Overview of Current Wind Energy Technologies

Photo from Gary Norton, USDOE

BOEM Offshore Renewable Energy Workshop

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

Topics

- Introduction
- Energy and power
- Wind characteristics
- Wind power potential
- Basic wind turbine theory
- Types of wind turbines
- Review of the current wind market
- Further information

Photo Hawaiian Electric Light Company, *NREL 14703*

Photo from Native Energy Inc., NREL 7593

What Is Wind Power?

The ability to harness power in the wind and put it to work

800-900 years ago in Europe for grain grinding and water pumping

Photo from Ruth Baranowski

140 years ago: agriculture water-pumping wind mills

Photo from Michael Milligan, NREL 13371

70 years ago: electric power

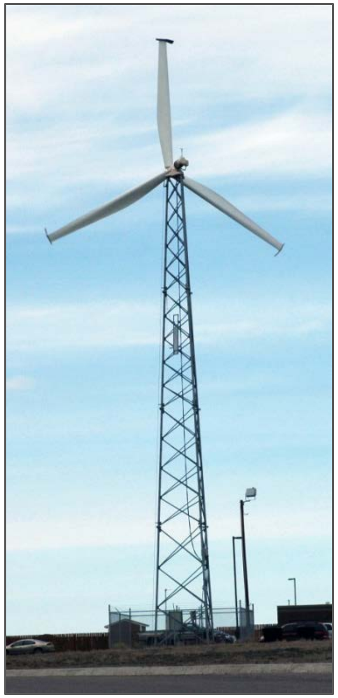
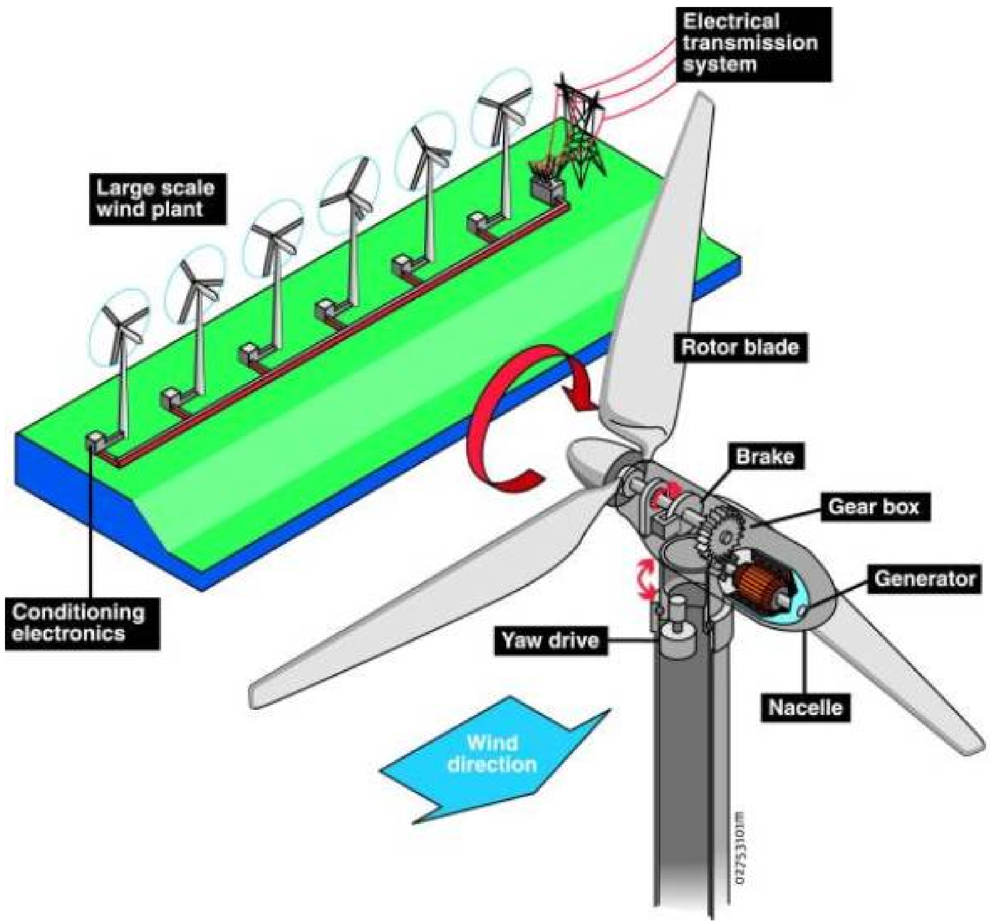


Photo from Bob Gough, NREL 16255

Wind Energy Technology

At it's 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.



Power in the Wind

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

P: power, Watt

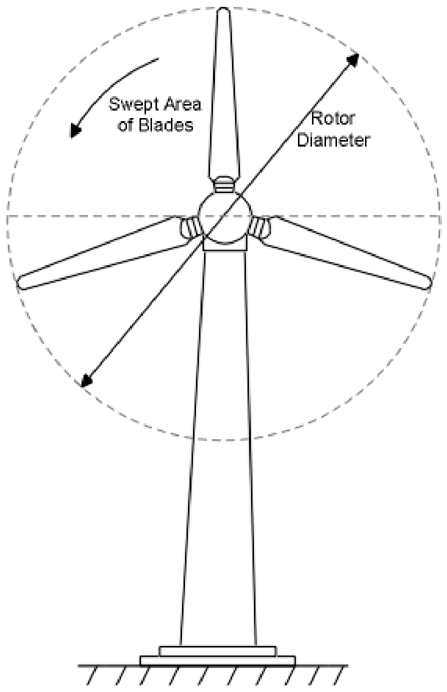
ρ: density of air, kg/m^3

V: wind speed, m/s

We call this the Wind Power Density (W/m^2), which is a measure of the power available in the wind at a specific point or as an average over a longer period of time.

Power From the Wind

$$P = 0.5\,\rho\,Cp\,v^3 A_s$$

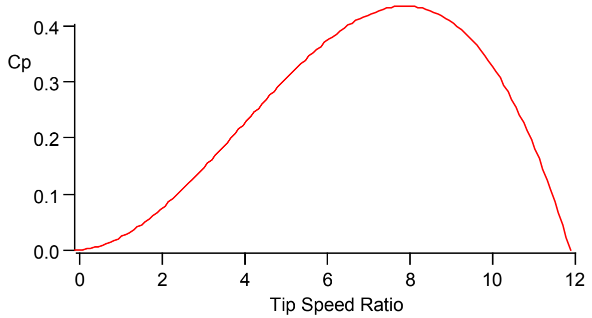


V^3: Doubling of the wind speed results in an eight-fold increase in power.

ρ: High-density air results in more power (altitude and temperature).

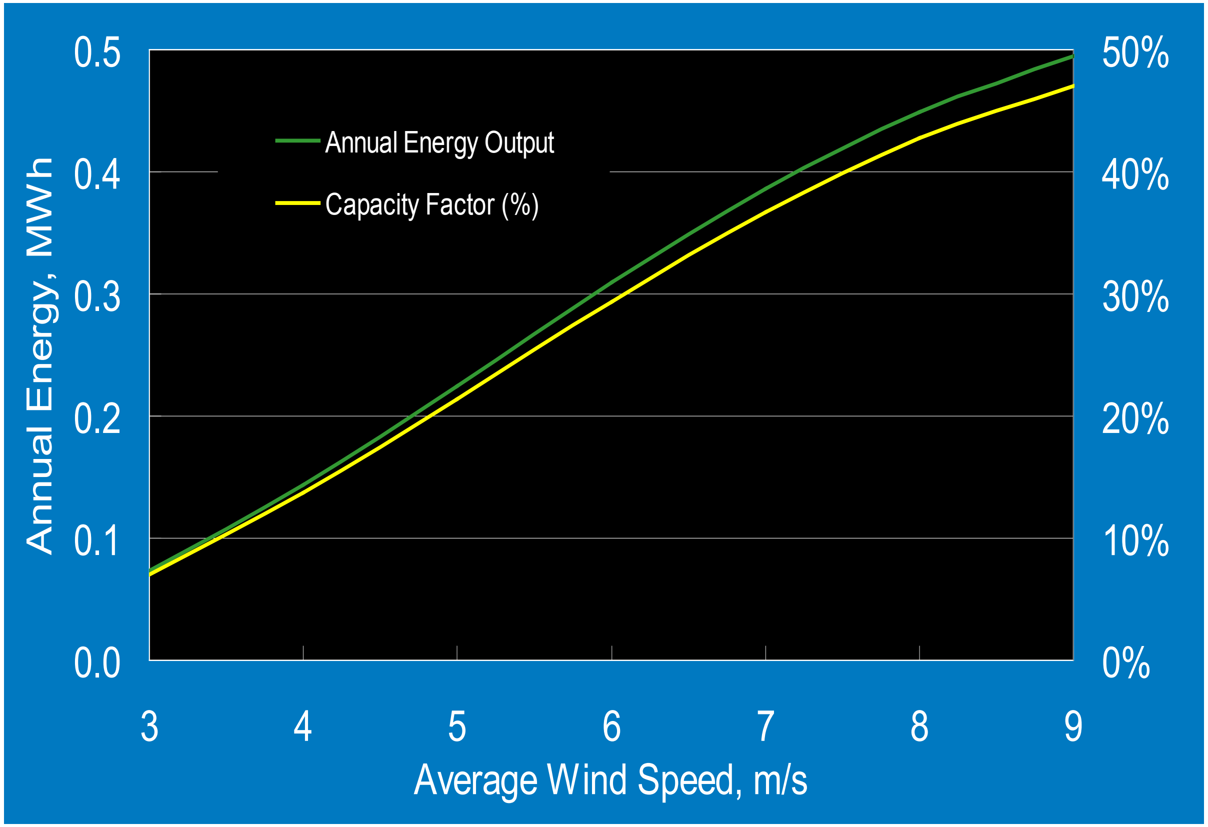
A_s: A slight increase in blade length greatly increases the area.

Cp: Power Coefficient reflects the amount of energy that can be captured from the wind - different types of wind turbines have different maximum theoretical efficiencies but usually between 40% to 50% of available energy (Betz limit ≈ 59%)



Velocity: The Impact of Increasing Wind Speed on Energy Production

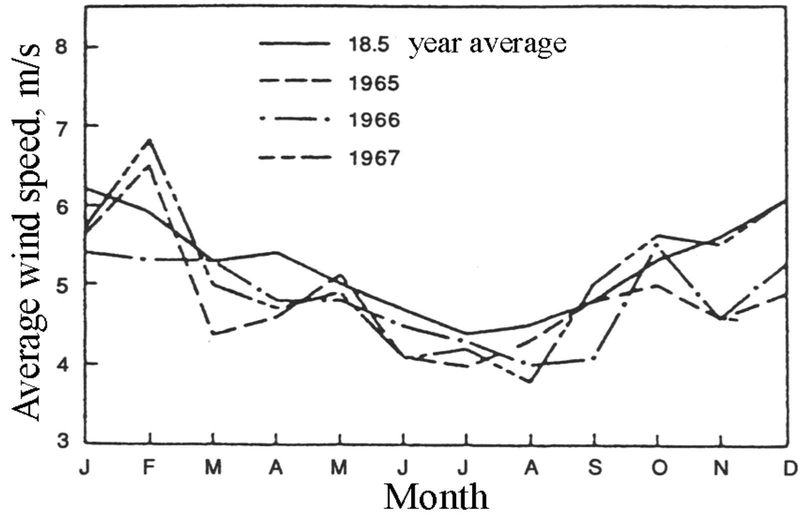
A small increase in wind speed can greatly increase the annual energy production.



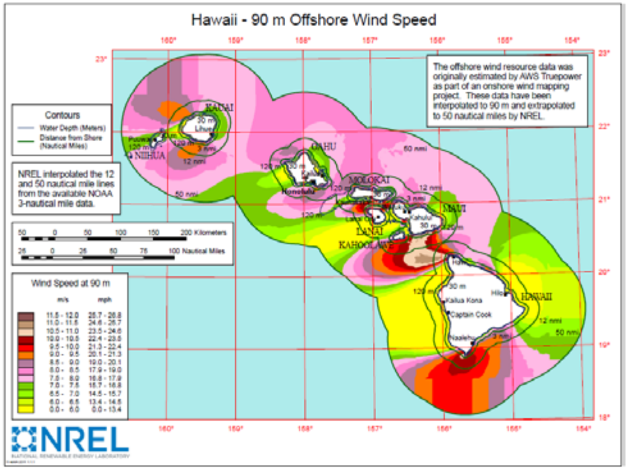
Wind Characteristics and Resources

Understanding the wind resource at your location is critical to understanding energy potential

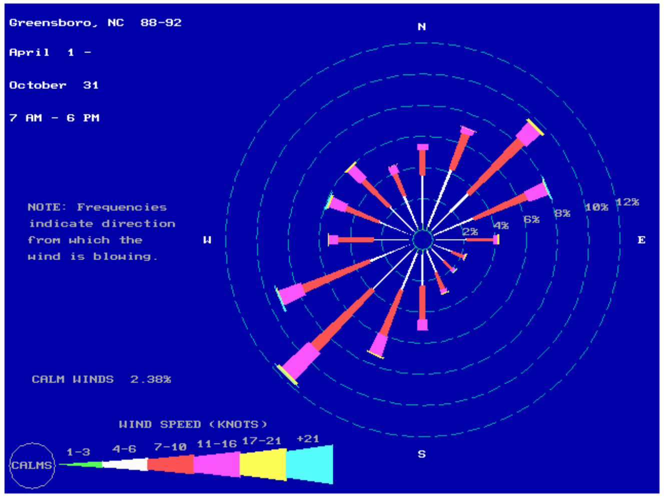
- Wind speed
  - Variability of resource
  - Different scales of data quality
- Wind direction
  - Directionality of strong winds



Seasonal and annual variability at a single location can be high

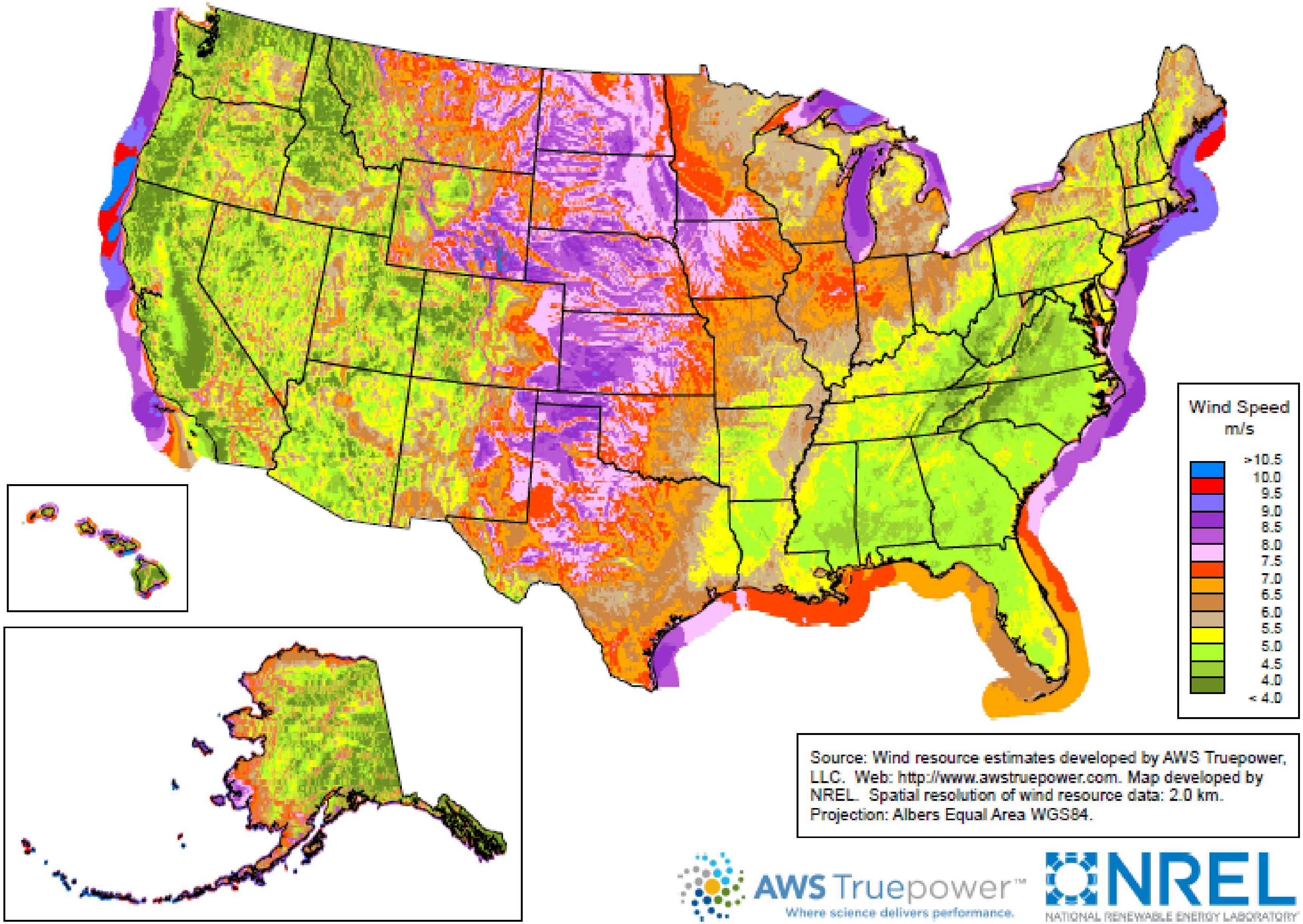


High level wind maps provide initial estimates, but are not sufficient

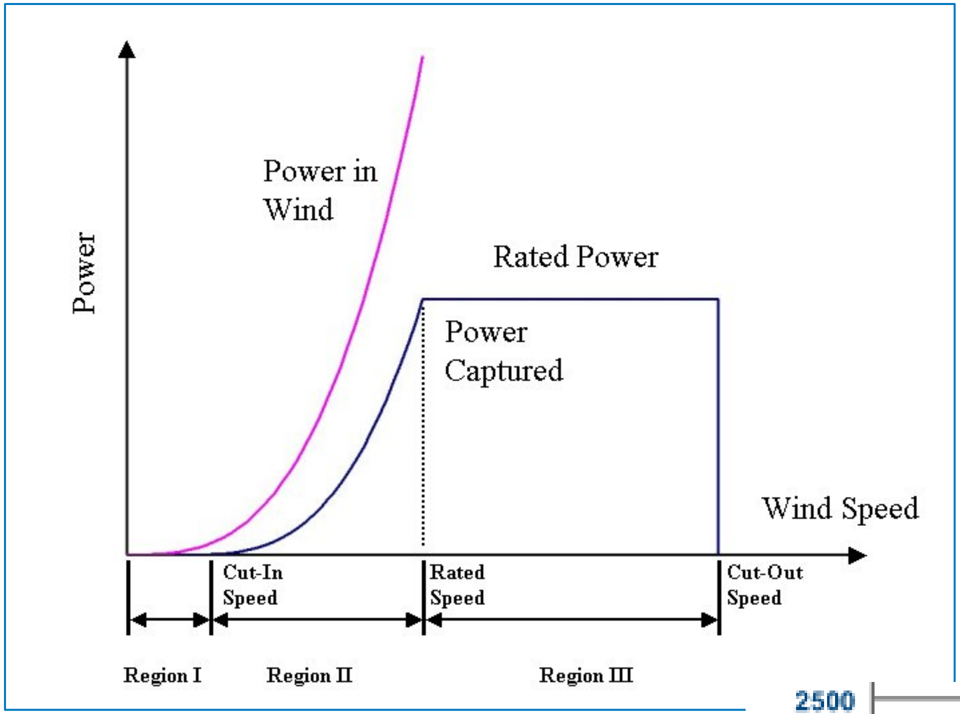


A wind power rose indicates which direction the energetic winds come from, which helps in turbine siting

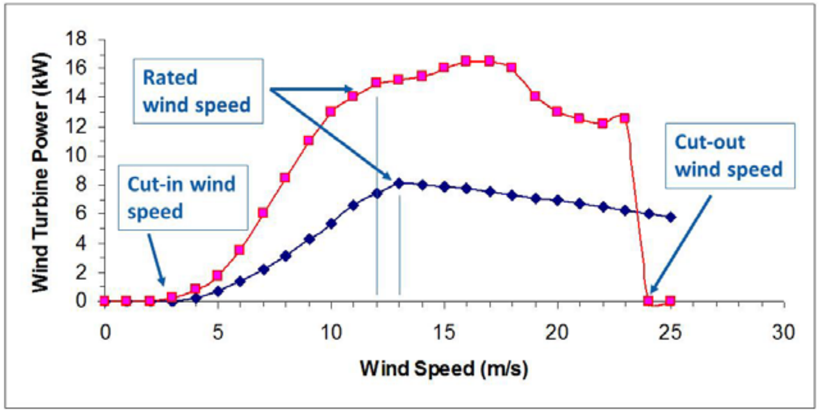
United States - Onshore and Offshore Annual Average Wind Speed at 80 m



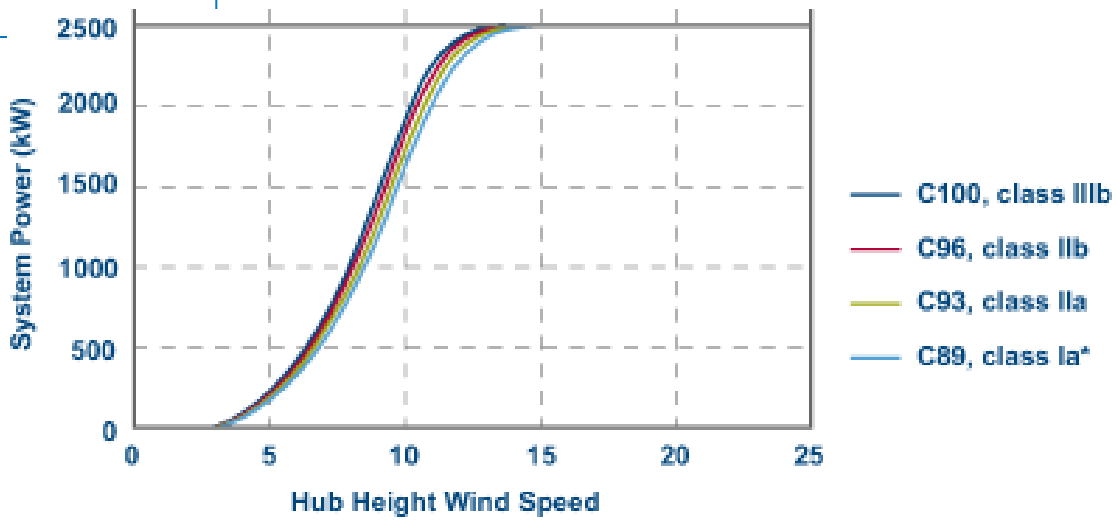
Wind Turbine Power Curve



Theoretical power curve showing different operational regions



Each turbine and turbine type have different theoretical power curves – DC and Stall (above) and variable pitch for multiple class turbines (below)



Important Terms

Cut-in wind speed: The wind speed at which the turbine begins producing power (may be different from the speed at which the turbine starts spinning)

Rated Wind Speed: The wind speed at which the turbine produces “rated power”

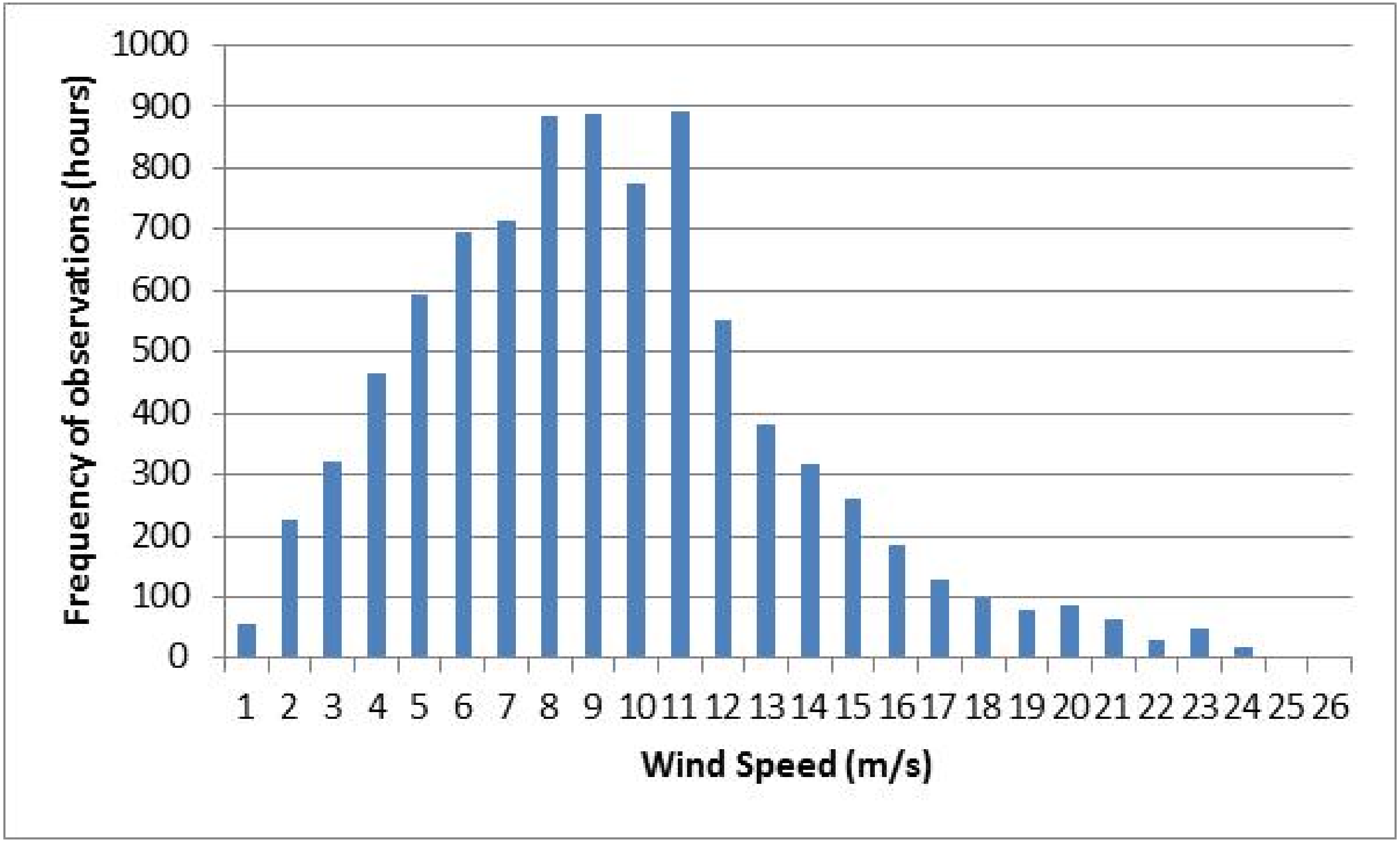
Cut-out wind speed: The wind speed at which the turbine shuts down because stops producing power because no longer sensible to operate

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

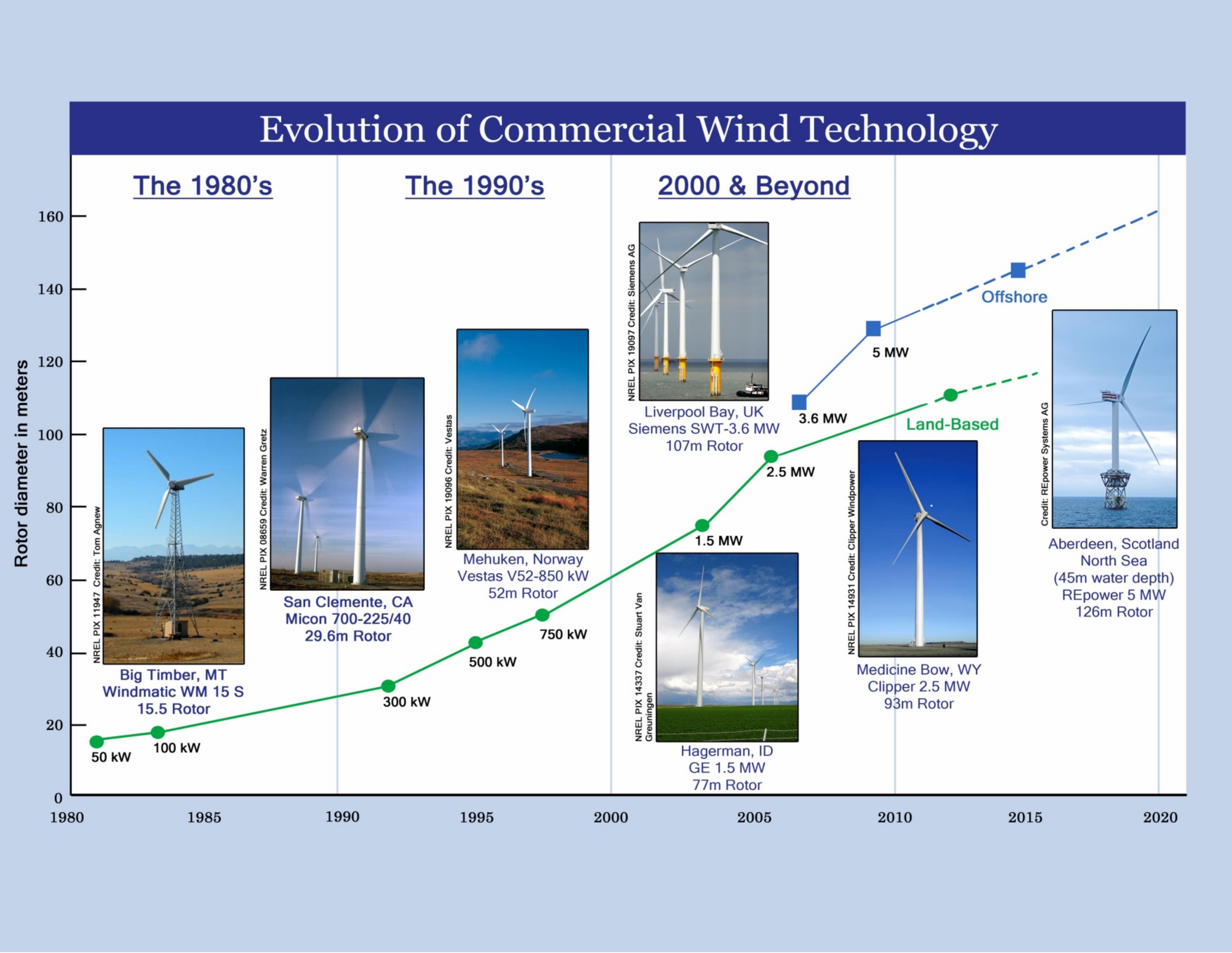
Design wind speed: Wind speed that the turbine is designed to withstand under international wind turbine certification standards

Capacity factor: Actual or estimated energy production at a specific location compared to the maximum production if the turbine ran all of the time

Wind Speed Frequency of Occurrence
Average Wind Speed: 8.8 m/s



Evolution of Commercial Wind Technology



Sizes and Applications


Photo from Bergey Windpower Co. Inc., NREL 02102

Small (≤100 kW)

- Homes
- Farms
- Remote applications (e.g., water pumping, telecom sites, icemaking)


Photo from Tjaden Farms, NREL 13764

Mid-scale (100-1,000 kW)

- Village power
- Hybrid systems
- Distributed power


Photo from Native Energy Inc., NREL 17593

Large, land-based (1-3 MW)

- Utility-scale wind farms
- Large distributed power


Photo from HC Sorensen, NREL 17855

Large, offshore (3-7 MW)

- Utility-scale wind farms, shallow coastal waters
- No U.S. installations

Types of Lift Turbines

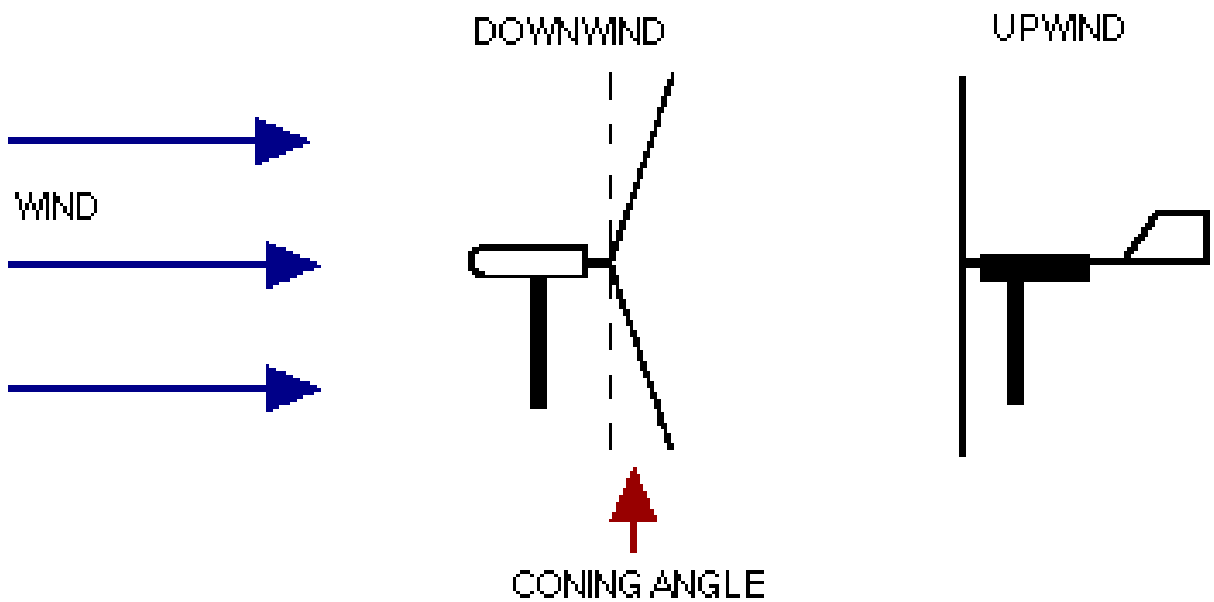
HAWT

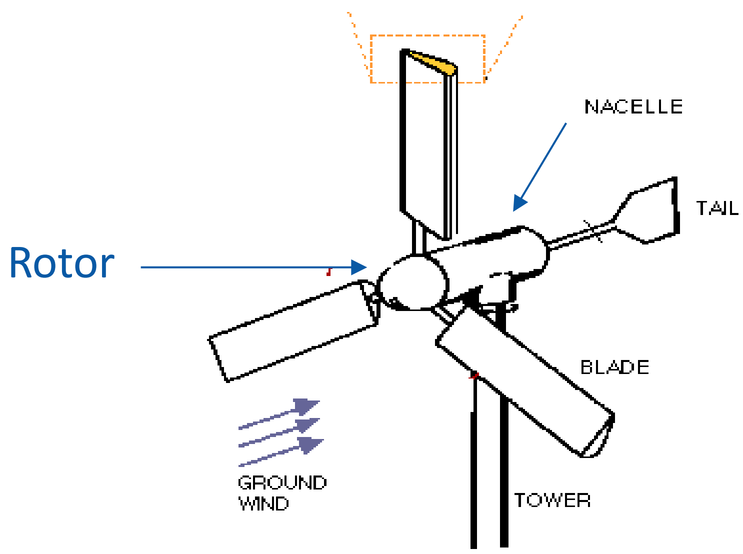
Photo by Lee Jay Fingersh, NREL 16389

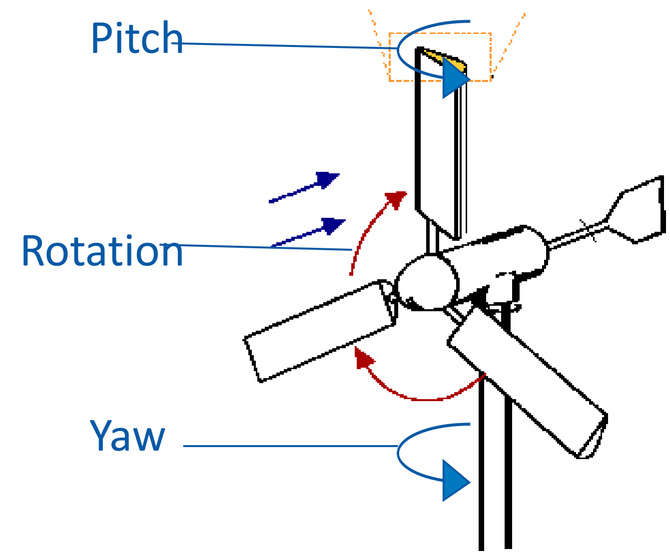
VAWT

Photo from aarchiba (Wikipedia Commons)

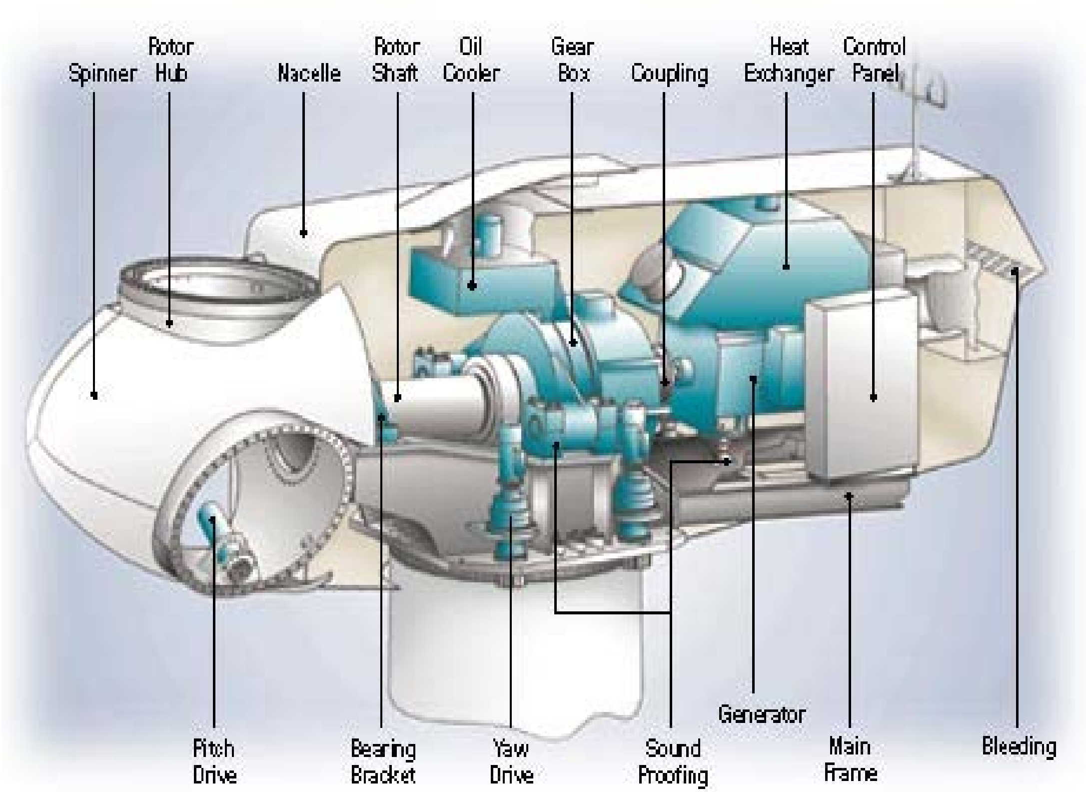
Basic Properties of HAWTs





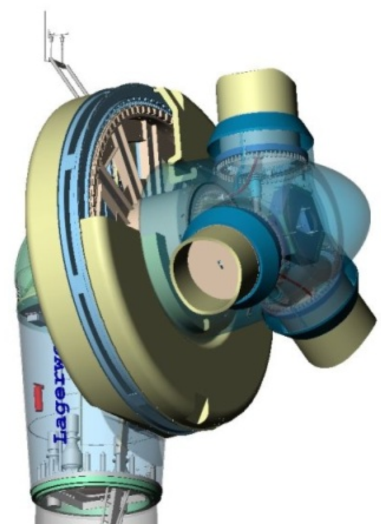


Large Wind Turbines



Components of a typical constant speed induction wind turbine

- Typically induction or variable-speed permanent-magnet generators
- Create AC power supplied to the grid
- Actively controlled



Direct drive generator (DDG) wind turbines simplify tower top components

Characteristics of Large WTGs

Direct drive or geared drivetrains

- Gear driven turbines have the lowest weight and initial cost
- Geared drivetrain failures contribute to O&M costs, many more moving parts
- DDG use of rare earth magnets – that have some supply challenges
- Technology improvements leading to lower weight (hence cost) DDG are sought by most major turbine manufacturers
- Power electronics in many DDG turbines allow much great control of wind turbine electrical output

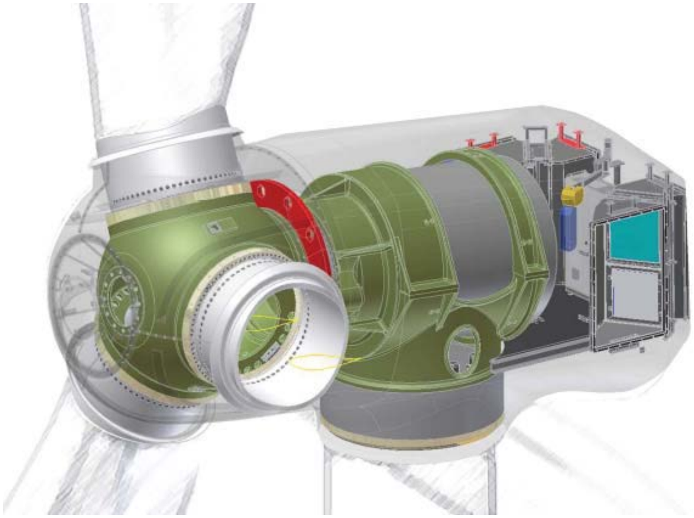
Power system control

- Variable pitch: The rotation (pitch) of each blade is individually controlled to control lift
- Fixed pitch (stall regulated): Blade shape varies over its length to control lift (Not typically used currently)

Innovative New Technologies

- Modular blades and drivetrains
- Advanced drivetrain configurations
- Flexible downwind turbines
- Active controls for load reduction
- Superconducting direct-drive generators
- Floating offshore turbines
- Taller towers with innovative installation systems

Bottom line is that the industry is continuing to innovate and technology is evolving rapidly



Graphic: Courtesy of American Superconductor

Siemens Wind Power

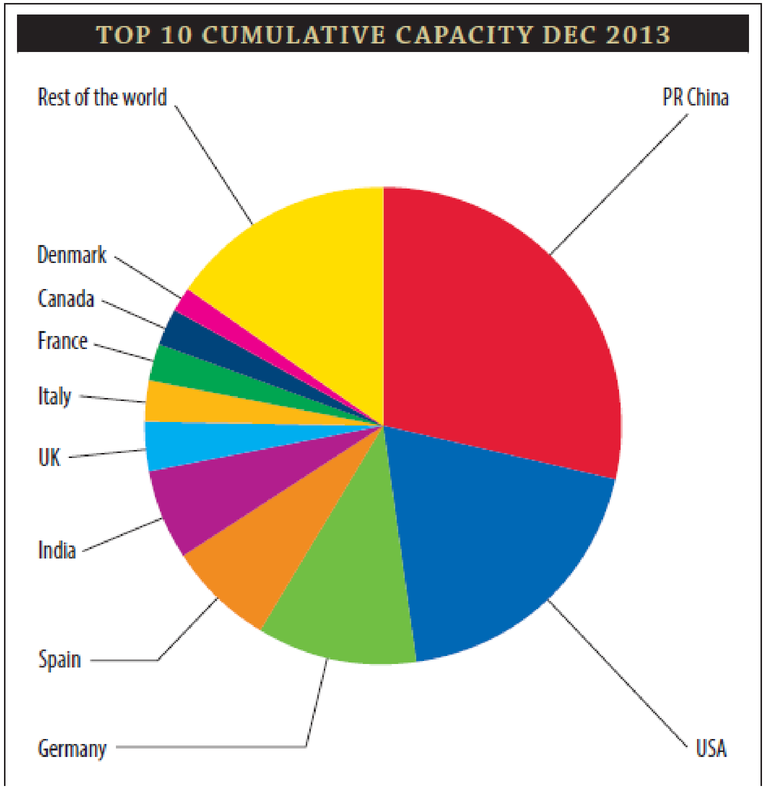
Standards in the Wind Industry

- International standards (International Electrical Commission or IEC) for utility scale turbines is very developed and supported by the industry.
  - IEC standards have some deficiencies for offshore but are being upgraded
  - Certification is not required for development in the USA.
  - Reliability is an issue (gearboxes, blades) and standards are being strengthened to address these issues as understanding improves
  - Warranties are general common – but contracting language is important.
- The small wind turbine industry is less organized & lacks working standards.
  - The current IEC small turbine standards were based on those for utility scale turbines and are generally not used due the high cost of compliance
  - Some turbines do not have a good track record
  - Small wind turbine testing & certification schemes for North America are in place (Small Wind Certification Council and AWEA Small Wind Test Standard).
  - Testing centers are being implemented to allow for independent testing
- Don't believe everything you read (e.g., a turbine is "bird friendly" or "a breakthrough technology") as these claims are generally unsupported.
- Some turbine manufactures and developers do not have much experience.

U.S. Decline in Annual Instillations, but Still Strong International Growth

Annual Capacity (2013, MW)		Cumulative Capacity (end of 2013, MW)	
China	16,088	China	91,460
Germany	3,237	**United States**	**61,110**
India	1,987	Germany	34,468
United Kingdom	1,833	Spain	22,637
Canada	1,599	India	20,589
United States	**1,087**	United Kingdom	10,946
Brazil	948	Italy	8,448
Poland	894	France	8,128
Sweden	724	Canada	7,813
Romania	695	Denmark	4,747
Rest of World	7,045	*Rest of World*	51,031
TOTAL	**36,137**	**TOTAL**	**321,377**

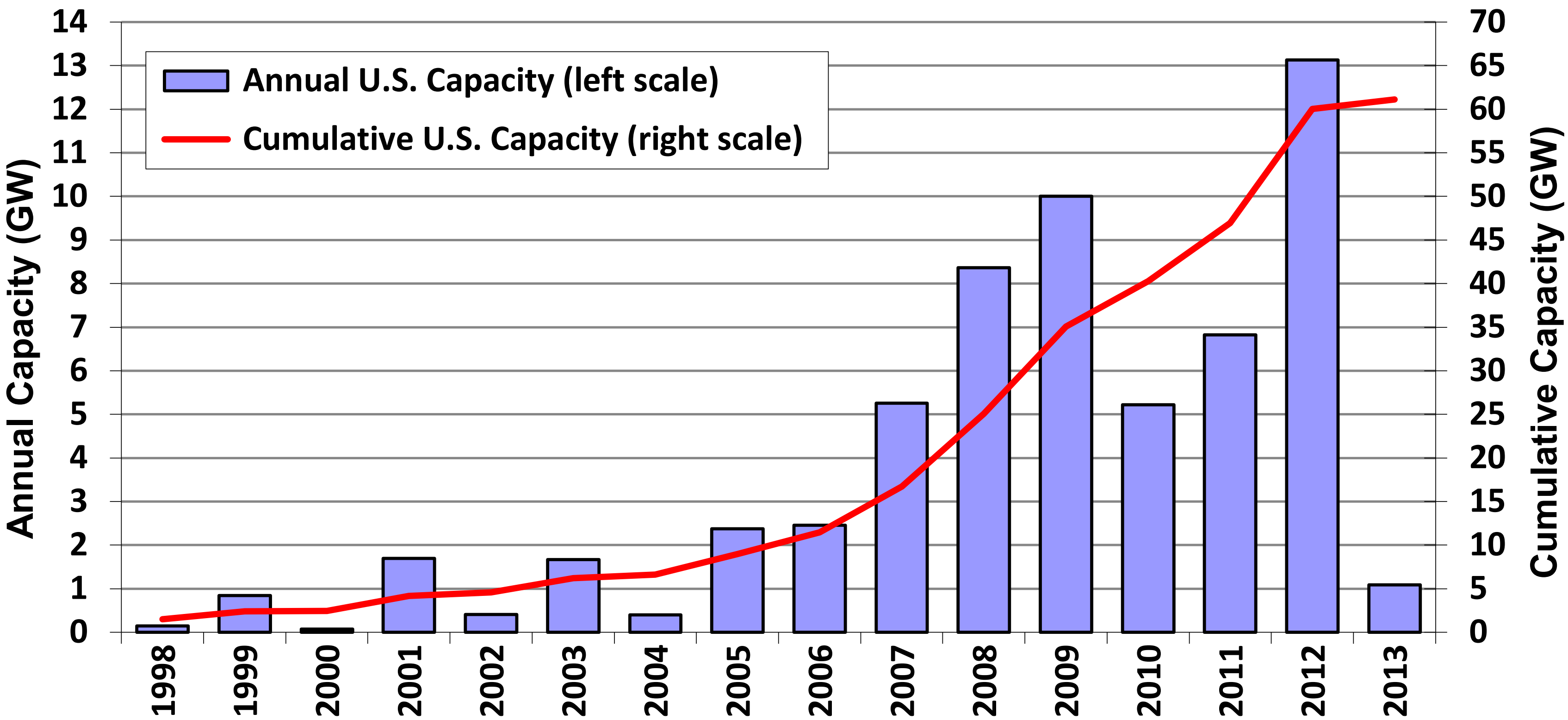
Source: Navigant; AWEA project database for U.S. capacity



Source: GWEC 2013 Annual Report

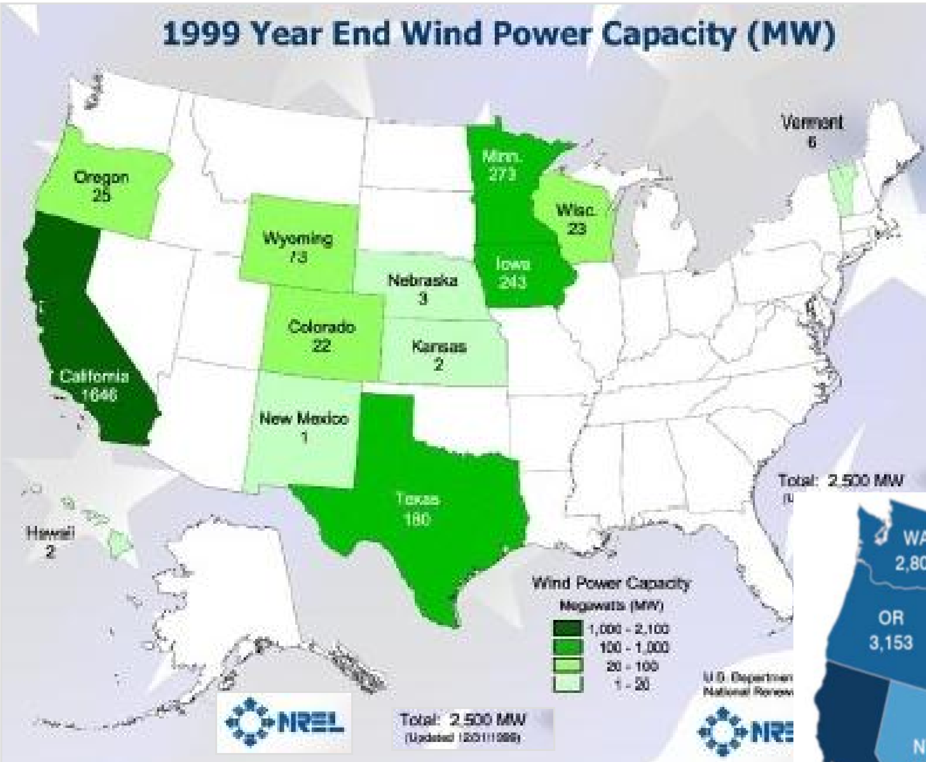
- 36 GW installed worldwide in 2013
- Global additions 20% lower in 2013, led by large decline in the U.S.
- China still seeing very strong growth, installing almost half of the capacity added in 2013

US Wind Power Additions Stalled in 2013



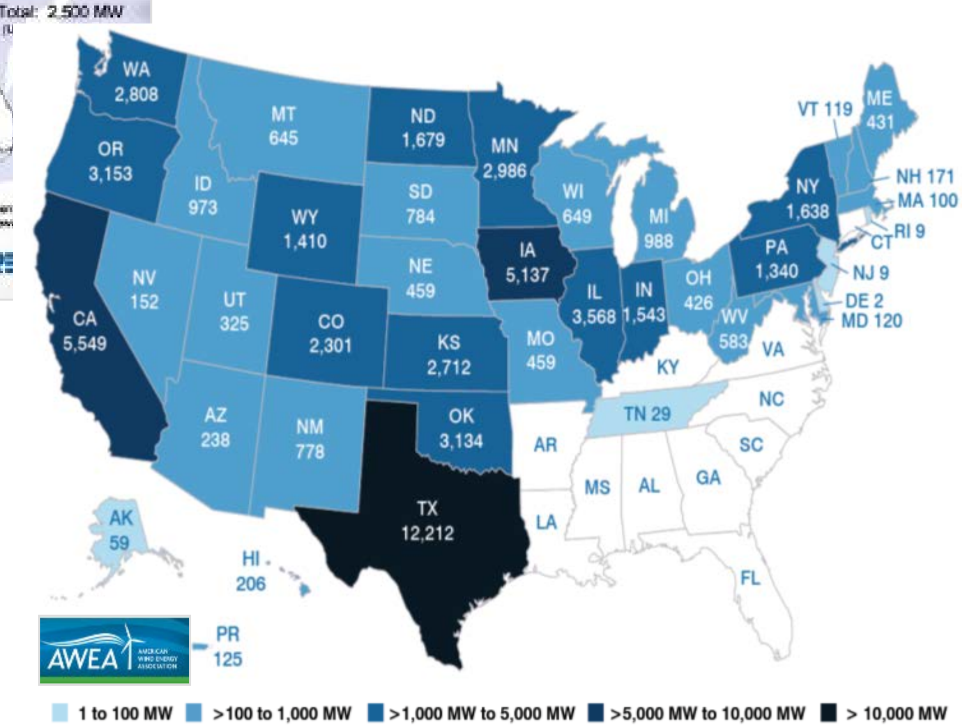
- Only 1,087 MW of New Capacity Added in 2013
- Capacity additions in 2013 were just 8% of 2012 additions
- $1.8 billion invested in wind power project additions in 2013
- Cumulative wind capacity up by less than 2%, bringing total to 61 GW

Installed Wind Capacities 1999 – 2014

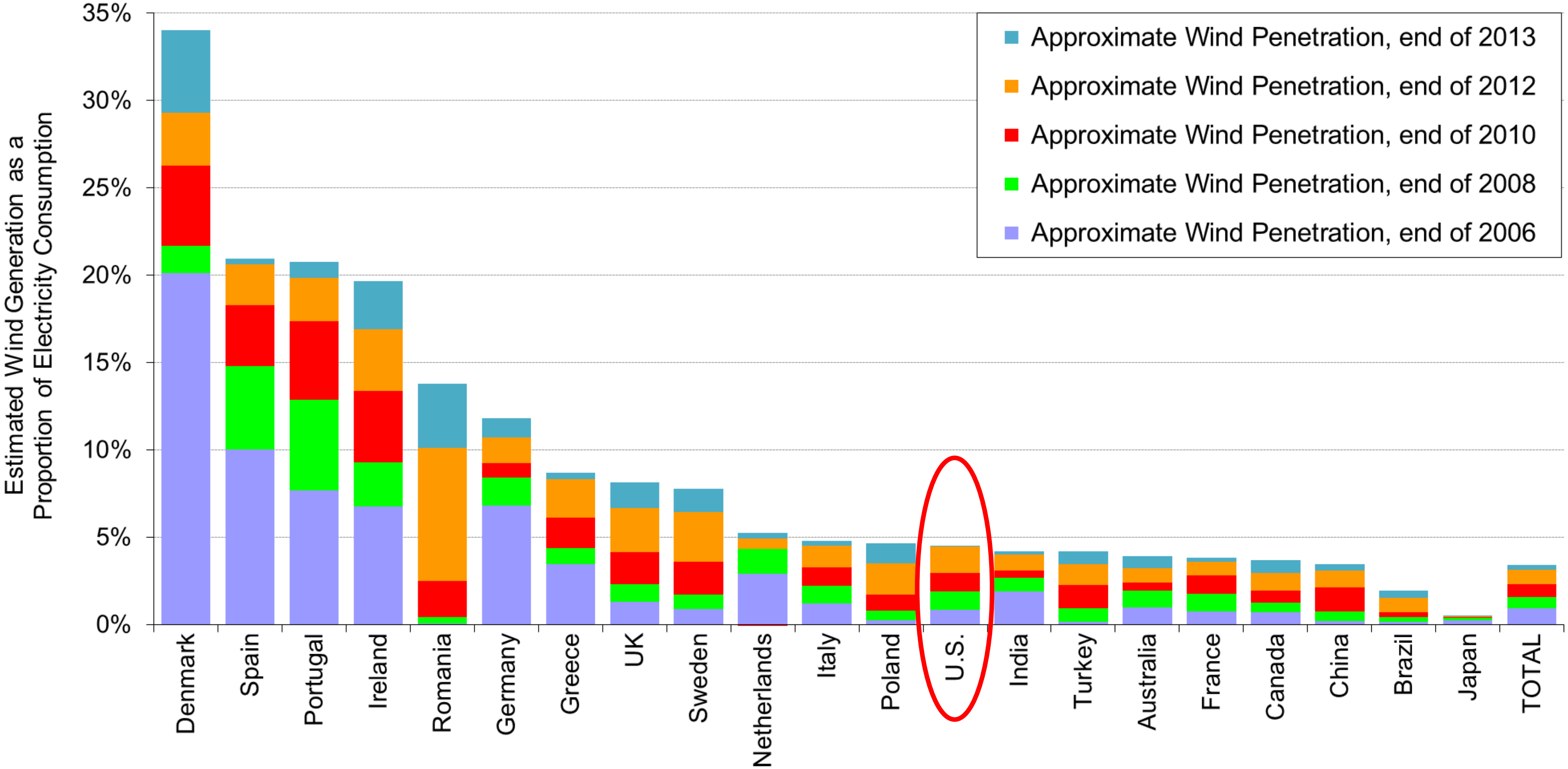


Total Installed Capacity:
2,500 MW
As of December 1998

Total Installed Capacity:
61,108 MW
As of January 2014

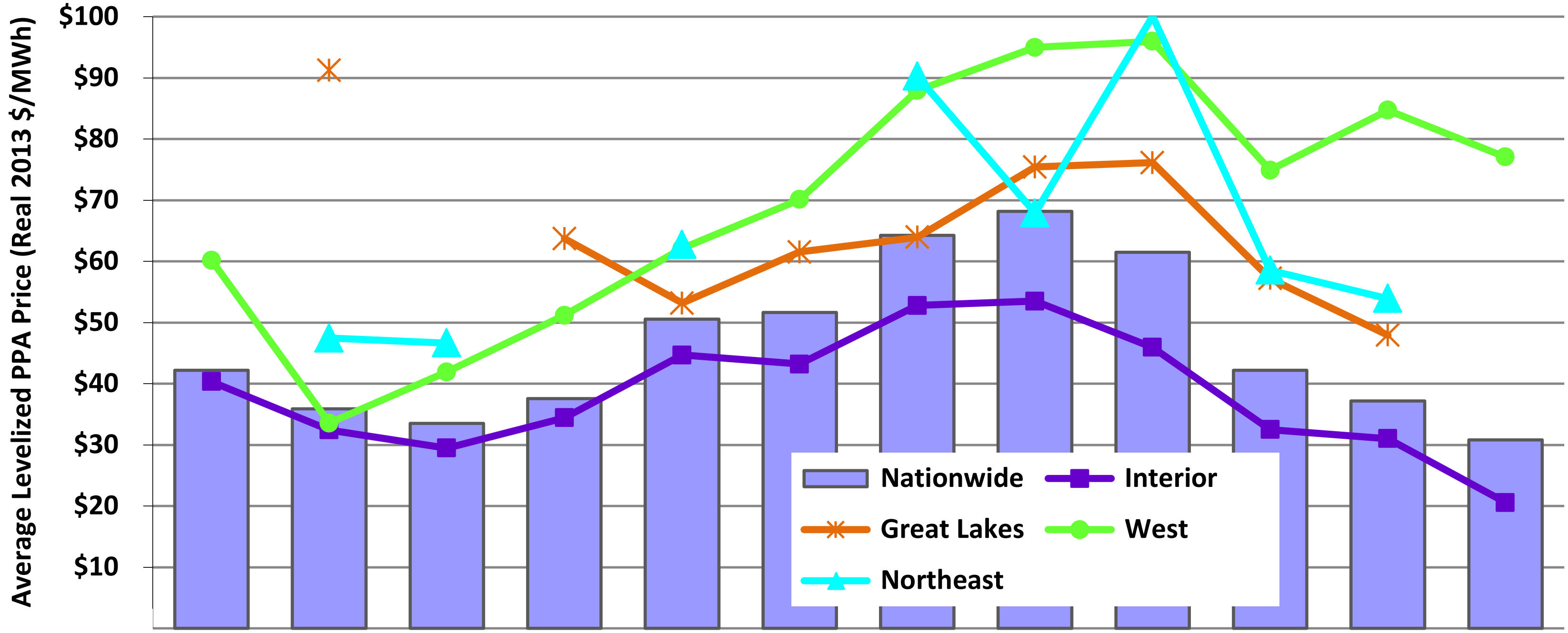


Wind as a Percentage of Electricity Consumption



- High wind contribution possible in nations with strong electrical interties (Ireland is the exception)
- In the US - nine states with > 10% wind generation, two states with ~ 24% wind generation and some instances of short term over 60%

Steep Recent Decline in Pricing

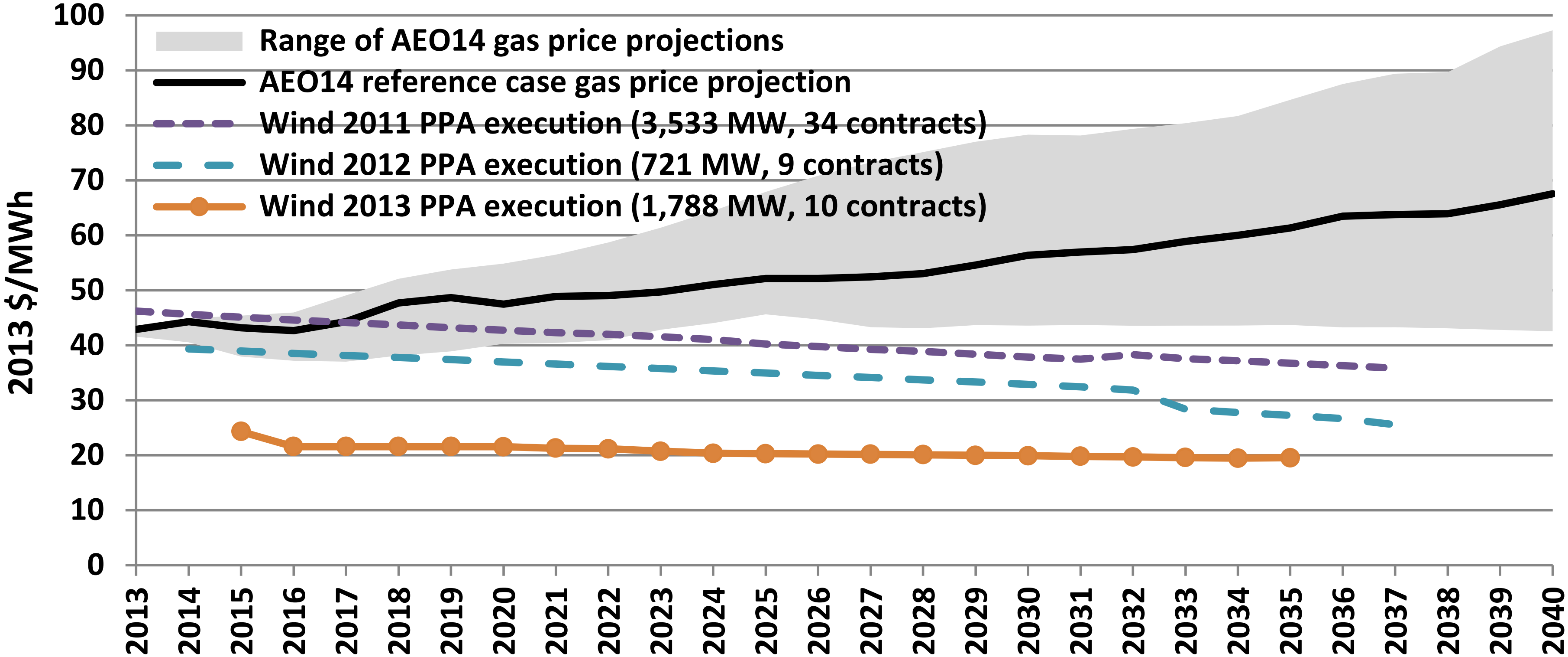


PPA Year:	1996-99	2000-01	2002-03	2004-05	2006	2007	2008	2009	2010	2011	2012	2013
Contracts:	10	17	24	30	30	26	39	48	41	34	9	10
MW:	553	1,249	1,382	2,190	2,311	1,781	3,465	4,040	4,197	3,533	721	1,788

- Current PPA prices rival lows reached a decade ago
- Turbine costs down significantly over last several years leading to an overall reduction in project costs
- Capacity factor has remained largely unchanged as turbine are forced into lower resource areas or transmission constraints (Curtailment)

2013 Wind Technology Market Report

Long term - Wind Prices are still Hard to Beat:



- Over the long term, wind can compete head to head in a subsidized energy market
- In the near term wind costs competitive with future cost of natural gas
- Even without the subsidies (PTC), wind still competes quite well against the subsidized NG and provides huge hedge against NG price volatility

Wind Power Drivers

- Declining costs
- Long term price certainty
- Public support leading to:
  - Federal and state policies
  - Green power markets
- Regional economic development
- Energy security
- Low environment / public impact
- Reduced carbon risk

Environmental Benefits

Environmental impacts of wind are limited to immediate locality.

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

Many studies shown that wind has one of the lowest impacts of any power generation technology

PIX 15215

Key Issues for Wind Power

- Policy uncertainty
- Transmission: FERC rules, access, new lines, allocation of costs
- Operational impacts: intermittency, ancillary services
- Accounting for non-monetary value: green power, no fuel price risk, reduced emissions
- Siting and permitting: environmental impacts, avian, federal land
- Social acceptance: noise, visual, home values, public perception

NREL 19498

Further Information / References

Web:

- WINDExchange: http://apps2.eere.energy.gov/wind/windexchange/
- American Wind Energy Association: www.awea.org
- Danish Wind Industry Association guided tour and information: www.windpower.org/en/tour/
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Carpe Ventum

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