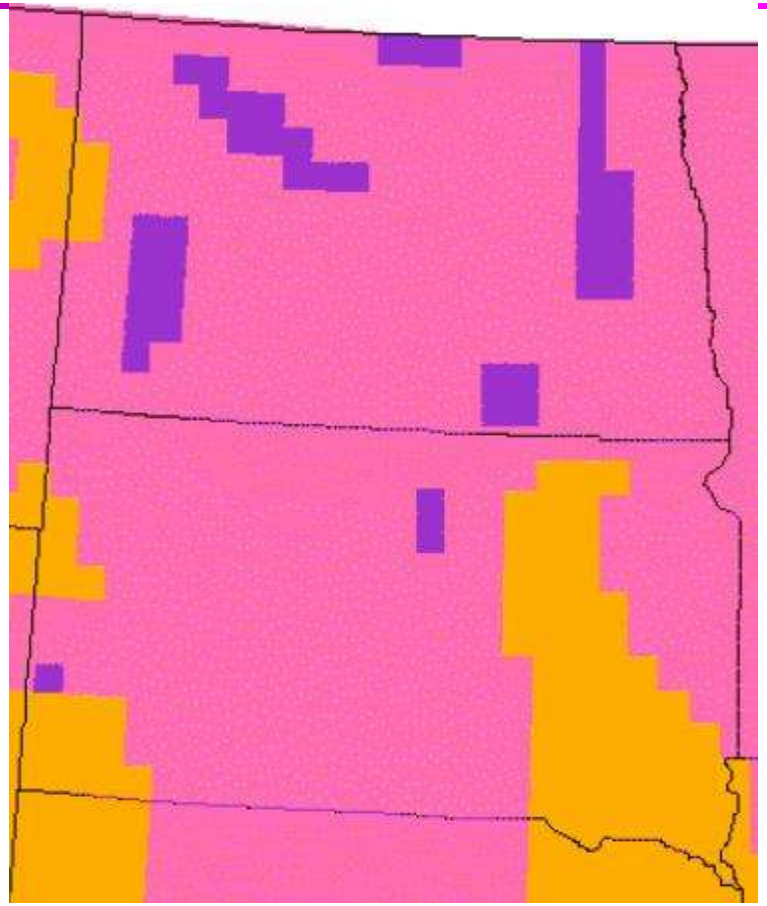
$410.7 B
JC: 1,007,200
JO: 3,237,400

U.S. Department of Energy
National Renewable Energy Laboratory

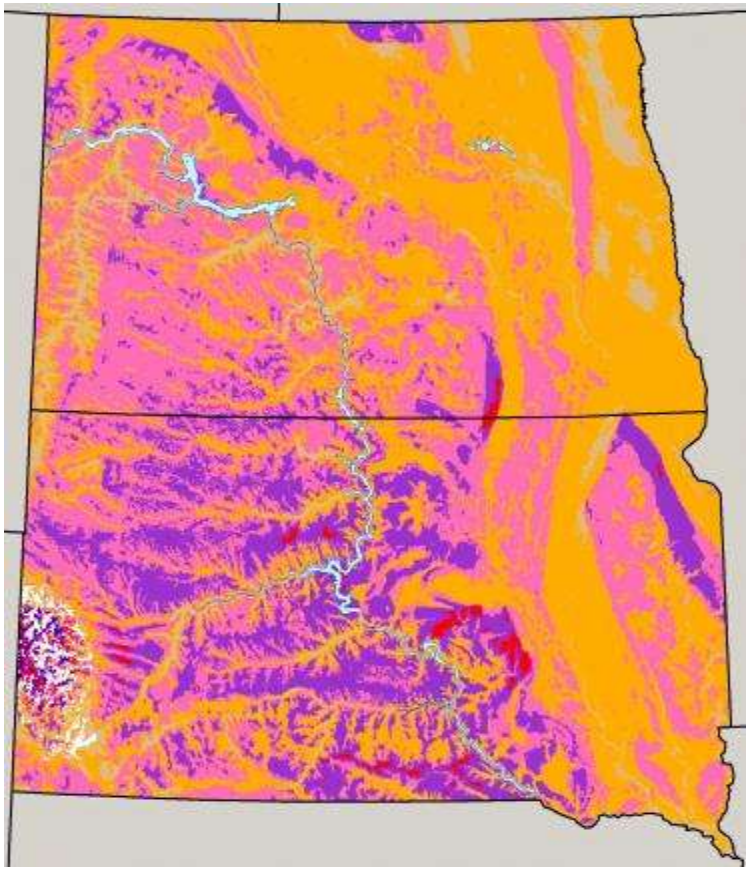
NREL

Wind_Vision_06-19-2007 - DRAFT

Comparison: Digital Wind Map from 1987 U.S. Wind Atlas and New (2000) High-Resolution (1-km^2) Wind Map



1987



2000

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed* at 50 m m/s	Wind Speed* 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

*Wind speeds are based on a Weibull k value of 2.0

Small Wind Market & Policy Universe

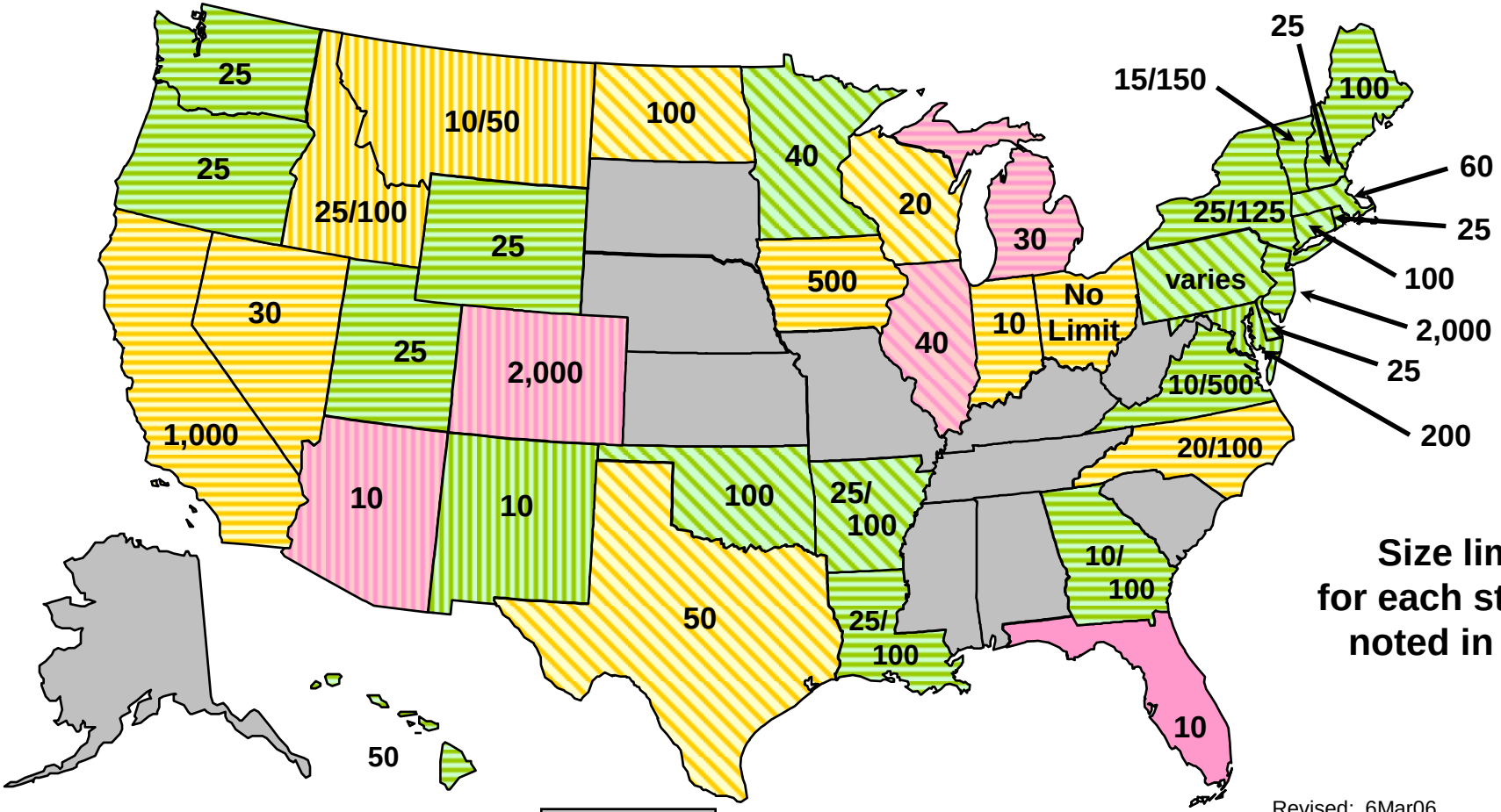
Small Wind Incentives

- Rebate/grant programs
- State tax credit
- Sales tax exemption
- Net metering,
- Reasonable interconnection requirements
- State zoning regulation or model ordinance
- Property tax exemption

Small wind incentives vary widely from state to state

Net Metering for Wind

22 states have net metering for all rural electric consumers



Size limits for each state noted in kW

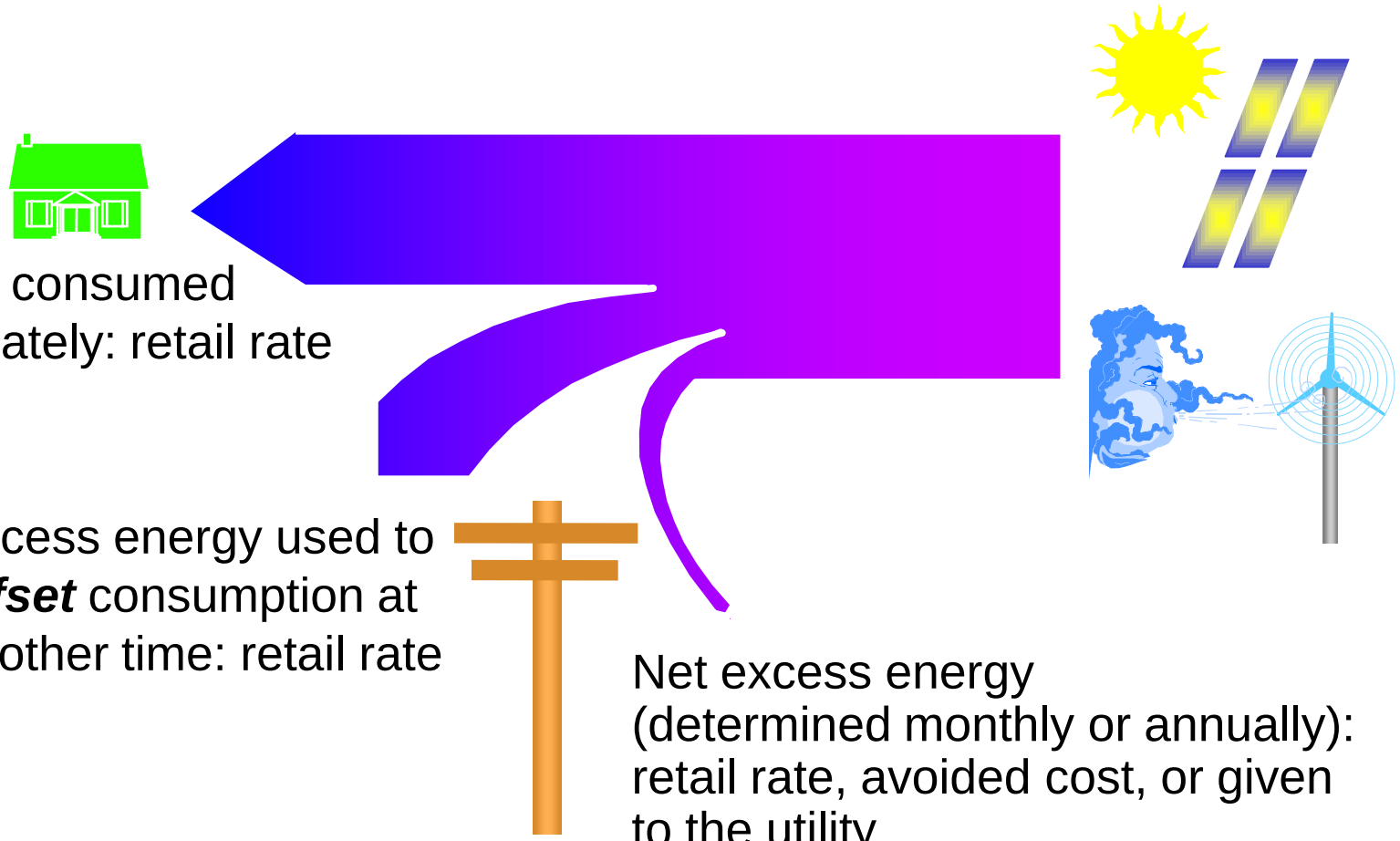
Revised: 6Mar06
Source: www.dsireusa.org

Settlement of Net Excess Energy:

- Monthly
- Annual
- Varies by utility

- None
- Individual Utilities
- Investor-Owned Utilities Only, Not Rural Cooperatives
- Investor-Owned Utilities and Rural Cooperatives

Net Metering of Renewable Energy



Energy consumed immediately: retail rate

Excess energy used to ***offset*** consumption at another time: retail rate

Net excess energy (determined monthly or annually): retail rate, avoided cost, or given to the utility

Project Development Process (You Are the Developer)

Project Development Process

Site Selection

Economic Modeling

Financing

Land Agreements

Interconnection Studies

Turbine Procurement

Wind Assessment

Permitting

Construction Contracting

Environmental Review

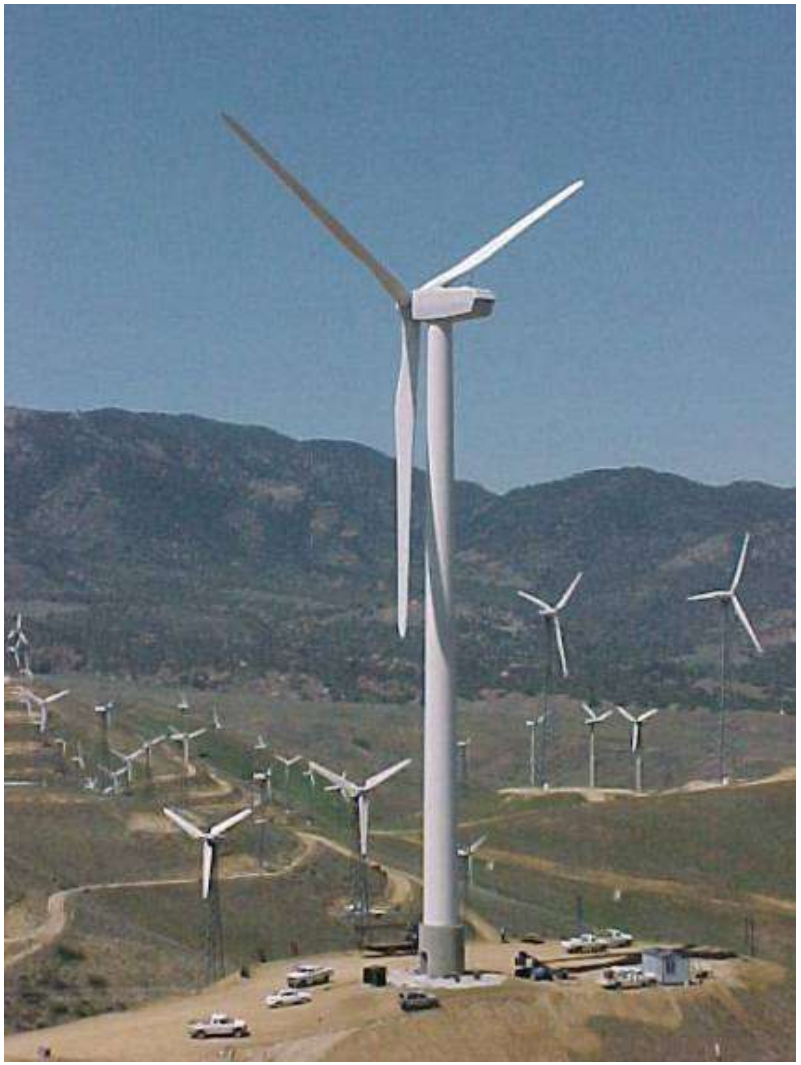
Sales Agreements

Operation & Maintenance

Source: DISGEN

Characteristics of a Good Wind Site

- Good wind resource
- Adequate transmission
- Reasonable road access
- Permitting
- Receptive community
- Few environmental concerns



Resources: On the Web

- AWEA Web site: http://www.awea.org
- NWTC Web site: http://www.nrel.gov/wind
- National Wind Coordinating Committee: http://www.nationalwind.org
- Utility Wind Interest Group site: http://www.uwig.org
- WPA Web site:
  http://www.windpoweringamerica.gov/
- Homepower Web Site: http://www.homepower.com
- Windustry Project: http://www.windustry.com
- Best Links: www.me3.org

Carpe Ventem

www.windpoweringamerica.gov

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