National Renewable Energy Laboratory
Innovation for Our Energy Future

Wind Energy

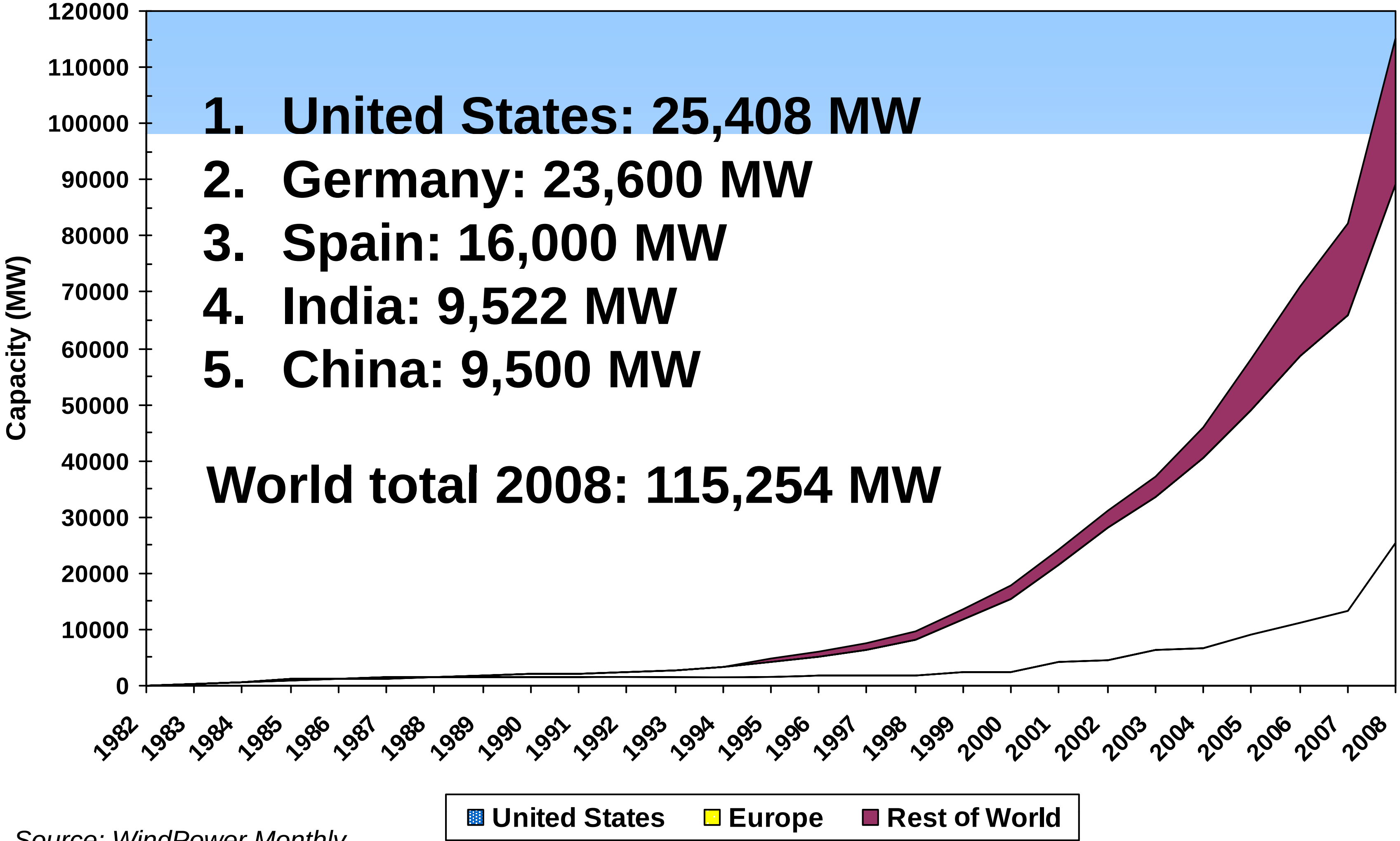
FUPWG Meeting
Robi Robichaud
November 18, 2009

Topics

- Introduction
- Review of the Current Wind Market
- Drivers for Wind Development
- Siting Issues
- Wind Resource Assessment
- Wind Characteristics
- Wind Power Potential
- Basic Wind Turbine Theory
- Types of Wind Turbines
- Facts About Wind Siting
- Wind Performance

Current Status of the Wind Industry

Total Global Installed Wind Capacity



1. **United States: 25,408 MW**
2. **Germany: 23,600 MW**
3. **Spain: 16,000 MW**
4. **India: 9,522 MW**
5. **China: 9,500 MW**

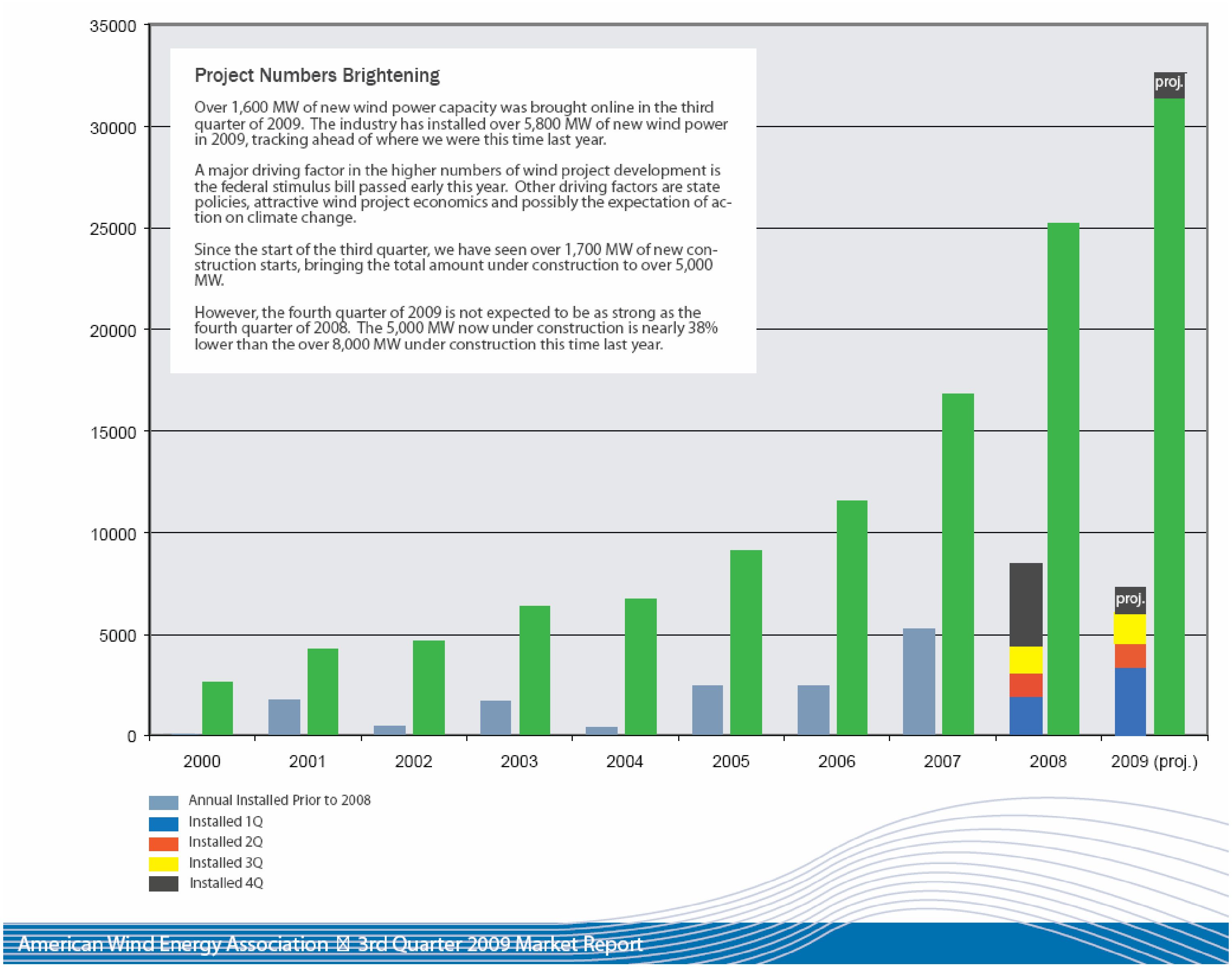
World total 2008: 115,254 MW

Source: WindPower Monthly

Five Years of Strong Growth

2008: 8,558 MW Added; $16 billion Investment

2009: Over 5,800 MW thru 3 quarters; 5,000 MW under construction



U.S. Wind Status

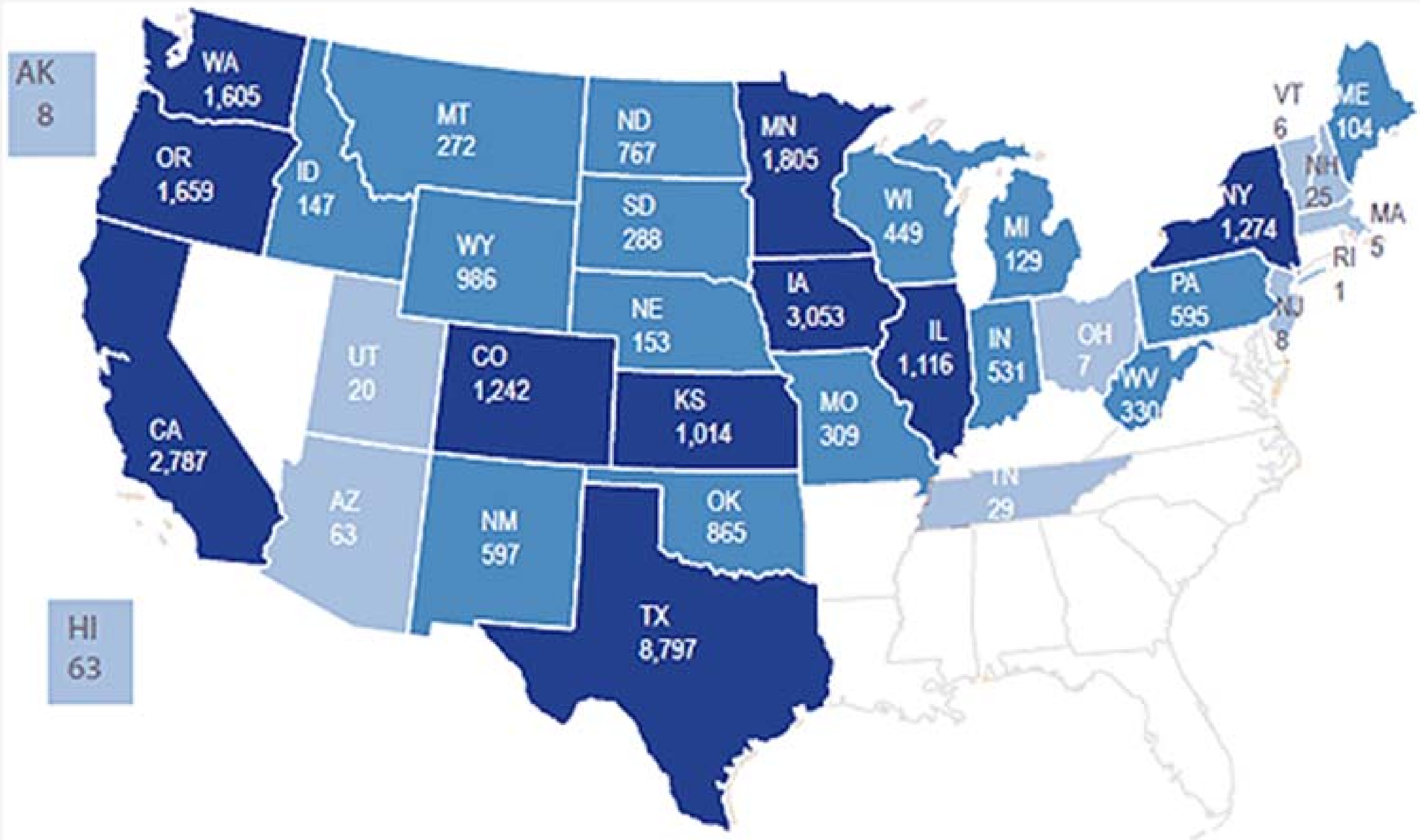
The total U.S. wind power capacity > 31,000 MW

- Electricity to power the equivalent of ~ 9 million homes
- Avoiding the emissions of 57 million tons of carbon/yr
- Reducing electricity sector carbon emissions by 2.5%

The top five states for new capacity added in 3rd quarter are:

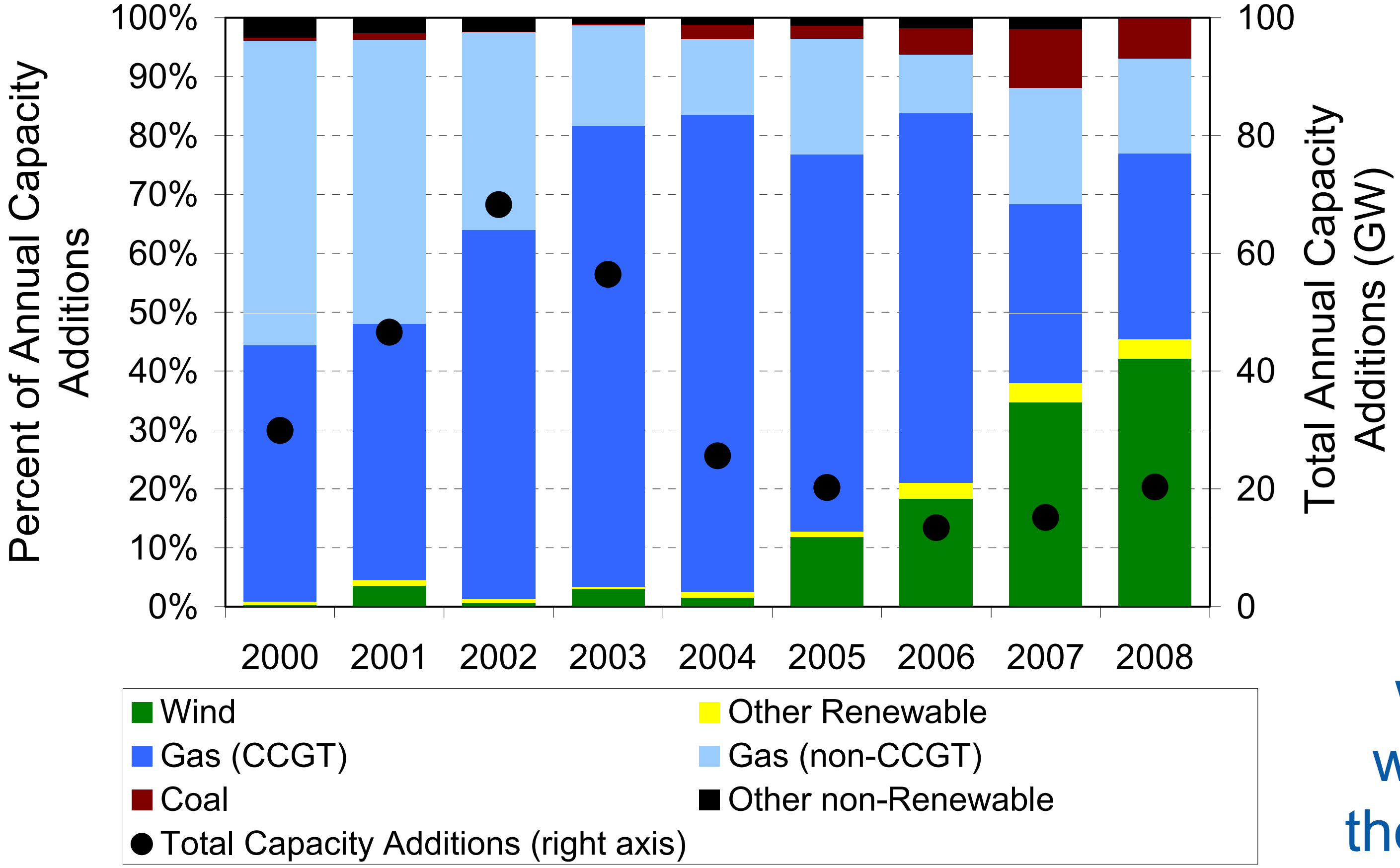
* Texas - 436 MW
* Oregon - 251 MW
* Illinois - 201 MW
* Colorado - 174 MW
* Wyoming - 170 MW

Installed Capacity by State (in MW)



Installed wind power capacity in the United States in Q3 2009. (Image: AWEA)

Major Source of New Generation Capacity Additions



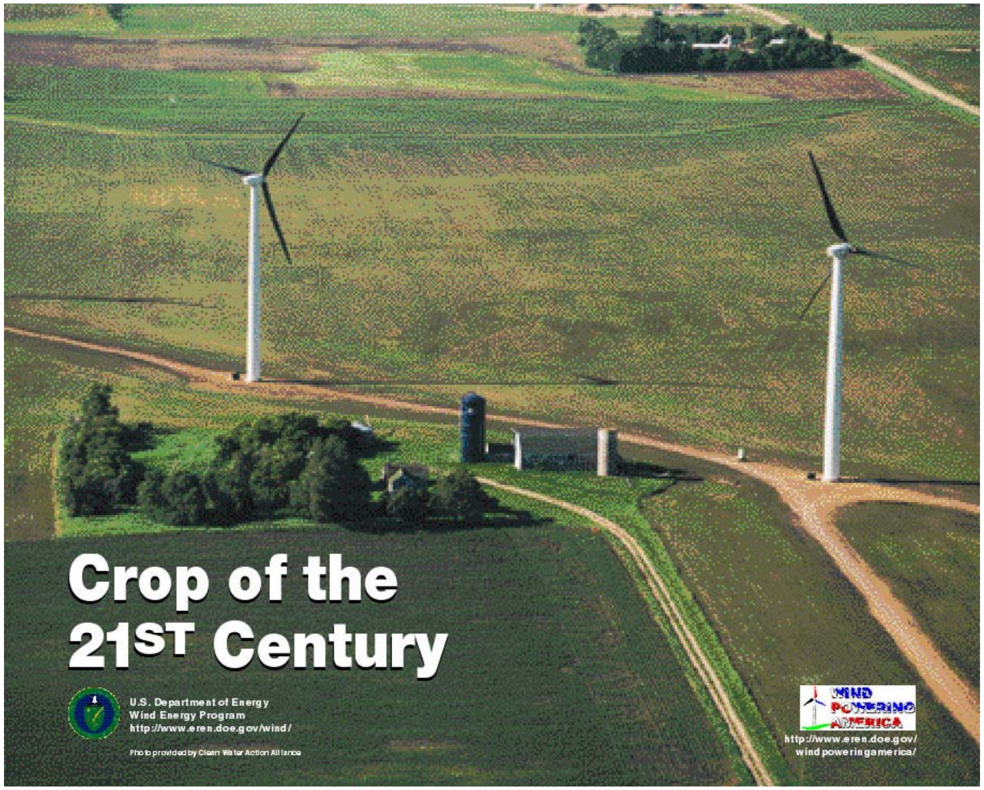
Source: EIA, Ventyx, AWEA, IREC, Berkeley Lab

2008: 42%
2007: 35%
2006: 18%
2005: 12%
2000-04: <5%

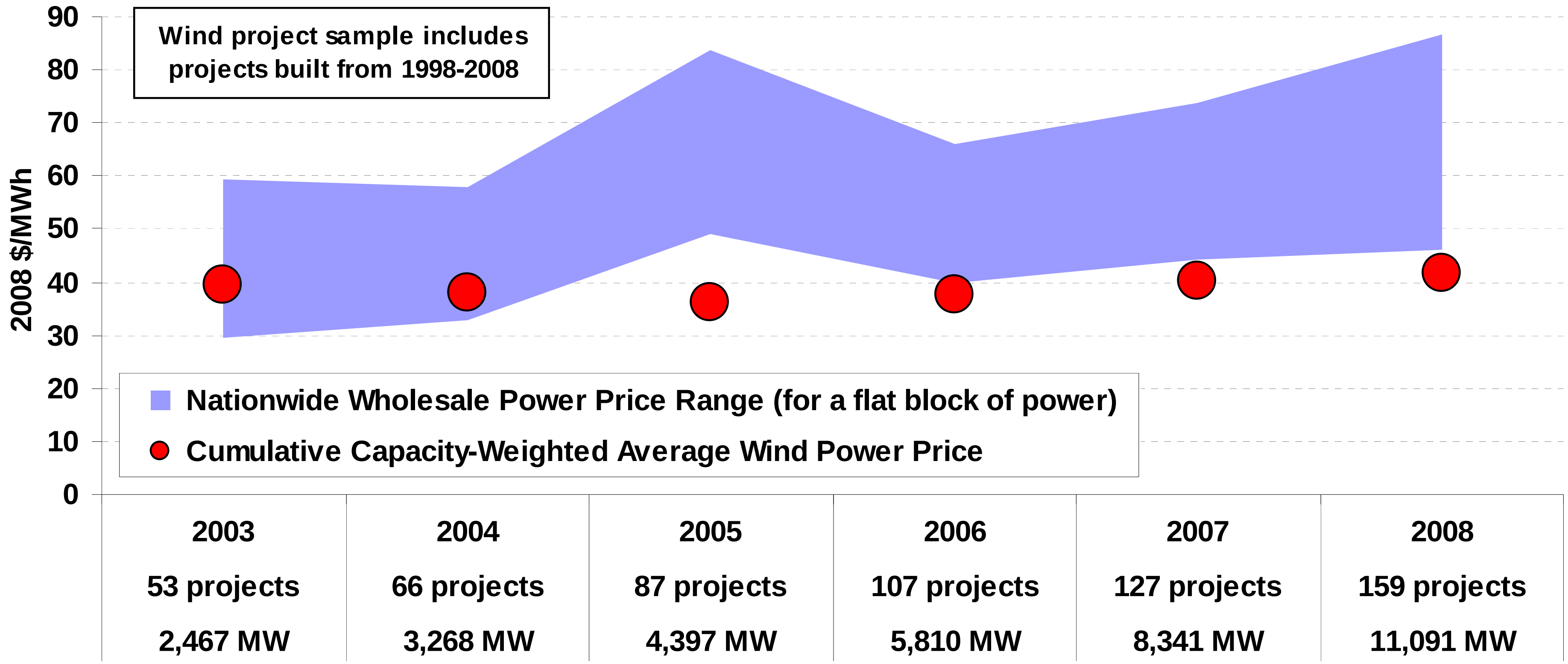
In 2008 more wind capacity was installed in the U.S. than any other generation technology

Drivers for Wind Power

- Declining Wind Costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Public Support
- Green Power
- Energy Security
- Carbon Risk



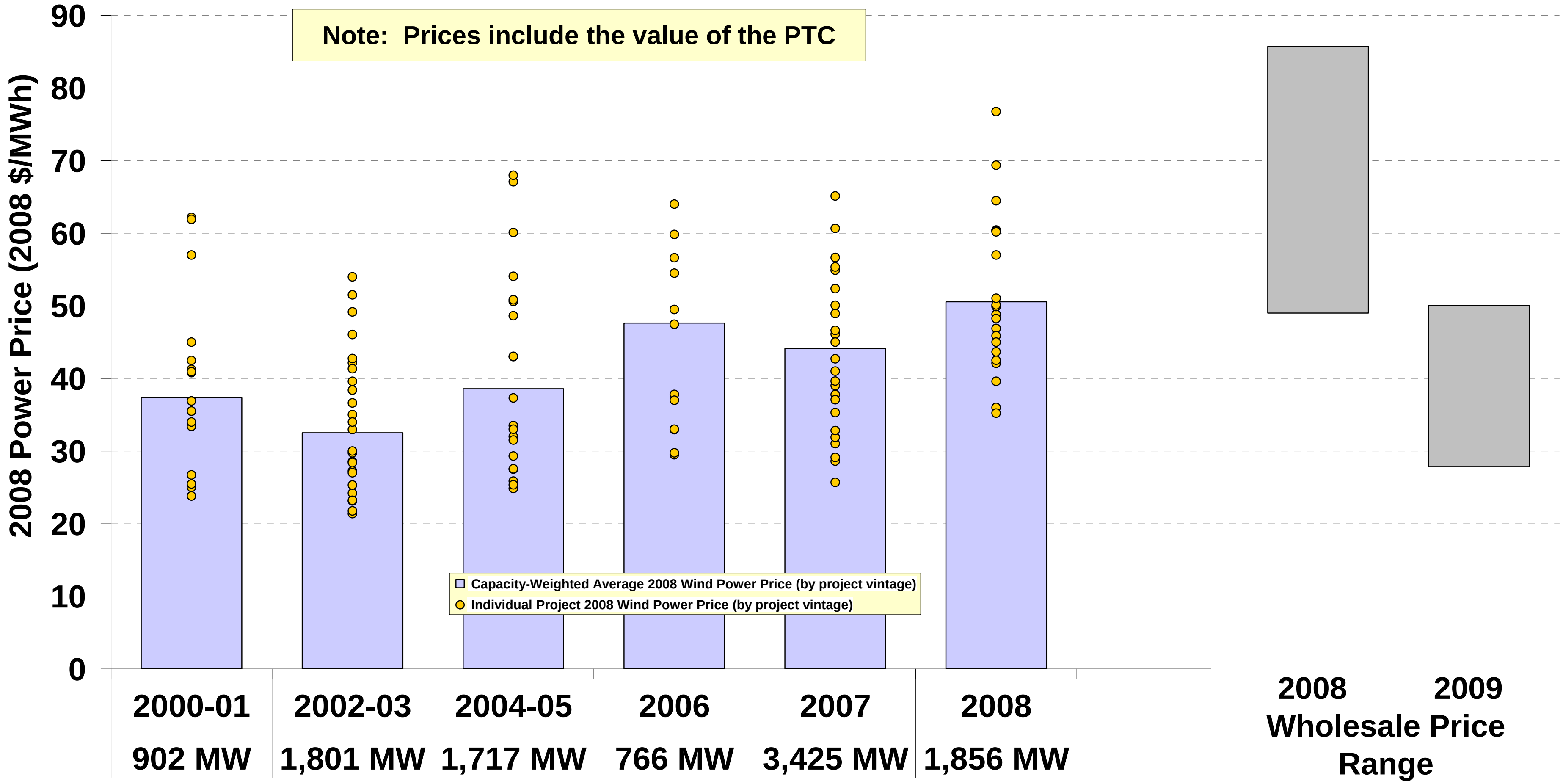
Wind Has Been Competitive with Wholesale Power Prices in Recent Years



Source: FERC 2006 and 2004 "State of the Market" reports, Berkeley Lab database, Ventyx, ICE

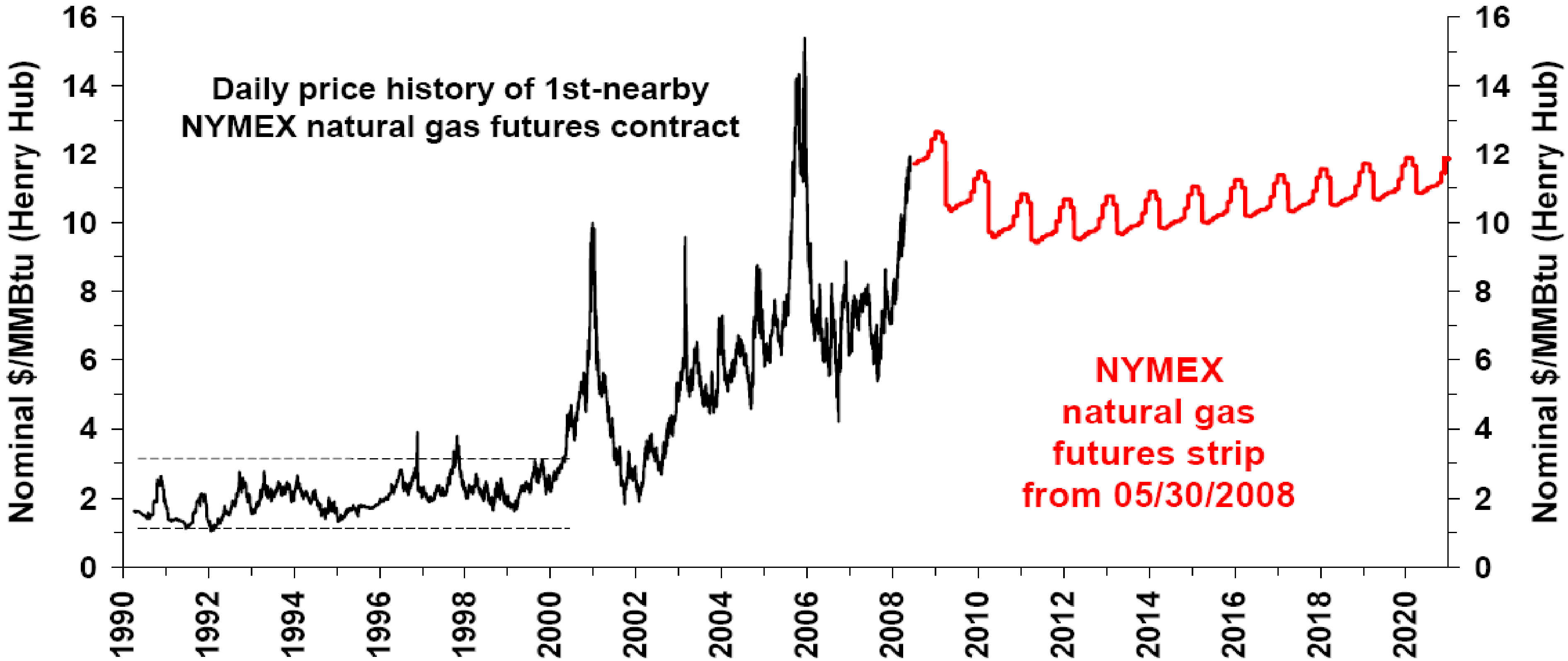
Note: Wholesale price range reflects flat block of power across 23 pricing locations; wind costs represent capacity-weighted average price for wind power for entire sample of projects built from 1998-2008

The Near-Term Wind has Become Somewhat Less Attractive



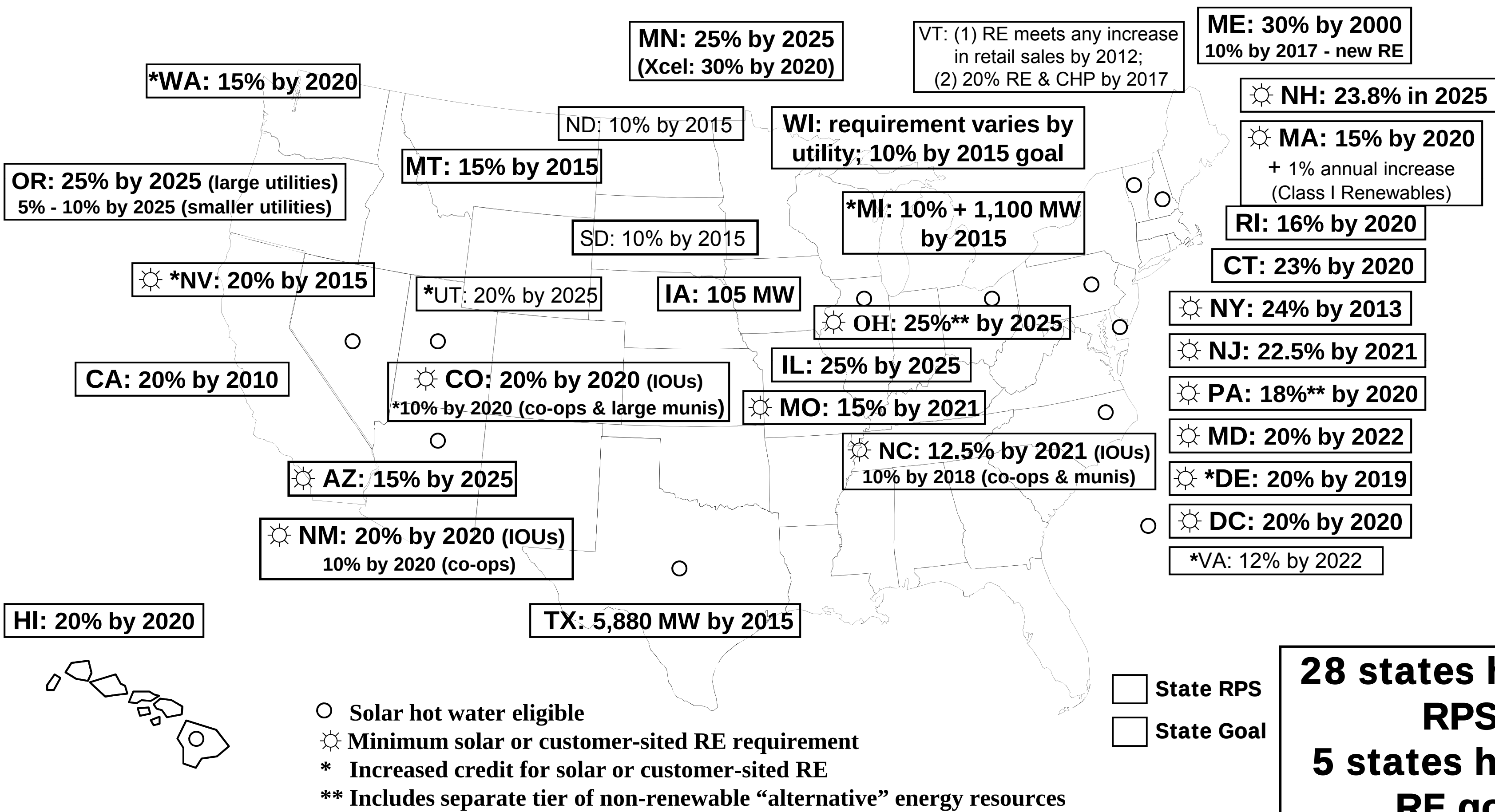
- Wind prices are likely to increase further in 2009 as installed costs will remain high as developers work through turbines ordered at peak prices, and given higher equity yields.
- Wholesale price’s are also likely to increase as the economic depression reverses course

Natural Gas Price Variability



Source: LBNL

Renewables Portfolio Standards



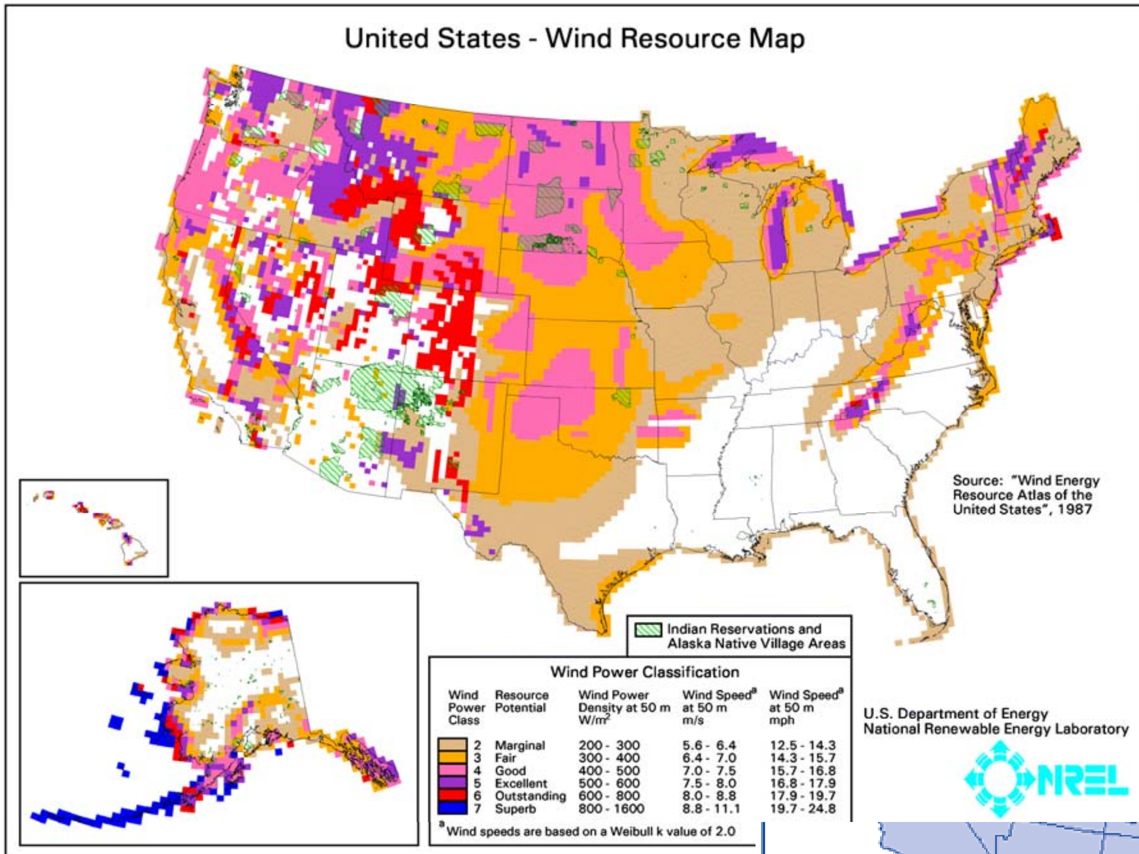
28 states have an RPS;
5 states have an RE goal

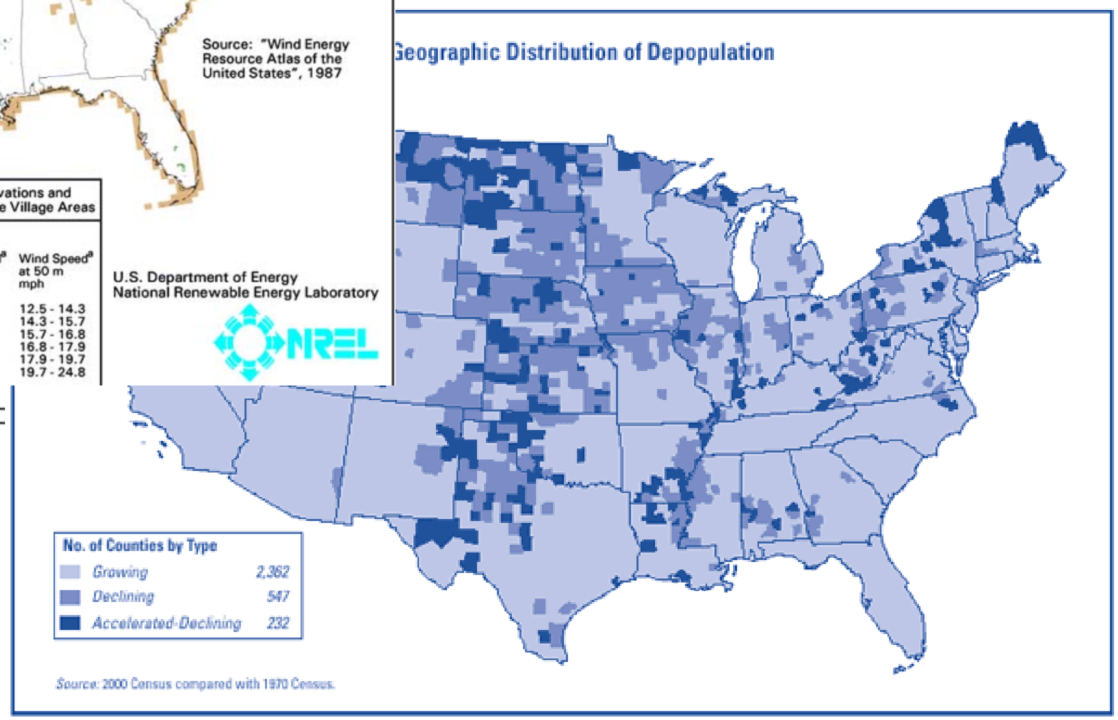
DSIRE: www.dsireusa.org
January 2009

Federal Goals:

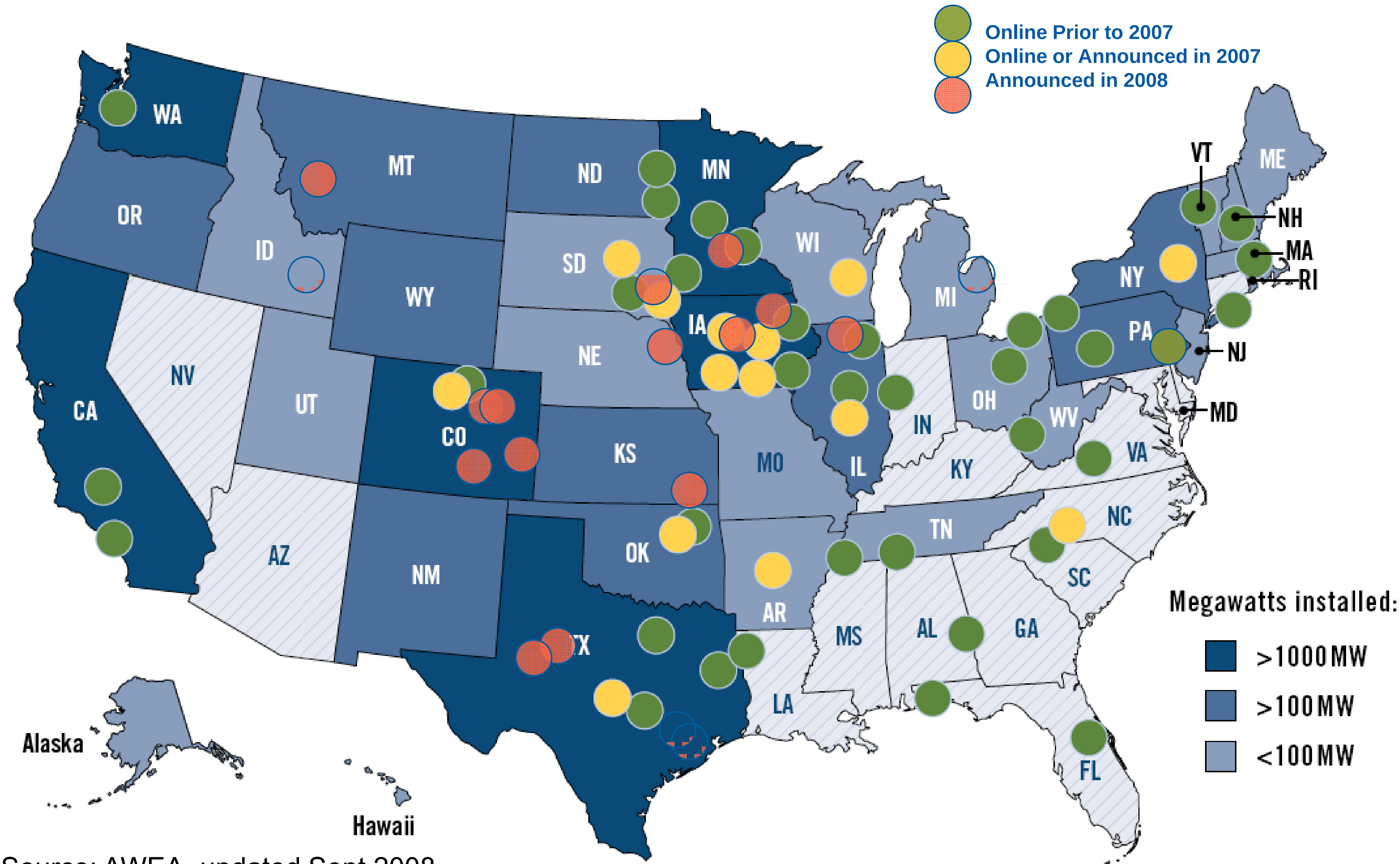
- EPAct 2005: 3% by FY09; 5% by FY12 and 7.5% by FY13
- Executive Order 13423: At least 50% new RE, on-site if possible

Windy Rural Areas Need Economic Development



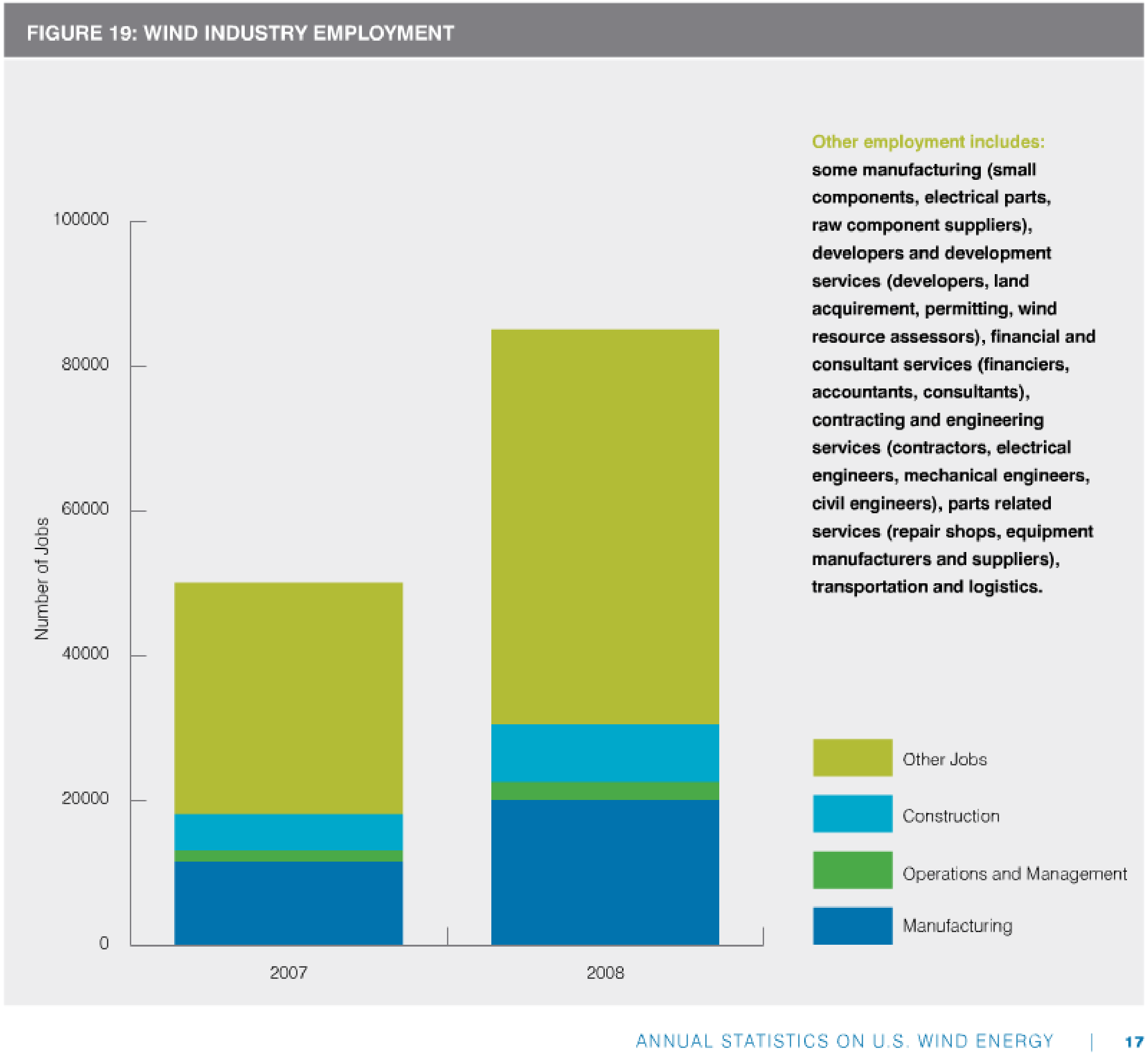


Soaring Demand Spurs Expansion of U.S. Wind Turbine Manufacturing



Source: AWEA, updated Sept 2008

Wind Industry Added 35,000 Jobs in 2008



Colorado – Economic Impacts

from 1000 MW of new wind development

Wind energy's economic "ripple effect"

Direct Impacts

Payments to Landowners:
- $2.5 Million/yr

Local Property Tax Revenue:
- $4.6 Million/yr

Construction Phase:
- 912 new jobs
- $133.6 M to local economies

Operational Phase:
- 181 new long-term jobs
- $19.3 M/yr to local economies

Indirect & Induced Impacts

Construction Phase:
- 807 new jobs
- $92.7 M to local economies

Operational Phase:
- 129 local jobs
- $15.6 M/yr to local economies

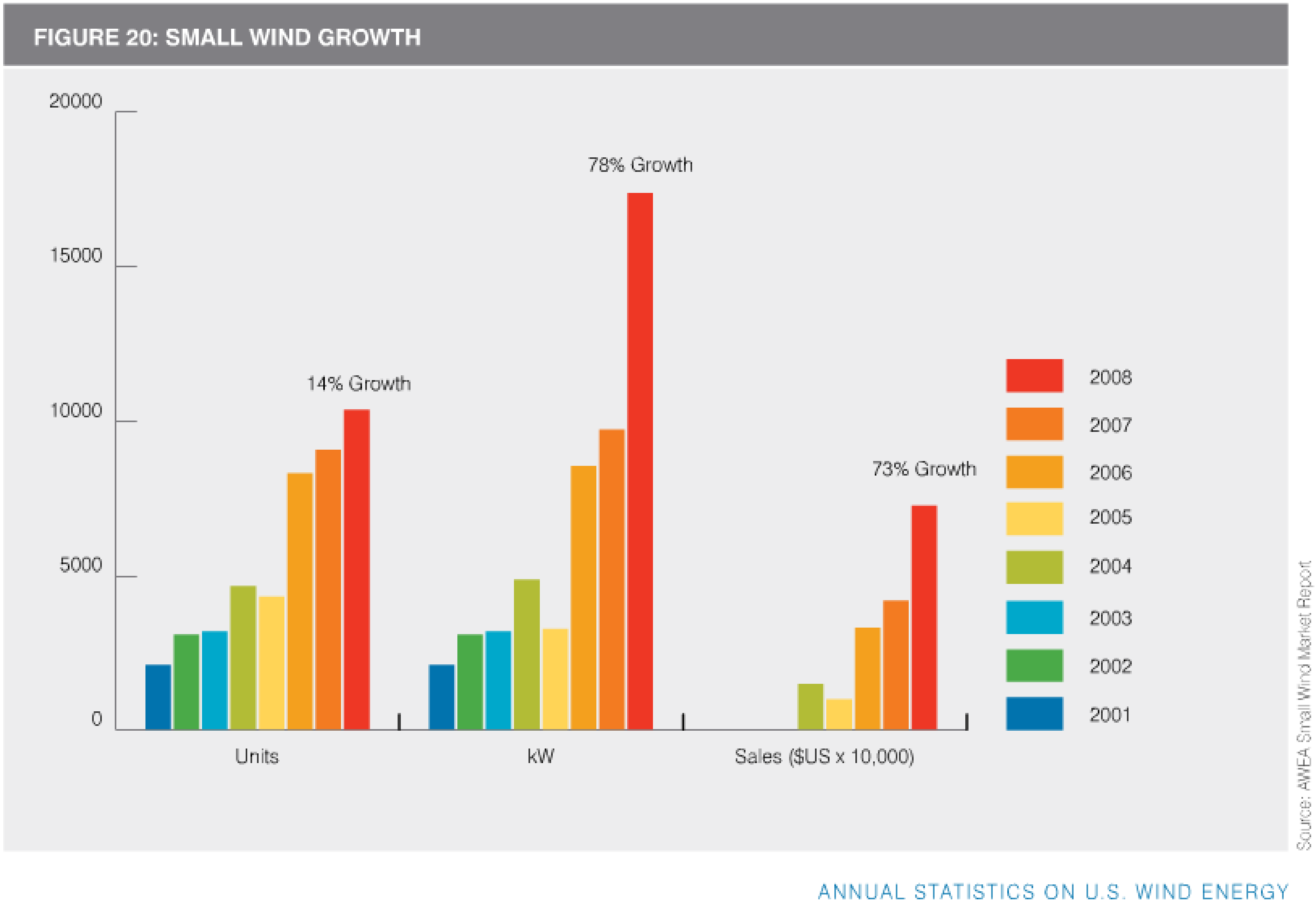
Totals
(construction + 20yrs)

Total economic benefit = $924.3 million
New local jobs during construction = 1,719
New local long-term jobs = 310

All jobs rounded to the nearest 50 jobs; All values greater than $10 million are rounded to the nearest million

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

Small Wind Benefits from Favorable Wind Policy



Environmental Benefits

No SOx or NOx

No particulates

No mercury

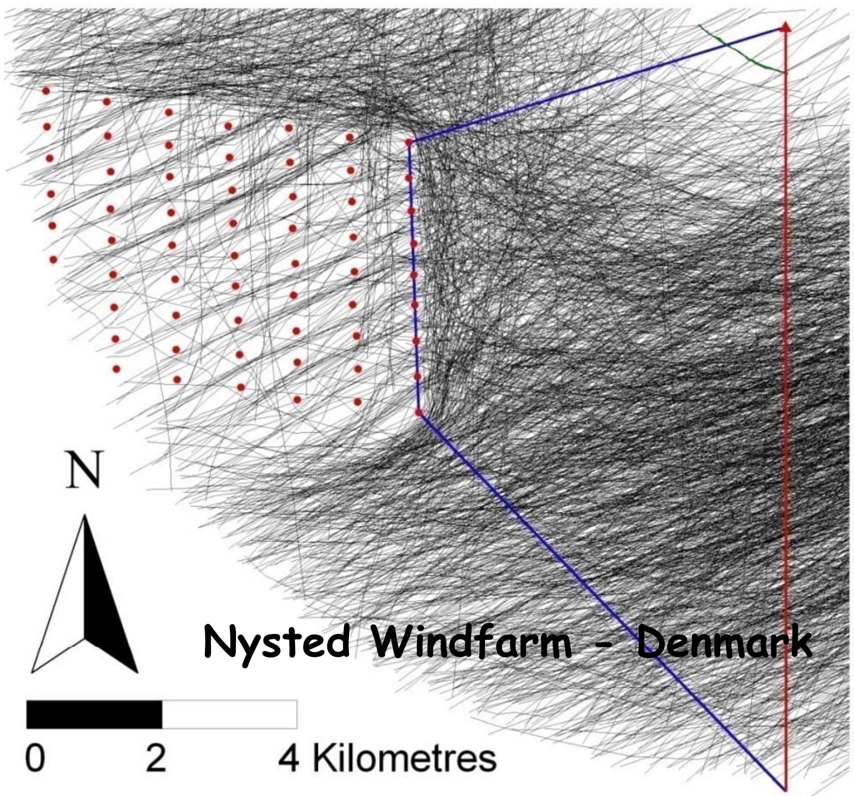
No CO2

No water

Siting Issues

Visual Impact &
Land Ownership

Noise



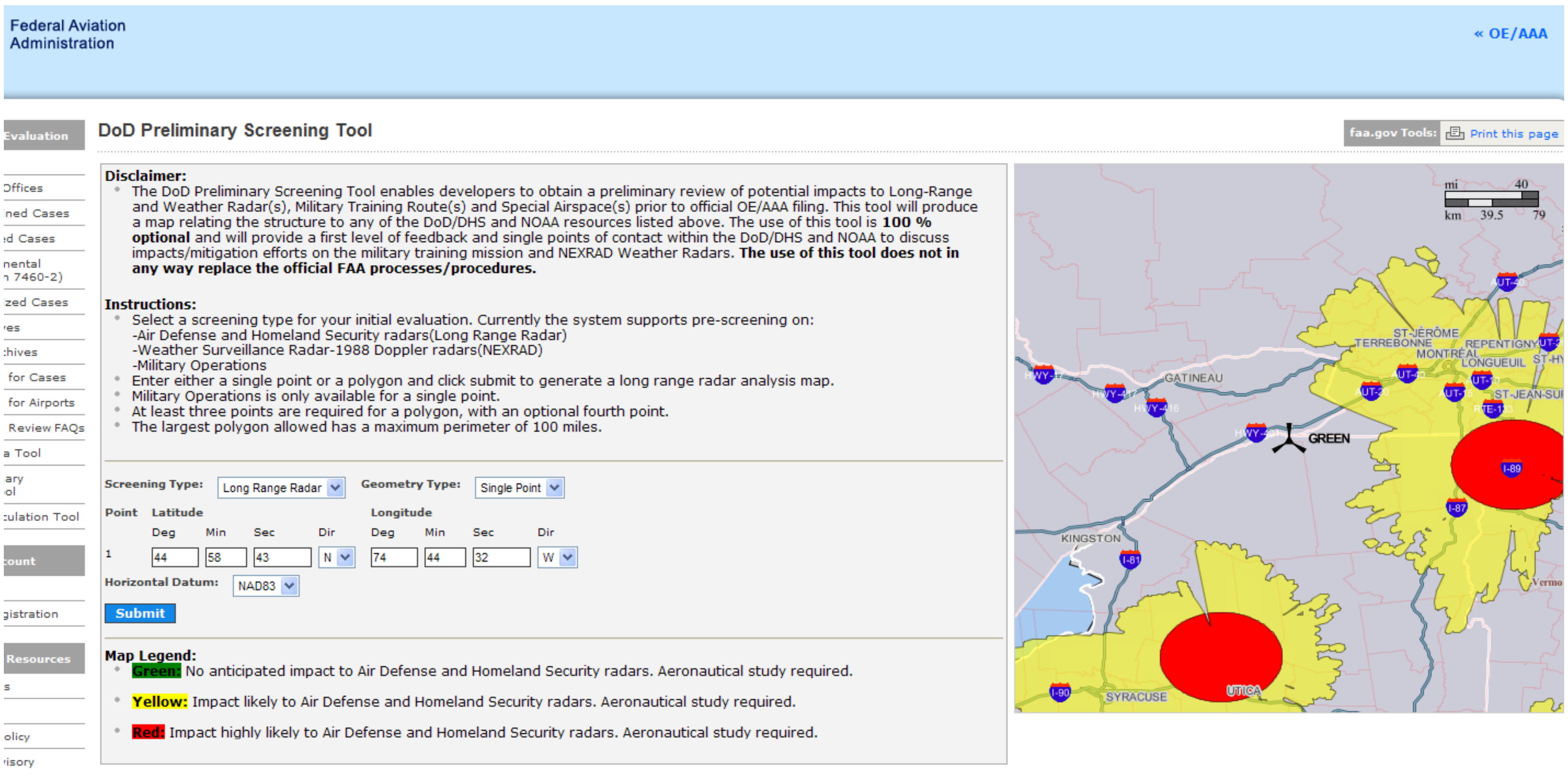
Avian and other wildlife:

- Over 200 projects, Three problem sites.
- Biggest avian problem was in the Altamont Pass.
- Managed by careful site selection.

Wind and Radar Issues - FAA

EERE – Wind and Hydropower Program has Wind Siting Tool web page:

http://www1.eere.energy.gov/windandhydro/federalwindsiting/wind_siting_tools.html



https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showLongRangeRadarToolForm

Wind and Radar Issues - NEXRAD

Federal Aviation Administration

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DoD Preliminary Screening Tool

faa.gov Tools: Print this page

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar(s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

Instructions:

- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
  -Military Operations
- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: NEXRAD   Geometry Type: Single Point

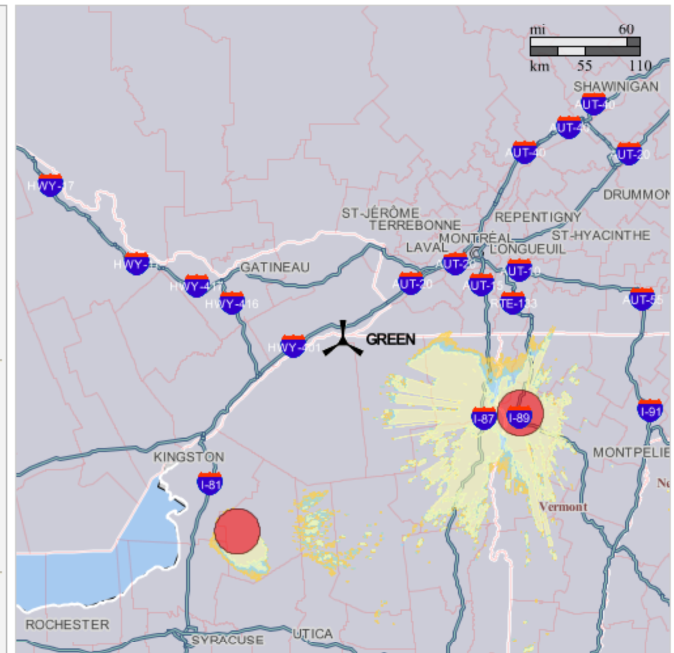
Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	44	58	43	N	74	44	32	W

Horizontal Datum: NAD83

Submit

Map Legend:

- **Green:** Minimal to no impact to Weather Surveillance Radar-1988 Doppler (WSR-88D) weather radar operations. National Telecommunications & Information Administration (NTIA) notification advised.
- **Yellow:** RLOS Coverage At or Below 130m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Blue:** RLOS Coverage At or Below 160m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Gold:** RLOS Coverage At or Below 200m AGL. Impact likely to WSR-88D weather radar operations. Turbines likely in radar line of sight. Impact study required. NTIA notification advised.
- **Red:** Impact highly likely to WSR-88D weather radar operations and wind turbine electronics. Turbines likely in radar line of sight. Aeronautical study required. NTIA notification strongly advised.



For more information, or to discuss the screening results, please contact NOAA at wind.energy.matters@noaa.gov

Wind and Radar Issues - DoD

Federal Aviation Administration

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DoD Preliminary Screening Tool

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Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
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Horizontal Datum: NAD83

Submit

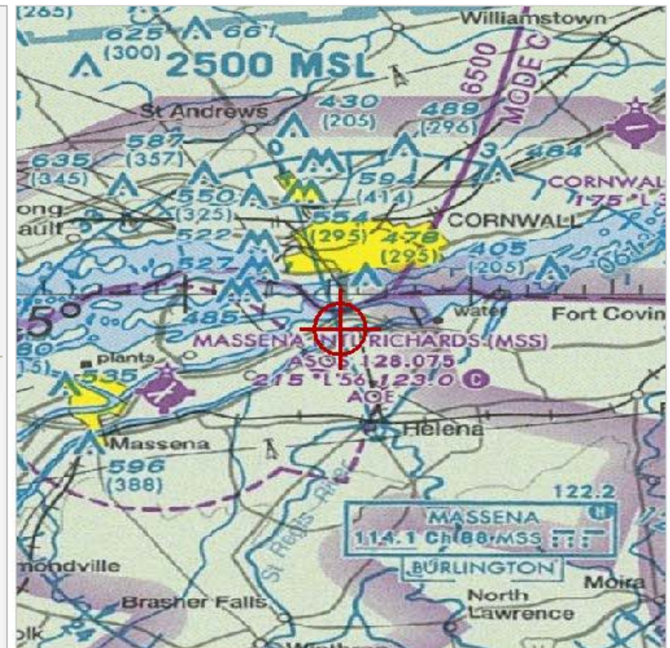
The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact David Brentzel at the USAF Regional Enviromental Coordinator at (404)562-4211 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact Anthony M. Parisi, PE at the USN Regional Enviromental Coordinator at (805)989-9209 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact LTC Jeff Mowery at the USA Regional Enviromental Coordinator at (404)305-6915 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact Mr. Paul Friday at the USMC Regional Enviromental Coordinator at (910)322-2128/449-9791 for confirmation and documentation.

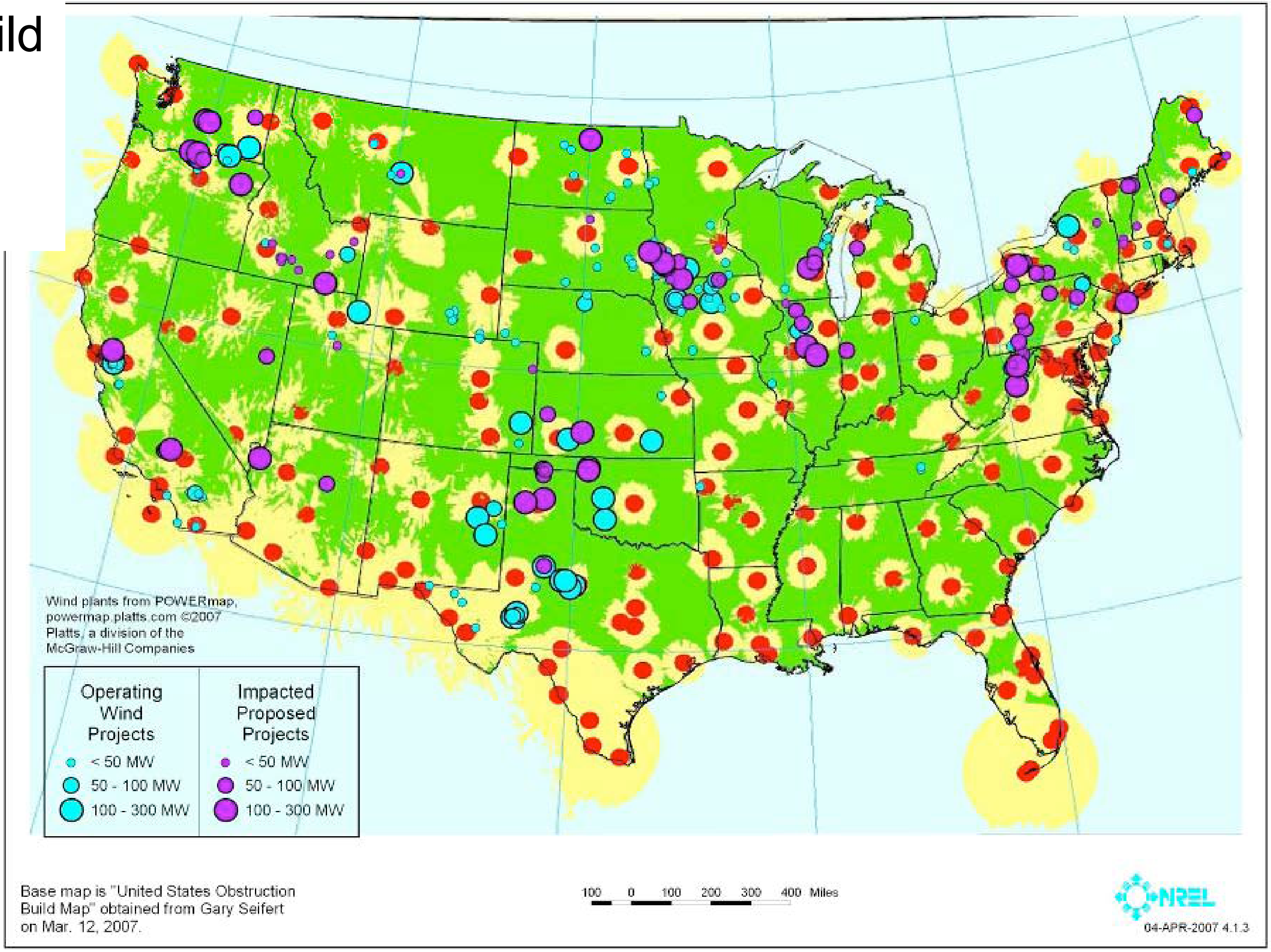
This is a preliminary review of your proposal and does not preclude official FAA processes.
Your search data is not retained and the privacy of all your searches is assured.



Any questions interpreting the map, please email Steve Sample with your question/s and phone number at steven.sample@pentagon.af.mil

FAA Radar and Proposed Wind Development

- ➢Red – no build
- ➢Yellow – modified build



Radar Interference

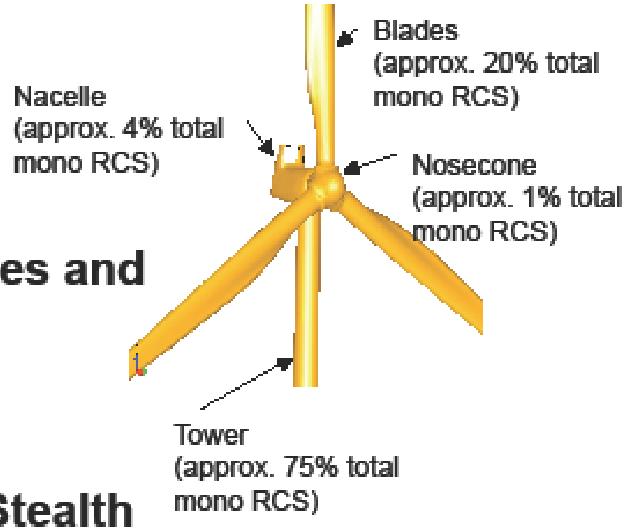
- **Wind Towers, Nacelles, and Blades all Reflect Radar Energy**
- **The Rotation of Wind Turbine Blades causes Doppler Reflections**
- **Wind Towers have a RCA greater than a 747, but so does a large high voltage tower**

ENERGY TRANSMITTED BY THE RADAR IS REFLECTED OFF OF THE BLADES GENERATOR AND TOWER AND RETURNED TO THE RADAR AS INTERFERENCE

Radar Mitigation

<u>Key issues currently being addressed</u>

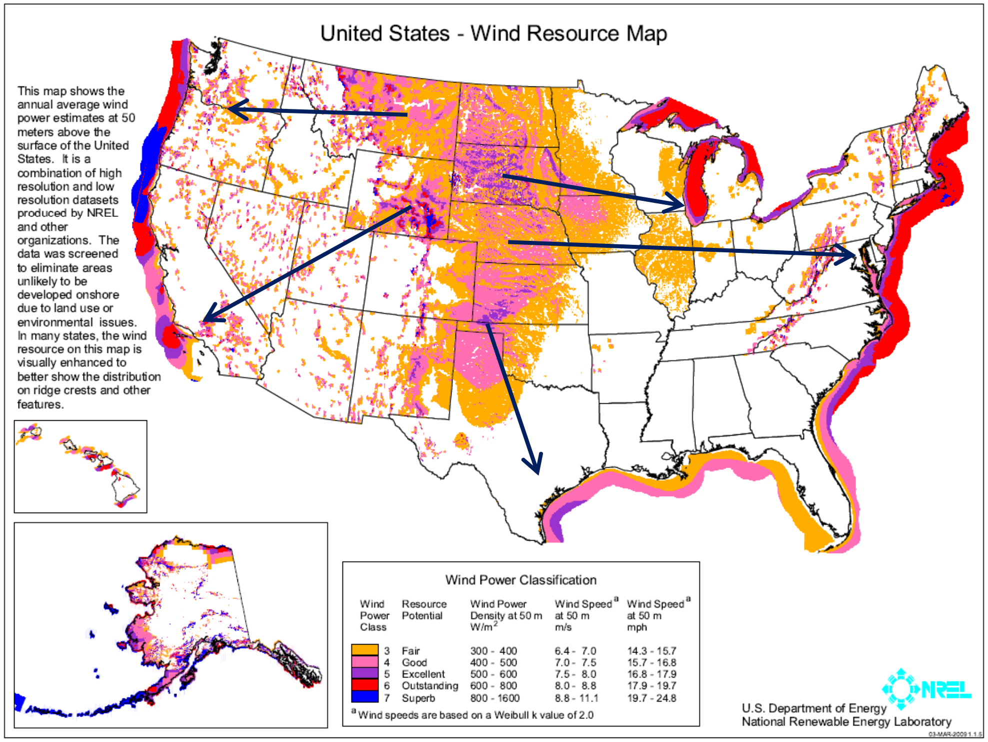
- **Develop Wind-Radar Checklist**
- **Expand Mitigation Toolbox**
- **Provide Outreach**
  - **Integrate screening tools**
  - **Educate developers on processes and risks**
- **Plan FY-08 Case Studies and R&D Elements**
- **Coordinate with Manufacturers of Stealth Turbines**
- **Support Field Tests (Mitigation and Stealth Technologies)**

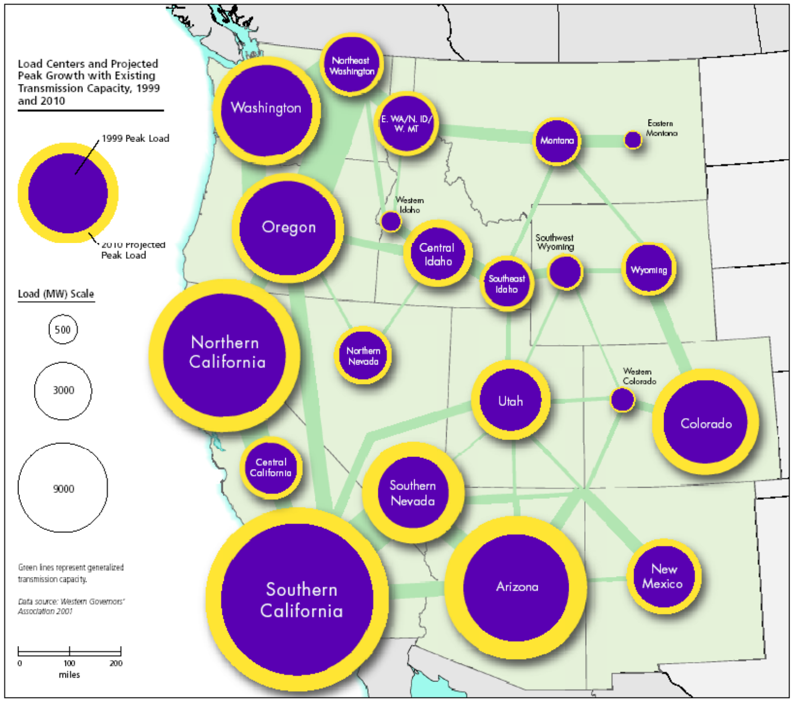


Idaho National Laboratory

Transmission

- Limitations
- Grid Access
- System studies
- Allocation of available capacity
- Scheduling and costs for usage





DOE work is underway to develop large scale transmission to take energy from the high resource areas to the high load areas. BPA, WAPA and OE working to facilitate planning and development activities.

Additional Considerations

Policy

- Encourage economic development and use of local resources
- Facilitate “green” markets
- Federal, state and local incentives such as the:
- Production Tax Credit (PTC) - extended to 2012
- 30% Investment Tax Credit (ITC) or cash grant in lieu of the PTC,
- Renewable Portfolio Standards (RPS)

Remote Systems

- Amount of energy from wind
- Control of system voltage and frequency
- Use of excess wind energy

External Conditions

- Lightning
- Extreme Winds
- Corrosion
- Extreme temperatures

Intermittency

- Operational Impacts - ancillary services including voltage/VAR control, load following, etc.
- 10-20% of system capacity is reasonable; some countries have gotten to 30%

Wind Resource Assessment

- Location
- Wind characteristics
- Collect & analyze wind data
- Energy estimates & uncertainty

3 Most Important Factors when Siting Wind Turbines

Wind Power Density Classes

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
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

Site Assessment

Basic steps to select a site:

Prospecting – evidence of significant wind (wind maps or physical)

Transmission/distribution lines?

Road access?

Environmental concerns?

Military, NEXRAD & FAA radar?

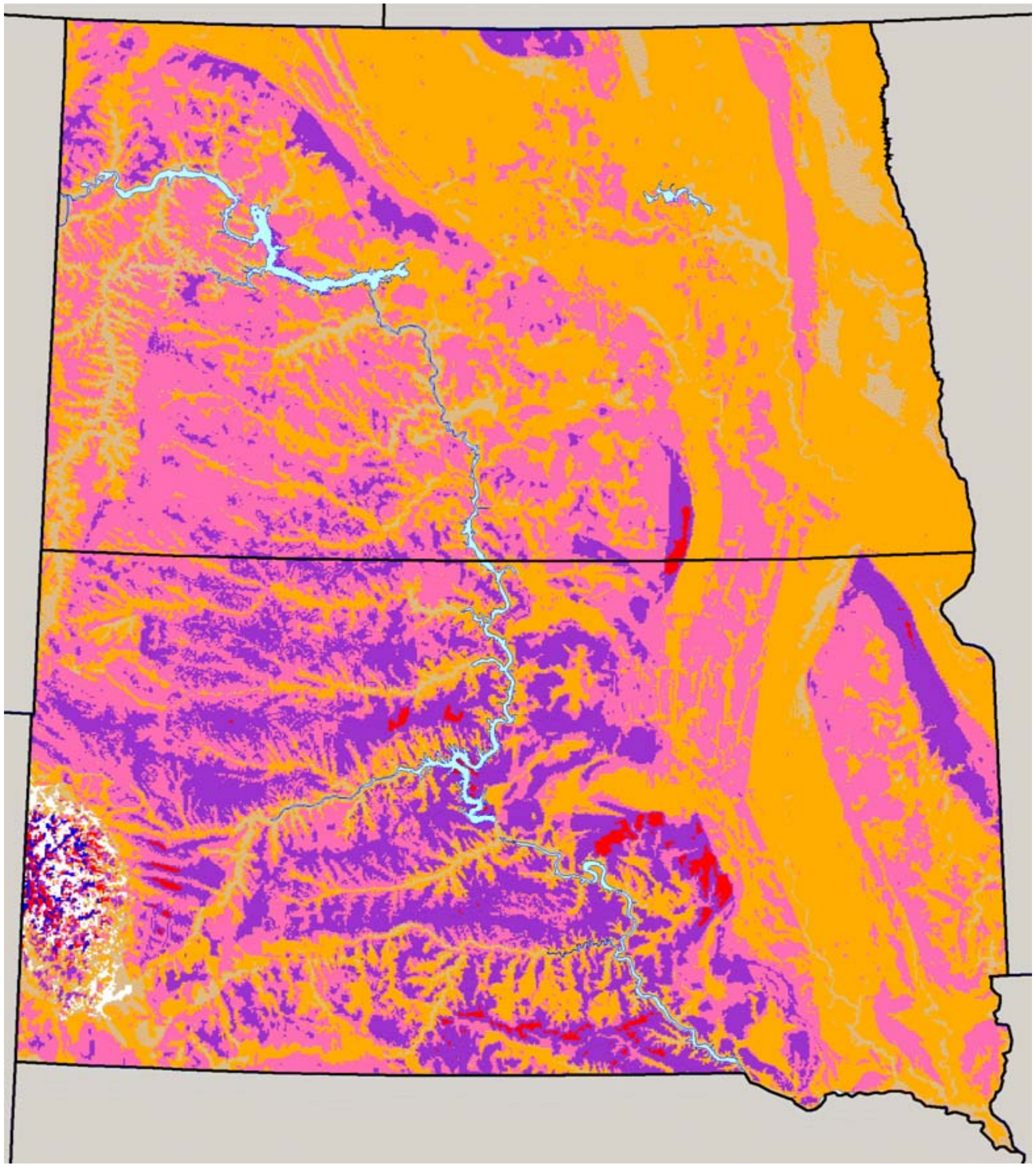
Military & Civilian airports?

Electricity market (sufficient on-site load)?

Receptive community?

Wind Data Sources

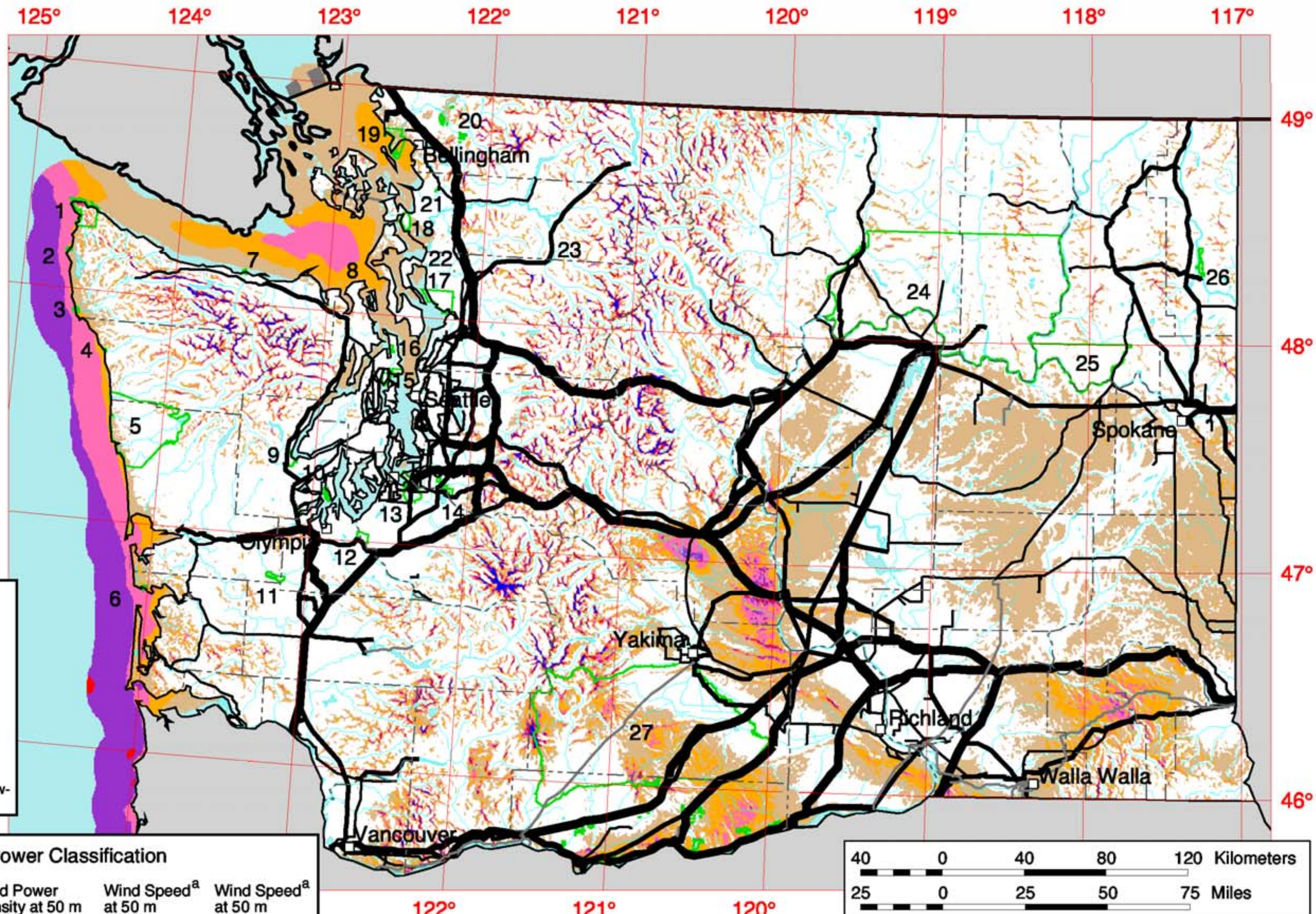
- Wind maps
- Regional wind atlases
- Biological indicators (vegetation)
- Environmental monitoring data
- Airport data
- Local knowledge



Washington - Wind Power Resource Estimates

Indian Reservation

1	Makah
2	Ozette
3	Quileute
4	Hoh
5	Quinault
6	Shoalwater Bay
7	Lower Elwha
8	Jamestown
9	Skokomish
10	Squaxin Island
11	Chehalis
12	Nisqually
13	Puyallup
14	Muckleshoot
15	Port Madison
16	Port Gamble
17	Tulalip
18	Swinomish
19	Lummi
20	Nooksack
21	Upper Skagit
22	Stillaquamish
23	Sauk-Suiatlle
24	Colville
25	Spokane
26	Kalispel
27	Yakama



Transmission Line*

Voltage (kV)

- 69
- 115
- 230 - 287
- 345
- 500
- 1000 (DC)

* Source: POWERmap, © 2002 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	> 8.8	> 19.7

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

The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.

U.S. Department of Energy
National Renewable Energy Laboratory

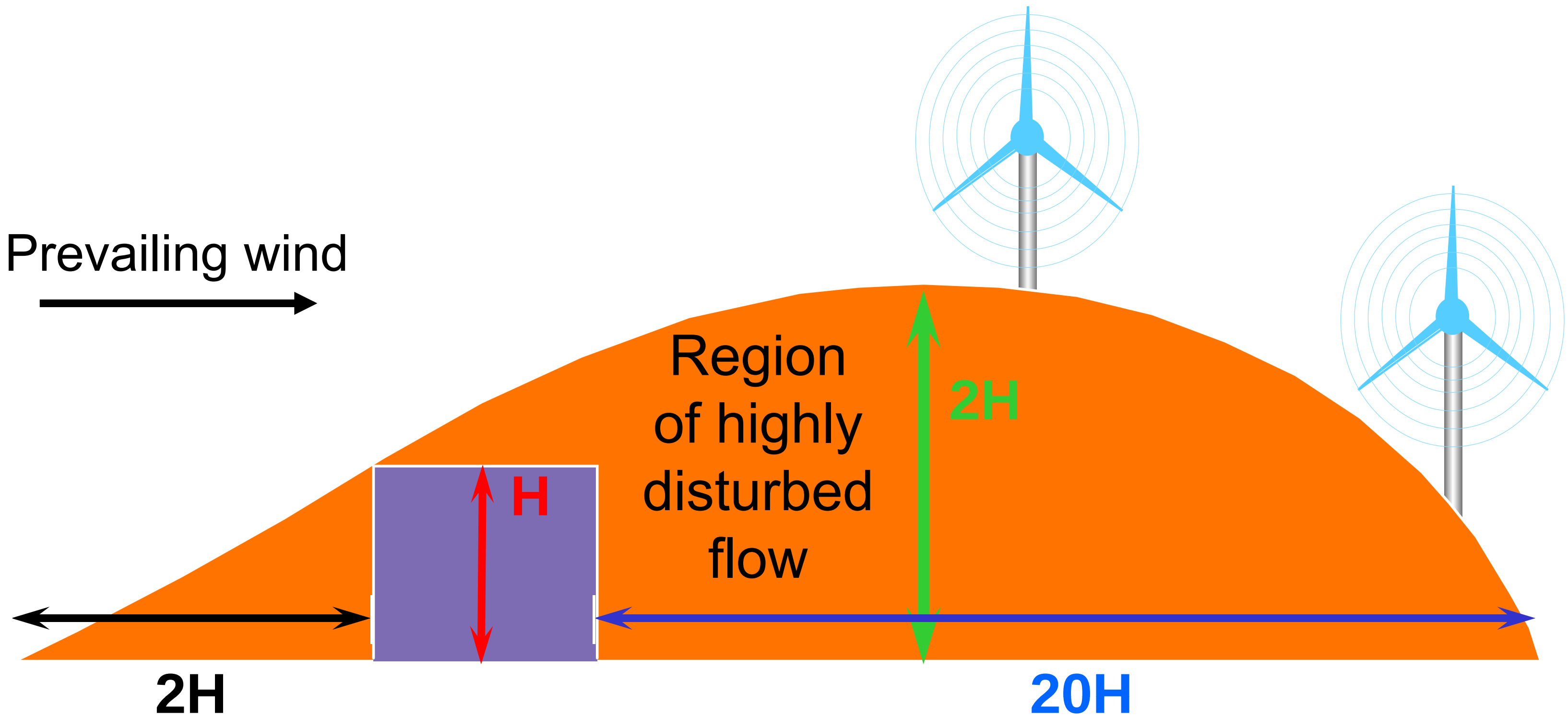
07-JUN-2002 1.1.11

Data Sources

- **Experiential Assessment of the Data – MET tower**
  - Widely practiced in the U.S.
  - Experience required
  - Subjectivity depends on amount of data
  - Data intensive
  - Characterize the prospective turbine locations
- Computer Modeling – FirstLook; windNAVIGATOR
  - Several widely used software packages
  - Similar results from all
  - Experience required
    Best suited to benign terrain
  - May require less wind data
- Combination

Micro-Siting

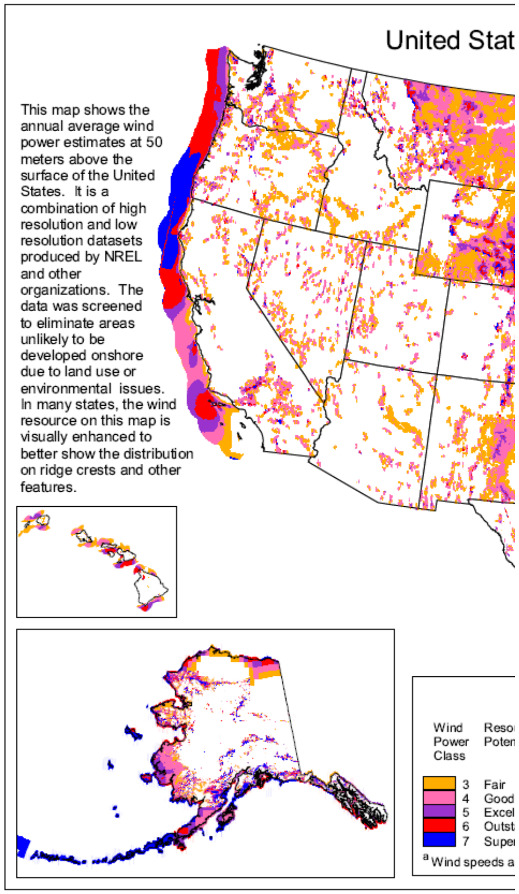
Obstruction of the Wind by a Building – Turbulence Impact

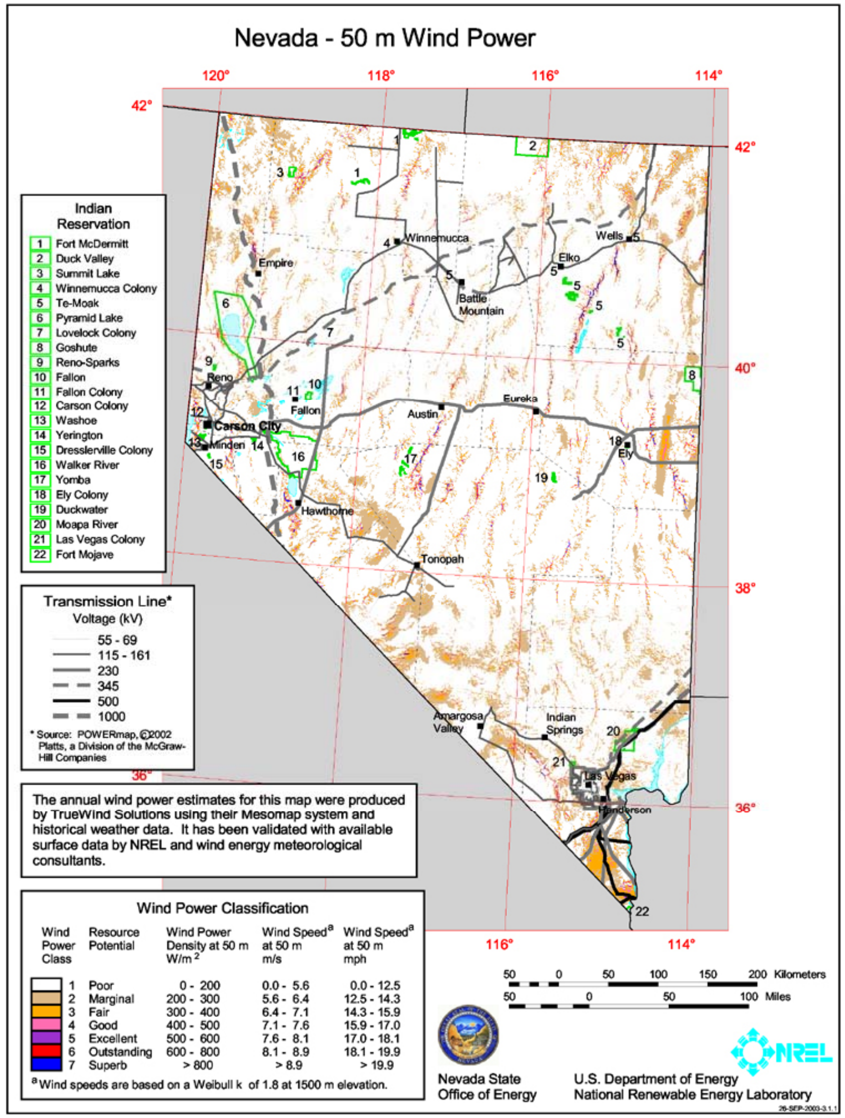


Wind Turbine Siting Matters

- Wind varies year-to-year, site-to-site.
- Developers want sites that maximize the wind resource, minimize risk
- Thorough assessment helps to minimize, not eliminate, the risk
- Uneven heating of the earth surface causes wind
  - seasonal change in vegetation can affect the wind seasonally – snow cover vs. dark green foliage vs. brown foliage vs. no foliage
  - terrain features like large valley can have upslope winds in morning and downslope winds in afternoon
  - drought or forest fire can impact winds generated from surface conditions
  - other earth system features impact wind irregularly – El Nino
- Terrain impacts wind
  - canyons, terrain undulations , trees/forests, buildings can contribute to turbulence which dissipates the wind

Wind is Very Area Specific

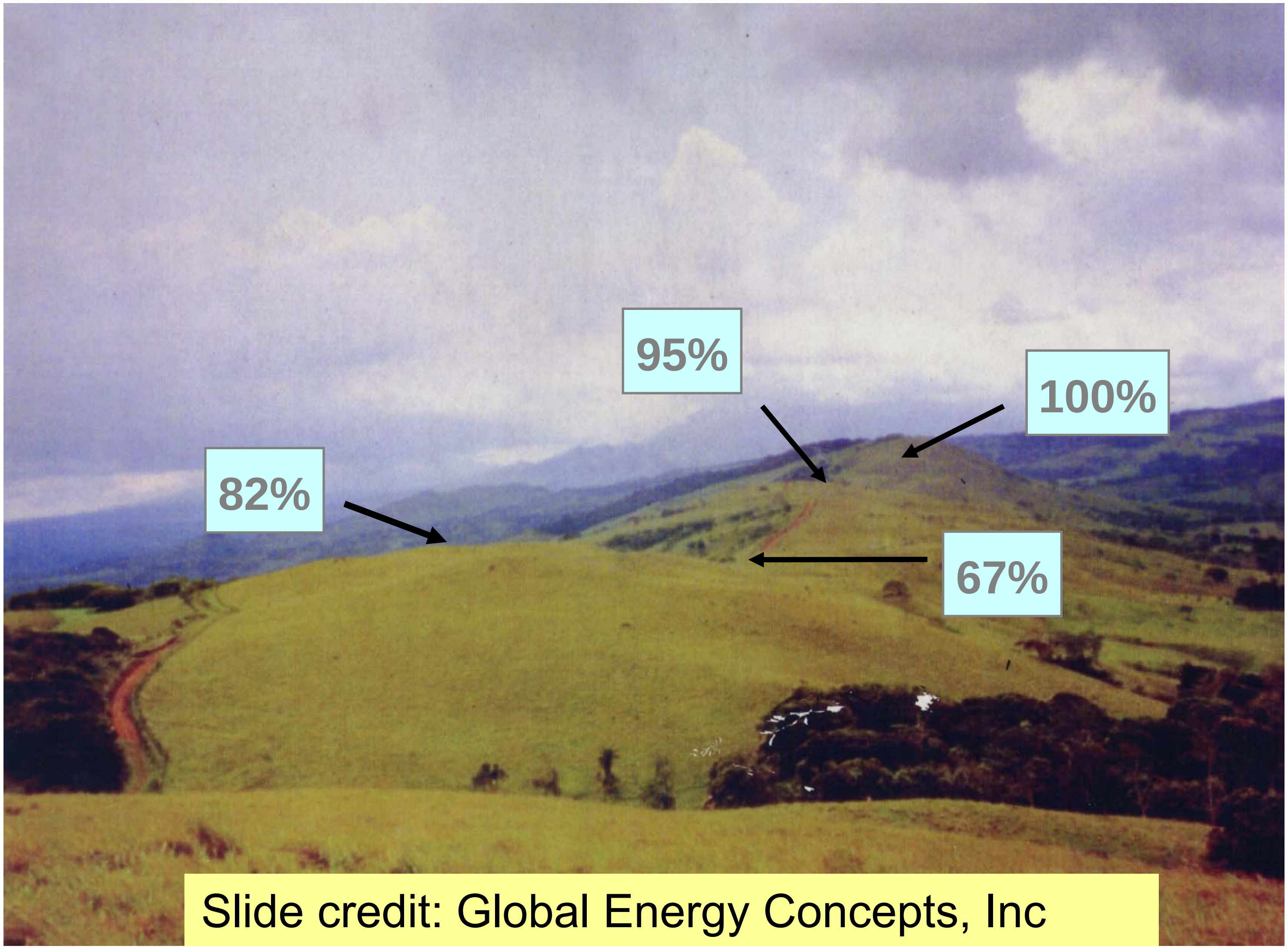




Wind in the west is driven primarily by topography

Access to ridges and mesa tops are critical to economic wind production

Siting makes a difference – for one or multiple turbines in both complex or simple terrain



Class 3 vs Class 6 Wind Site

Class 3 – at 50m – wind speeds 6.4 – 7.0 m/s
Mean wind speed of 6.7 m/s used for calcs

BASE CASE - CLASS 3 WIND		
Annual Energy	2,085,849	kWh/yr
Annual Revenue/turbine	$125,151	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$25,030,184	$/yr/farm

What is means :
Class 3 site = 150 turbines
Class 6 sites = 58 turbines

Need 159% more wind turbines at Class 3 site

Class 6 – at 50m – wind speeds 8.0 – 8.8 m/s
Mean wind speed of 8.4 used for calcs

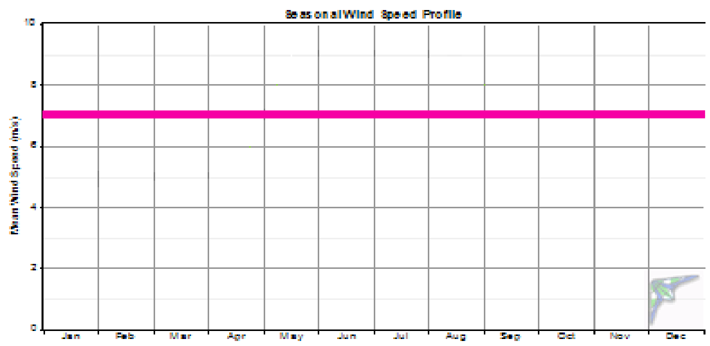
CLASS 6 WIND		
Annual Energy	5,025,063	kWh/yr
Annual Revenue/turbine	$301,504	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$60,300,755	$/yr/turb
Increase in Rev/Yr	$37,763,470	$/yr/farm
Energy & Rev Increase	167.6%	

The revenue "increase" at this Class 6 site is greater than "annual revenue" at Class 3 site !

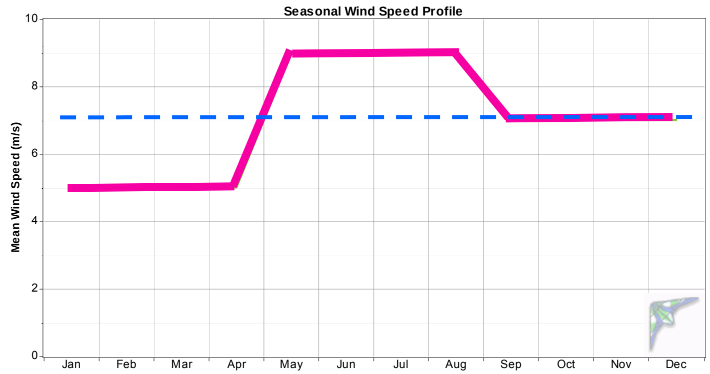
Importance of Wind Resource Assessment

Mean Annual Wind Speed = 7 m/s

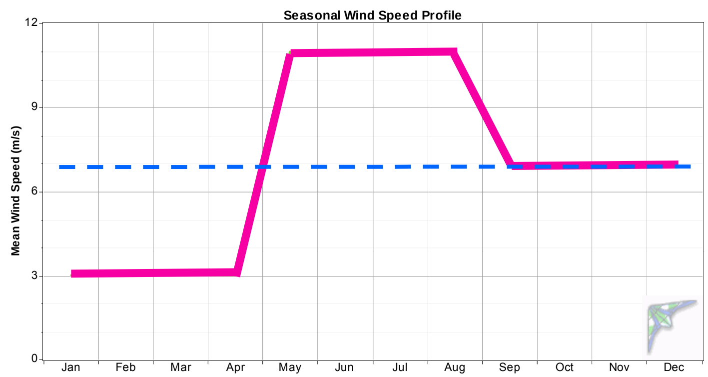
Steady 7 m/s



1/3 of year at 5 m/s
1/3 of year at 7 m/s
1/3 of year at 9 m/s

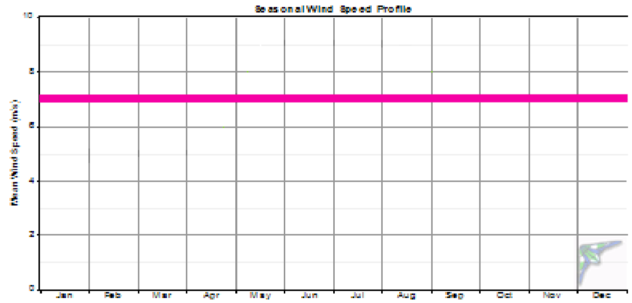


1/3 of year at 3 m/s
1/3 of year at 7 m/s
1/3 of year at 11 m/s

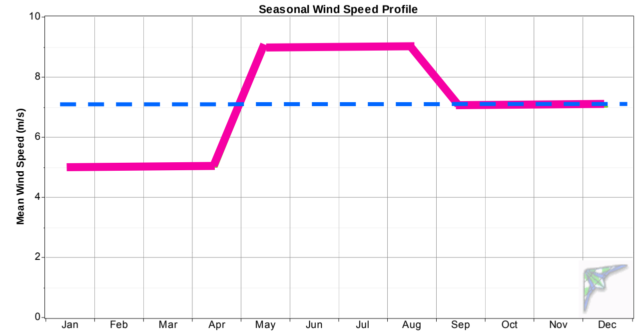


Not All 7 m/s Sites are the Equal !

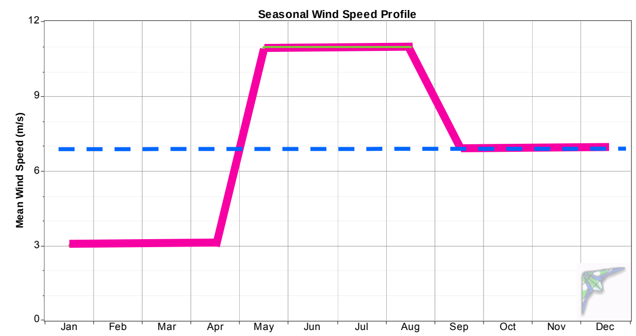
BASE CASE - STEADY WIND AT 7 M/S		
Annual Energy	1,878,107	kWh/yr
Annual Revenue/turbine	$112,686	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$22,537,284	$/yr/turb



WIND SPEED AT 5 - 7 - 9 M/S		
Annual Energy	2,466,956	kWh/yr
Annual Revenue/turbine	$148,017	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$29,603,471	$/yr/turb
Increase in Rev/Yr	$7,066,187	$/yr/farm
Energy & Rev Increase	31.4%	



WIND SPEED AT 3 - 7 - 11 M/S		
Annual Energy	3,912,763	kWh/yr
Annual Revenue/turbine	$234,766	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$46,953,158	$/yr/turb
Increase in Rev/Yr	$24,415,874	$/yr/farm
Energy & Rev Increase	108.3%	



Wind energy is kinetic energy

Mass and momentum

Derived from K.E. = $\frac{1}{2} mv^2$

$P = A \times \rho V^3/2$

P – Power of the wind [Watts]

– A = Windswept area of rotor (blades) = $\pi D/4 = \pi r^2$ [m^2]

– ρ = Density of the air [kg/m^3] (at sea level at 15°C)

– V = Velocity of the wind [m/s]

Wind energy is proportional to velocity cubed (V^3):

–If velocity is doubled, power increases by a factor of eight ($2^3 = 8$).

–Small differences in average speed cause big differences in energy production.

Actual Wind Turbine Performance

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

- Effect of wind$_{spee}$ d, V (cubed)
- Effect of rotor diameter on swept area
  A = p D^2 / 4
- Effect of elevation and temperature
  on air density, ρ
- Limits on power coefficient (efficiency):
  C_p @ 0.2 - 0.4

• Annual Energy from wind turbine

= Turbine power x # of hours at that wind speed

(method of bins)

Capacity Factor (CF)

CF = Actual Energy Production / Maximum Possible Energy

- CF = (Annual kWh) / (Rated Power x 8760)
- CF depends on wind speed distribution and wind turbine
- More wind = higher capacity factors
- Typical CF = 0.15 - 0.45 [better wind sites have higher CF's]

Capacity Factor (cont)

Example: What Capacity Factor does to 1000 kW (1MW) rated turbine

1000kW (nominal rated) turbine x 0.25 capacity factor x 8760 hours/year = **2,190,000 kWh annual production**

NOT 1000kW x 8760 = 8,760,000 kWh

Some call it " 0.25 average MW or 0.25MWa turbine"

Wind Applications

Distributed

Homes

Farms

Small business

Remote Applications

Schools

Wind Farms

Large Central Station Power

Community Projects

Large businesses

Municipal loads

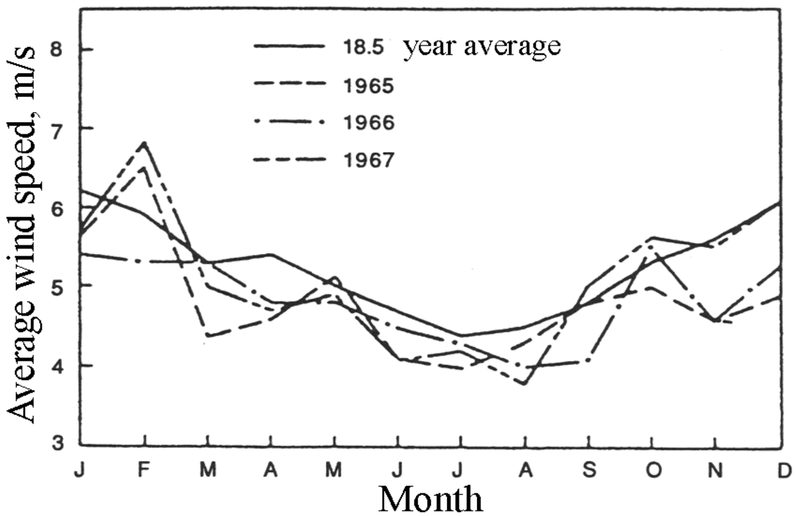
Schools

Federal Loads

Basic Wind Turbines

- Understanding the wind resource at your location is critical to understanding the potential for using wind energy
  - Wind speed
  - Wind direction
  - Wind speed change with height
- Lift and Drag – The different types of wind turbines
- Power Curves – The performance of wind turbines
- Power Availability - Power your can get from the wind

Wind Speed

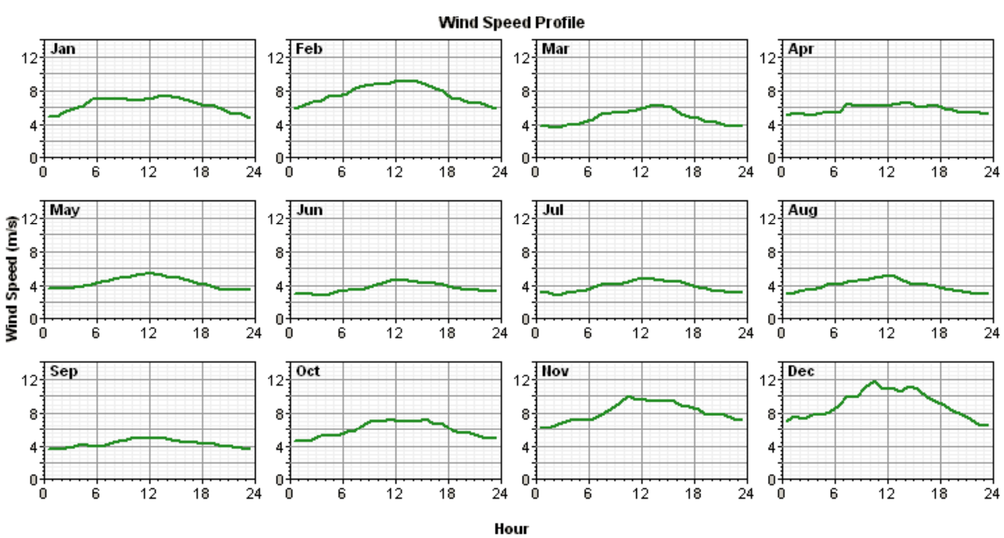


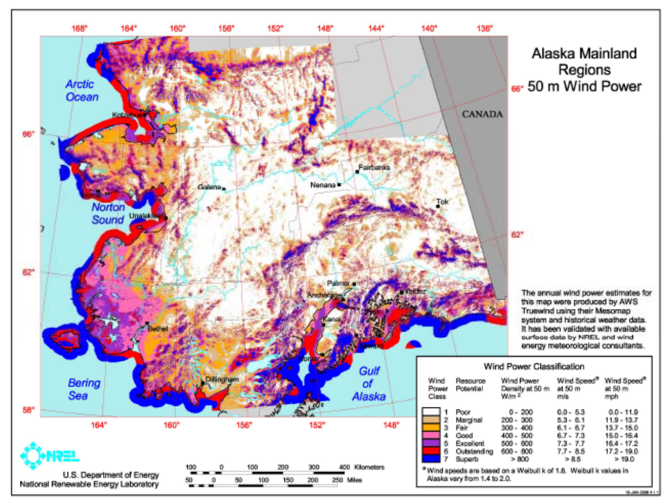
Measured in m/s or mph

Varies by the second, hourly, daily, seasonally and year to year

Usually has patterns

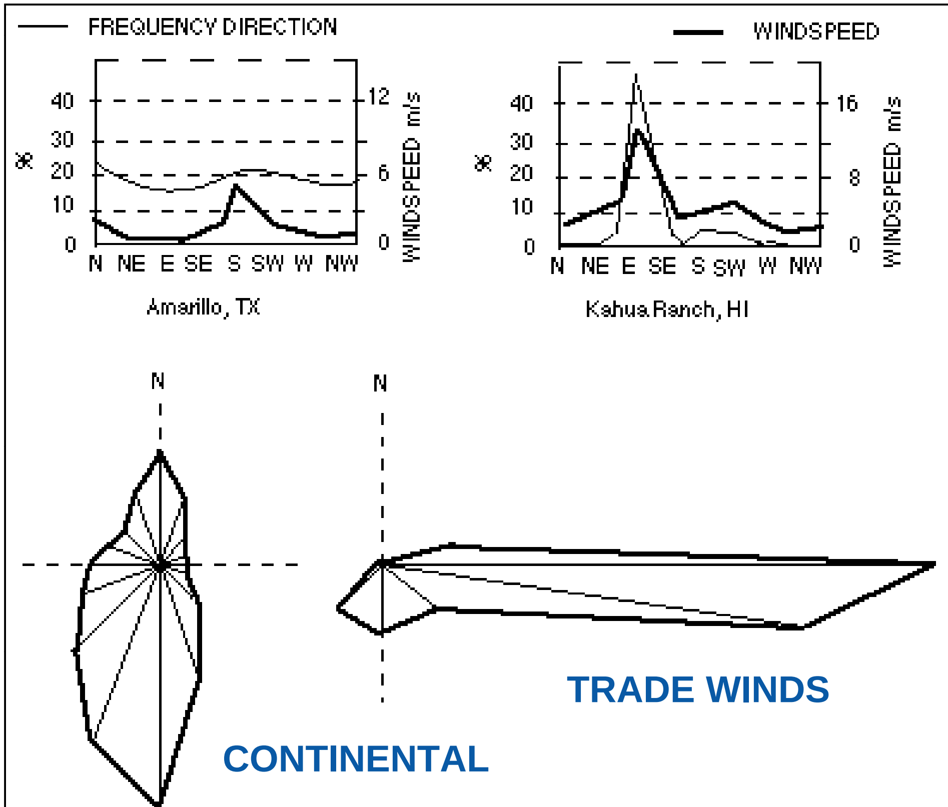
- Diurnal - it always blows in the morning
- Seasonal – The winter winds are stronger
- Characteristics – Winds from the sea are always stronger and are storm driven.



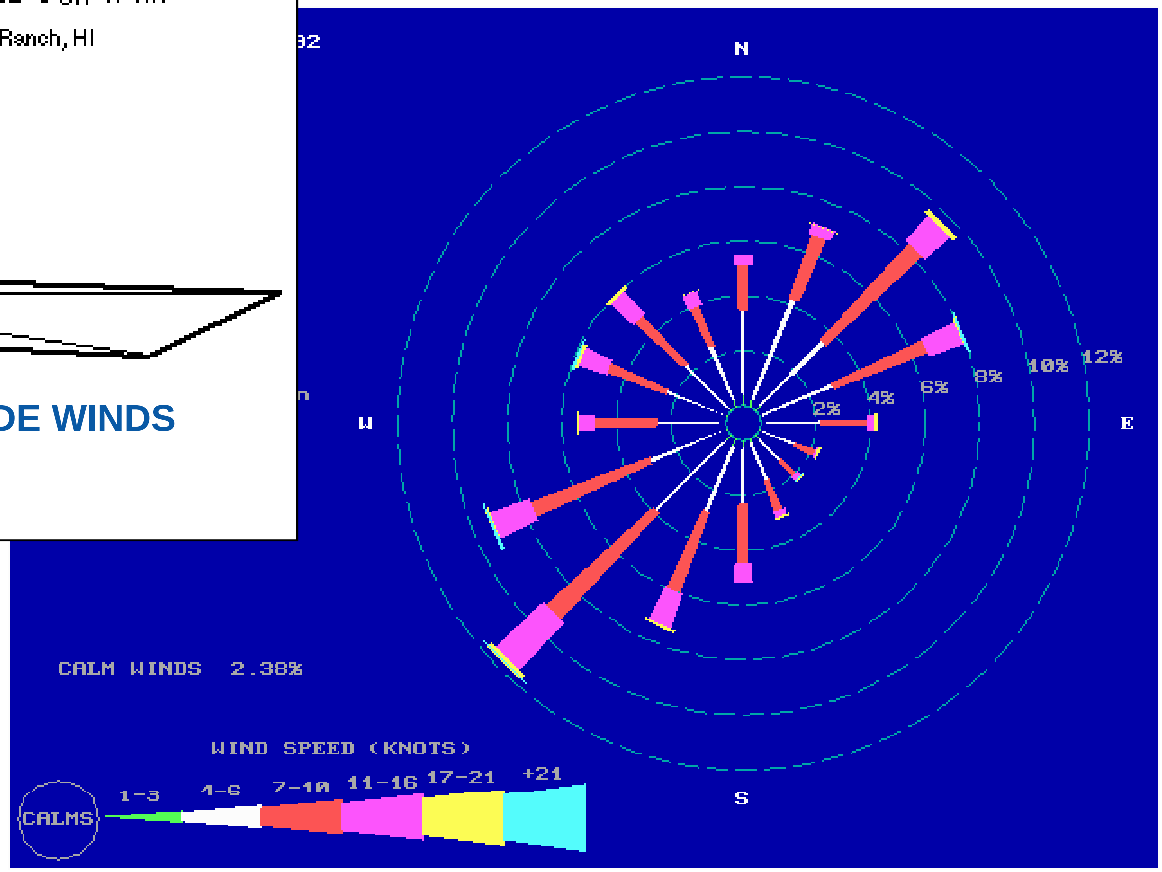


Wind Direction

Wind Rose

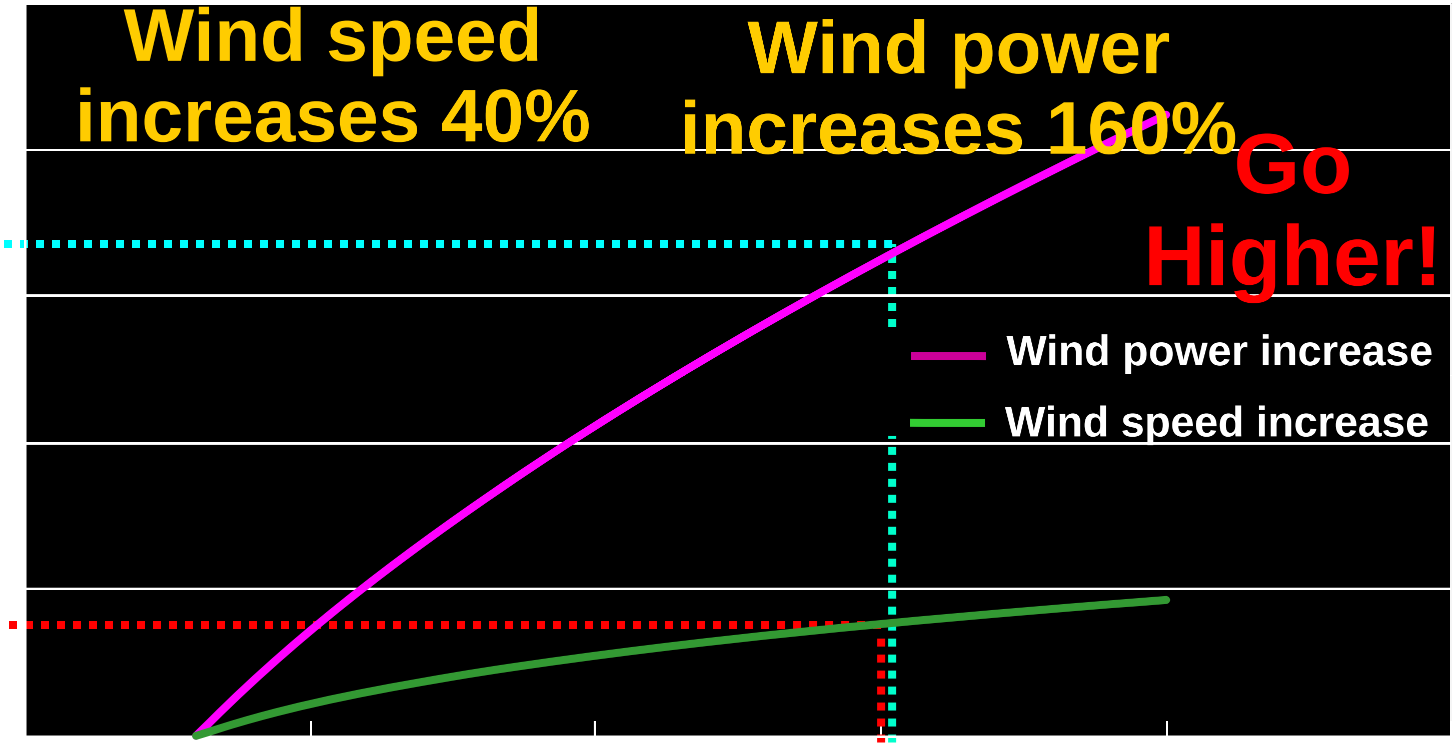


Wind Speed Rose



Can also have a wind direction change intensity – similar to turbulence

Wind Speed and Power Increase with Height Above the Ground

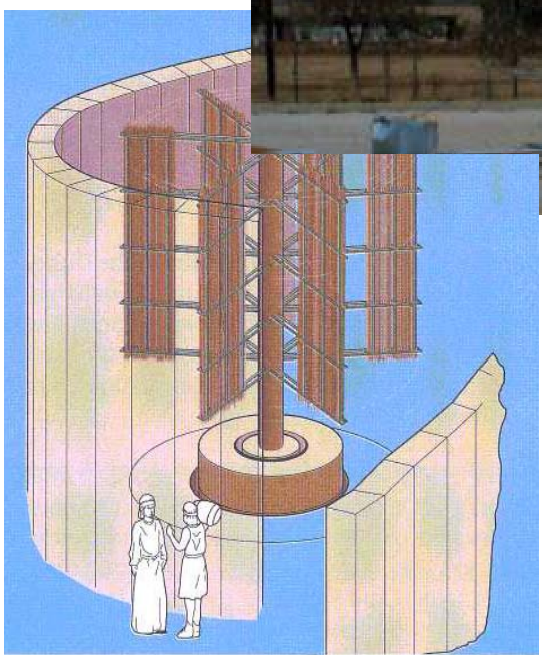


Lift Wind Turbines

Types of Lift Turbines

HAWT VAWT

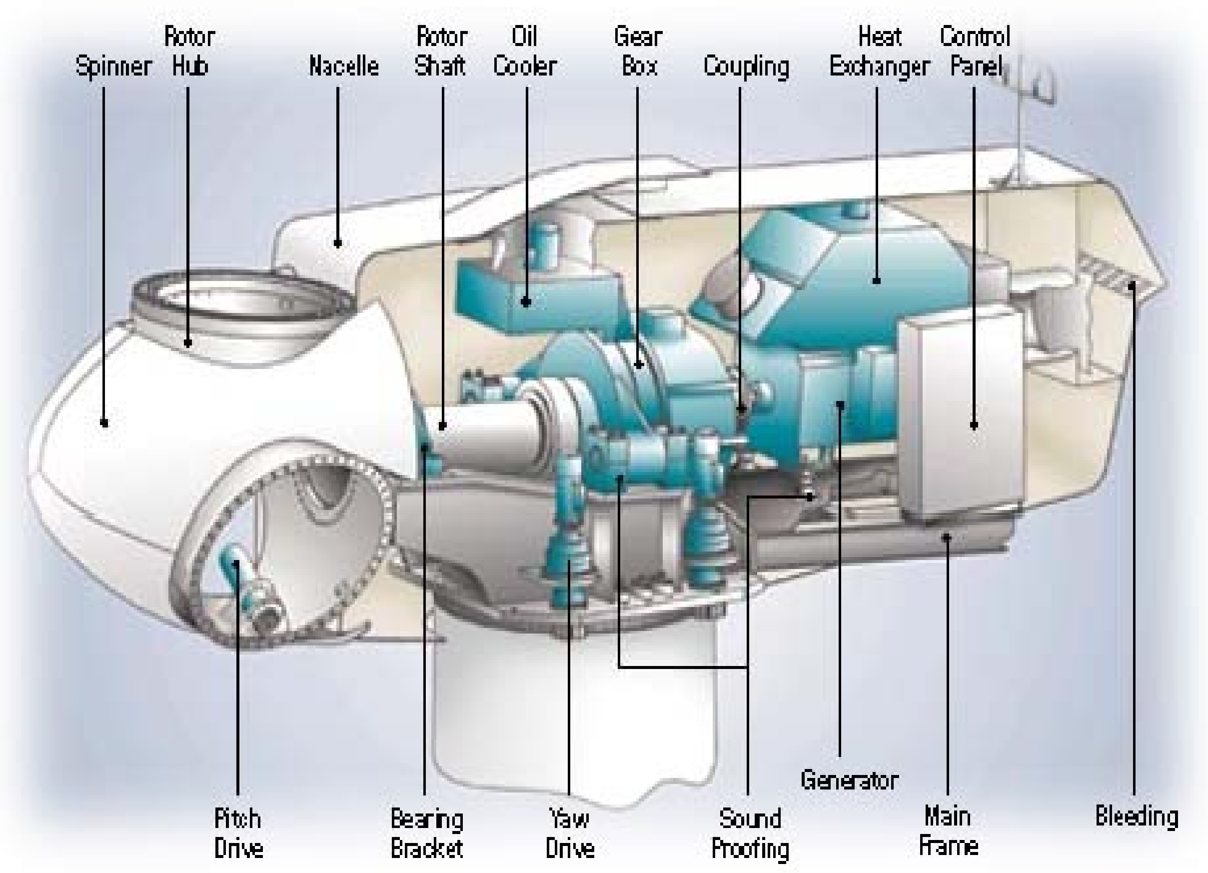
Classic Drag Devices



Use aerodynamic drag to produce power. Typically have high torque and work well in low wind speeds, but not at high wind speeds.

Typically higher costs per kWh.

Large Wind Turbines



Generator/gearbox:

- Induction
- variable speed
- Direct Drive

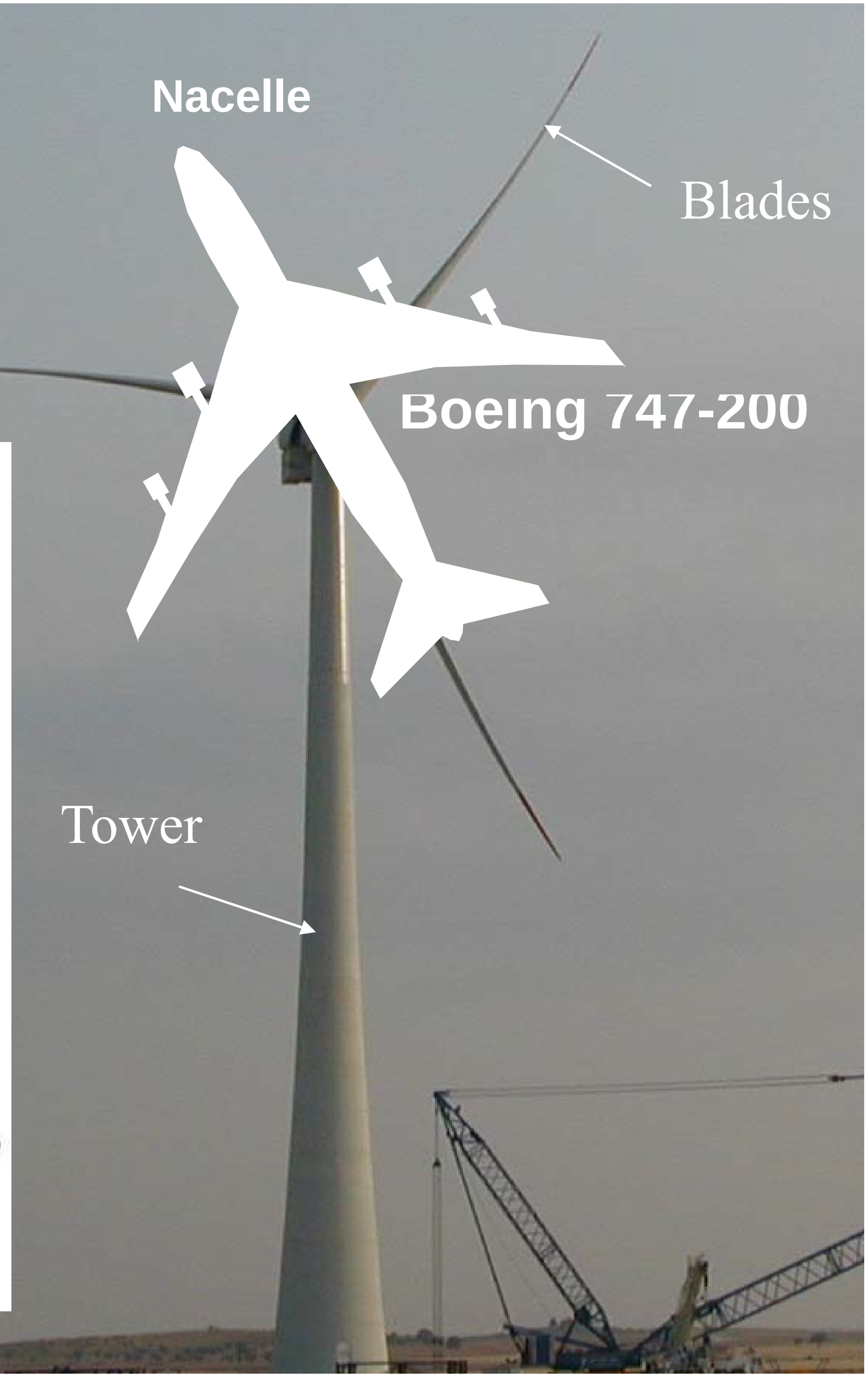
Control:

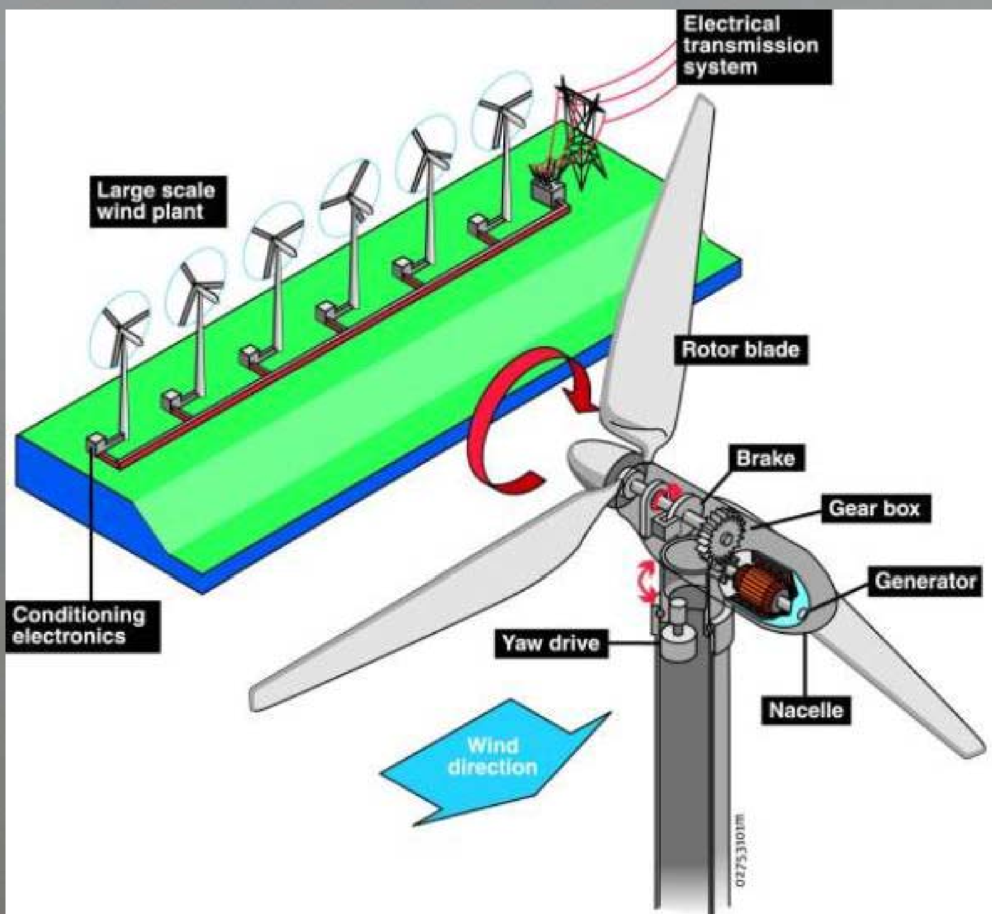
- Stall (passive)
- Active pitch
- Power control

Active Yaw control

Connected at the transmission or distribution level

Parts of a Wind Turbine Power Plant





Characteristics of Large WTG

Power Types

- Induction (Constant speed)
- Permanent Magnet (Variable speed) using power electronics

Control:

- Stall (passive)
- Active pitch
- Power control

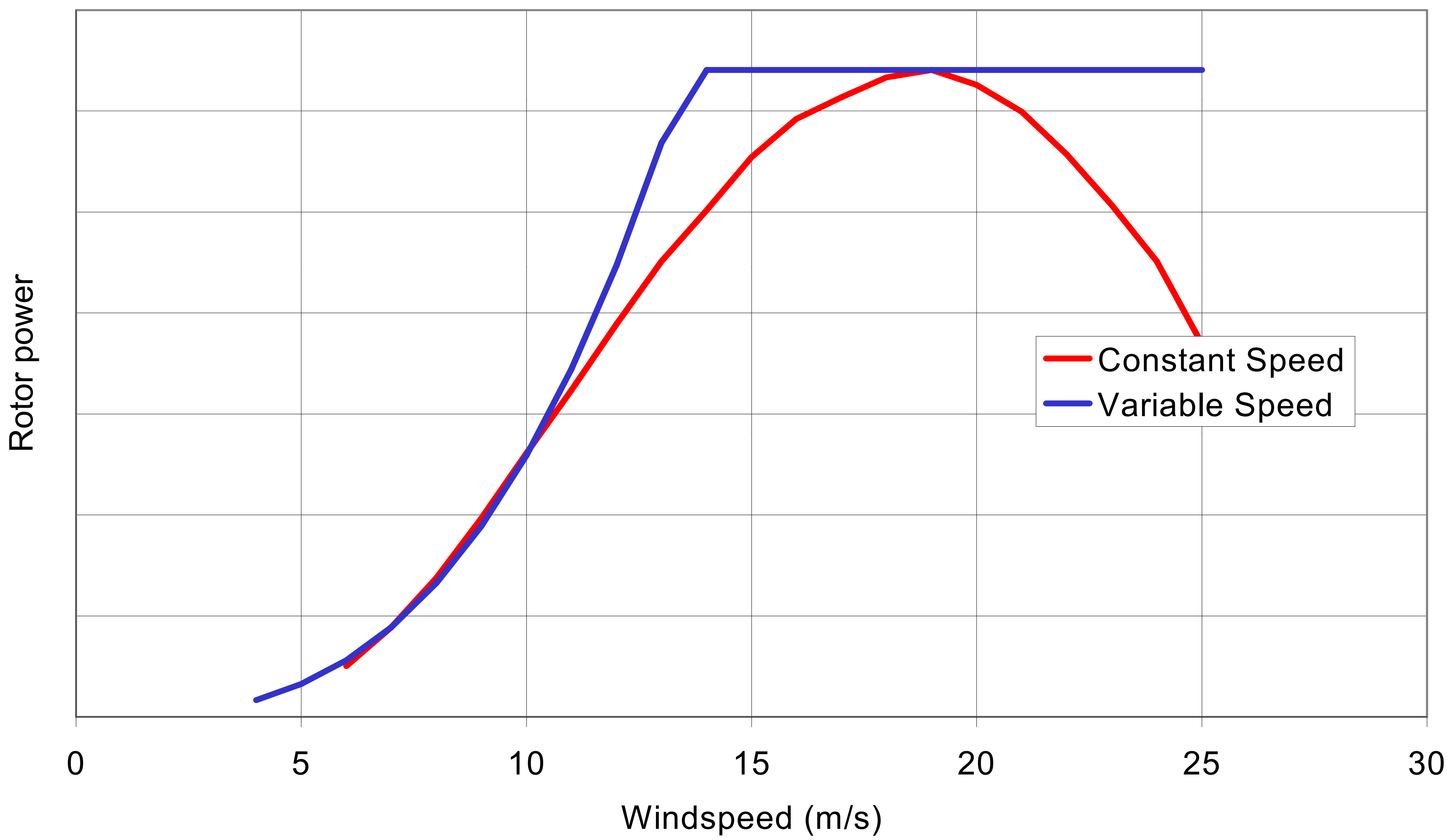
Active Yaw control

Connected at the transmission or distribution level

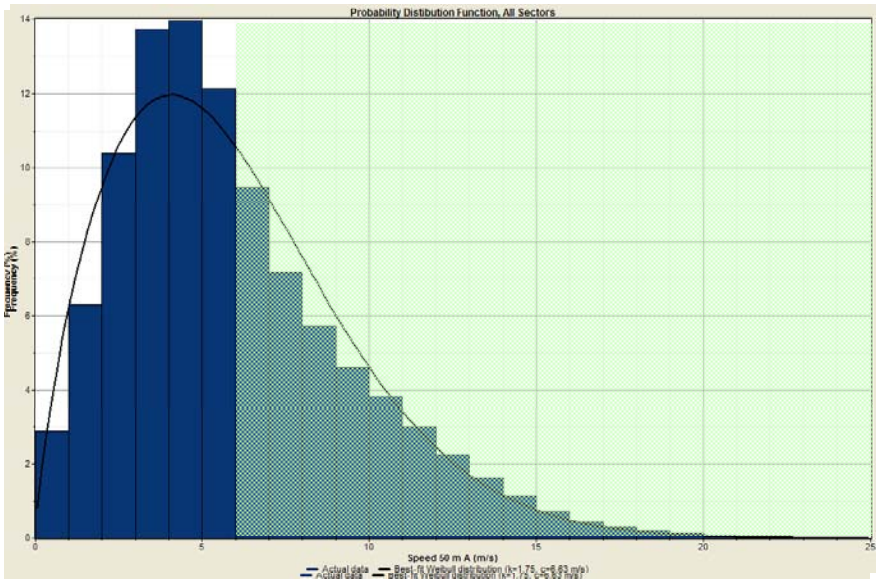
Remote monitoring standard

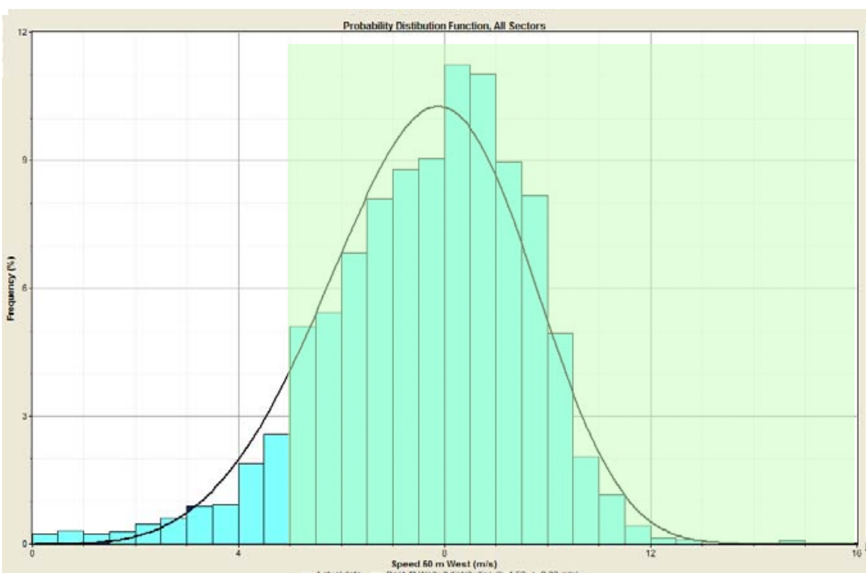
Dedicated maintenance staff for large projects

Power curves



Frequency Distribution





Wind frequency distribution:

Inform us on how many **<u>hours per year</u>** the wind blows at each wind speed

Top graph – Very few hours that the turbine will be operating

Bottom graph – Many more hours a year that the turbine will be operating

Constant versus Variable speed

Constant speed is cheaper

Constant speed is easier to implement

Variable speed can collect more energy

Variable speed can control loads better

Direct Drive Design

Wind Turbine O&M and Failure Issues

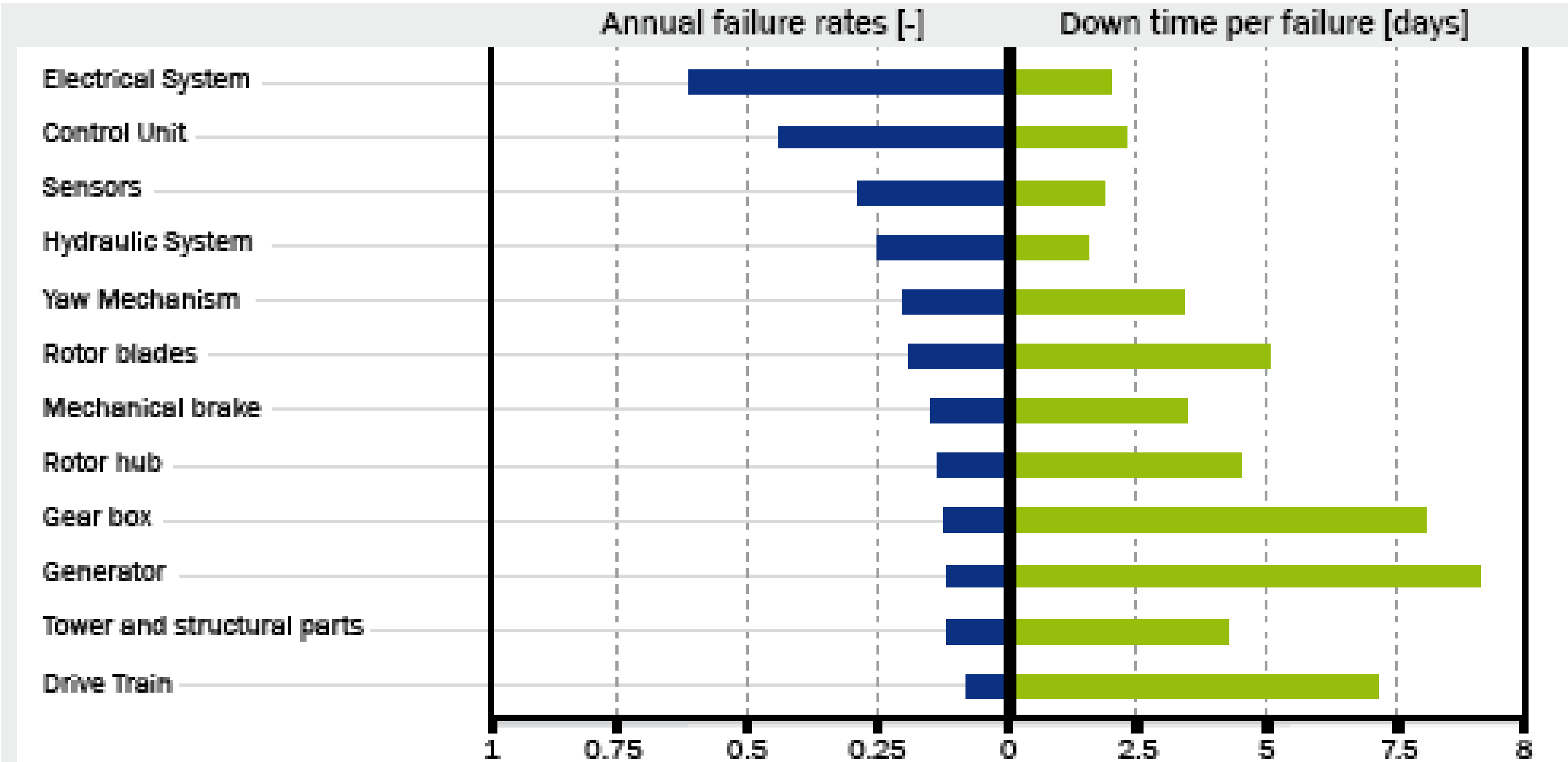
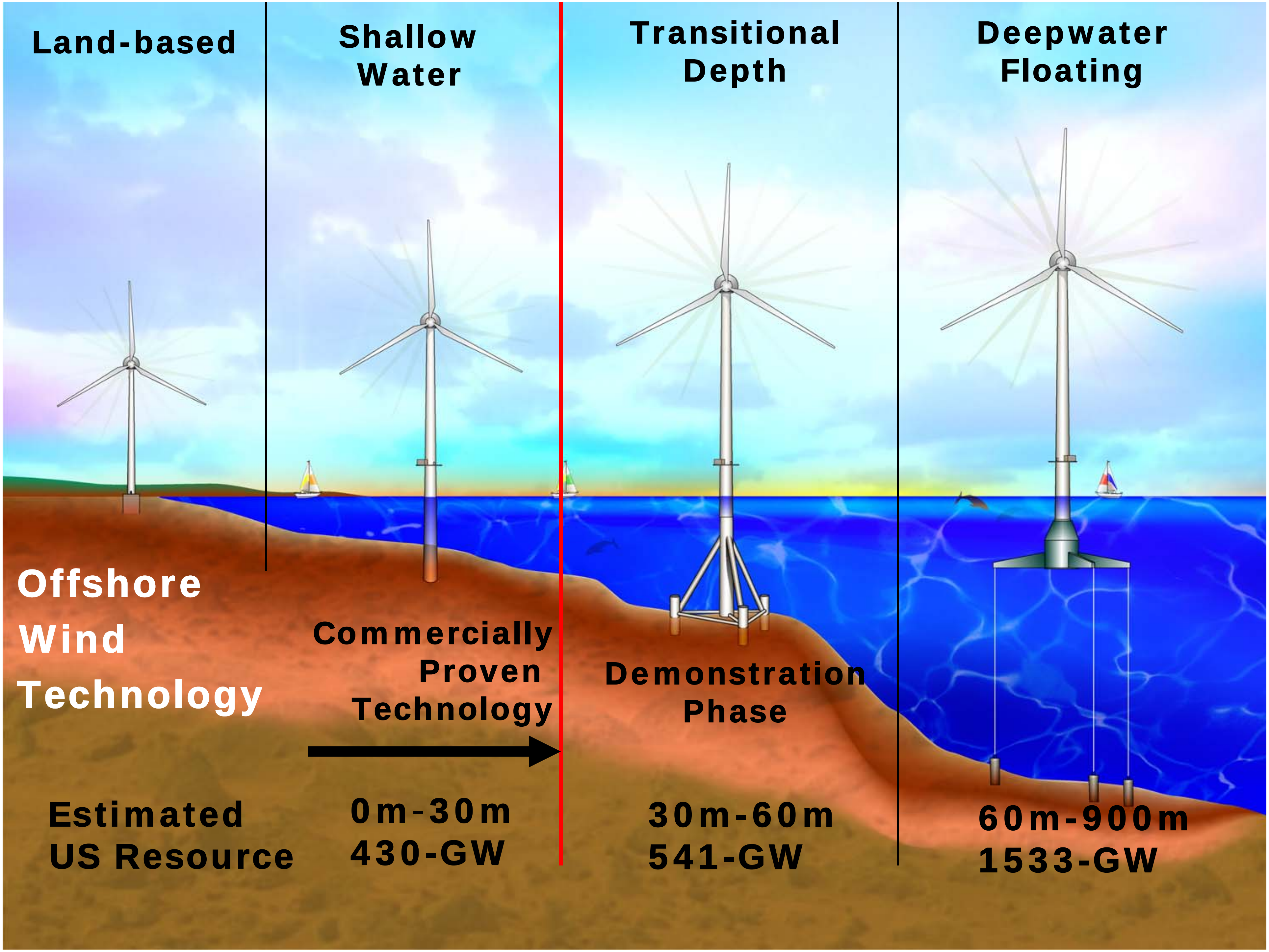


Figure 4: Comparison of wind turbine components according to thier annual failure rates and resulting downtimes.

Source: Sandia National Laboratories - http://www.sandia.gov/wind/other/080983.pdf



Land-based
Shallow Water
Transitional Depth
Deepwater Floating
Offshore Wind Technology
Commercially Proven Technology
Demonstration Phase
Estimated US Resource
0m-30m
430-GW
30m-60m
541-GW
60m-900m
1533-GW

Federal Wind Capacity

Federal Wind Sites	# of Turbines	Turbine Size	Wind Plant Capacity	Install Year
	[#]	[kW]	[kW]	[Year]
San Clemente Island, CA	3	225	675	1998
Guantanamo Bay, Cuba	4	950	3,800	2005
Warren Air Force Base, Cheyenne, WY	1	2,000	3,200	2009
	2	600		2005
Air Force Ascension Island, St Helena, UK Territory	4	225	2,700	1996
	2	900		2004
Victorville Prison, Victorville, CA	1	750	750	2005
Camp Williams, Riverton, UT	1	225	225	1999
	1	660	660	2005
Marine Corps, Barstow, CA	1	1,500	1,500	2008
Total	**20**		**12,010**	

Federal Wind Activities - West

San Nicholas Island CA – MET towers

Marines – Barstow CA 1.5MW 2008

Navy – Guam – MET –2008-9

Navy– Yokusuka, Japan MET 2009

EPA – Leviathan Mine CA MET –2010-11

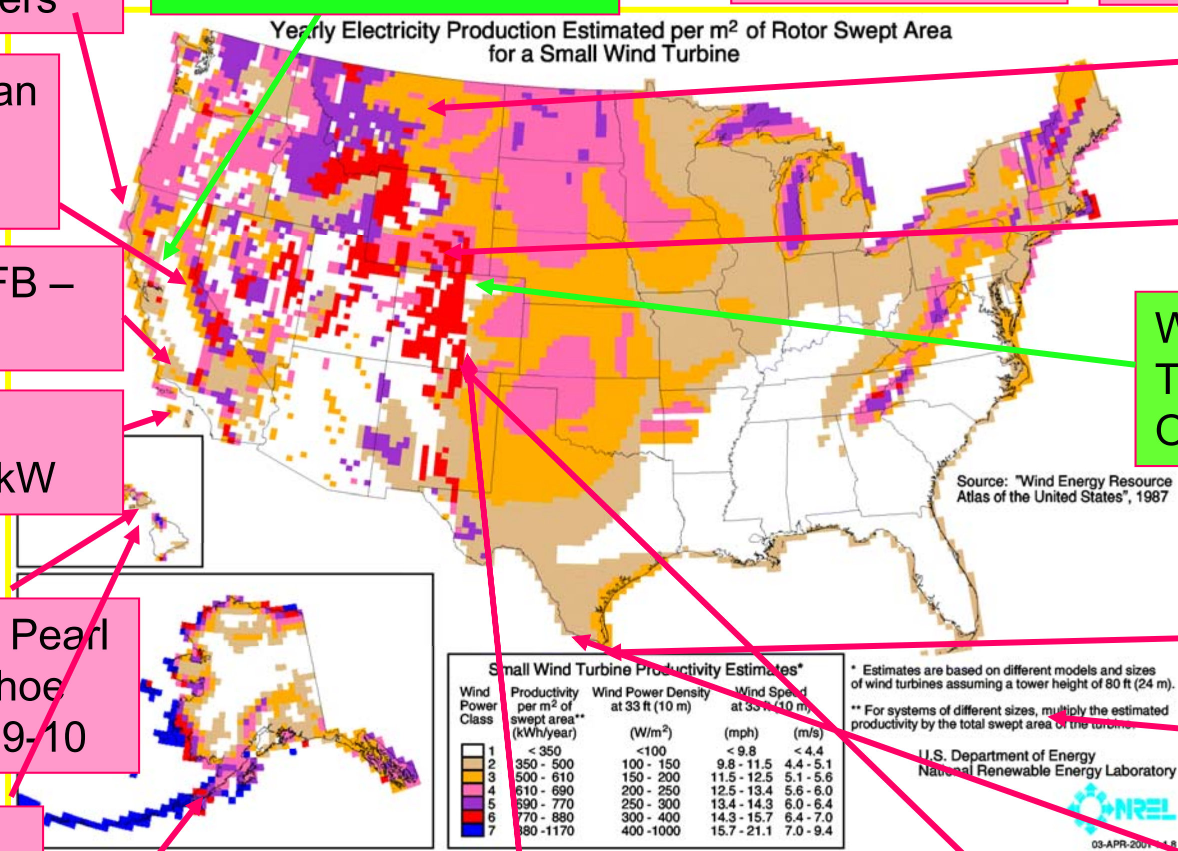
EPA – Anaconda MT MET 2009-10

Vanderberg AFB – MET towers

EPA– Gilt Edge SD MET 2009-10

San Clemente Island – 3 225kW

Warren AFB
Two 660kW – 2005
One 2.0 MW - 2009



DOD-Hawaii – Pearl City and Kanehoe 2 METs - 2009-10

GSA – Donna TX MET — 2008-9

Navy – Hawaii METs -2009-10

Guantanamo Bay 4 950kW - 2006

USCG – MET Kodiak AK 2005-8

Fort Carson , Colo Springs CO MET & SODAR -– 2008-9

Schriever AFB MET - Colo Spgs CO-2007-8

GSA – MET – McAllen TX – 2008-9

Federal Wind Activities - East

McConnell AFB KS
MET – 2009-10

Nat Park Ser – Truro, Cape Cod
MET 2006-7 RFP 2009

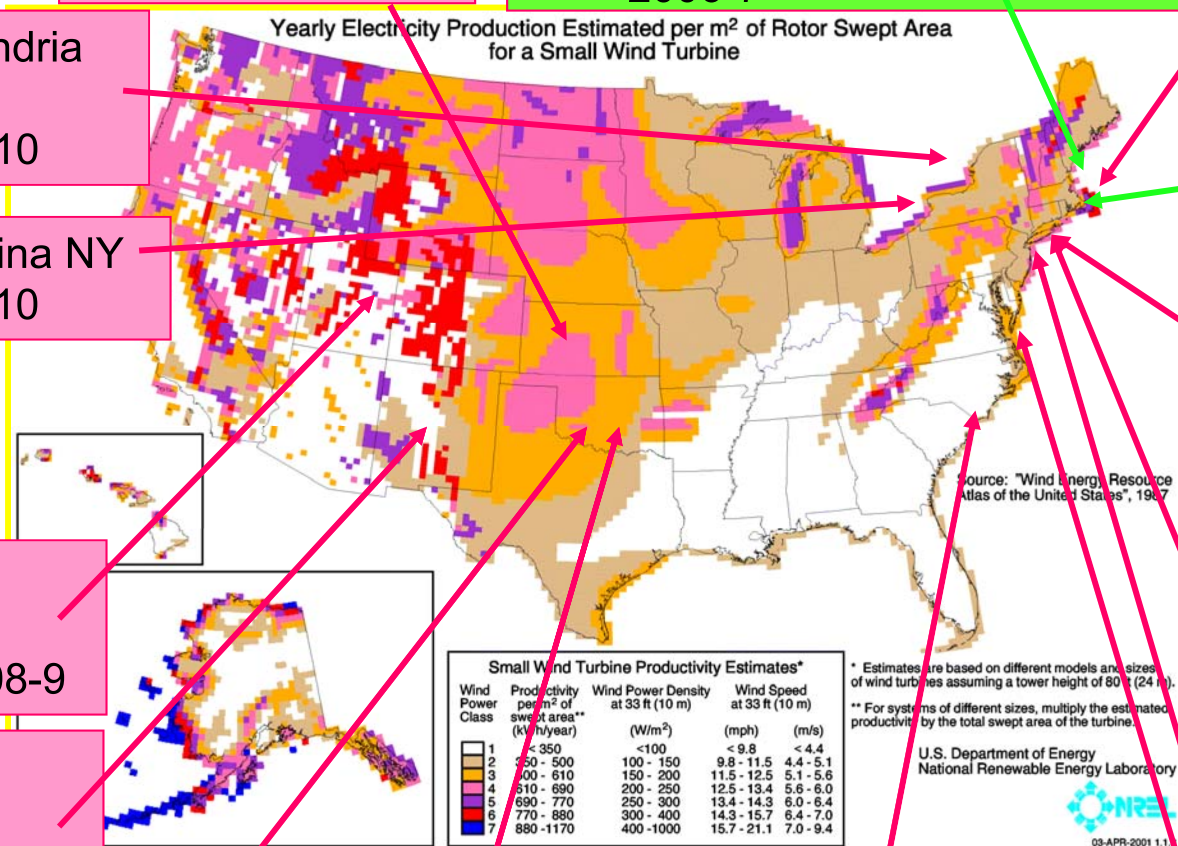
Army NG Cape
Cod 1-2 600kW
turbines–2009-10

GSA - Alexandria
Bay NY
MET –2009-10

AFCEE Cape Cod
1.5MW turbine 2009

GSA – Messina NY
MET –2009-10

Navy Newport RI
MET & SODAR
2009-10



Army Nat Guard –
Sea Girt NJ
MET & SODAR –
2008
GE 1.5MW - 2010

Idaho NL
2 MET &
SODAR 2008-9

Sandia NL
2 MET &
SODAR 2008-9

USCG –Cape May
NJ- TALL MET –
2007-9

Altus Air Force Base
OK MET –2009-10

McAlester OK
MET –2009-10

NPS, Harkers Island NC
MET – 2009-10

NASA – 2006-7
Wallops Island VA

Utah Army National Guard
Camp Williams, Utah

Figure   Vestas V-47 installation at Camp Williams in May 2005

NREL contracted with Vestas for installation of 660kW Vestas V-47wind turbine

Combined with existing 225kW NEG Micon
Total capacity = 885kW

Figure 2 Newly installed Vestas V-47 660kW wind turbine at left and NEG Micon 225 kW wind turbine at right.

Load: 5.5-6.3 GWh/yr
Wind Energy: 1.1-1.2 GWh/yr

COE: $0.035/kWh (2004)

Annual Savings: $40-45k/yr
Payback: 25-30 yrs

Army - Fort Carson CO

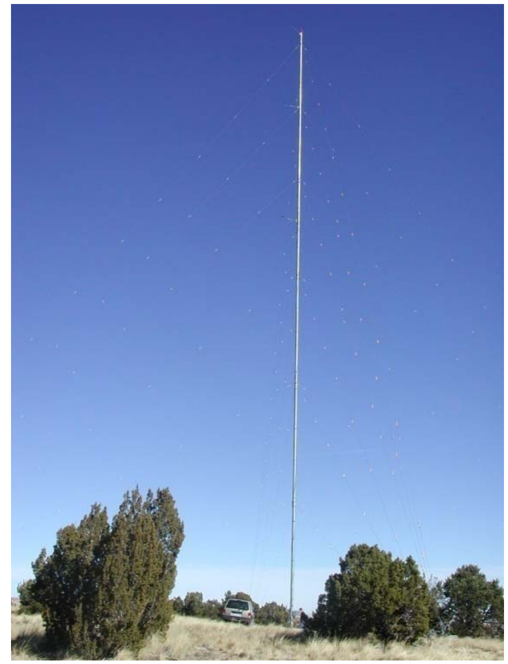
Ft. Carson Summary

Sodar

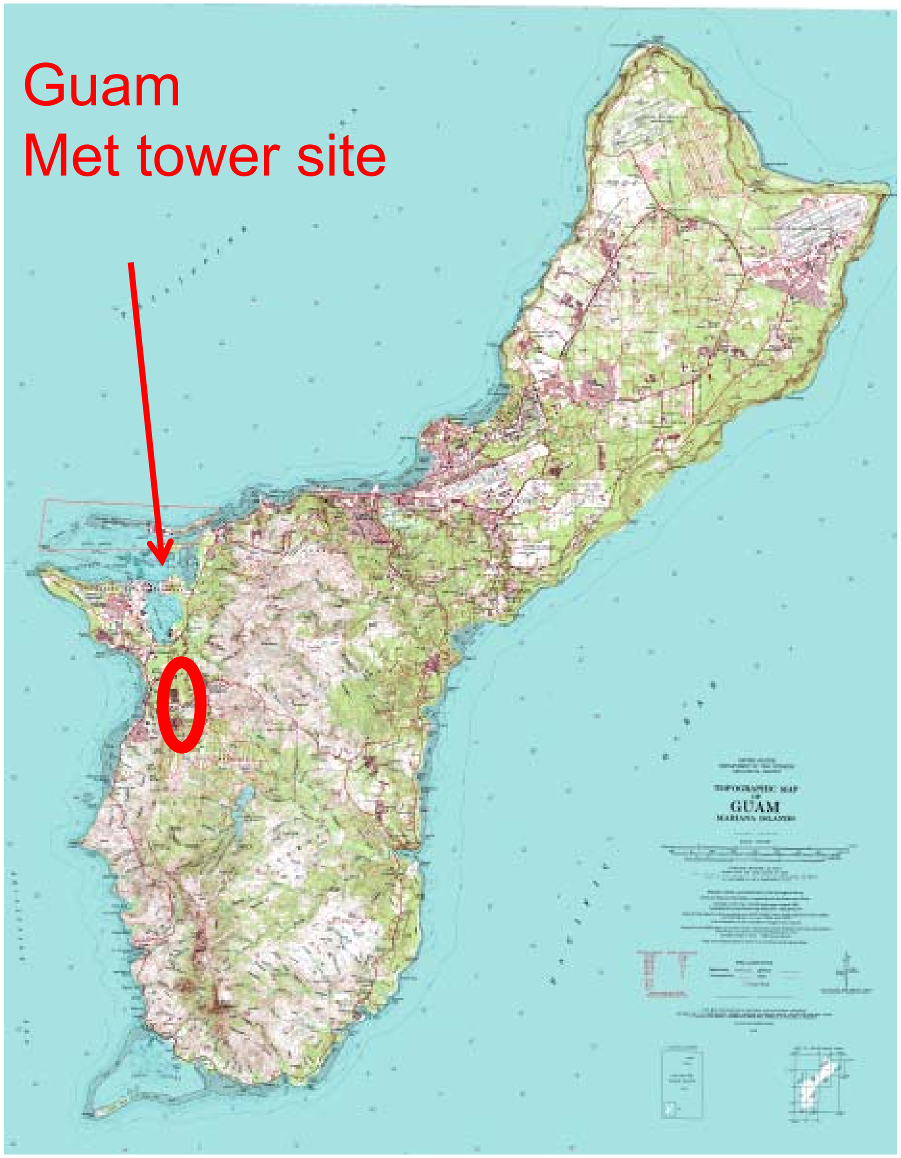
	40m	50m	60m	70m	80m	90m	100m
Data Points Recov	21193	21175	21078	20834	20398	19768	18909
Ave Spd All Data	5.32	5.65	5.94	6.18	6.40	6.58	6.74
Shear	n/a	0.27	0.27	0.26	0.25	0.25	0.22
Ave Spd January	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ave Spd February	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ave Spd March	5.96	6.37	6.70	7.03	7.33	7.63	7.88
Ave Spd April	6.02	6.42	6.72	7.00	7.26	7.49	7.68
Ave Spd May	6.29	6.69	7.00	7.28	7.50	7.70	7.83
Ave Spd June	4.98	5.29	5.54	5.80	6.00	6.19	6.39
Ave Spd July	4.57	4.84	5.09	5.27	5.41	5.53	5.61
Ave Spd August	4.68	4.98	5.27	5.51	5.71	5.90	6.04
Ave Spd Septemb	4.80	5.08	5.36	5.56	5.75	5.93	6.10

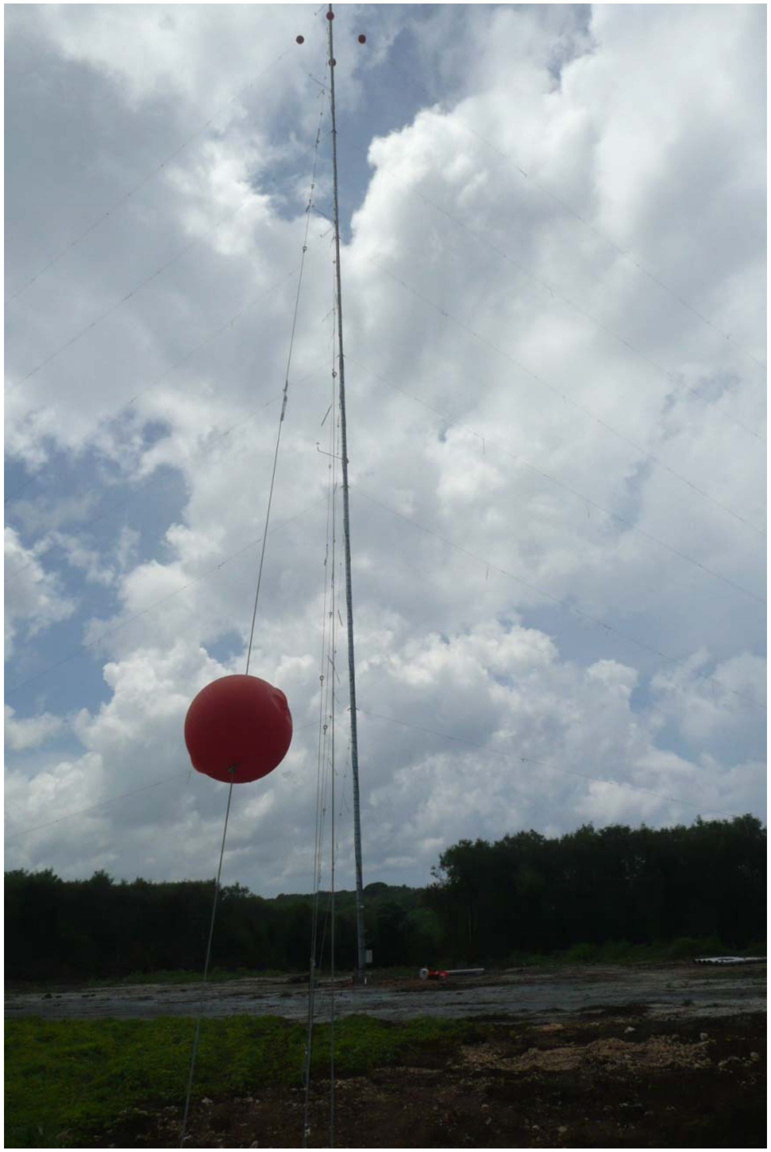
Tower

	30m	40m	50m	50m
Data Points Recov	21193	21193	21193	21193
Ave Spd All Data	5.42	5.72	5.86	5.73
Shear	n/a	0.24	0.13	0.01
Ave Spd January	n/a	n/a	n/a	n/a
Ave Spd February	n/a	n/a	n/a	n/a
Ave Spd March	6.08	6.42	6.60	6.56
Ave Spd April	6.16	6.51	6.66	6.63
Ave Spd May	6.46	6.84	6.97	6.88
Ave Spd June	5.15	5.39	5.52	5.42
Ave Spd July	4.72	4.95	5.13	4.96
Ave Spd August	4.71	4.98	5.13	4.93
Ave Spd Septemb	4.79	5.08	5.20	4.99

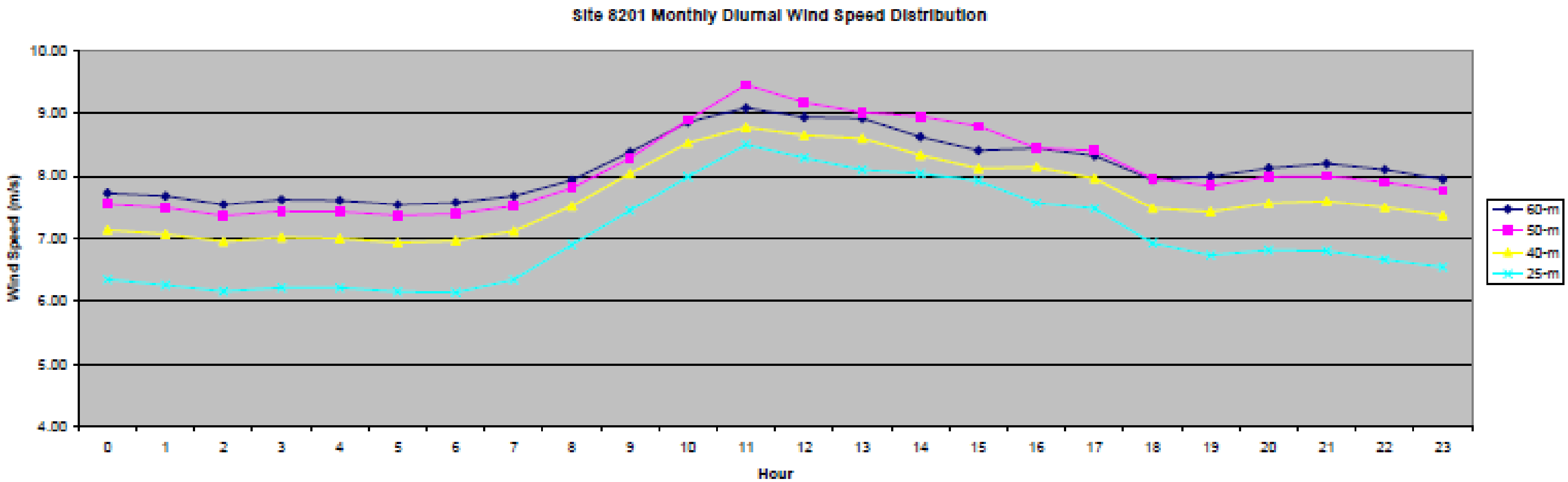


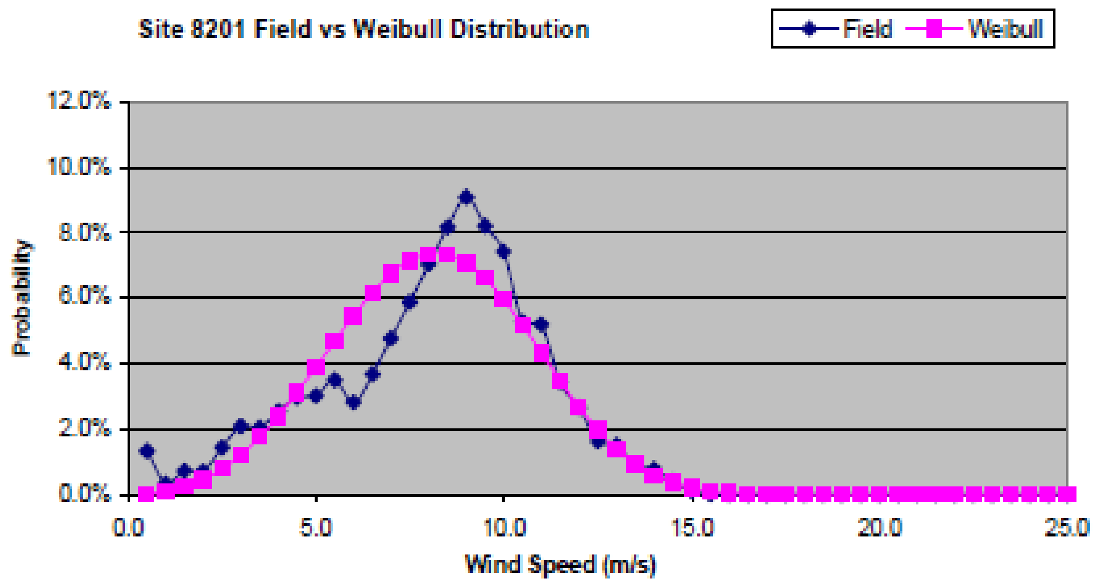
Guam - Navy



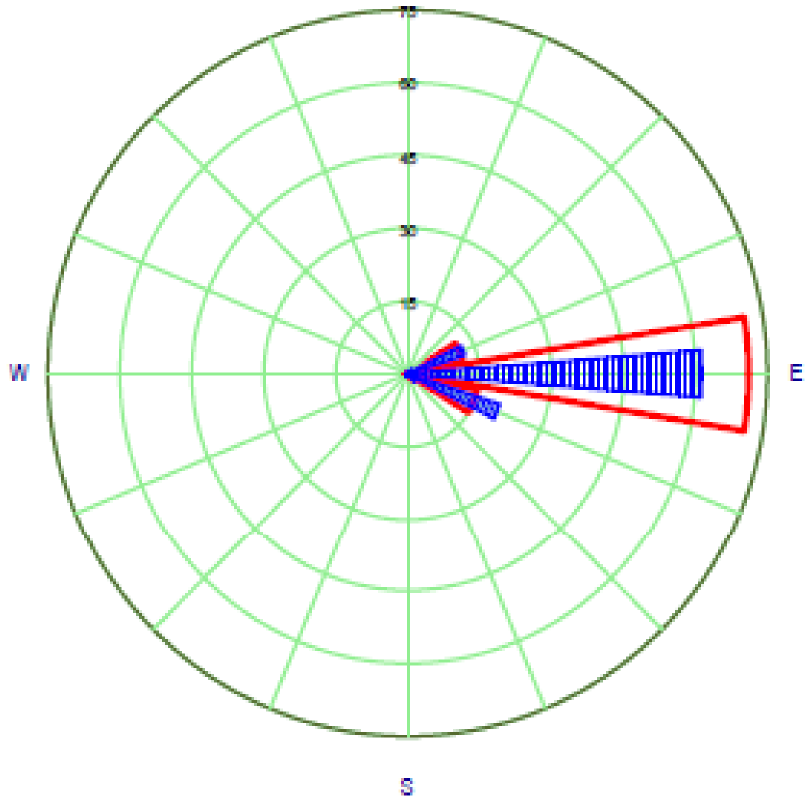


GUAM – Diurnal Wind Profile & Distribution





Guam Wind Report - Wind Rose



Cumulative Wind Rose - Site 8201 (60 m)

VERY steady wind out of the east
– the trade winds

Using Wind Data

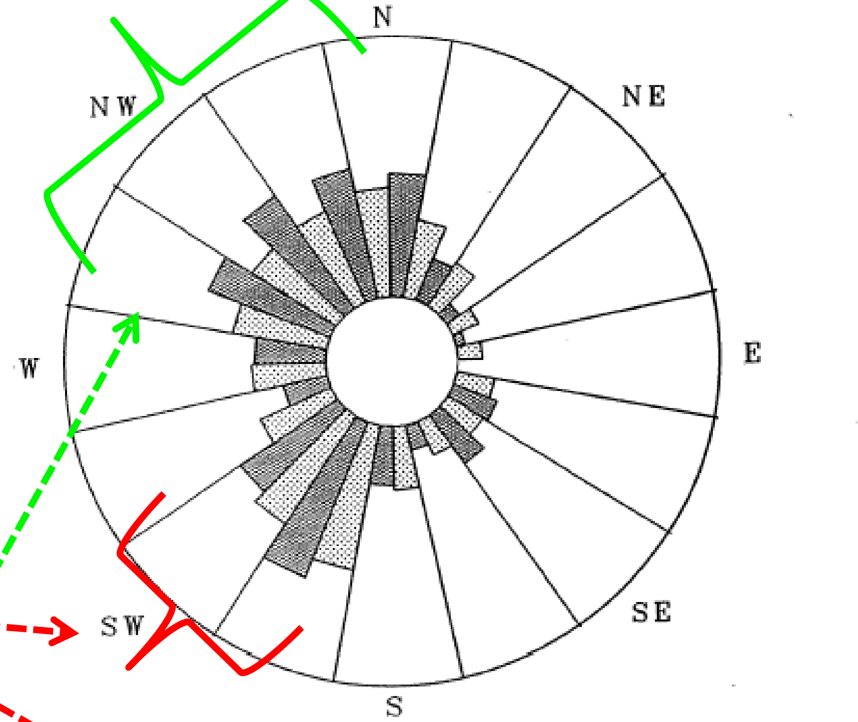
Portsmouth wind data
Sept/98 Aug/99

Summer winds - ~SW
23.5% of the time
23.8% of the wind energy

Winter winds - ~NW -> N
33.6% of the time
43.9% of the wind energy

WIND ENERGY ROSE

Rhode Island
Portsmouth 145-ft level -LH
09-01-1998 to 08-31-1999



= % Turbine Energy = % Time Inner Circle = 0 % Outer Circle = 20 %

Compass Direction				% Time	% Turbine Energy	Mean Speed (MPH)
N	349	-	11	9.1	10.3	13.9
NNE	11	-	[illegible]	6.8	3.8	11.7
NE	34	-	56	4.2	1.3	10.0
ENE	[illegible]	-	79	2.3	0.7	9.9
E	79	-	101	2.1	0.4	8.7
ESE	101	-	124	[illegible]	3.9	13.7
SE	124	-	146	3.5	5.1	15.2
SSE	146	-	169	3.2	2.2	12.1
S	169	-	191	6.4	5.1	13.4
SSW	191	-	214	12.6	14.3	14.3
SW	214	-	236	10.9	9.8	12.8
WSW	236	-	259	6.4	3.7	10.7
W	259	-	281	6.1	5.9	12.7
WNW	281	-	304	7.9	10.9	14.9
NW	304	-	326	8.3	11.6	14.6
NNW	326	-	349	8.3	11.1	14.3

8622 HOURS OF VALID DATA 98% DATA RECOVERY 10-22-1999

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Carpe Ventem

Robi Robichaud

303-384-6969

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National Wind Technology Center &
Deployment & Industrial Partnerships

National Renewable Energy Laboratory

www.windpoweringamerica.gov

Further Information / References

Web Based:

Wind Powering America http://www.eere.energy.gov/windpoweringamerica/

Federal wind siting information center:
hppt://www1.eere.energy.gov/windandhydro/federalwindsiting/index.html

DOE Wind Energy Program: hppt://www1.eere.energy.gov/windandhydro/

American Wind Energy Association http://www.awea.org/

Danish Wind Industry Association guided tour and information.
http://www.windpower.org/en/tour/

Publications:

Ackermann, T. (Ed's), *Wind Power in Power Systems*, John Wiley and Sons, west Sussex, England, (2005).

Hunter, R., Elliot, G. (Ed's), *Wind-Diesel Systems*. Cambridge, UK: Cambridge University Press, 1994.

Wind Energy Explained, J. F. Manwell, J. G. McGowan, A. L. Rogers John Wiley & Sons Ltd. 2002.

Paul Gipe, Wind Energy Basics: A Guide to Small and Micro Wind Systems, Real Goods Solar Living Book.

AWS Scientific Inc. "Wind Resource Assessment Handbook" produced by for the National Renewable Energy Laboratory, Subcontract number TAT-5-15283-01, 1997

Thanks to:

Ken Starcher, Alternative Energy Institute, West Texas A&M University

Important Terms

Cut in wind speed: The wind speed that the turbine starts producing power (may be different than the speed at which the turbine starts spinning)

Rated Wind Speed: The wind speed at which the turbine is producing "rated power" – though "rated power" is defined by the manufacture

Cut out wind speed: The wind speed at which the turbine stops producing power

Shut down wind speed: The wind speed at which the turbine stops to prevent damage

Survival wind speed: Wind speed that the turbine is designed to withstand without falling over

Availability: The amount of time that the wind turbine is available to produce power (Maintenance parameter)

Capacity Factor: The annual energy production of a wind turbine divided by the theoretical production if it ran at full rated power all of the time (Resource parameter)

- The stronger the resource the higher the Capacity Factor
- Usually reported monthly or yearly
- 25-40% is typical, up to 60% has been reported
- Reason for the "only works 1/3 of the time" quote.

Offshore Wind Technology Today

Vestas 2.0 MW Turbine
Horns Rev, DK

Talisman Energy:
Repower 5-MW
Beatrice Fields,
Scotland

GE 3.6 MW Turbine
Arklow Banks

Seimens 2.3 MW Turbines
Middlegrunden, DK

- Initial development and demonstration stage; 22 projects, 1135 MW installed
- Fixed bottom shallow water 0-30m depth
- 2 – 5 MW upwind rotor configurations
- 70+ meter tower height on monopoles and gravity bases
- Mature submarine power cable technology
- Existing oil and gas experience is essential
- Reliability problems and turbine shortages have discouraged early boom in development.
- Cost are not well established in the US.

Offshore Wind Turbines Accessibility is a Challenge