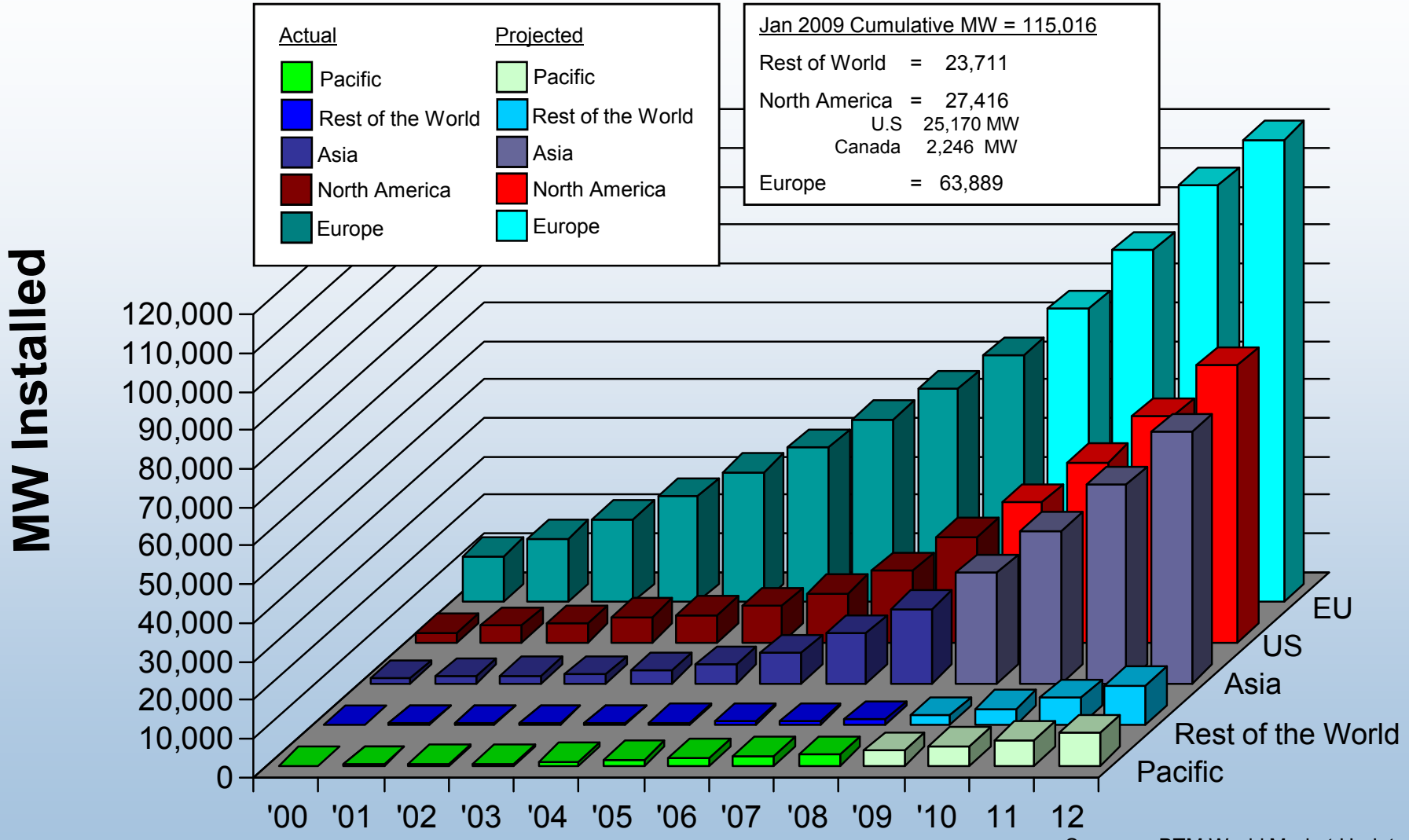
The Status and Future of Wind Energy

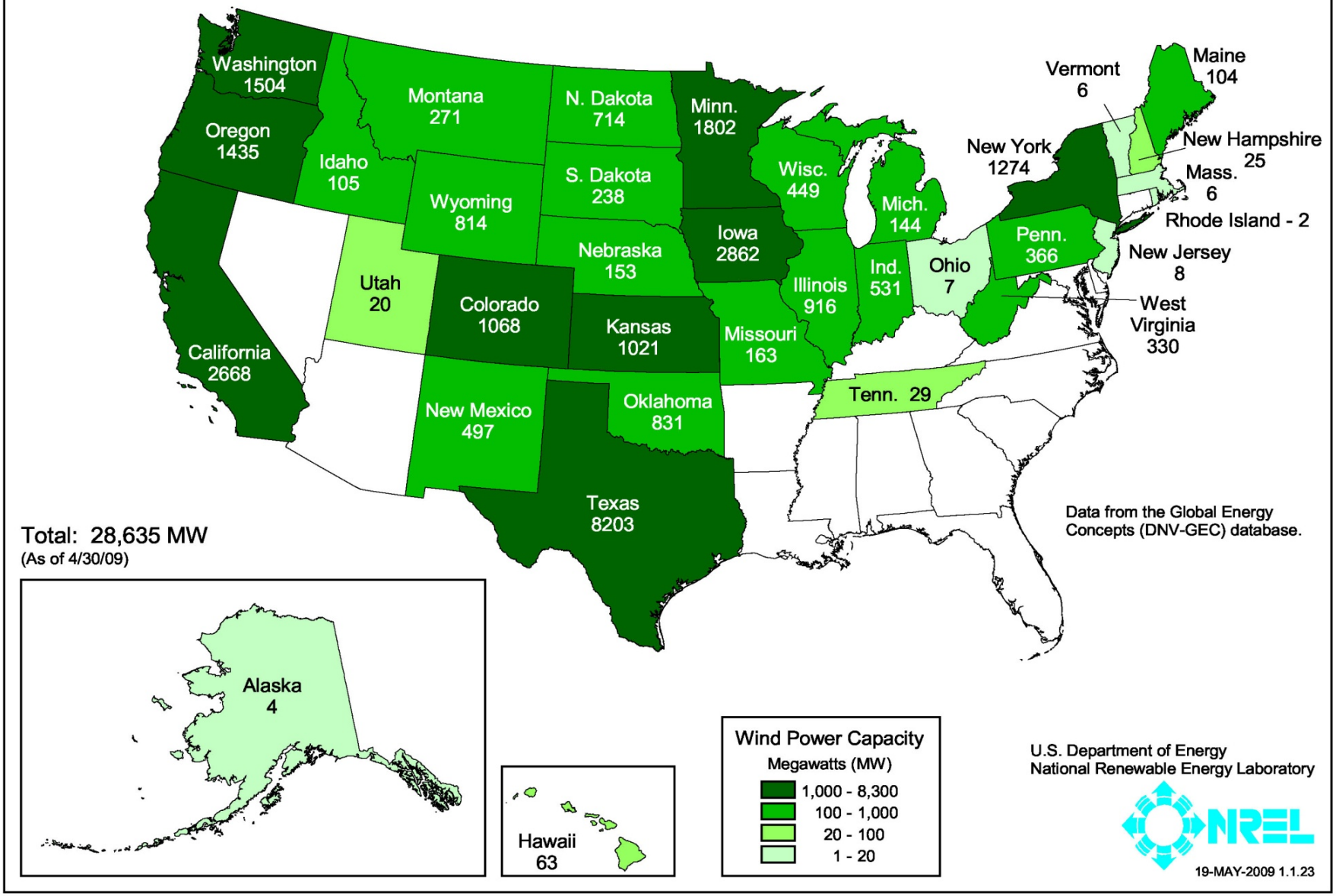
Presented by
Fort Felker, Director
National Wind Technology Center

Growth of Wind Energy Capacity Worldwide



Sources: BTM World Market Update 2007
AWEA, January 2009
Windpower Monthly, January 2009

United States - Current Installed Wind Power Capacity (MW)



Total: 28,635 MW
(As of 4/30/09)

Data from the Global Energy Concepts (DNV-GEC) database.

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

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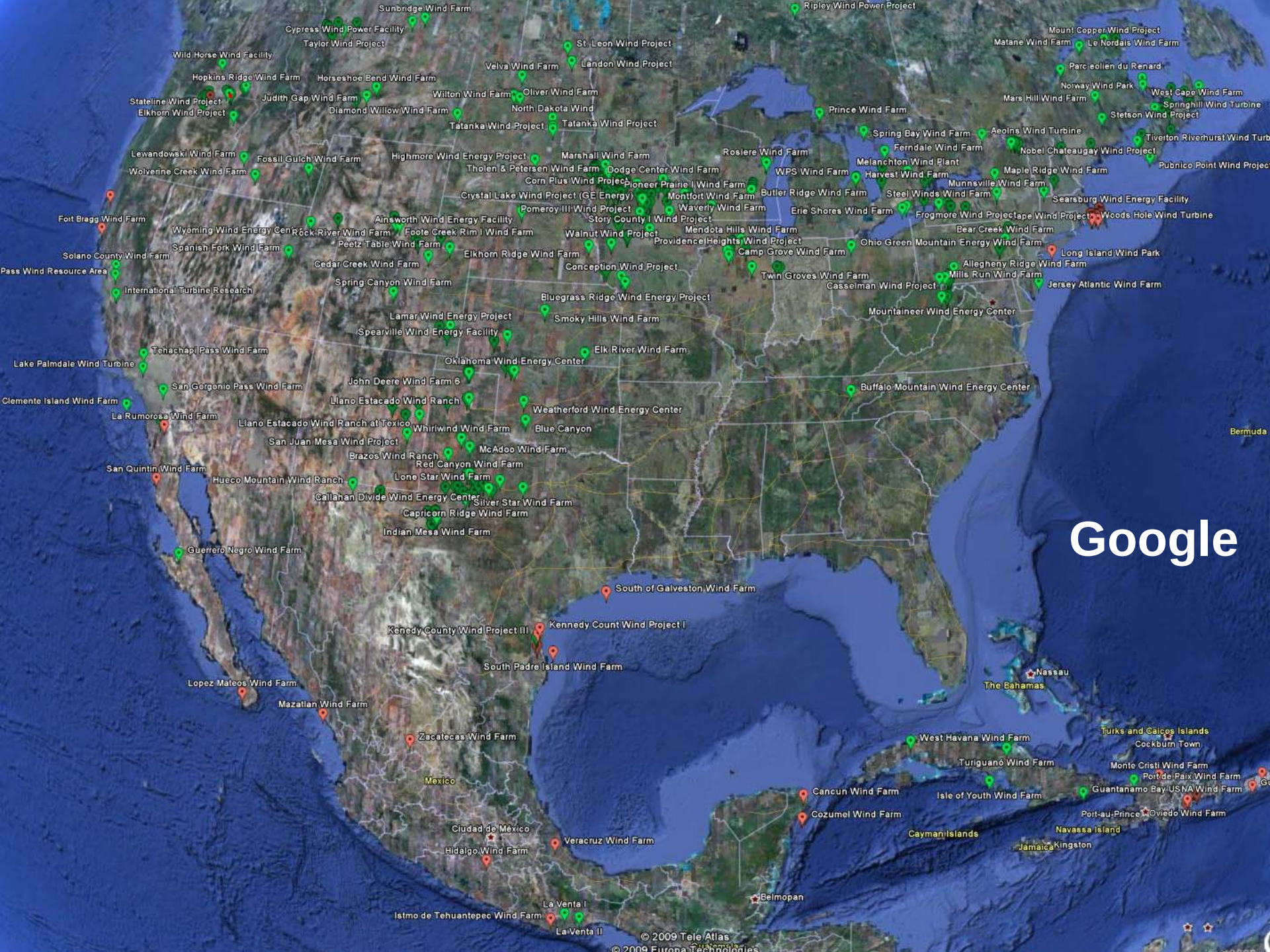
Sunbridge Wind Farm
Ripley Wind Power Project
Cypress Wind Power Facility
Taylor Wind Project
St. Leon Wind Project
Mount Copper Wind Project
Matane Wind Farm
Le Nordais Wind Farm
Wild Horse Wind Facility
Velva Wind Farm
Landon Wind Project
Parc eolien du Renard
Hopkins Ridge Wind Farm
Horseshoe Bend Wind Farm
Norway Wind Park
West Cape Wind Farm
Stateline Wind Project
Judith Gap Wind Farm
Wilton Wind Farm
Oliver Wind Farm
Mars Hill Wind Farm
Springhill Wind Turbine
Elkhorn Wind Project
Diamond Willow Wind Farm
North Dakota Wind
Prince Wind Farm
Stetson Wind Project
Tatanka Wind Project
Tatanka Wind Project
Spring Bay Wind Farm
Aeolns Wind Turbine
Tiverton Riverhurst Wind Turb
Lewandowski Wind Farm
Fossil Gulch Wind Farm
Highmore Wind Energy Project
Marshall Wind Farm
Rosiere Wind Farm
Ferndale Wind Farm
Nobel Chateaugay Wind Project
Wolverine Creek Wind Farm
Tholen & Petersen Wind Farm
Dodge Center Wind Farm
Melanchton Wind Plant
WPS Wind Farm
Harvest Wind Farm
Maple Ridge Wind Farm
Pubnico Point Wind Project
Corn Plus Wind Project
Pioneer Prairie I Wind Farm
Munnsville Wind Farm
Crystal Lake Wind Project (GE Energy)
Montfort Wind Farm
Butler Ridge Wind Farm
Steel Winds Wind Farm
Searsburg Wind Energy Facility
Pomeroy III Wind Project
Waverly Wind Farm
Erie Shores Wind Farm
Frogmore Wind Project
Woods Hole Wind Turbine
Fort Bragg Wind Farm
Ainsworth Wind Energy Facility
Story County I Wind Project
Wyoming Wind Energy Cen
Rock River Wind Farm
Foote Creek Rim I Wind Farm
Mendota Hills Wind Farm
Bear Creek Wind Farm
Wainut Wind Project
Providence Heights Wind Project
Ohio Green Mountain Energy Wind Farm
Spanish Fork Wind Farm
Peetz Table Wind Farm
Solano County Wind Farm
Elkhorn Ridge Wind Farm
Camp Grove Wind Farm
Long Island Wind Park
Cedar Creek Wind Farm
Conception Wind Project
Allegheny Ridge Wind Farm
Pass Wind Resource Area
Twin Groves Wind Farm
Mills Run Wind Farm
Spring Canyon Wind Farm
Casselman Wind Project
Jersey Atlantic Wind Farm
International Turbine Research
Bluegrass Ridge Wind Energy Project
Mountaineer Wind Energy Center
Lamar Wind Energy Project
Smoky Hills Wind Farm
Spearville Wind Energy Facility
Tehachapi Pass Wind Farm
Elk River Wind Farm
Lake Palmdale Wind Turbine
Oklahoma Wind Energy Center
John Deere Wind Farm 6
San Gorgonio Pass Wind Farm
Buffalo Mountain Wind Energy Center
Clemente Island Wind Farm
Llano Estacado Wind Ranch
Weatherford Wind Energy Center
La Rumorosa Wind Farm
Llano Estacado Wind Ranch at Texico
Whirlwind Wind Farm
Blue Canyon
Bermuda
San Juan Mesa Wind Project
McAdoo Wind Farm
Brazos Wind Ranch
San Quintin Wind Farm
Red Canyon Wind Farm
Hueco Mountain Wind Ranch
Lone Star Wind Farm
Callahan Divide Wind Energy Center
Silver Star Wind Farm
Capricorn Ridge Wind Farm
Indian Mesa Wind Farm
Guerrero Negro Wind Farm
Google
South of Galveston Wind Farm
Kennedy County Wind Project III
Kennedy Count Wind Project I
South Padre Island Wind Farm
Nassau
The Bahamas
Lopez Mateos Wind Farm
Mazatlan Wind Farm
Zacatecas Wind Farm
West Havana Wind Farm
Turks and Caicos Islands
Cockburn Town
Turiguanó Wind Farm
Monte Cristi Wind Farm
Mexico
Port de Paix Wind Farm
Cancun Wind Farm
Isle of Youth Wind Farm
Guantanamo Bay USNA Wind Farm
Cozumel Wind Farm
Port-au-Prince
Oviedo Wind Farm
Ciudad de Mexico
Cayman Islands
Navassa Island
Veracruz Wind Farm
Jamaica
Kingston
Hidalgo Wind Farm
Belmopan
La Venta I
Istmo de Tehuantepec Wind Farm
La Venta II
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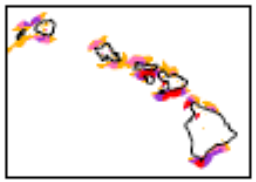
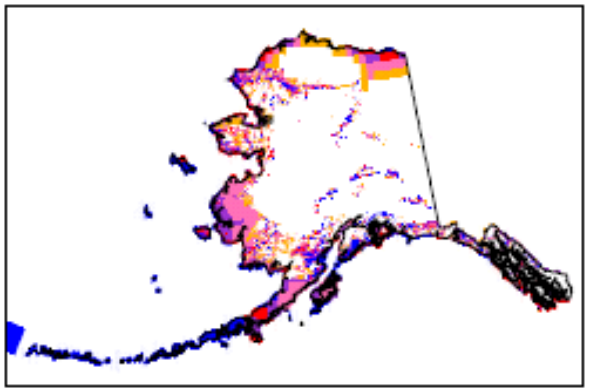
United States - Wind Resource Map





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

U.S. Department of Energy
National Renewable Energy Laboratory

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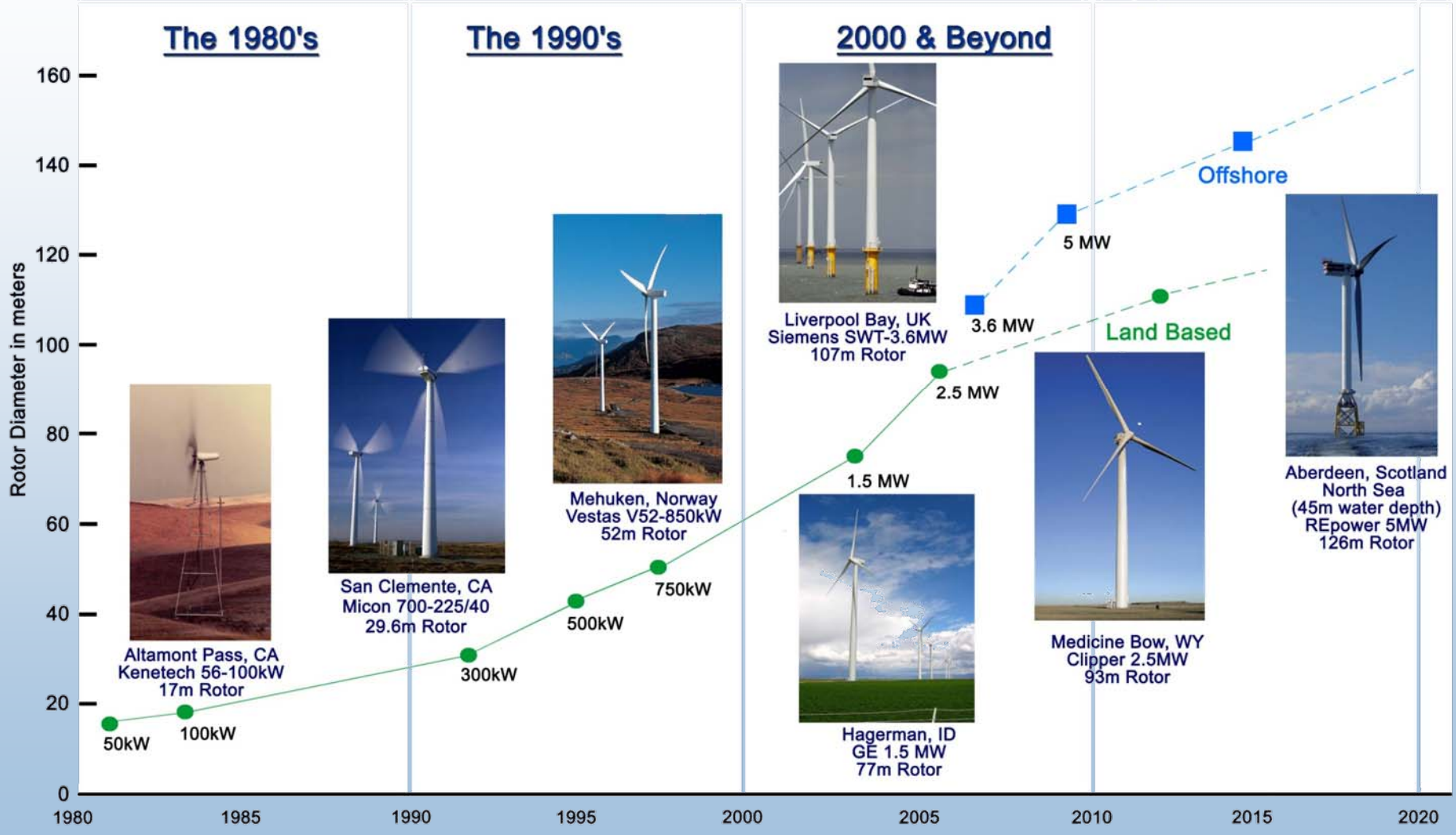
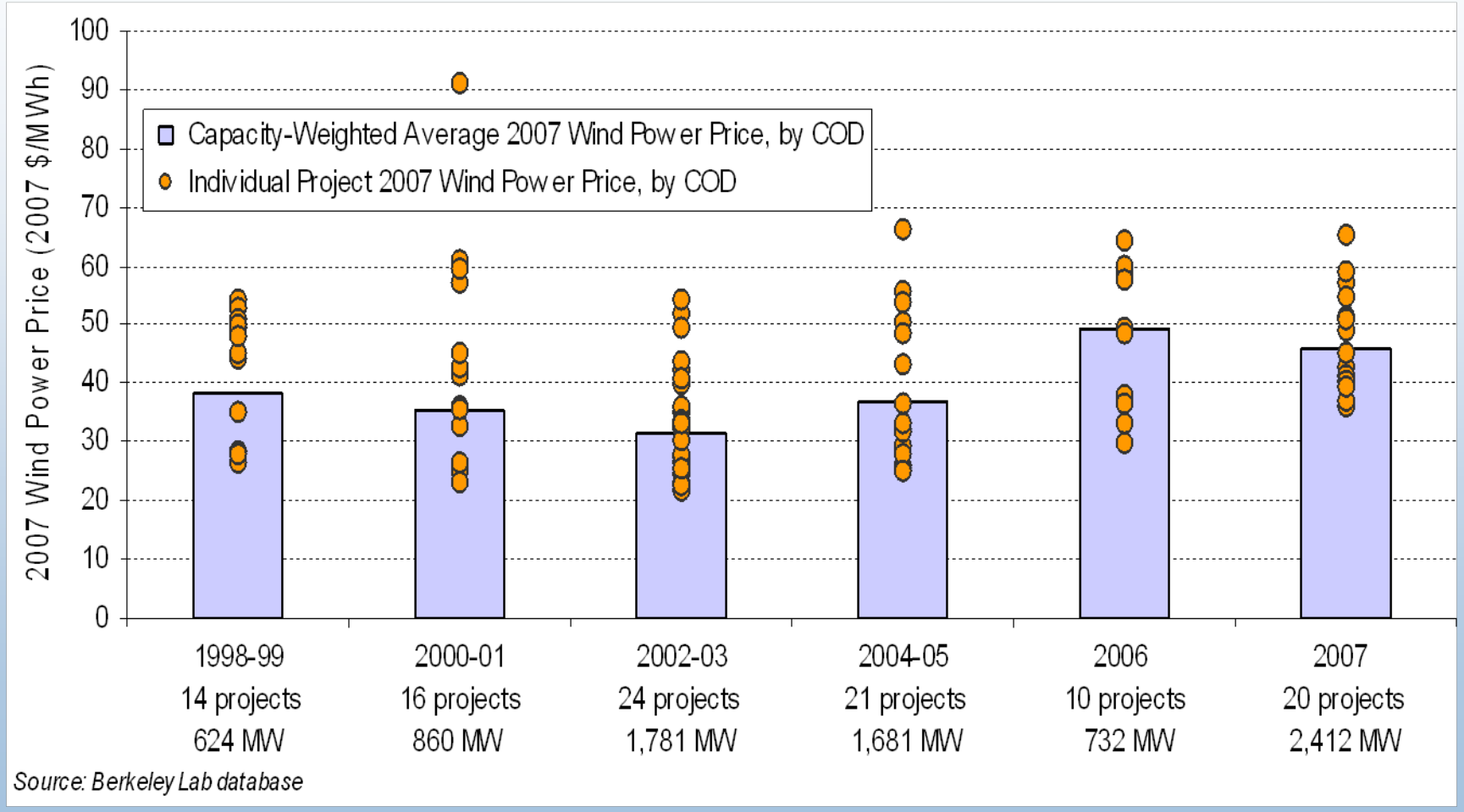
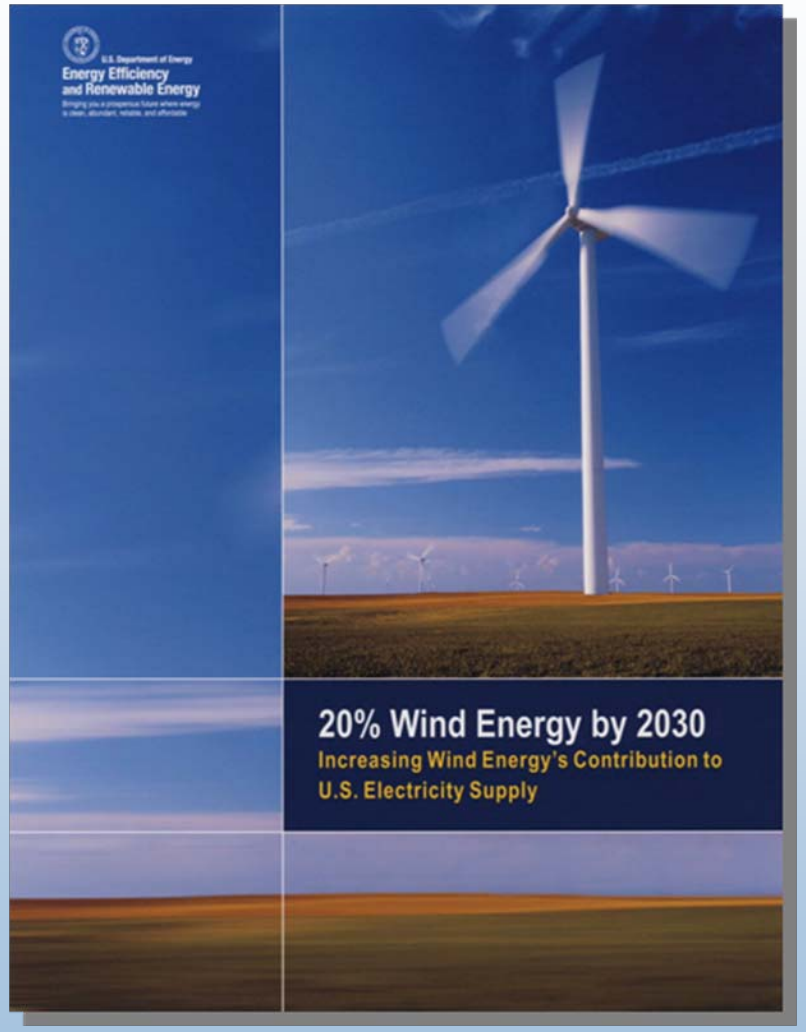
Evolution of Commercial Wind Technology



Wind Power Purchase Price (Including PTC of 2 cents/kWh)

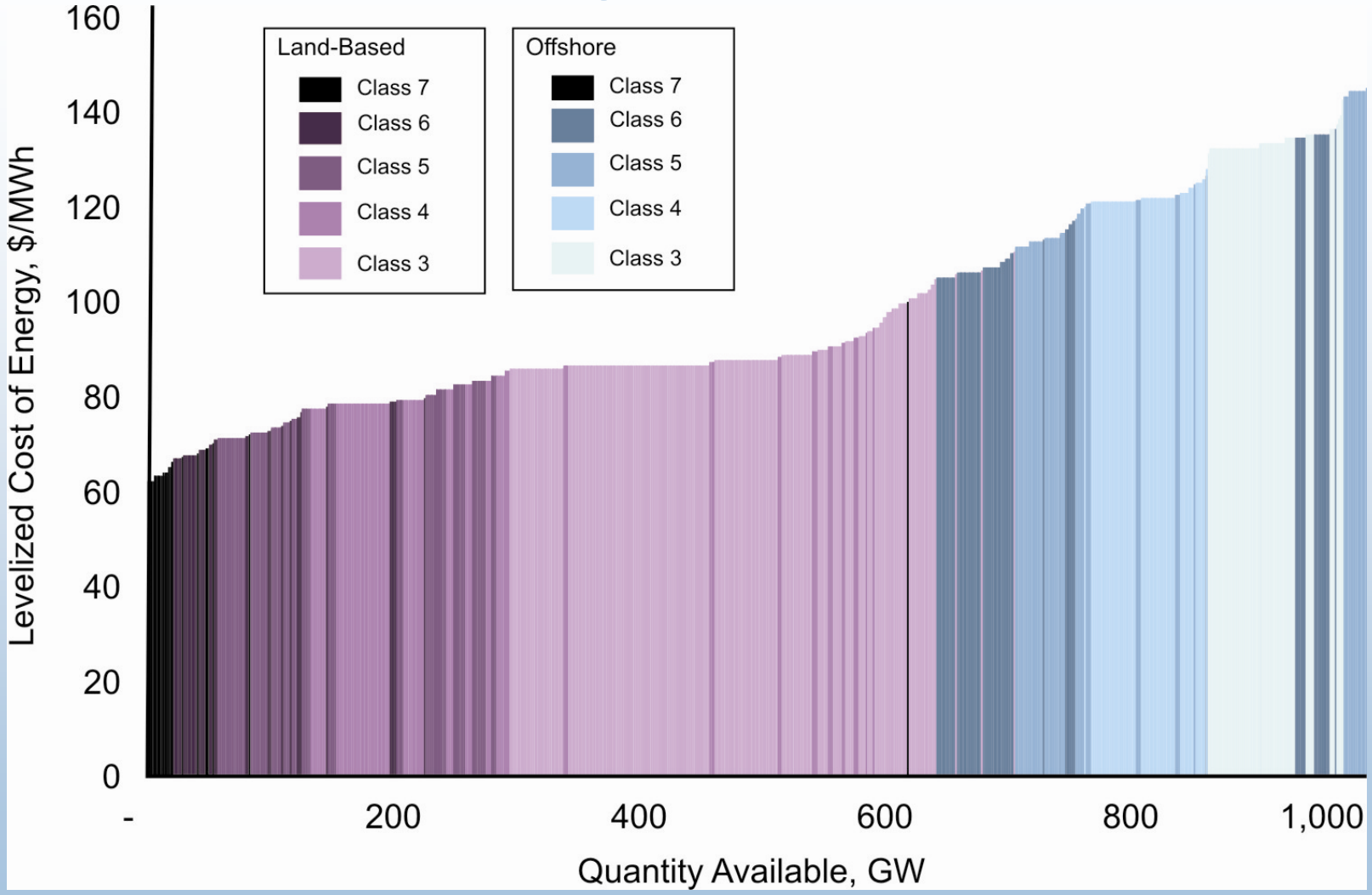


A New Vision for Wind Energy
"20% Wind Energy by 2030"



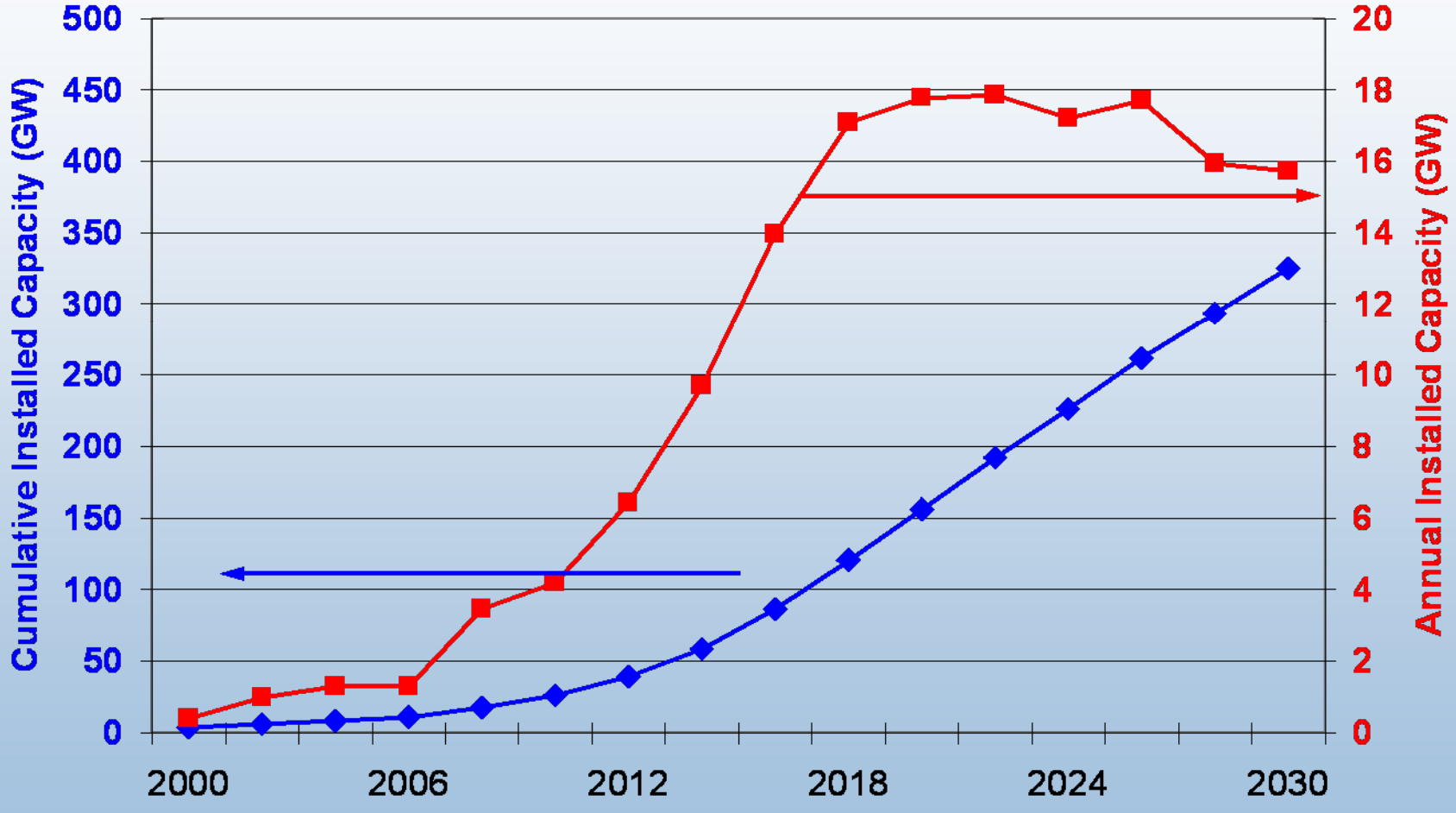
www.eere.energy.gov/windandhydro

Wind Energy Supply Curve



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

What does 20% wind electricity look like?



Installed Wind Nameplate Capacity by State (2030)

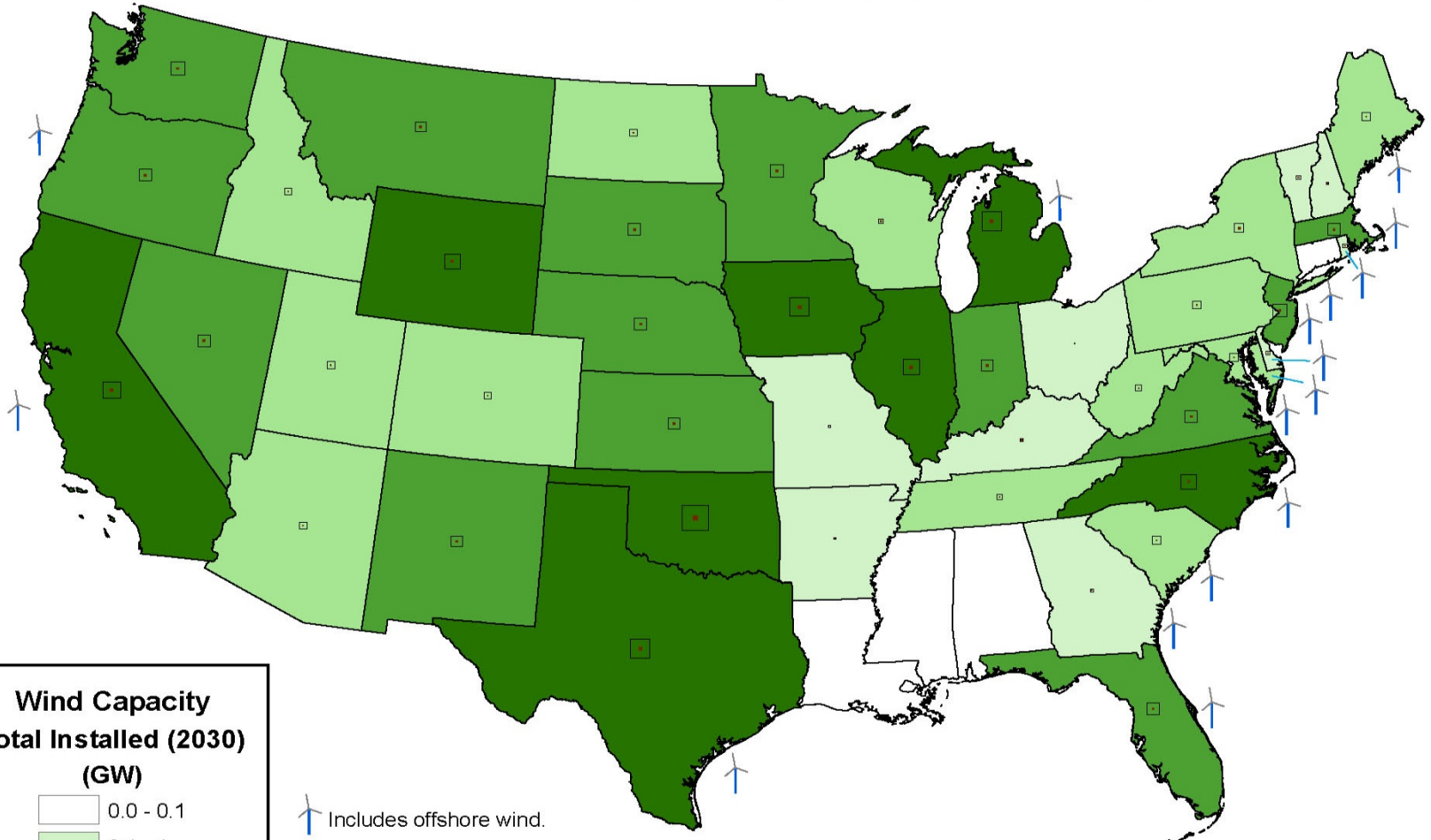
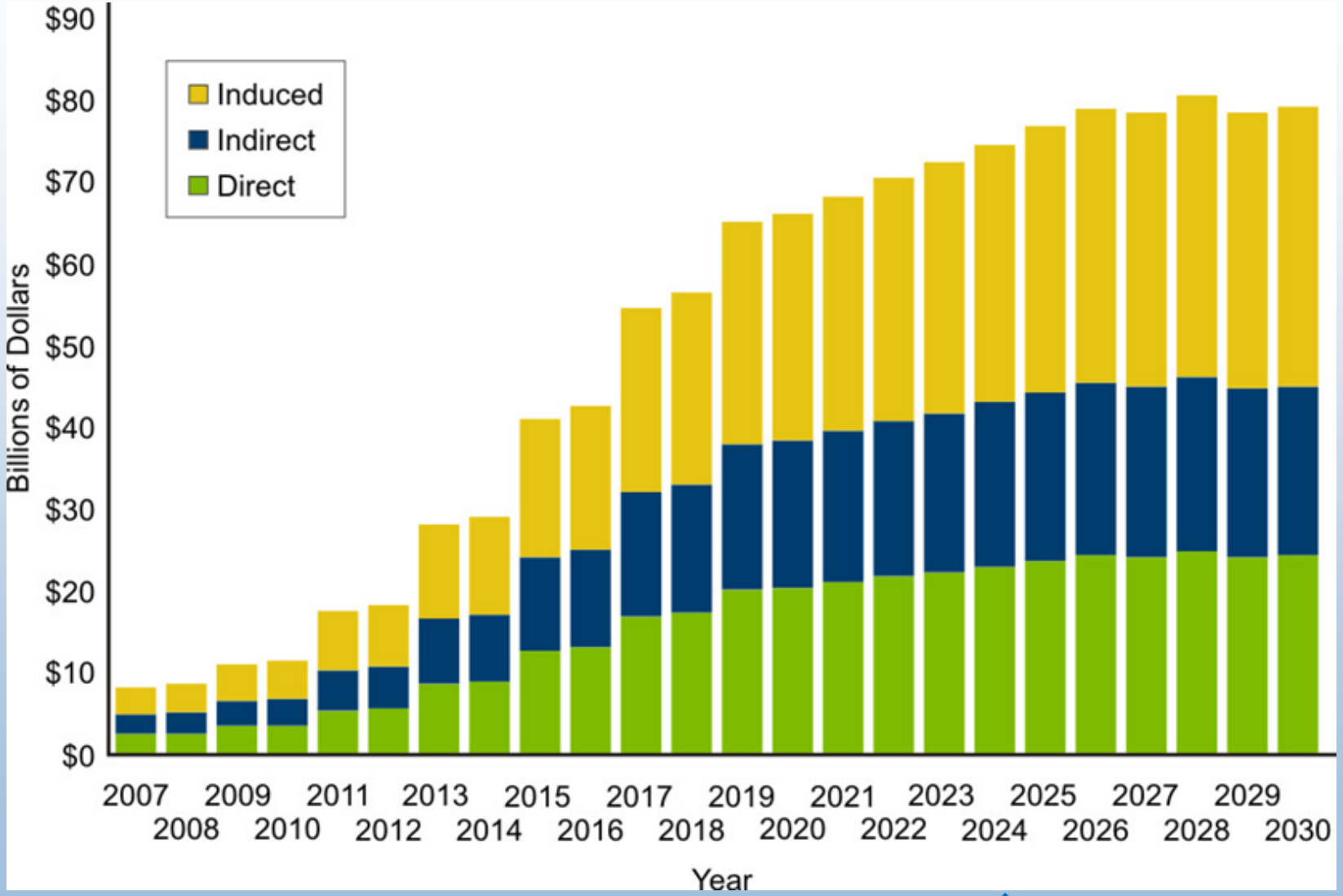


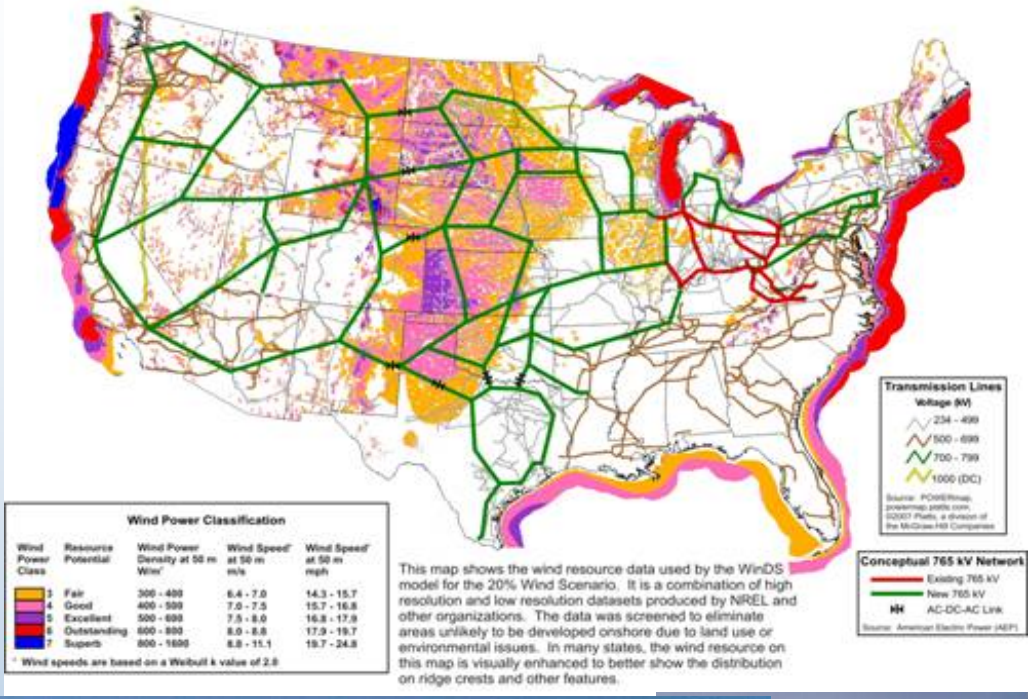
Fig 1-6

Annual direct, indirect and induced economic impacts from 20% scenario



Critical Elements for 20% Scenario

- **Improved Performance**
  - 10% reduction in capital cost
  - 15% increase in capacity factor
  - Address Wind Farm underperformance
- **Mitigate Risk**
  - Reduce O&M costs by 35%
  - Foster the confidence to support continued 20% per year growth in installation rates from now until 2018
- **Enhanced Transmission System (AEP)**
  - $60 billion cost estimate over 20 yrs
  - 19,000 mi of line
  - Supports 200-400 GW addition
- **Siting and Environmental Effects**
- **Policy, Communication & Outreach**

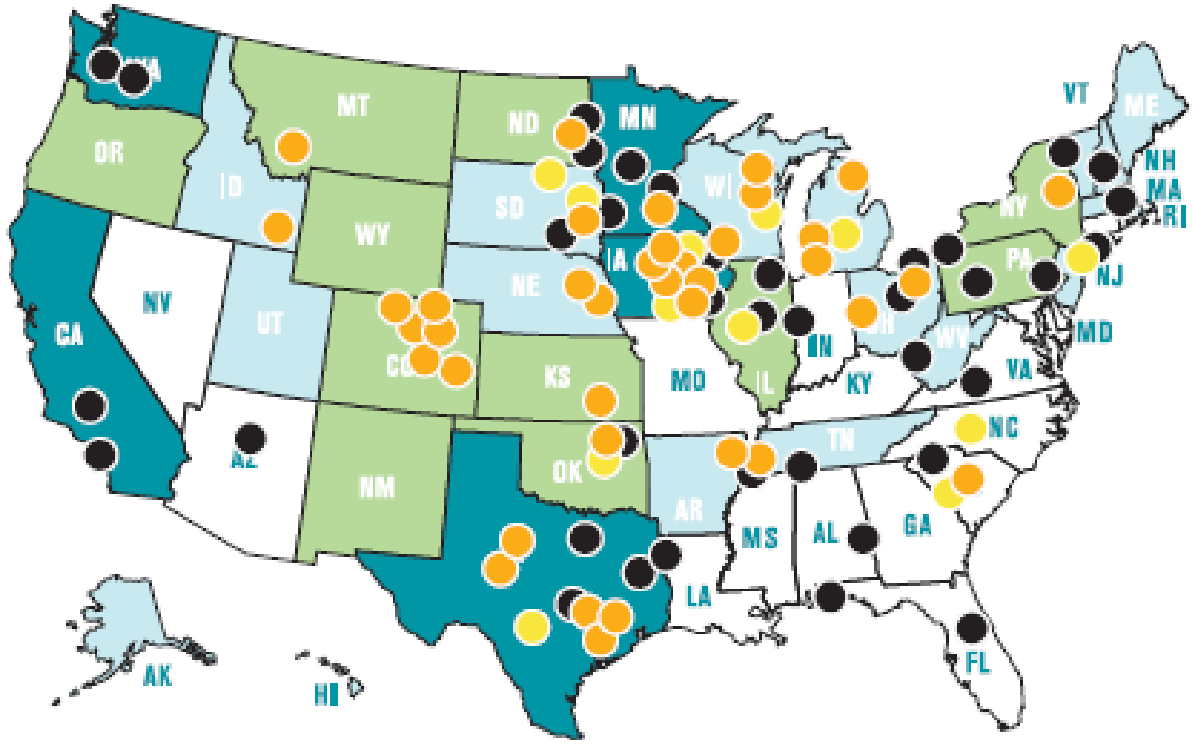


This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

Administration's National 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**

Wind Power Jobs: Revitalizing Our Domestic Manufacturing Base



Wind generation capacity installed (megawatts, MW*)	Manufacturing facilities (existing or announced)
> 1000 MW	Online Prior to 2007
> 100 MW	Online, Expanded or Announced in 2007
< 100 MW	Online, Expanded or Announced in 2008

* One MW generated enough electricity to power the equivalent of 250-300 average homes.

Source: The Governors' Wind Energy Coalition

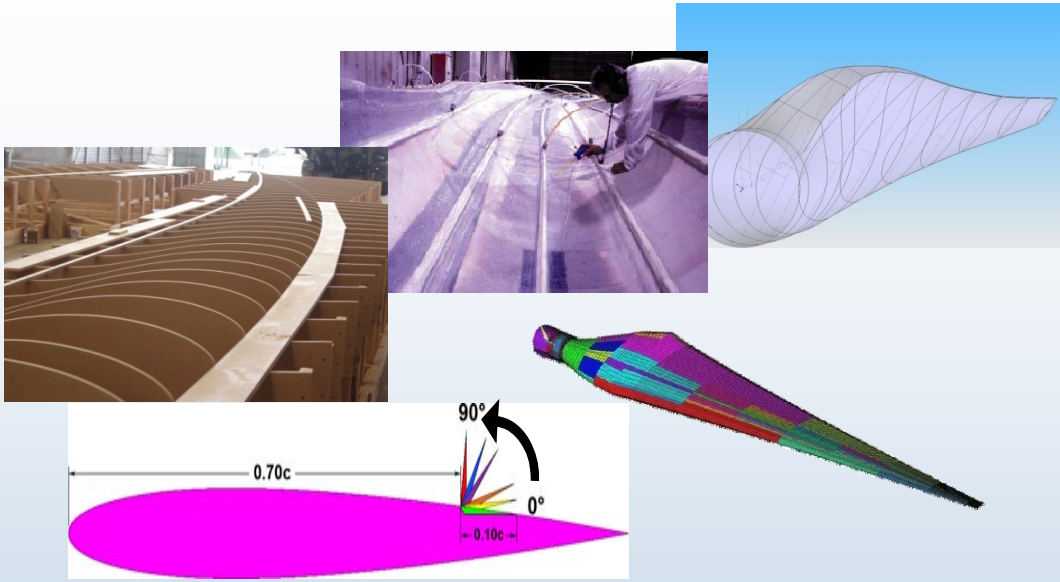
U.S. Wind Energy Challenge

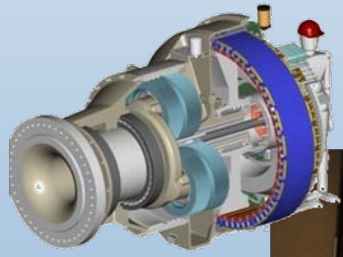
- Rising costs driven by inconsistent policies and increased competition
  - PTC inconsistency
  - Copper and Steel prices
  - Transportation
  - Permitting and siting costs
- Poor performance and reliability
  - Drivetrains
  - Other components
- Understanding and acceptance by financial sector, regulators, utilities, public
  - A disruptive technology
  - A new technology with limited experience
  - Different operating characteristics
  - Highly visible generating a NIMBY reaction
  - Wildlife and environmental concerns
- Integrating wind onto the grid at a large scale
  - Fluctuating output
  - Not Dispatchable
  - Transmission access

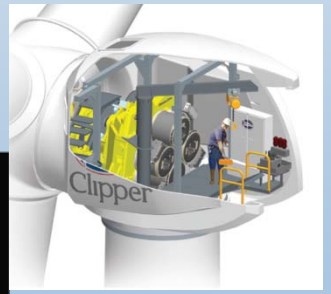
Land Based Technology Improvement Options

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







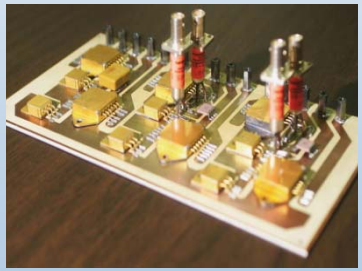
Power Train Enhancements

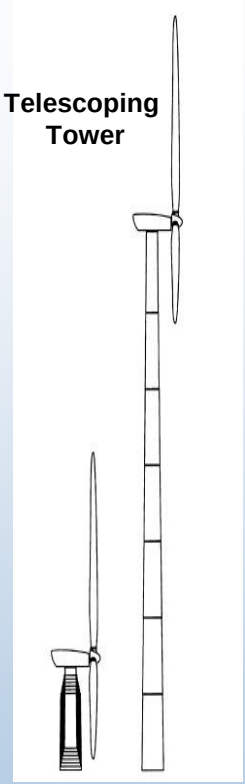
- Permanent Magnet DD Architectures
- Split load path multi-stage generation topologies
- Reduced stage (1-2) integrated gearbox designs
- Convoloid gearing for load distribution

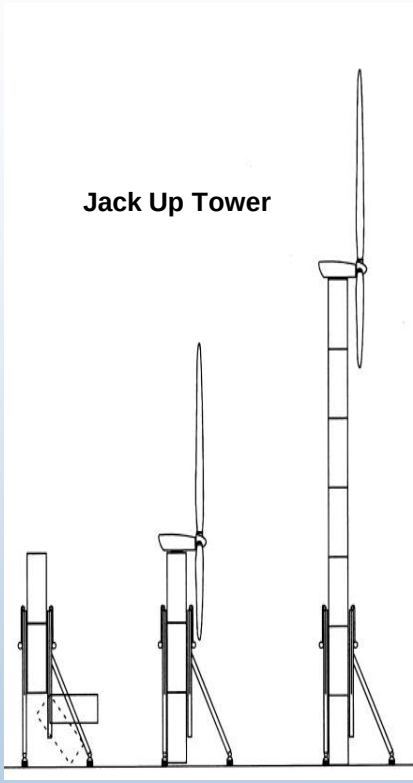
Land Based Technology Improvement Options

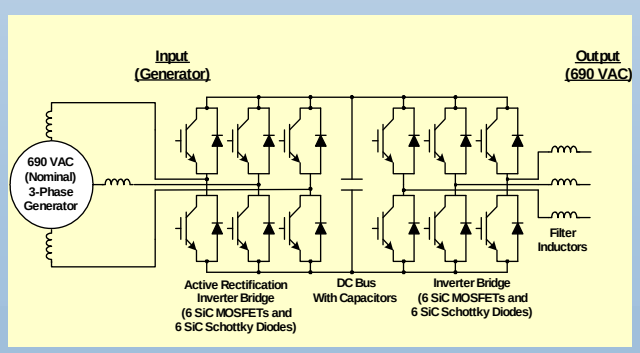
Power Conversion

- 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









Tower Support Structures

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

NREL Partners with Industry to Advance Technology

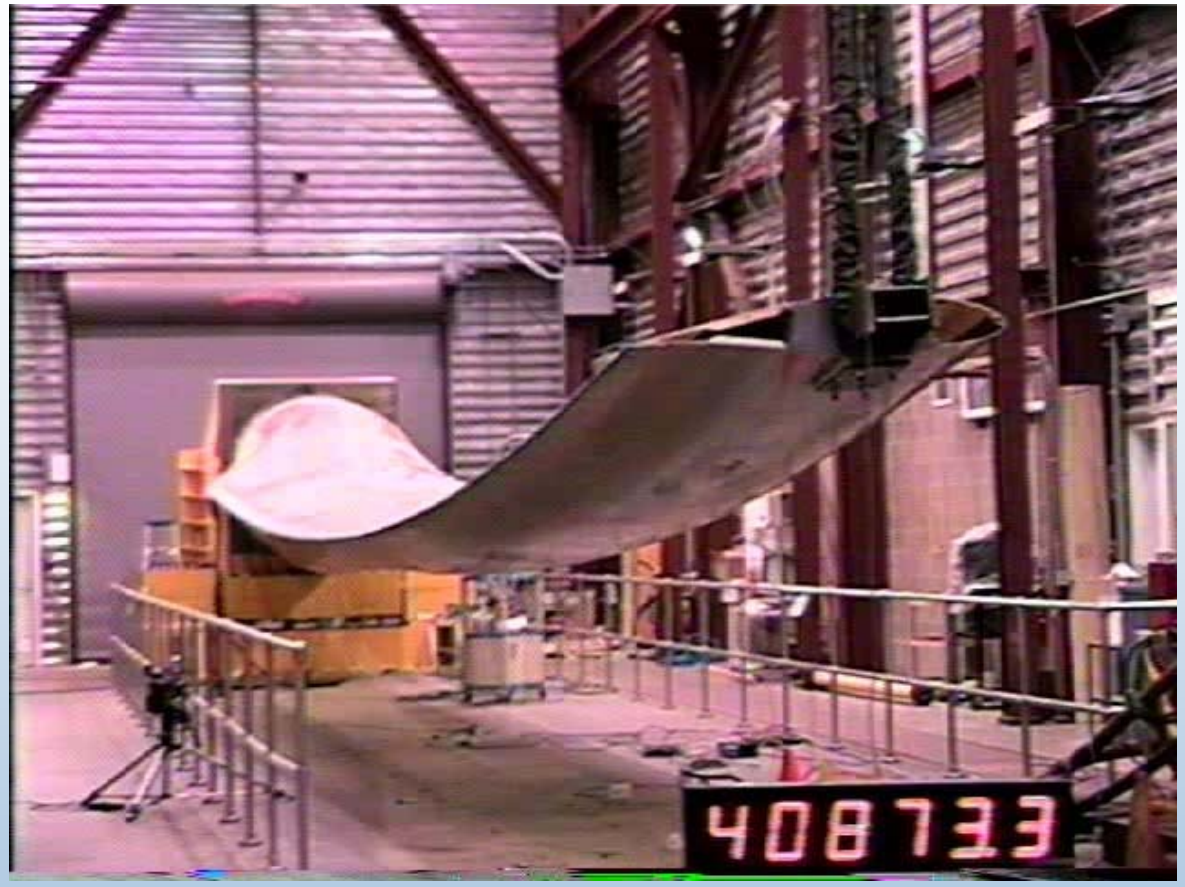
Clipper LWST Prototype
2.5 MW with 93 m Rotor

Southwest Windpower Storm
1.8 kW Wind Turbine, 3.7 m diameter

NREL Tests Innovative Wind Industry Blades Designs

Structural Test of Knight and Carver Blade

Test preparation of a swept blade providing twist-flap coupling for gust load reduction



Ultimate Strength Testing of a new Blade Design

NREL's Estimate of the Technology Improvement Potential

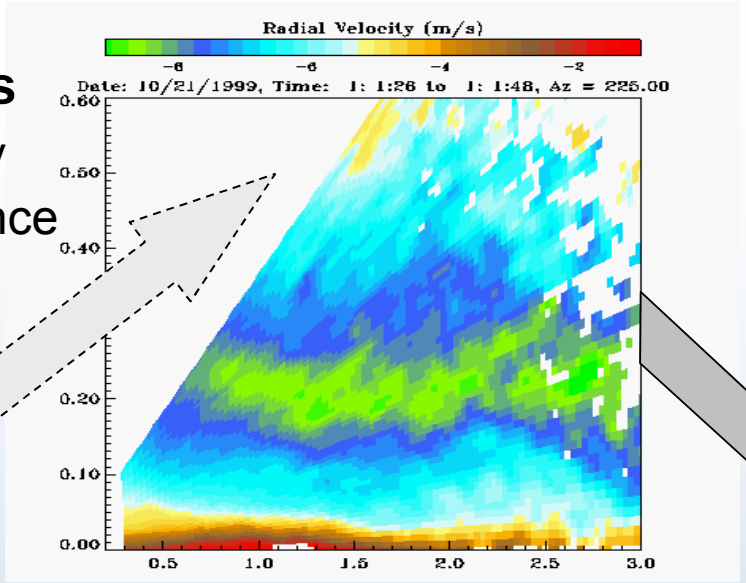
Subsystem	Description	Increased Energy	Cost
Towers	Taller with new materials/self erecting	+11/+11/+11	+8/+12+20
Rotors	Lighter & larger with smart structures	+35/+25/+10	-6/-3/+3
Energy	Improved reliability – less losses	+7/+5/0	0/0/0
Drive Train	Innovative designs – high reliability	+8/+4/0	-11/-6/+1
Manufacturing	Process evolution and automation	0/0/0	-27/-13/-3
Totals		+61/+45/+21	-36/-10/+21

Powerful winds

U_∞, direction vary

Coherent turbulence

Turbine wakes

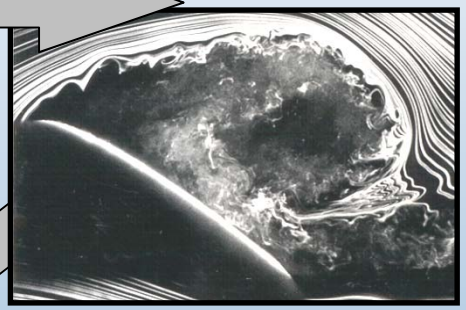


Energetic flowfield

Globally separated

Steep gradients

Dynamically active



Basic R&D Needs: Aeroelasticity

Nonlinear & coupled

Multiple physics

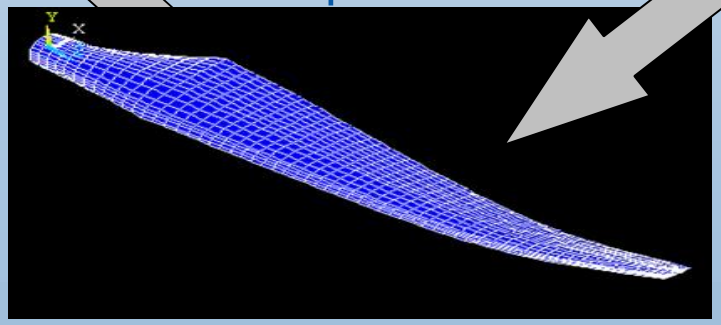
Multiple Scales

Complex wake

Trailed vortices

Shed vortices

Persistent



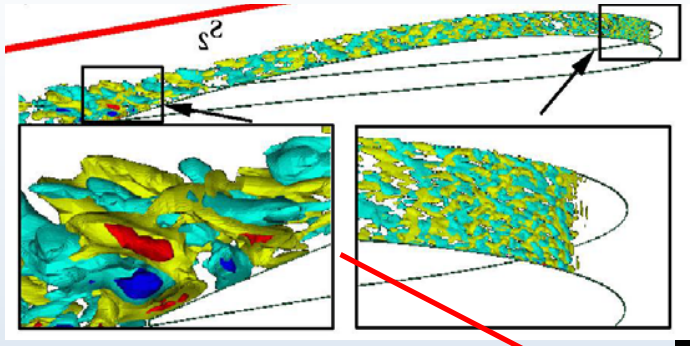
Responsive structure

Light and flexible

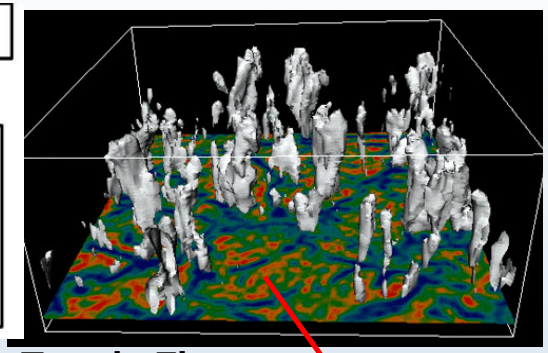
Advanced materials

Aeroelastic load control

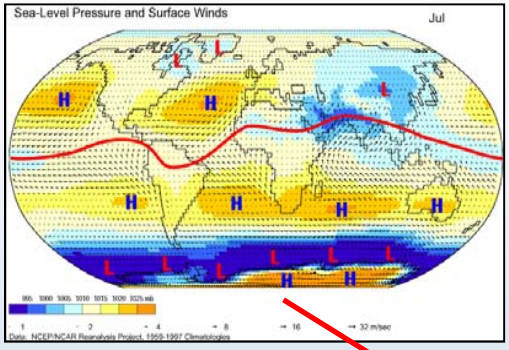
Wind Energy Computational Research Challenges
Scales Range Over 10 Orders of Magnitude



Airfoil Turbulence



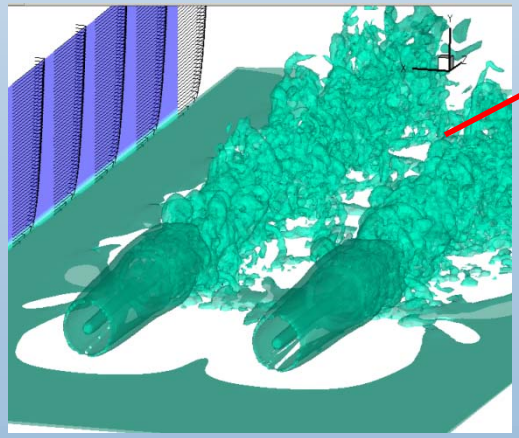
Terrain Flows



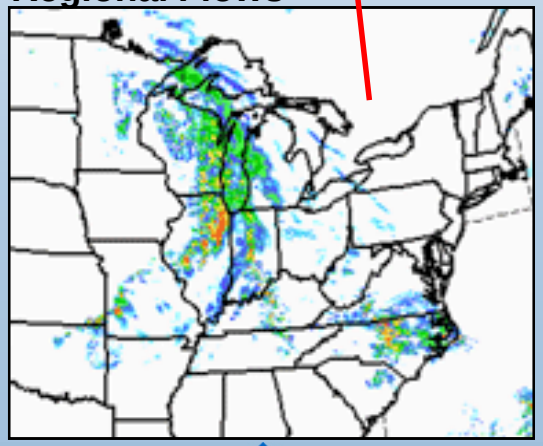
Global Flows

$\Delta x(m)$ 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

Turbine Wake Turbulence



Regional Flows



Impacts of Multi-Array & Complex Terrain

- Multi-array environments are unique.
- Microclimatology impacts becoming a greater concern
- Power performance and reliability influenced by several factors.
- Understanding inflow / array interaction is key.
- Computational models, control paradigms and hardware development will be required.
- Requires a detailed understanding of:
  - Rotor Wake Interactions
  - PBL Characteristics
  - Inflow / Wind farm Interaction
  - Complex Terrain Effects

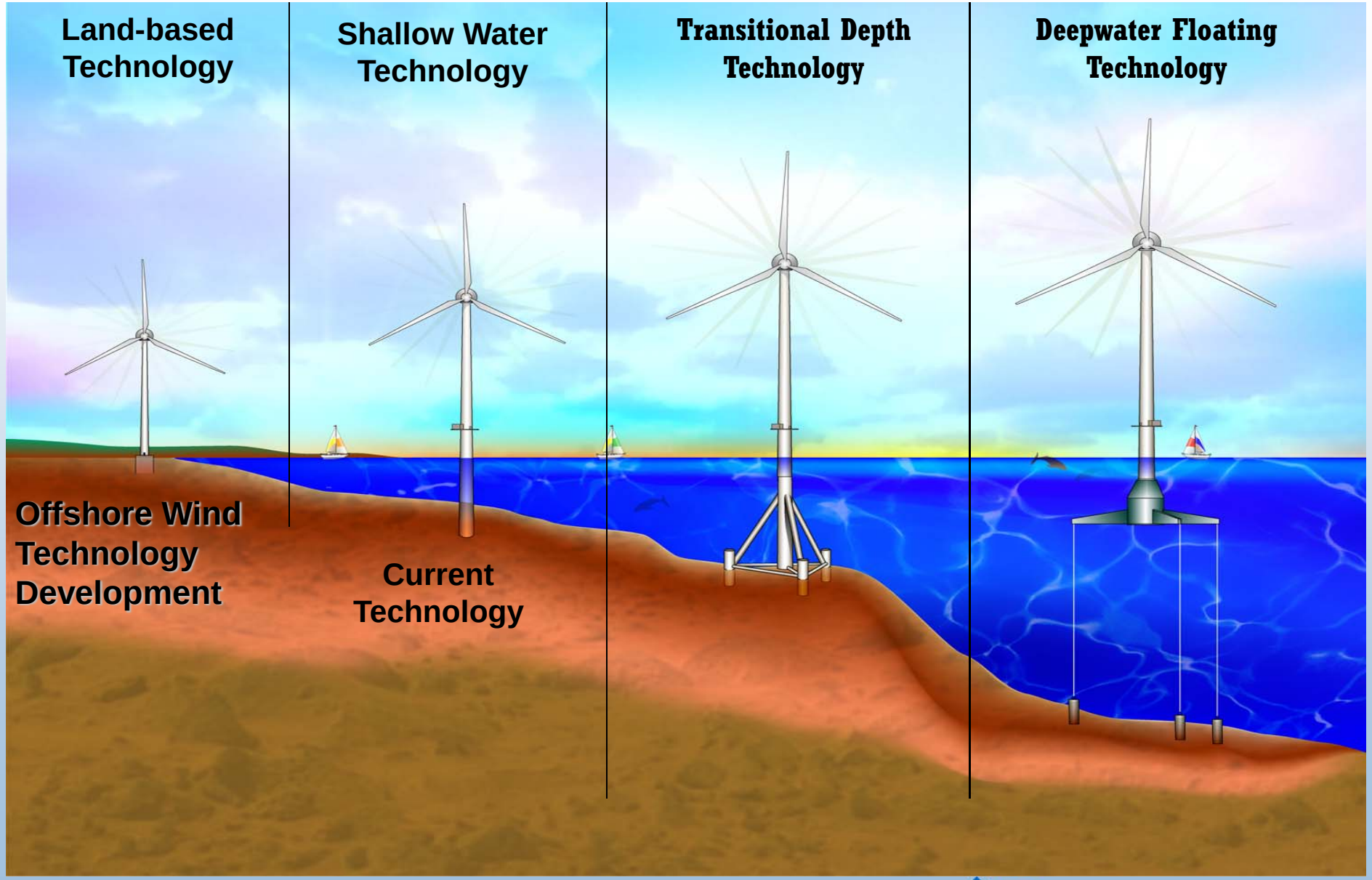
The Siting and Permitting Challenge

To reach 20% wind energy by 2030 will require minimizing the barriers to siting and permitting by "understanding, minimizing and, mitigating environmental impacts to wildlife". The issues that must be addressed through further research are:

- Understanding, minimize, avoiding, and mitigating specific species impacts:
  - Birds
  - Bats
  - Other species using the windfarm habitat
- Habitat modification and fragmentation effects
- Individual animal versus cumulative population impacts
- The influence of variables such as weather, lighting, turbine height, turbine rotation speed
- Effective mitigation measures and methods, both onsite and offsite

Source: Adapted from 20% Wind Energy by 2030

Future Research on Offshore Wind Technology



Offshore: Opportunities & Challenges

Goal: facilitate & support US offshore wind technology

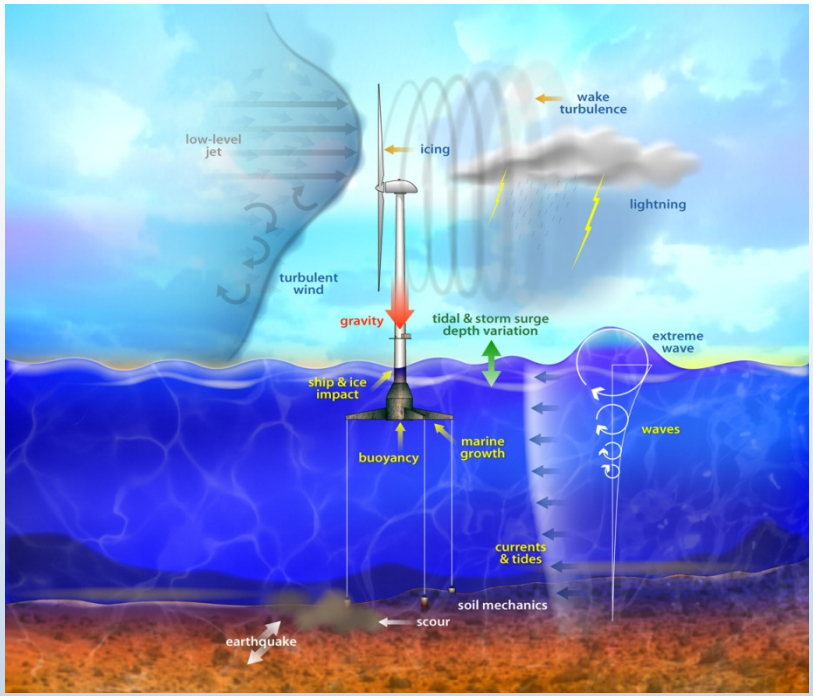
Current Activities:

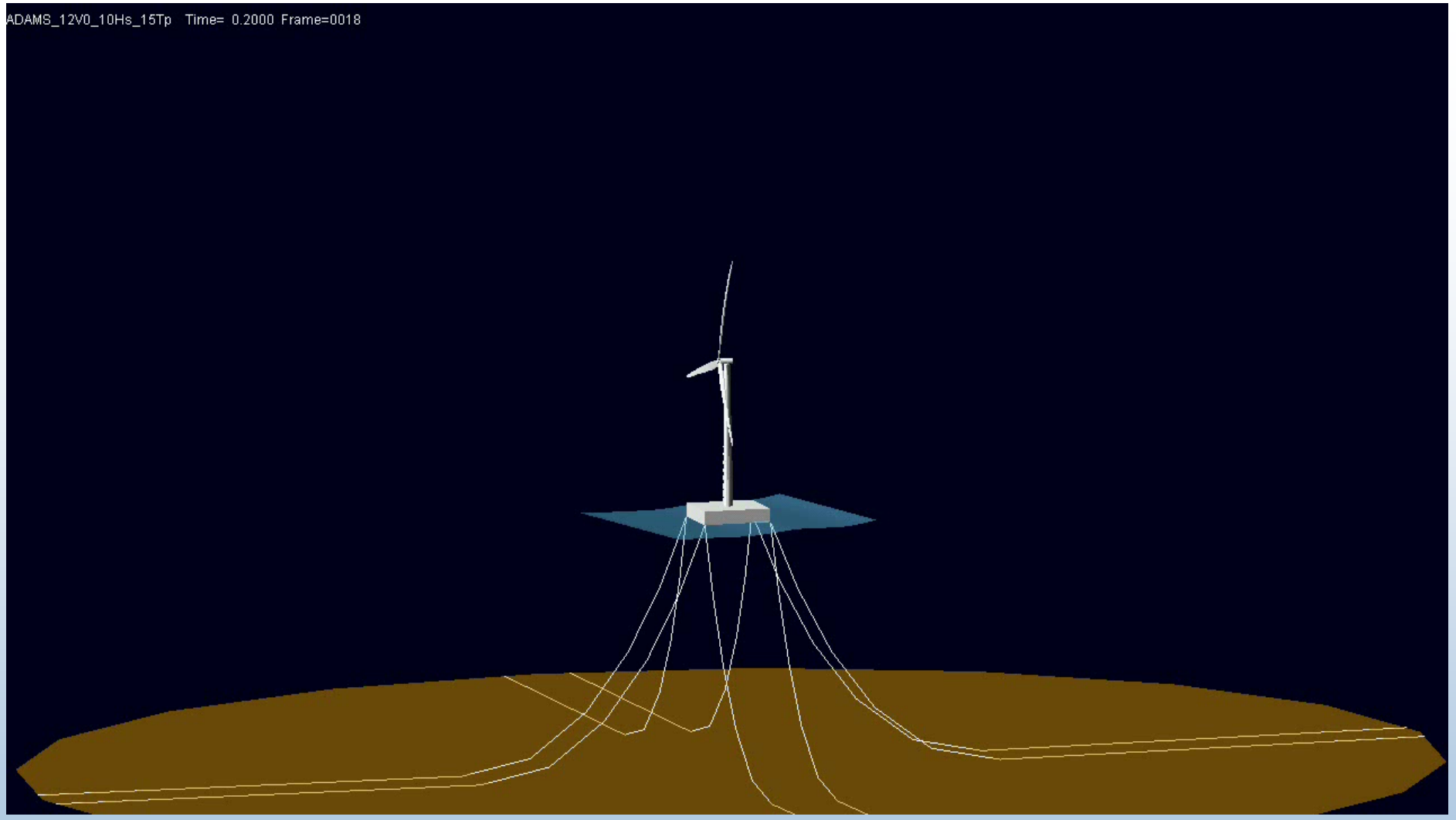
- **Technology characterization to frame development of R&D needs**
- **Coupled wind/wave design code development**
- **Resource assessments – by state, distance, depth**
- **Regulatory interface**
- **International Collaborations (IEA, IEC, UpWind)**

Recommendations:

- **Develop risk reduction measures for first projects**
- **Technology development for different depths**
- **Characterization of conditions – remote sensing and measurement methods.**
- **Code development for floating systems**
- **Design competition to build POC platform.**
- **Hardware, grid integration, environmental studies for large scale development**

National Renewable Energy Laboratory
Innovation for Our Energy Future

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The Big Players in Wind

World Manufactures

- Vestas (DK) - 20%
- GE Wind (US) - 18.6%
- Gamesa (ES) - 12%
- Enercon (GE)- 10%
- Suzalon (IND) - 9%
- Siemens (GE) - 7%
- Sinovel (PRC) - 5%
- Acciona (ES) - 5%

World Developers and Operators

- Iberdrola Renewables (ES) – 8960 MW
- FPL Energy (US) – 6374 MW
- EDP Renovavies (P) – 5052 MW
- Acciona Energy (ES) – 4566 MW
- Long Yuan Electric Power (CN) – 2924 MW

Interesting Players

- DeWind
- Nordic
- Clipper
- RePower
- Mitsubishi
- Fuhrlander
- TPI Composites
- AMSC – Windtec
- RES
- Cielo Wind Power

United States Wind Consultancies

- Garrad – Hassan
- Global Energy Concepts - DNV
- Windward Engineering

A Future Vision for Wind Energy Markets

Tomorrow

Today 2009

Bulk Power Generator
5-9¢ at 13mph* With No PTC

- Land Based
- Bulk Electricity
- Wind Farms

Less than 2% of Electricity Market

Land Based Electricity Path

Land-Based Turbines 2–5 MW

Transmission Barriers

Land-based Turbines:
- Cost Reduction
- Increased Energy & Reliability
- 20% of Electricity Market

Offshore Electricity Path

Offshore Turbines 5 MW and Larger

Cost & Regulatory Barriers

Offshore Turbine:
- Higher Wind Sites
- Shallow/***Deep*** *water*
- Coastal Cities
- 35% Cost Reduction needed

New Applications Path

- **Hydrogen**
- **Clean Water**
- **Storage: PHEV-CAES**

Cost & Infrastructure Barriers

Custom Turbines for Multi-markets:
- Electricity
- H2 production
- Desalinate water

2020 and Beyond

* Note: The site wind speed is measured at 10m and assumes a 1/7 power law wind shear giving a hub height wind speed of 18mph, while the siting, land and related project costs are assumed to be average for the US.

Changing the way we Power America