NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Research Needs in Wind Energy

Natural Gas – The Path to Clean Energy Forum

November 18, 2010

Scott Schreck

NREL's National Wind Technology Center

NREL/PR-5000-49975

Overview

- Genesis of 20% wind energy
- How much energy is 20%
- Is there enough wind to reach 20%
- Technology opportunities & challenges

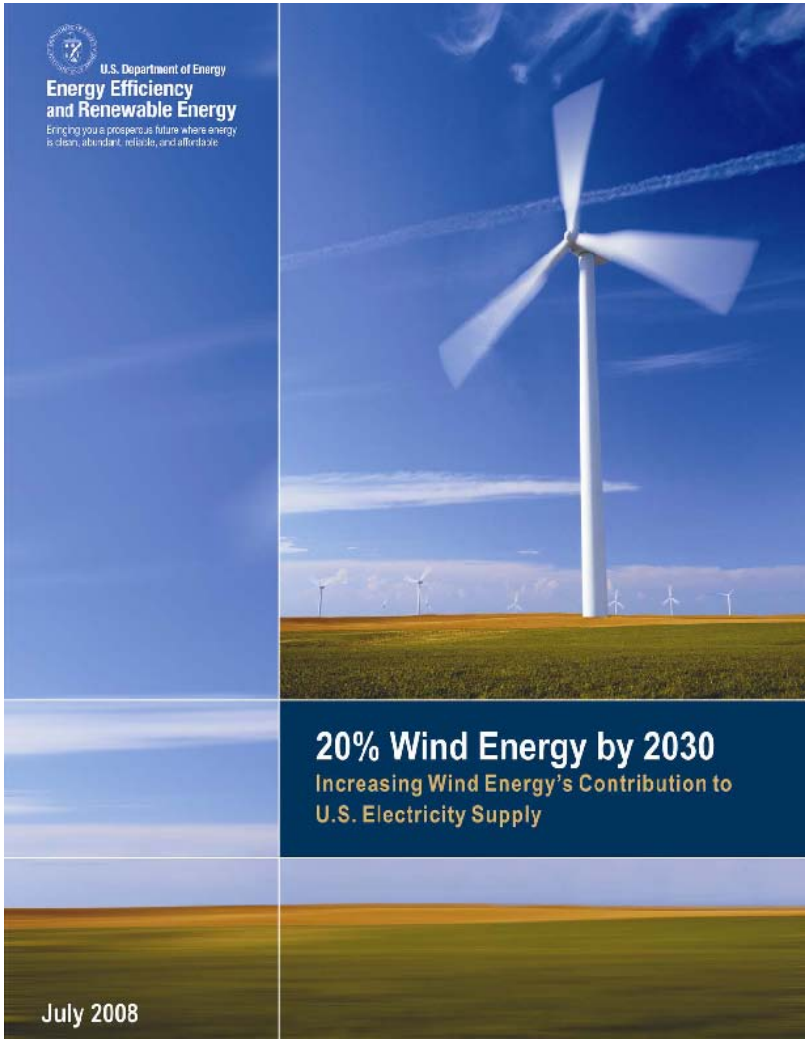
A New Vision For Wind Energy in the U.S.

State of the Union Address

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

Advanced Energy Initiative

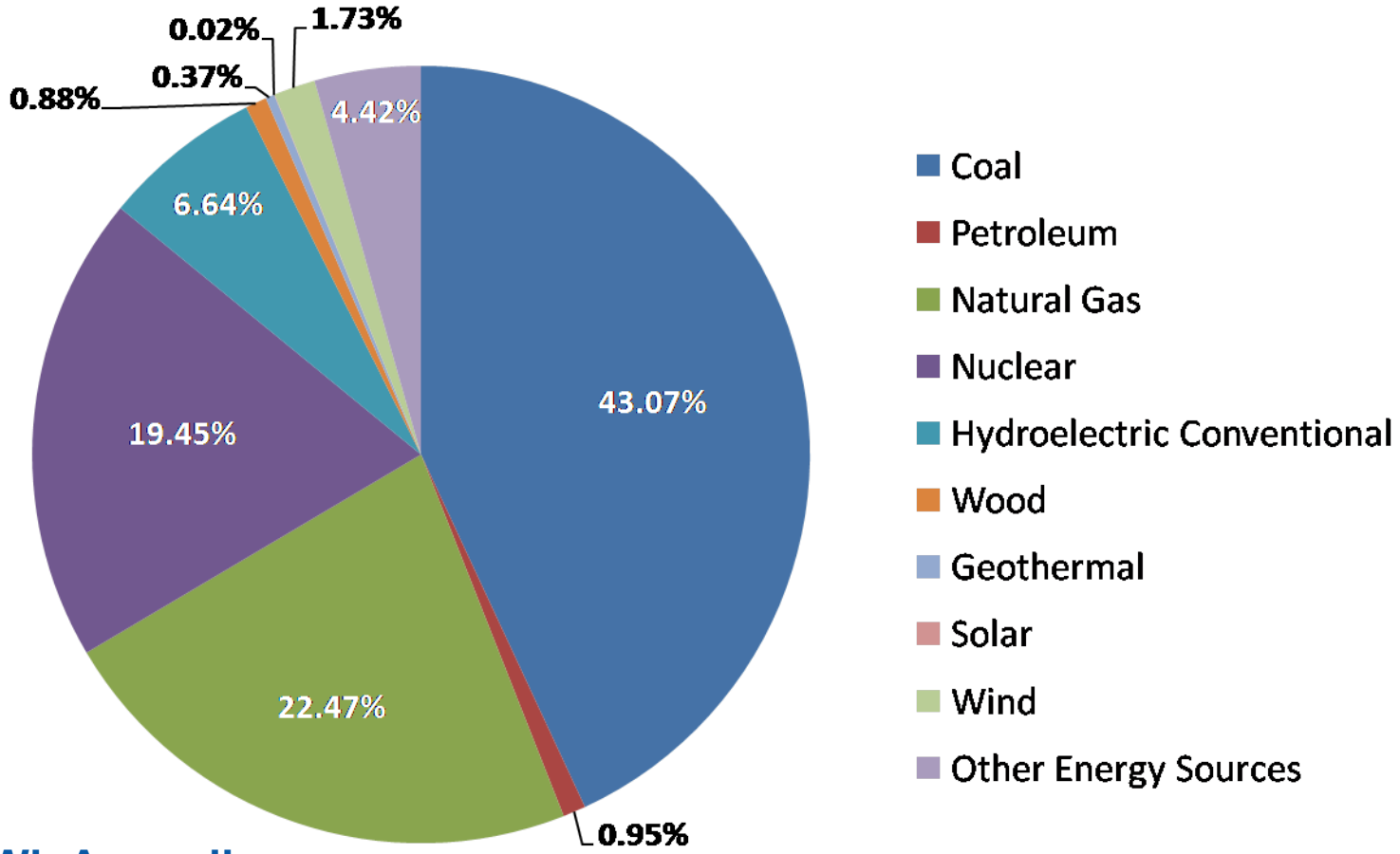
"Areas with good wind resources have the potential to **supply up to 20% of the electricity** consumption of the United States."



Administration's Renewable Energy Goals

- Double renewable energy capacity by 2012
- 10% renewable energy by 2012
- 25% renewable energy by 2025
- Create 5 million new green jobs
- 80% GhG reduction (from 1990 levels) by 2050
- Informed by “20% wind energy by 2030” landmark report issued by DOE in May 2008

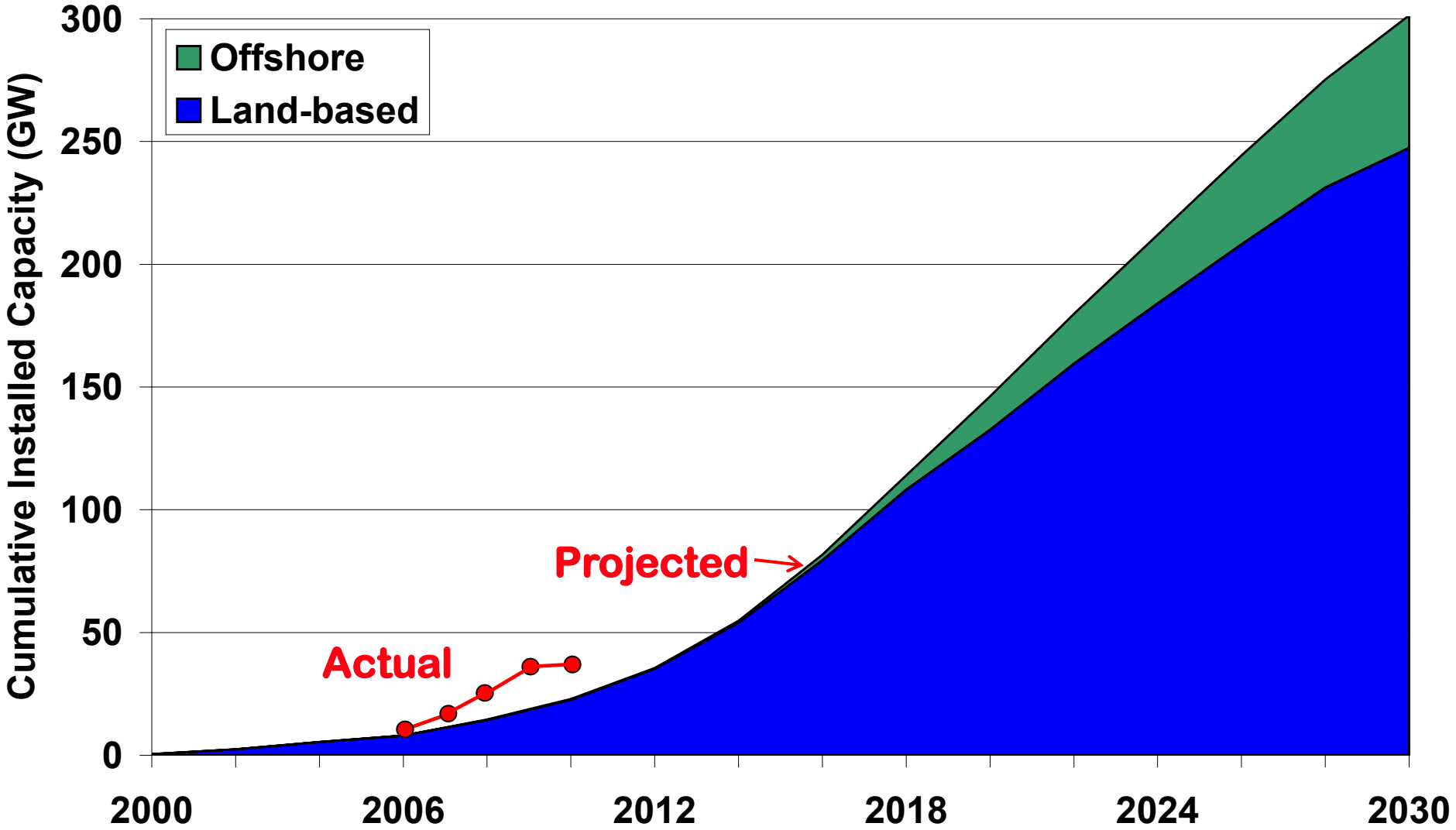
Electrical Power Generation by Source



3700 TWh Annually
(0.42 TW Continuous energy use)

Source: *Electric Power Monthly*, March 15, 2010
http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

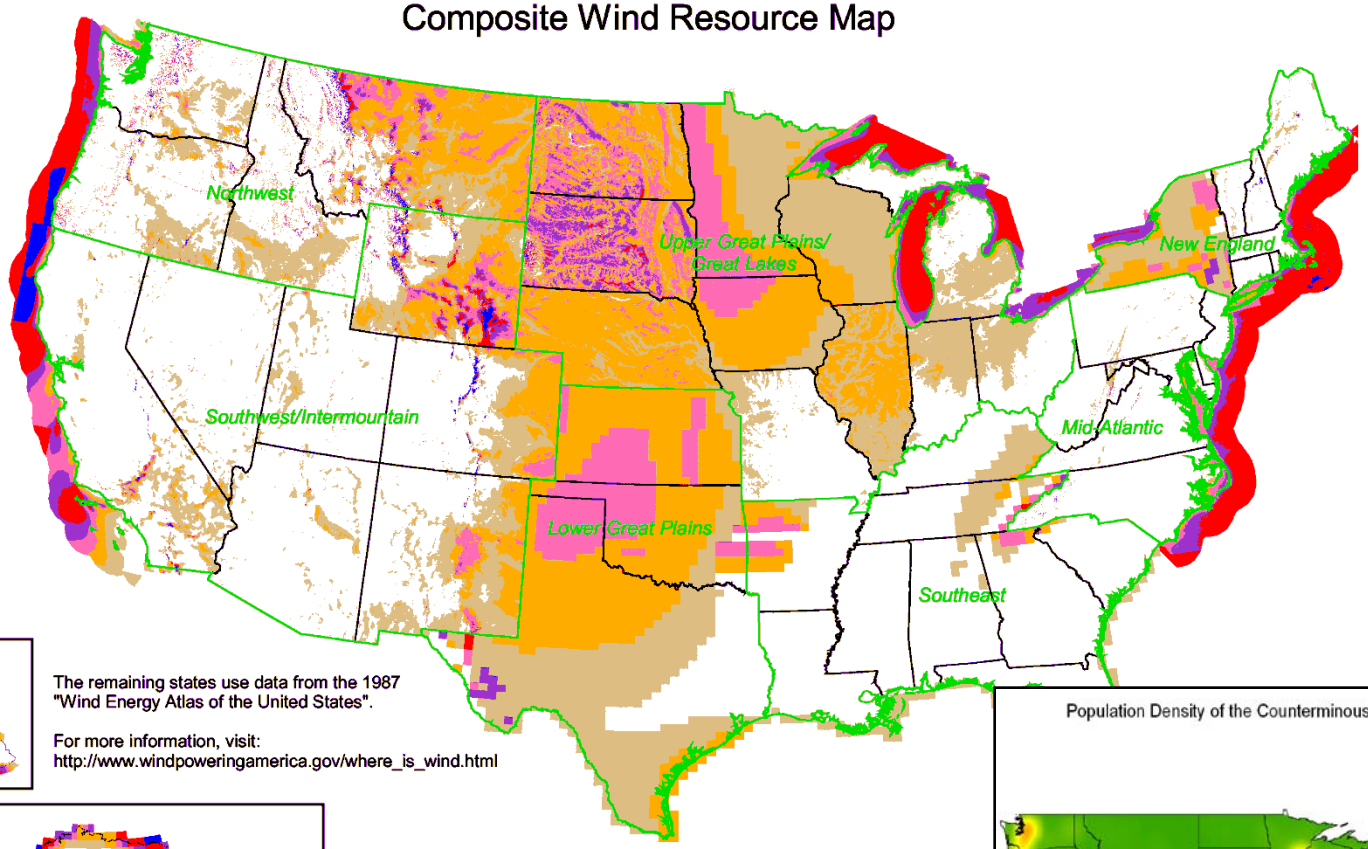
20% Requires 300 GW - Land & Offshore

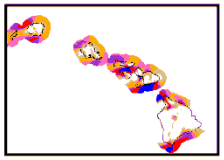


U.S. Wind Resource & Electrical Load

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)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)

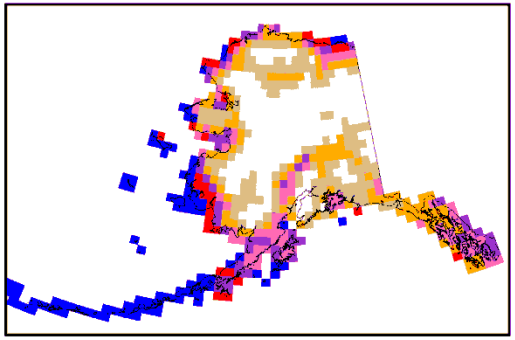
Composite Wind Resource Map





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

For more information, visit:
http://www.windpoweringamerica.gov/where_is_wind.html

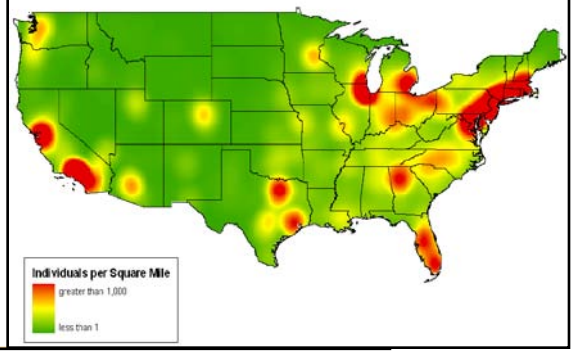


Wind Power Classification

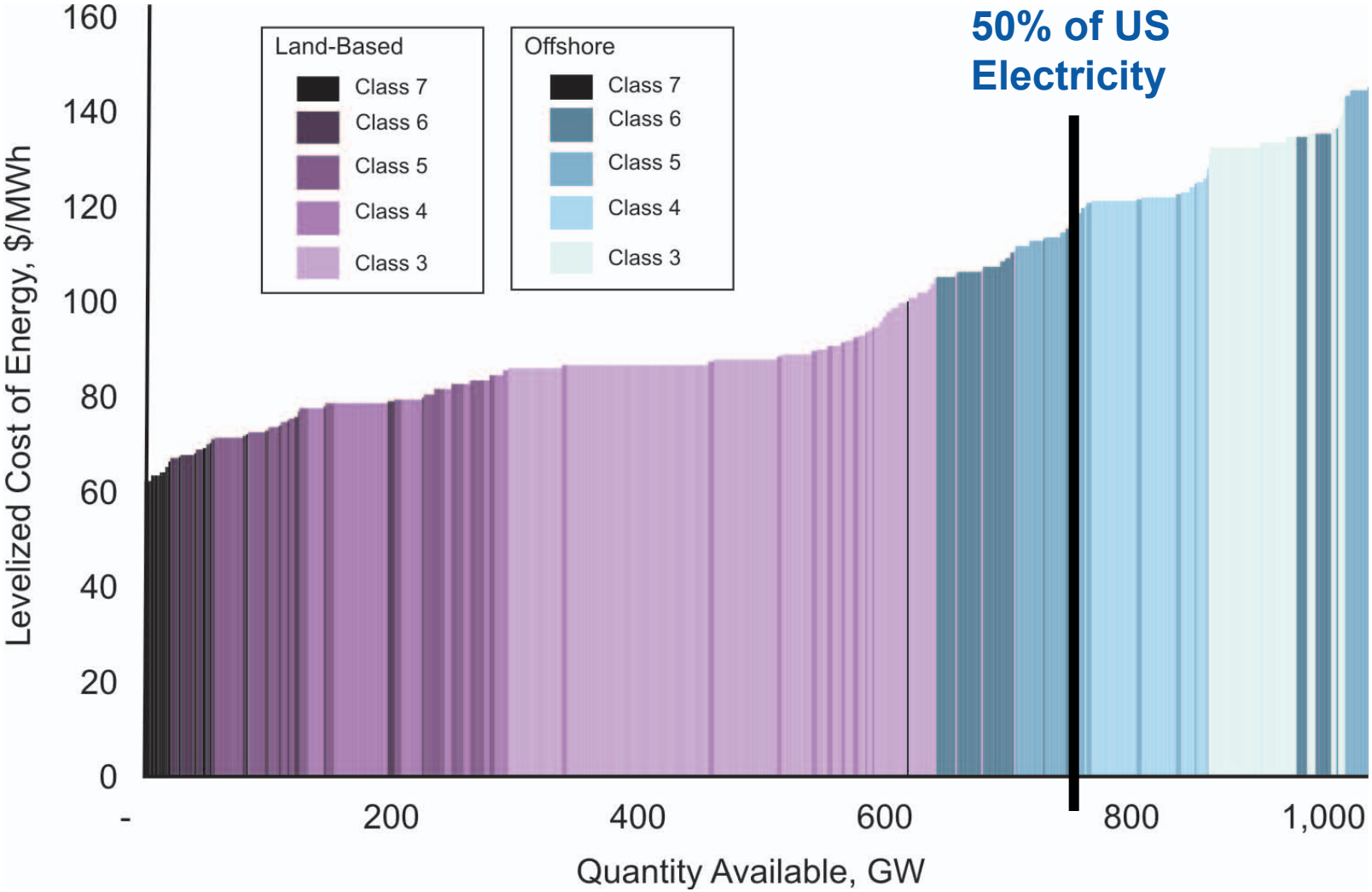
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding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

Population Density of the Counterminous United States



How Much Wind is Available … Really?



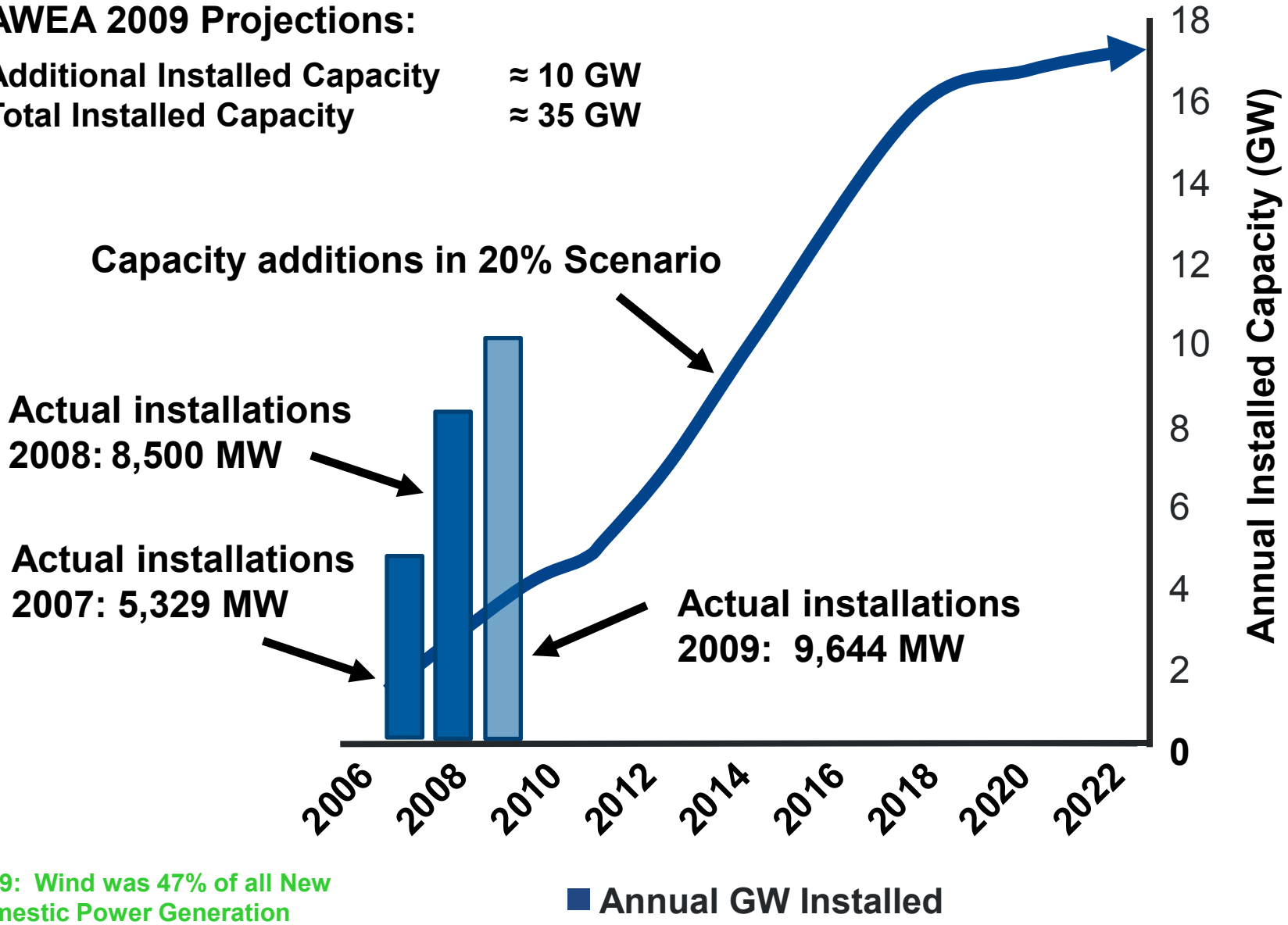
Excludes PTC; includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.

Source: Black & Veatch/NREL

Required Manufacturing Capacity

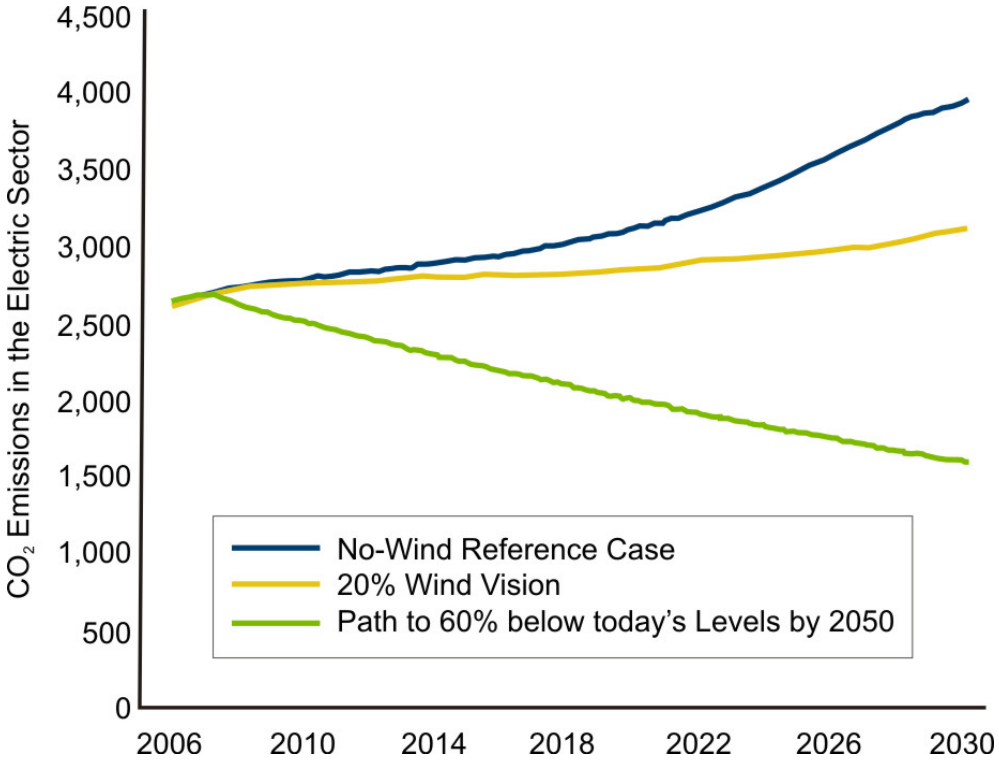
AWEA 2009 Projections:

Additional Installed Capacity ≈ 10 GW
Total Installed Capacity ≈ 35 GW



2009: Wind was 47% of all New Domestic Power Generation

Electric Sector CO2 Emissions



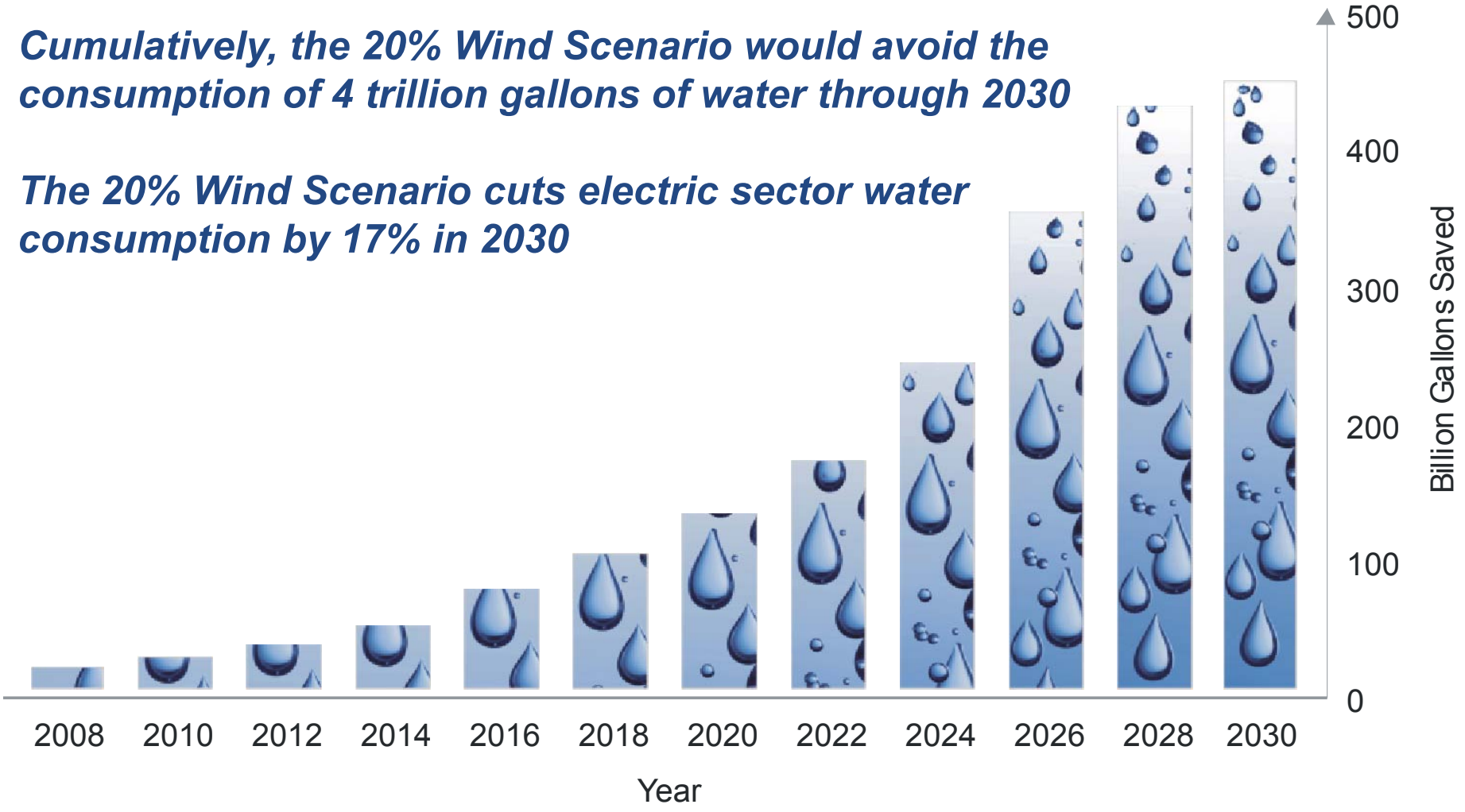
Cumulative CO_2 Savings (2007-2050, MMTons)	Present Value Benefits (billion 2006$)	Levelized Benefit of Wind ($/MWh-wind)
15,300 MMTCO_2	**50 - 98 - 145**	**9.7 - 19 - 28.2**

CO_2 regulation fees from Synapse (2006). $/ton CO_2: Lo 10; Med 22; Hi 34.

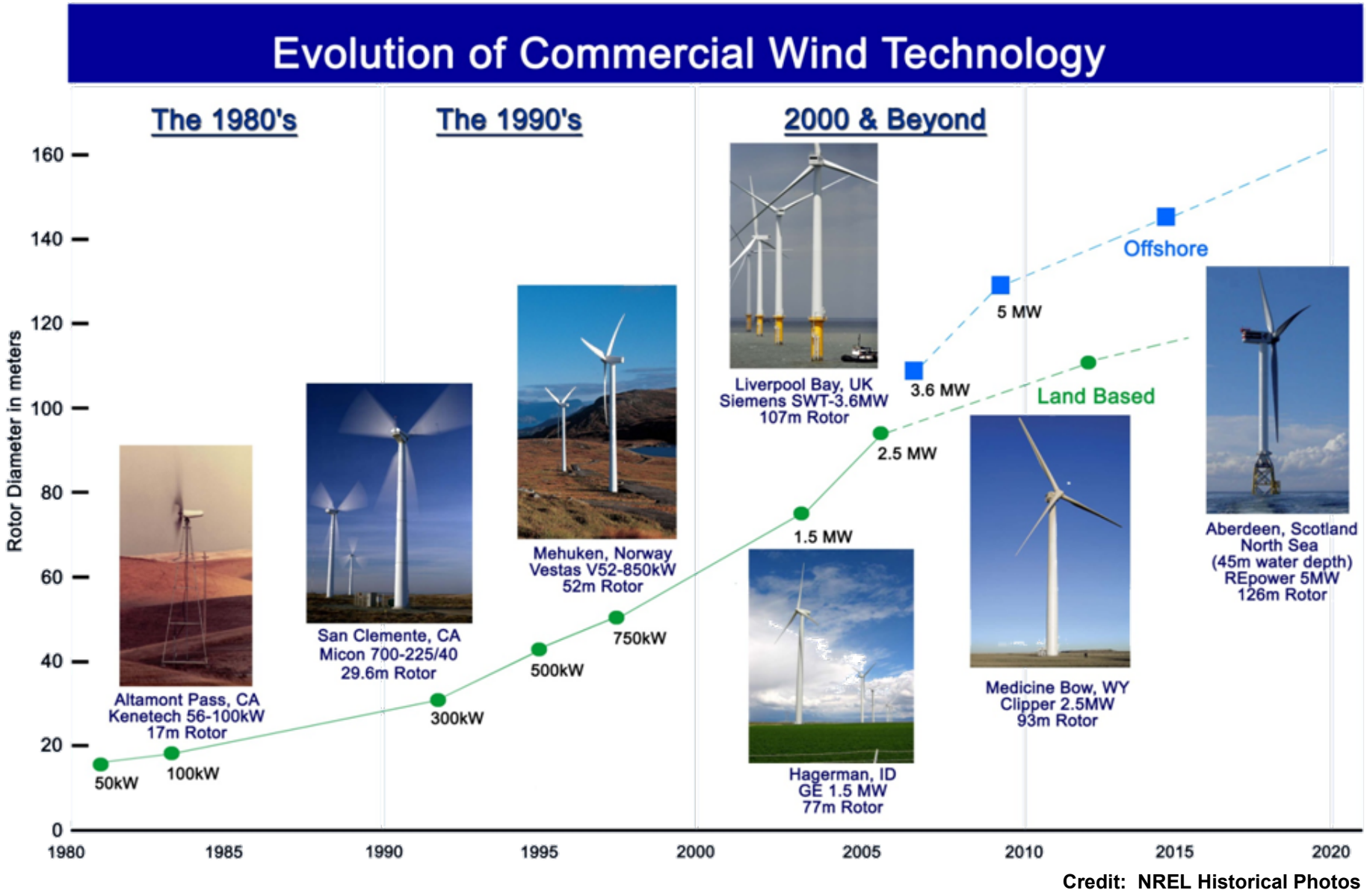
Significant Water Use Savings

Cumulatively, the 20% Wind Scenario would avoid the consumption of 4 trillion gallons of water through 2030

The 20% Wind Scenario cuts electric sector water consumption by 17% in 2030



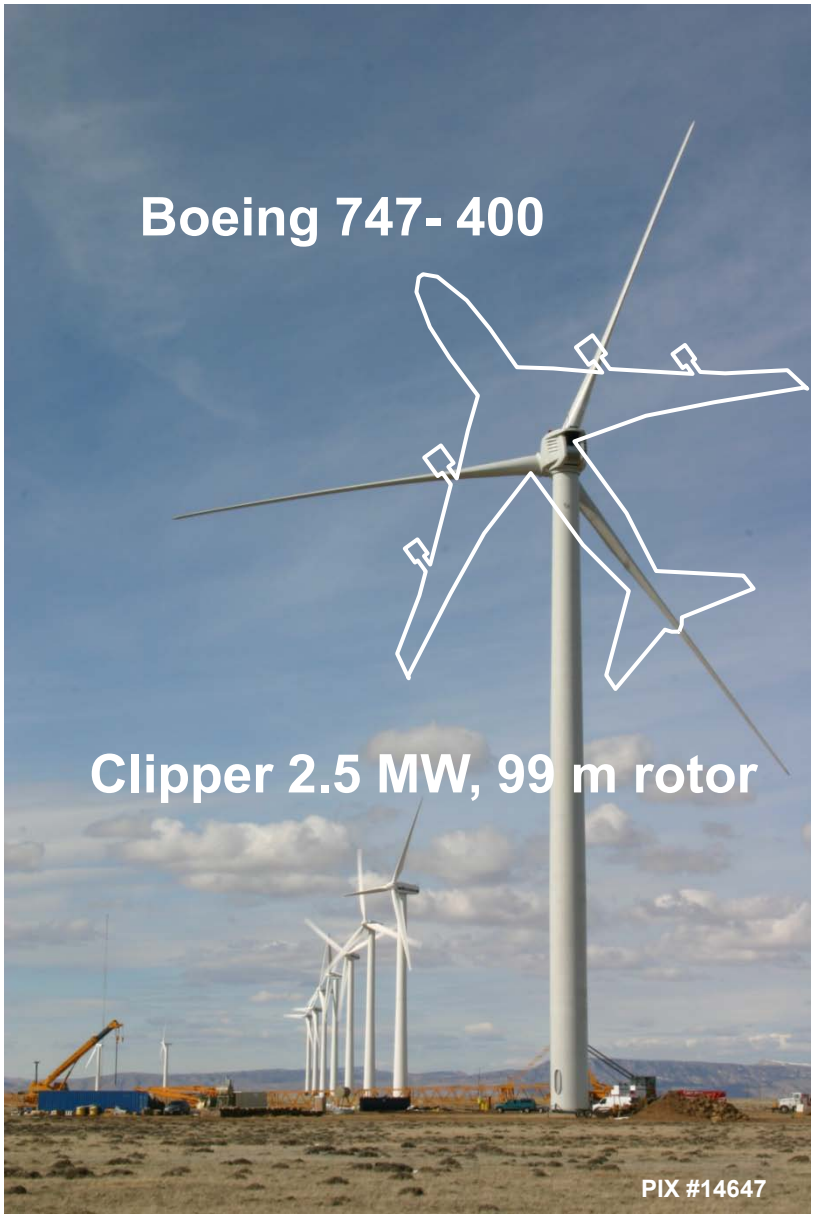
Technology Evolution



Credit: NREL Historical Photos

Wind Turbine Scale – Present and Future

- 2.5 MW - typical commercial turbine Installation
- 5.0 MW prototypes being installed for testing in Europe
- Clipper Wind Power developing an 8.5 MW turbine
- Most manufacturers have a 10 MW machine in design
- Large turbine development programs targeting offshore markets
- Development Outpacing Test & Validation Capability

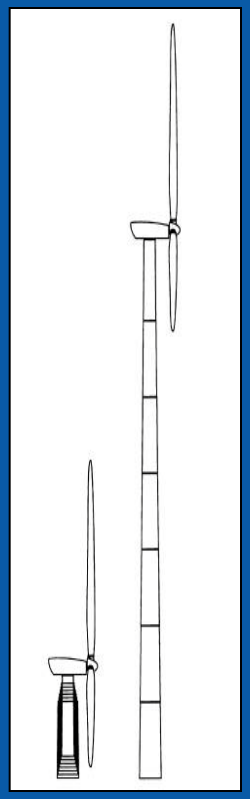


Technology Opportunities

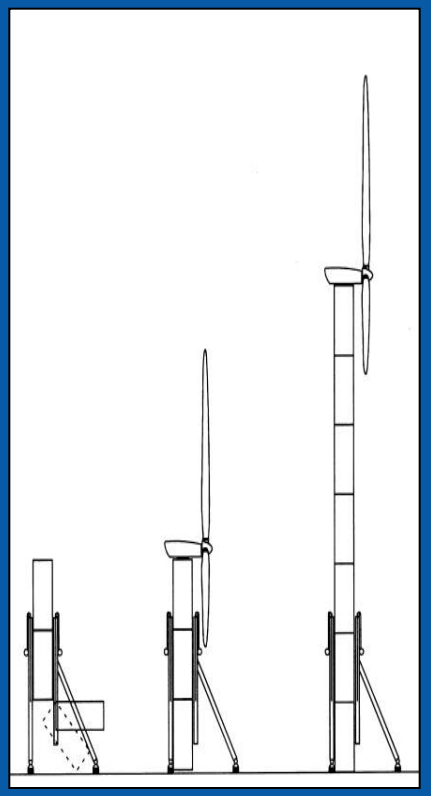
Power Conversion

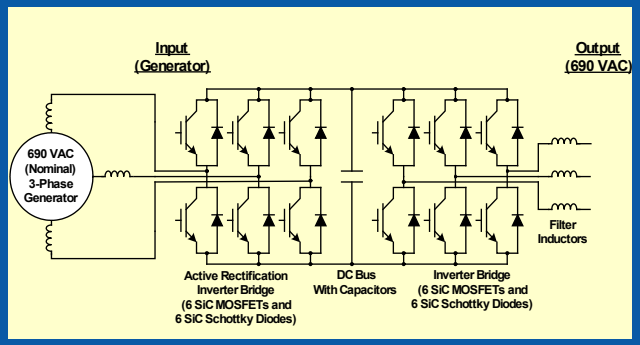
- High temperature silicon carbide device; improved reliability & reduce hardware volume
- Novel circuit topologies for high voltage & power quality improvement
- Medium voltage designs for multi-megawatt architectures

Telescoping Tower



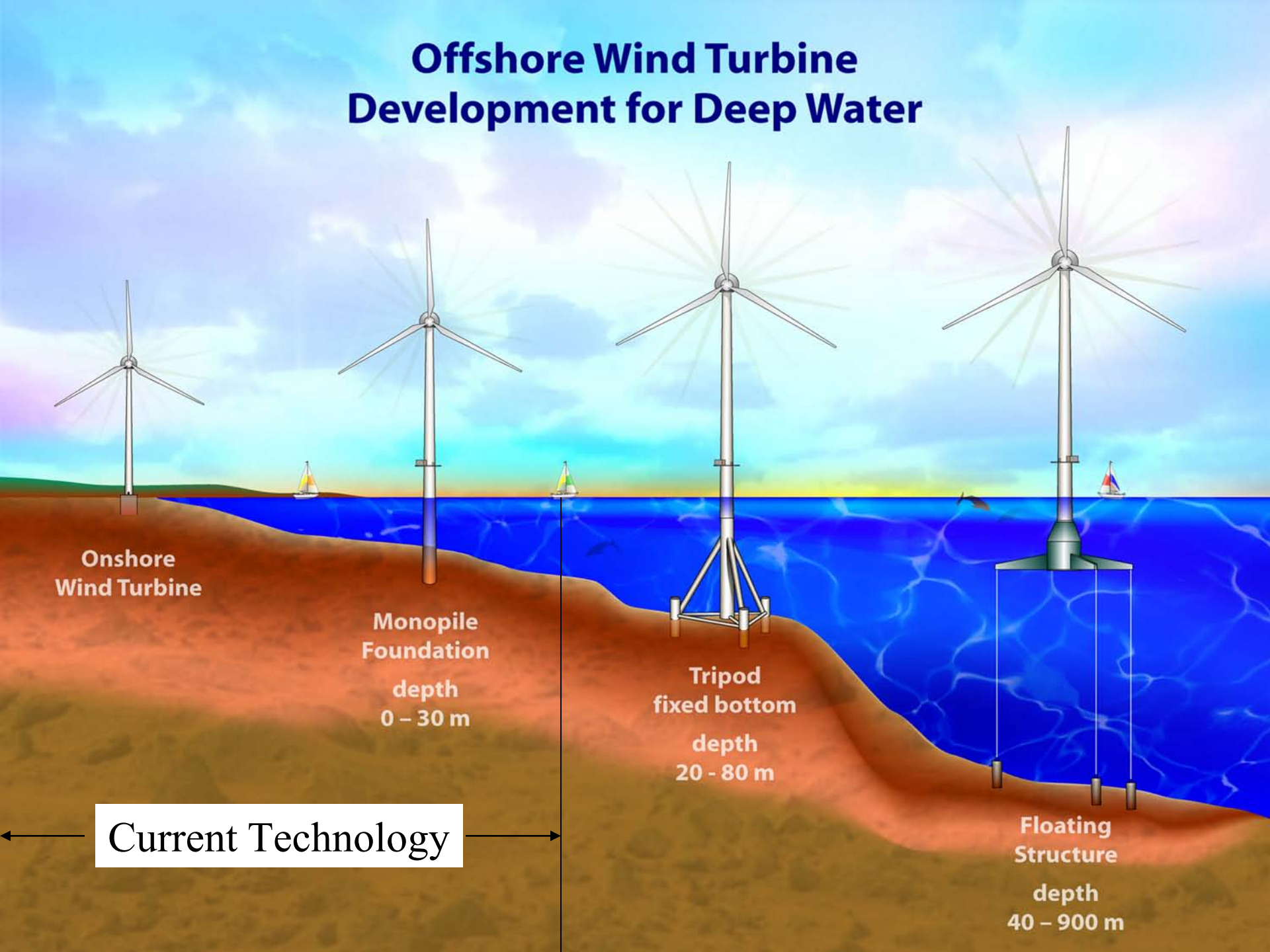
Jack Up Tower





Tower Support Structures

- Tall tower & complex terrain deployment
- Advanced structures & foundations
- New materials and processes
- Self erecting designs


Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

Technology Opportunities

Advanced Rotor Technology

- Extended rotor architectures through load control
- Incorporate advanced materials for hybrid blades
- Cyclic & independent blade pitch control for load mitigation
- Sweep and flap twist coupled architectures
- Light weight, high TSR with attenuated aeroacoustics

Power Train Enhancements

- Permanent Magnet DD Architectures
- Split load path multi-stage generation topologies
- Reduced stage (1-2) integrated gearbox designs
- Convoloid gearing for load distribution

Technology Opportunities

Critical need for advanced wake models

Key to understanding array effects for performance & loads

Current Activity:

NREL - Siemens 2.3 MW Aerodynamics Test

- Extensive pressure measurements
- LIDAR wake measurements
- Understand rotor / wake interaction
- CFD model validation
- Advanced aerodynamics / performance / loads control

Aeroacoustic array development – testing of Northwind, testing in Bushland with Sandia

Planned/Recommended:

- **Wakes** – Comprehensive effort including CFD, wind tunnel test, field test; leading to improved design codes
- **Acoustic testing of Siemens (array)** – GE, CART3 – removable tip testing for noise
- **"Siemens Part II":** wind farm atmosphere/turbulent inflow/aero/wake

Serious Challenges Remain

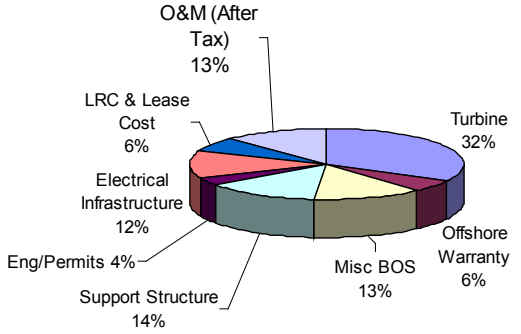
Needs Improvement:

- Gearbox performance
- Operating expenses to high
- Capital expenses still exceed DOE performance goals
- Rotor stretching strategy
- Wind plants under-performing 10%

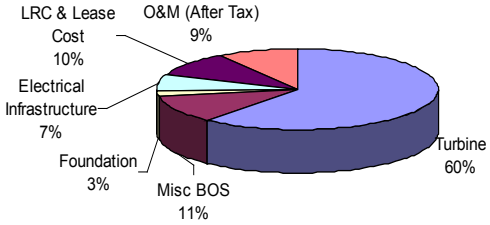
Why:

- Bearing failures; inaccurate internal loads?
- Unscheduled maintenance, low reliability, lack O&M automation
- Fatigue load & deflection control required
- Tower clearance limit, materials, aeroacoustics limiting tip speed, dynamic stability?

Offshore COE Cost Breakdown



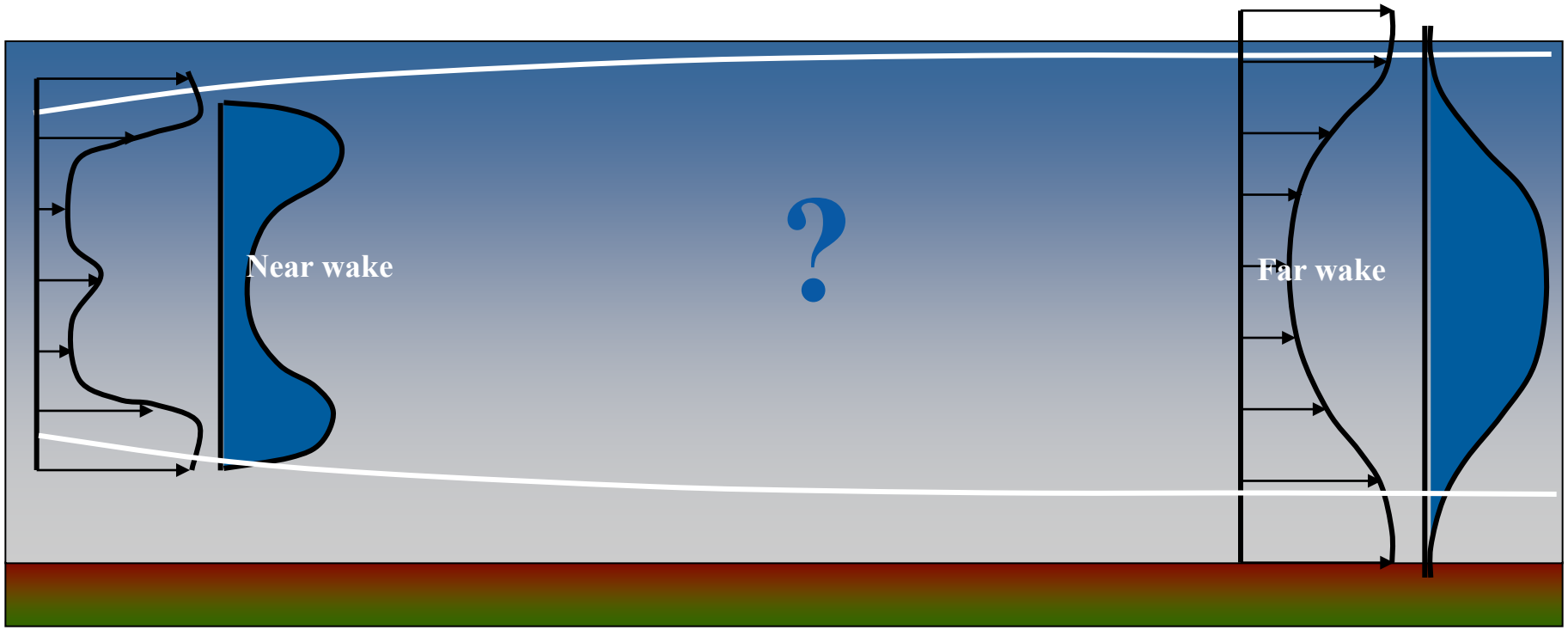
Onshore COE Cost Breakdown

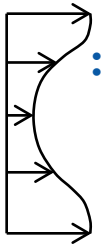


Existing design codes & tools should achieve 20 year life & reliable power performance predictions;

What are we missing?

Wake Structure Development

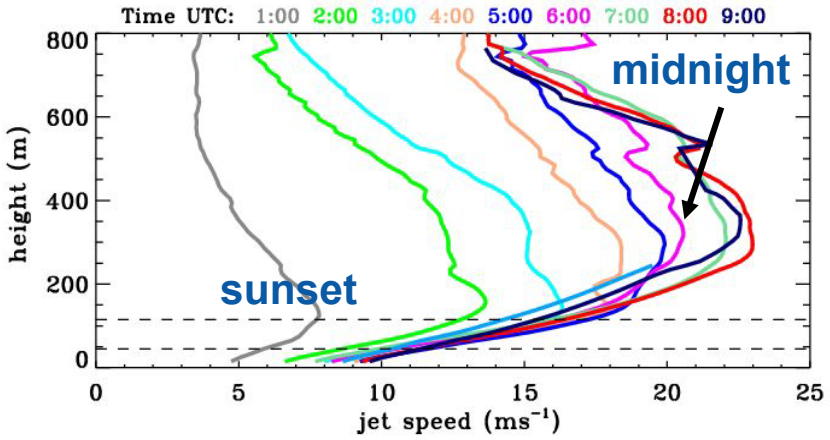


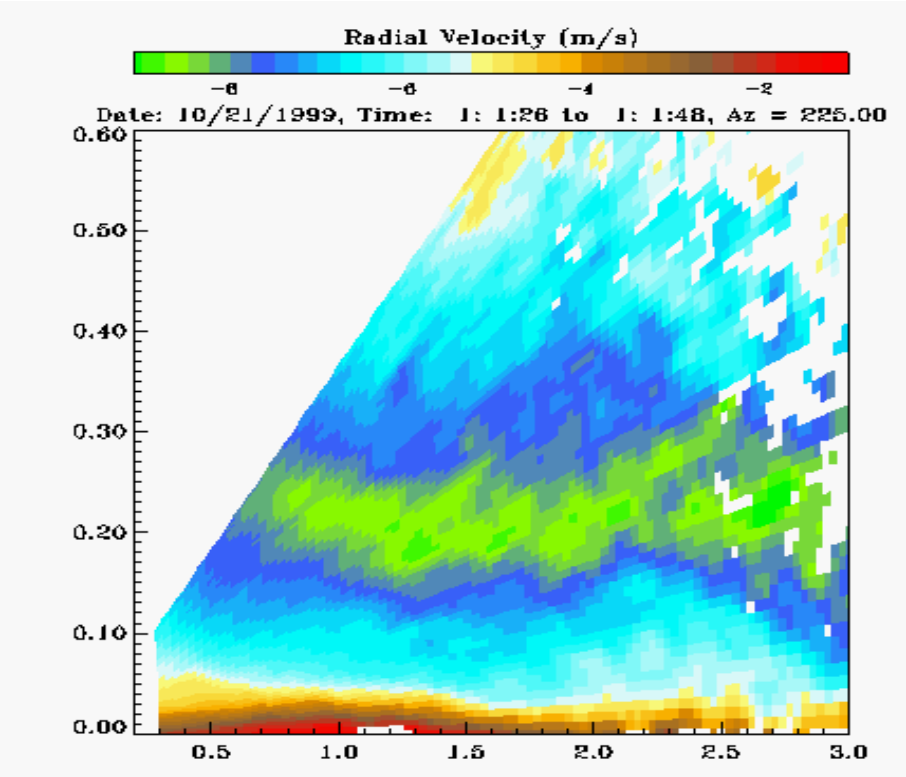

: Axial velocity


: Turbulence intensity

Sørensen, EWEC 2007

Planetary Boundary Layer (PBL)





- Turbine, wind farm, PBL; similar dimensional scales
- Farm / inflow interactions not quantified
- Characterization & prediction remain an issue
- Detailed inflow information required for turbine design and optimized control
- Diurnal variation
- Growing concerns include:
  - Quality of the downwind resource
  - Microclimatology changes
  - Agriculture impacts
  - Permitting

Multi-MW Turbines at NWTC

DOE 1.5 MW

PIX #17694

Siemens 2.3 MW

PIX #17720

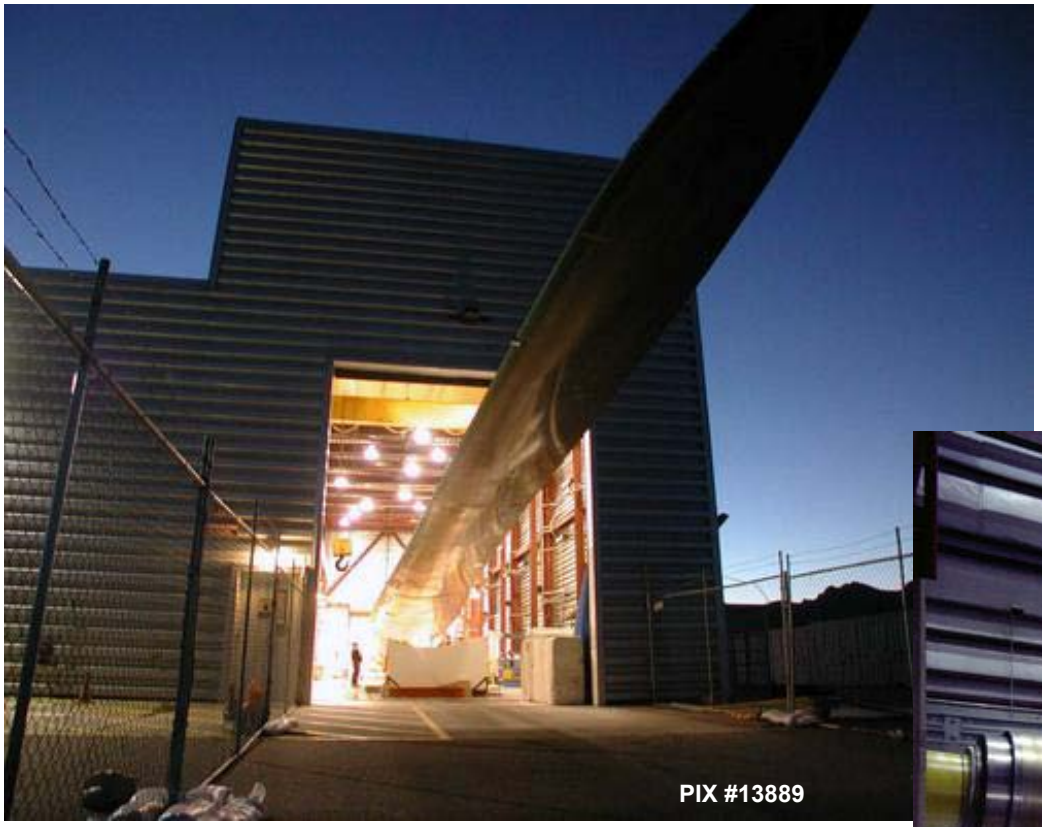
DOE 1.5 MW GE Turbine:

- Model: GE 1.5SLE
- Tower Height: 80 m
- Rotor Diameter: 77 m
- DOE owned; used for research and education

Siemens 2.3 MW Turbine:

- Model: SWT-2.3-101
- Tower Height: 80 m
- Rotor Diameter: 101 m
- Siemens owned and operated
- Multi-year R&D CRADA; aerodynamics and rotor performance

Large Facility Requirements



New Large Blade Test Facility

- Boston, MA with Massachusetts Technology Collaborative

New Dynamometer Test Facility

- Charleston, SC with Clemson University

A 45-meter wind turbine blade undergoing fatigue testing at the NWTC, July 2004.

PIX 17245

Questions?

Scott Schreck
National Wind Technology Center

Phone: +1 (303) 384-7102
Email: scott.schreck@nrel.gov