WIND AND WATER POWER PROGRAM

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Quadrennial Technical Review
Wind Energy Program

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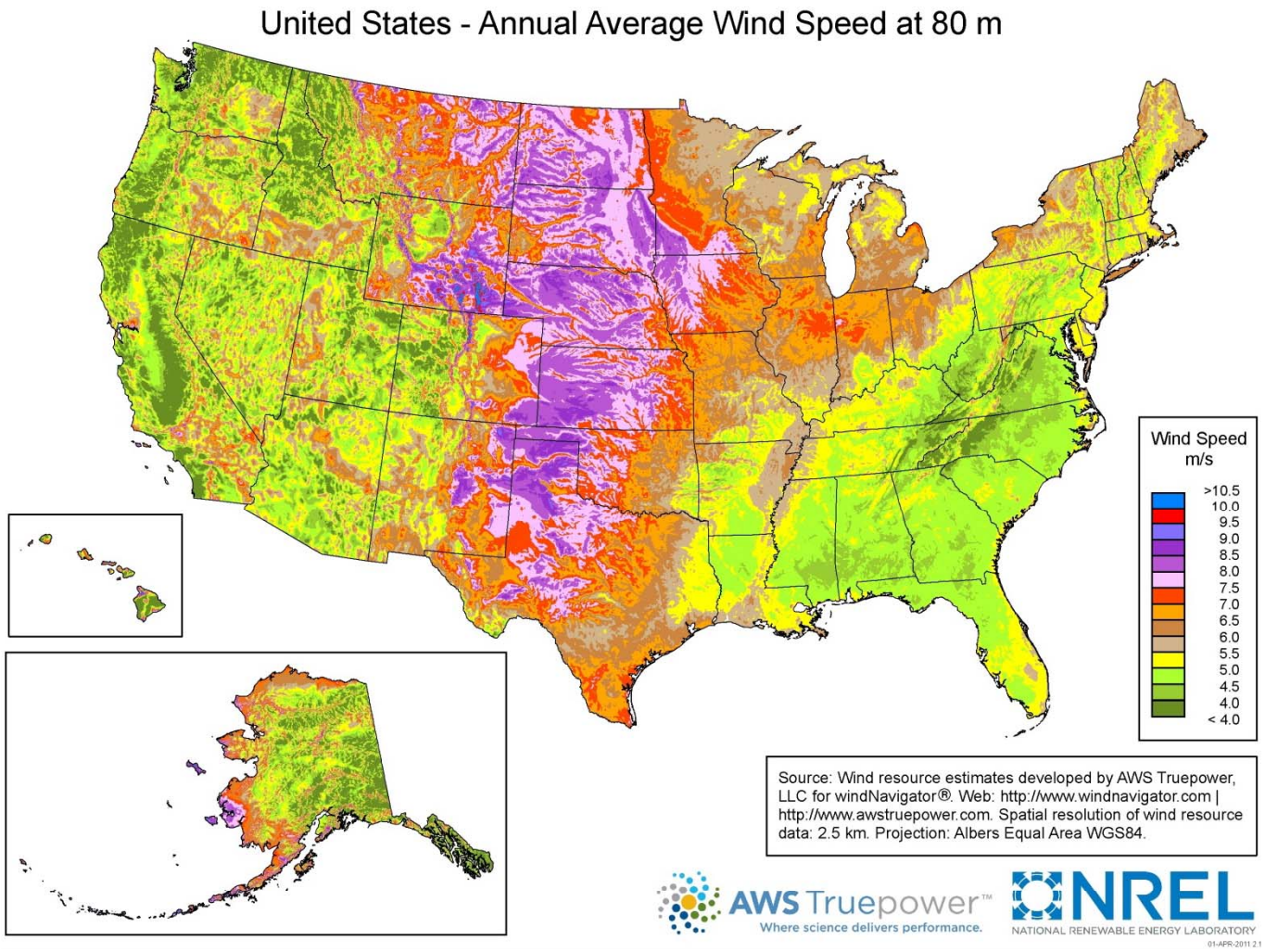
Chief Engineer - Wind

Wind and Water Power Program

Wind Energy Resource Potential



- 40 GW installed domestically
- 8,000 GW of economical land-based resource
- 4,000 GW of offshore resource
- Lack of transmission & siting barriers push developers to build in lower-quality wind regimes
  - ✓ decreasing capacity factor
  - ✓ increasing LCOE

Decreasing Capacity Factor with Lower Wind Speed Sites

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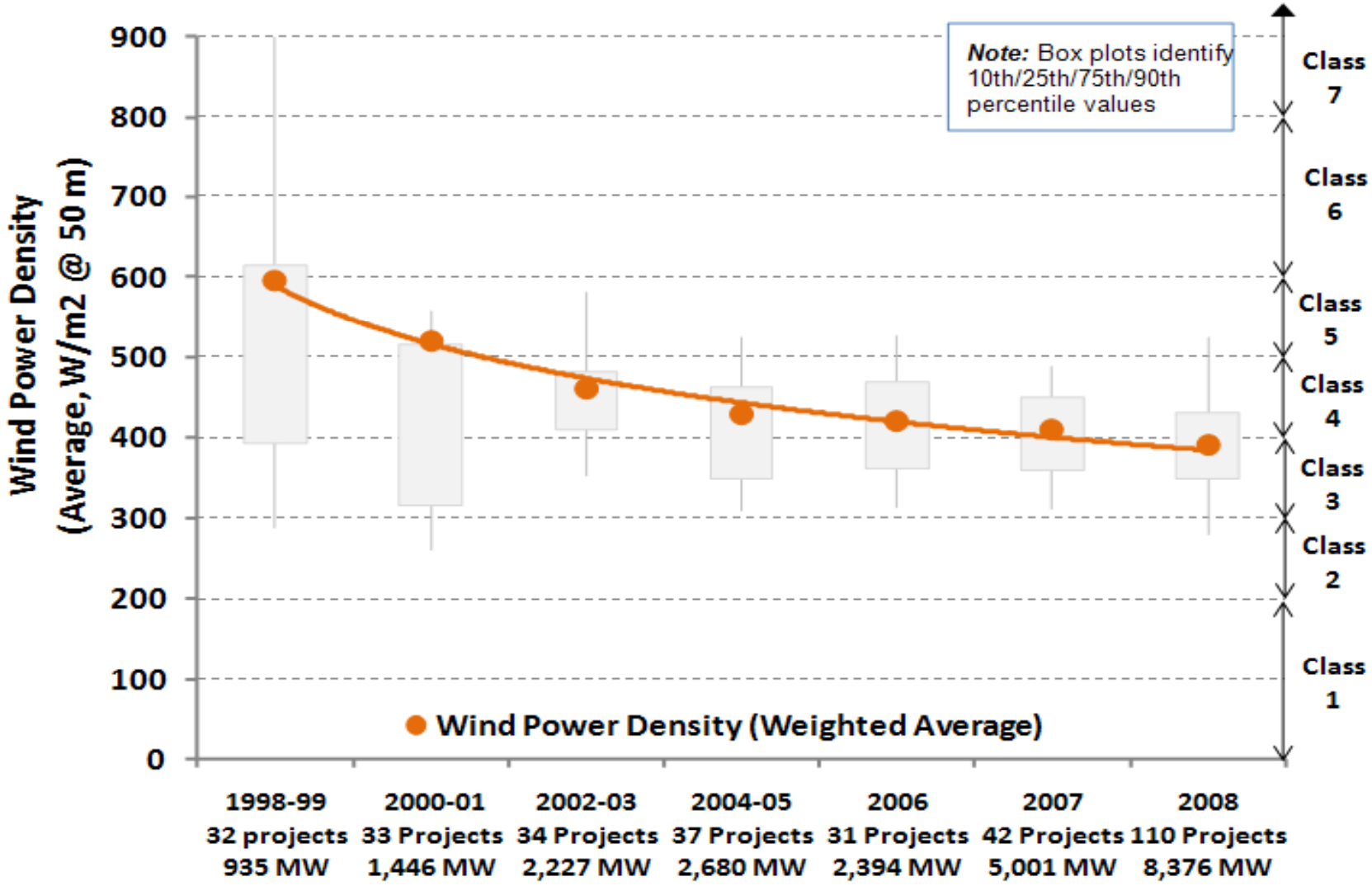
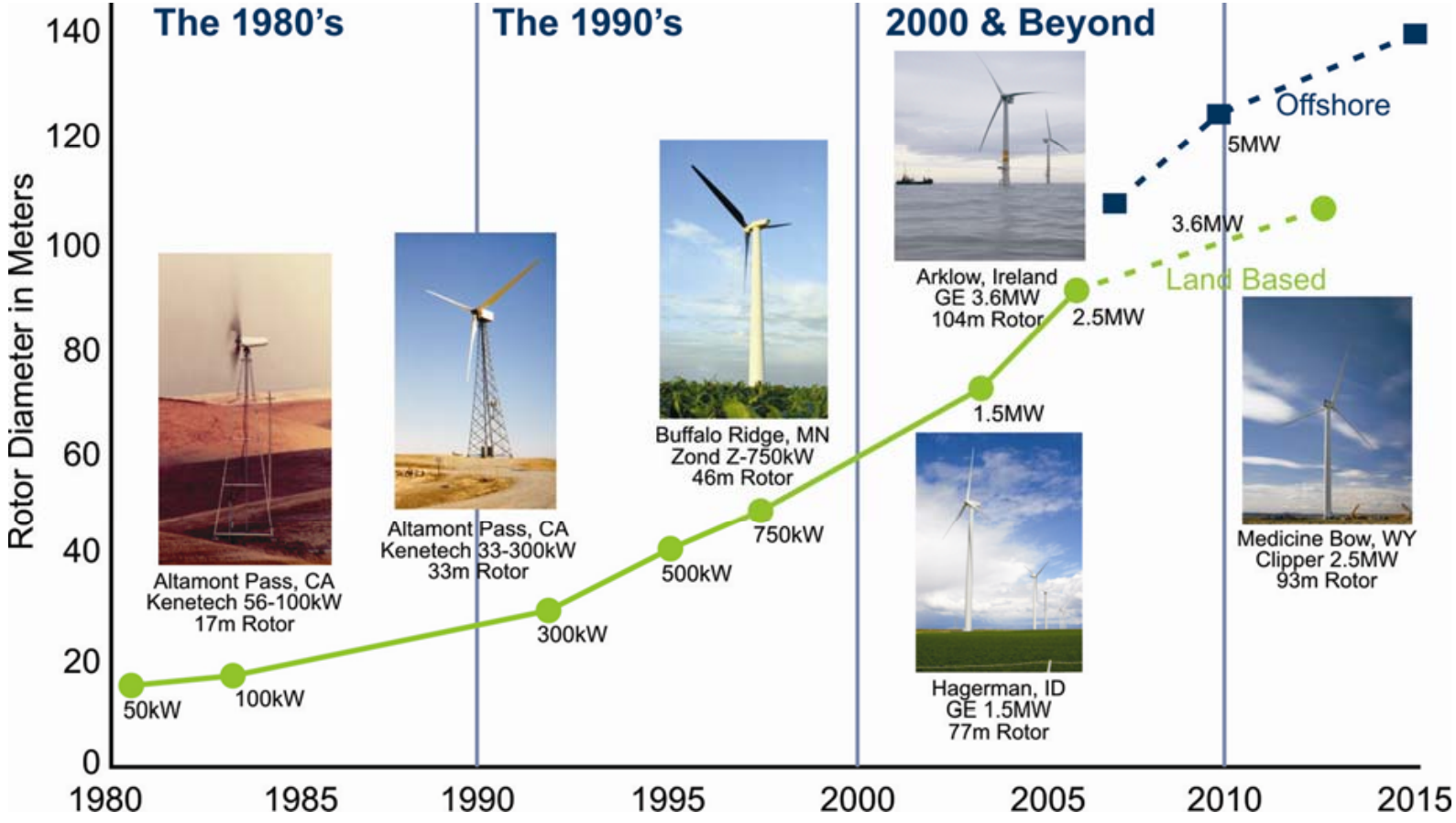


Evolution of Wind Power Technology



- Taller towers & larger rotors provide access to better winds and more energy production
- Improvements in turbine efficiency increase annual energy production and capacity factor
- Existing technology will continue to benefit from scaling principals and efficiency improvements

U.S. Wind Power Market

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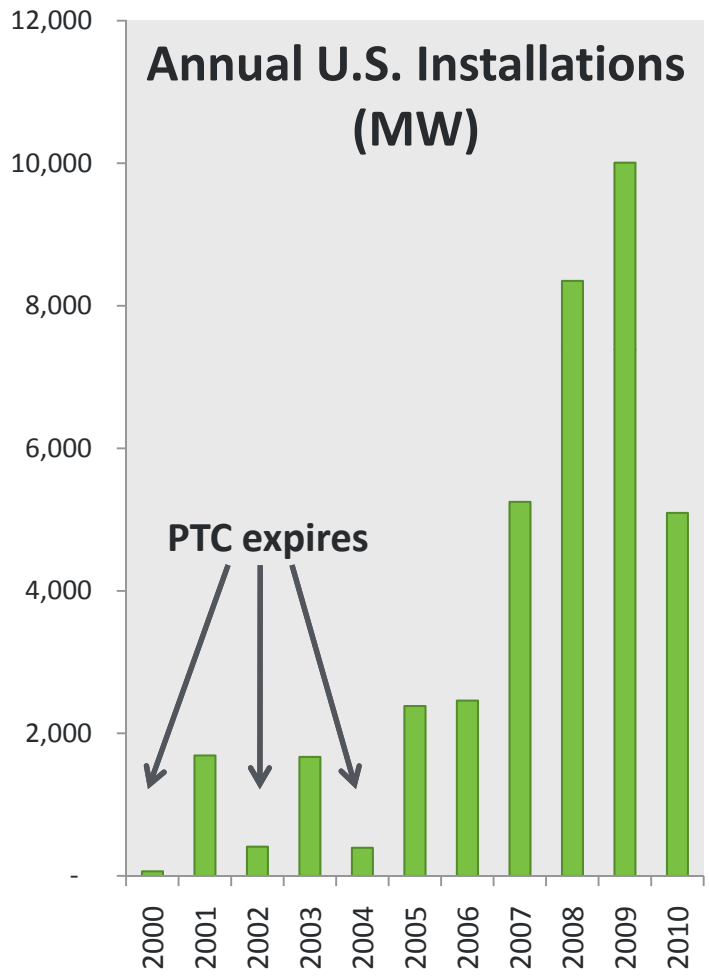
- **Recent market news**
  - 40,180 MW installed capacity, 2% of U.S. electricity generation
  - $20 billion dollar investment and 85,000 workers in 2009
  - Recovery Act has supported investment ($5.6B in grants supporting over $18B investment since August 2009)
  - Slowed growth due to economic downturn, natural gas prices
  - 200 manufacturing facilities in U.S. across more than 30 states
- **Technology**
  - U.S. market share in 2010: GE 50%, Siemens 16%, Gamesa 11%, Mitsubishi 7%, Suzlon 6%, Vestas 4%
  - Larger machines are needed to lower balance of system costs
  - Average turbine capacity ratings, hub heights, and rotor diameters are expected to continue to increase
  - Shallow water offshore technology is proven in Europe, with 3,000 MW of capacity installed
- **Policy**
  - Loan Guarantee Program is essential to address very high financial costs associated with the first US offshore projects.
  - Manufacturing Tax Credit (MTC): 30% credit for investments in new, expanded, or re-equipped advanced energy manufacturing projects
  - Production Tax Credit (PTC): $21/MWh for the first ten years of operation of a wind energy facility
  - Federal emissions standards: CO2 , SO2 , NOx & Mercury



Cost breakdowns

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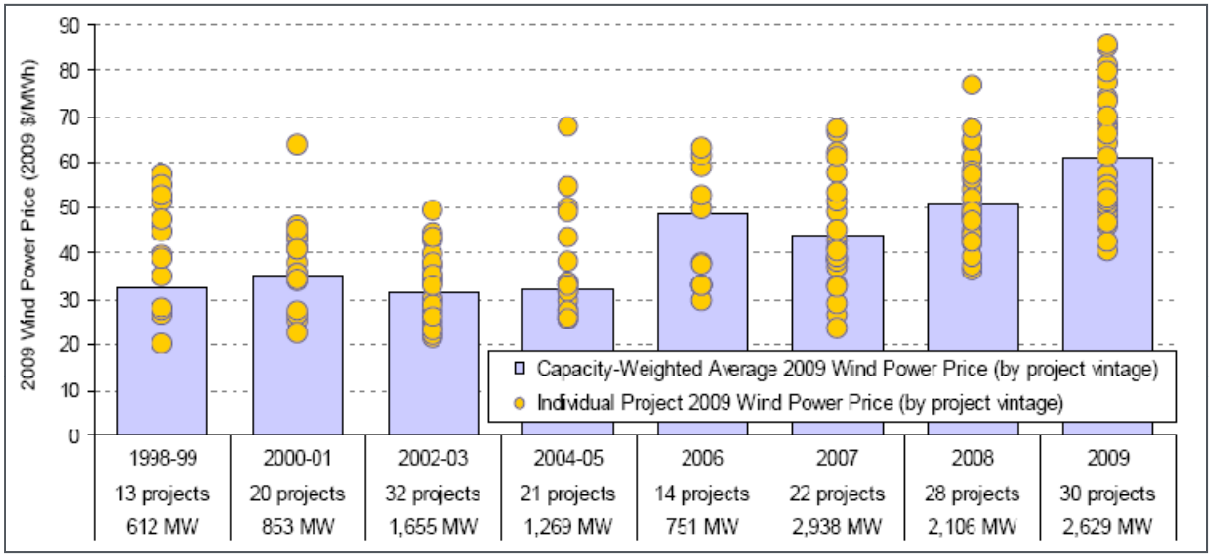
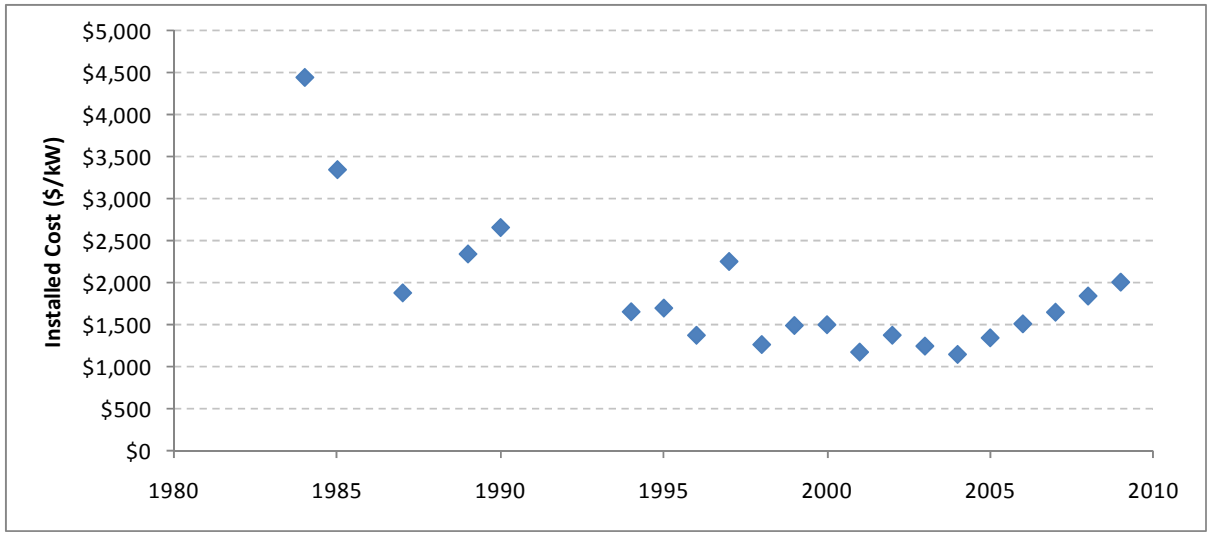
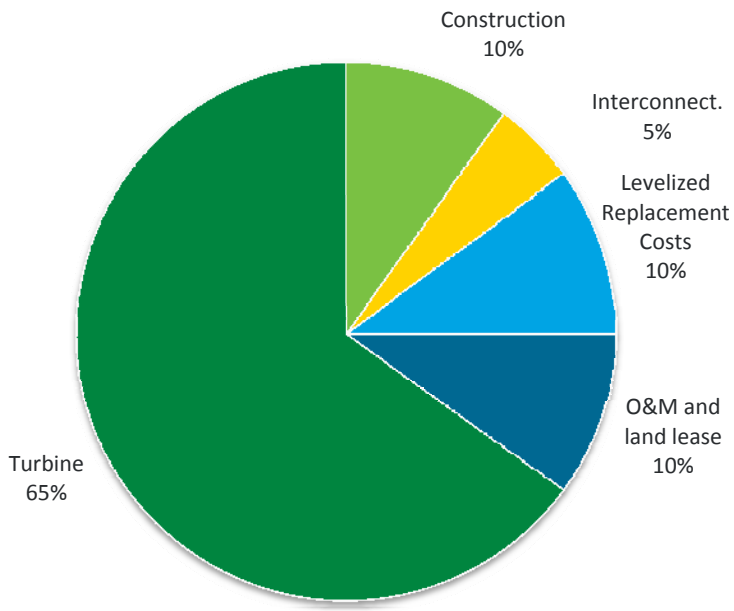
- The factors that drove up the capital cost of wind installations in 2008
  - ✓ higher commodity prices,
  - ✓ relatively weak dollar
  - ✓ reliance on European supply,
  - ✓ supply/demand constraints,
  - ✓ increased labor costs
- U.S. 2010 land-based wind costs similar to 2009
- Recent trends indicates cost reductions on the order of 25% for projects to be built 1 to 2 years into the future
  - ✓ increased domestic content,
  - ✓ build-out of new manufacturing capacity
  - ✓ lower demand
  - ✓ foreign competition



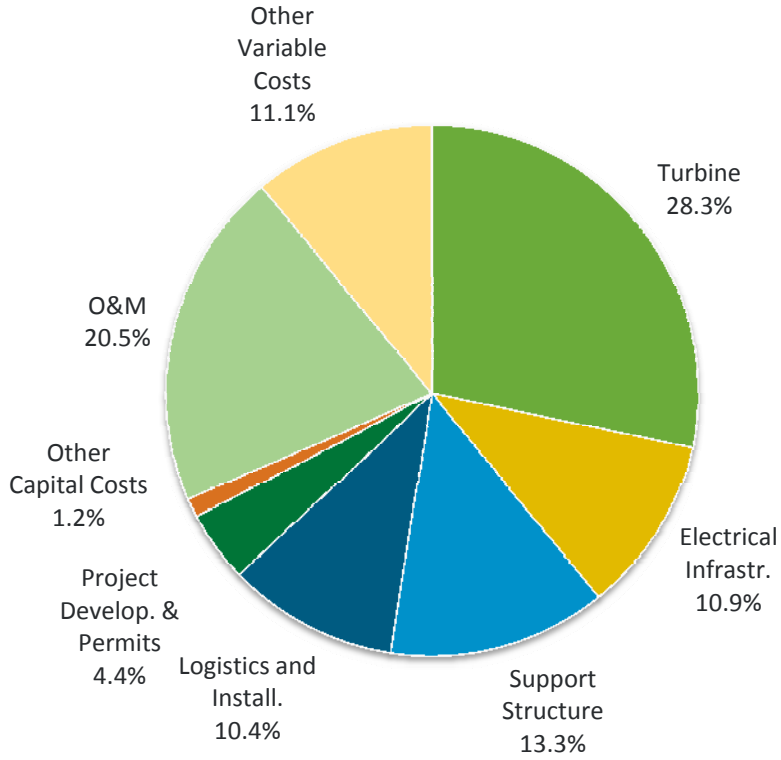


Cost breakdowns

Land-based



Shallow Offshore Fixed Bottom



- **Turbine represents only a fraction of the overall wind plant system costs**
- **The related balance of system hardware, and support infrastructure represents a greater portion of the overall wind plant cost drivers**
- **Substantial opportunity for domestic suppliers for both domestic deployment and potential export**

COE Reduction Pathway

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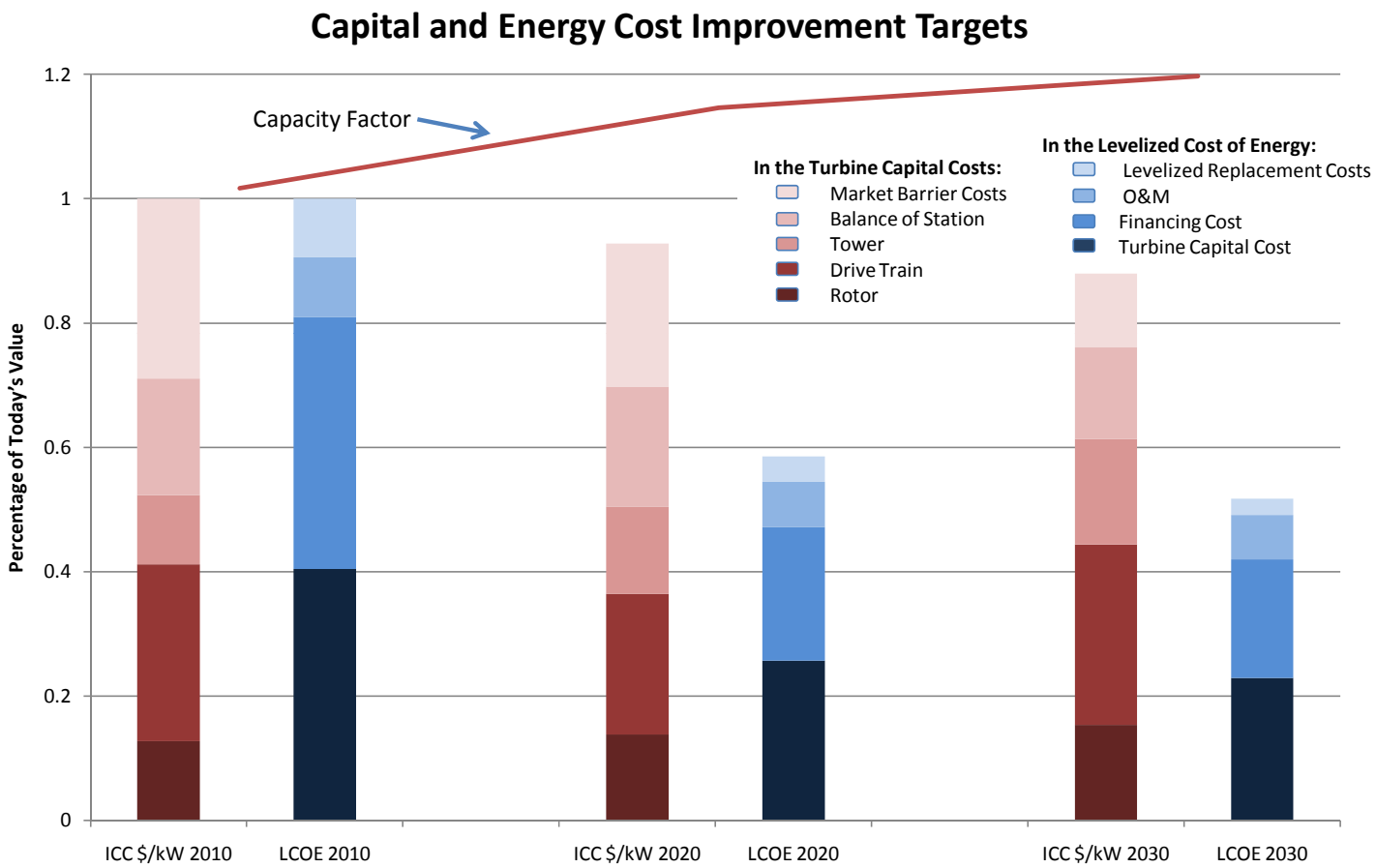
- Further advances in land & offshore wind technology can achieve cost of energy parity with conventional fossil fuel generation
- Reductions in installed costs expected by 2030:
  - Land-based wind: 25-35%
  - Offshore: 9% to 44%
- Principal technology cost drivers:
  - Lowering Installed Capital Cost of the wind plant system –turbine and balance of station
  - Increasing plant capacity factor - yielding greater annual energy production.
- Major strategies for technology innovation:
  - Developing larger, light weight turbine architectures
  - Reducing integrated wind plant systems (energy) losses
  - Improving plant system performance
  - Demonstrating innovative technology to reduce perceived risk

Scaling



Assumptions:
1.5 MW Turbine
77 meter rotor diameter
80 meter tower
Mid-class 4 wind speed
Availability of 97%
Geared gearbox

Assumptions:
3.5 MW Turbine
118 meter rotor diameter
110 meter tower
Mid-class 4 wind speed
Availability of 98%
Single stage gearbox

Assumptions:
5 MW Turbine
141meter rotor diameter
133 meter tower
Mid-class 4 wind speed
Availability of 98%
Permanent Magnet Direct Drive

Cost of Energy Reduction Pathway: Land-based Wind

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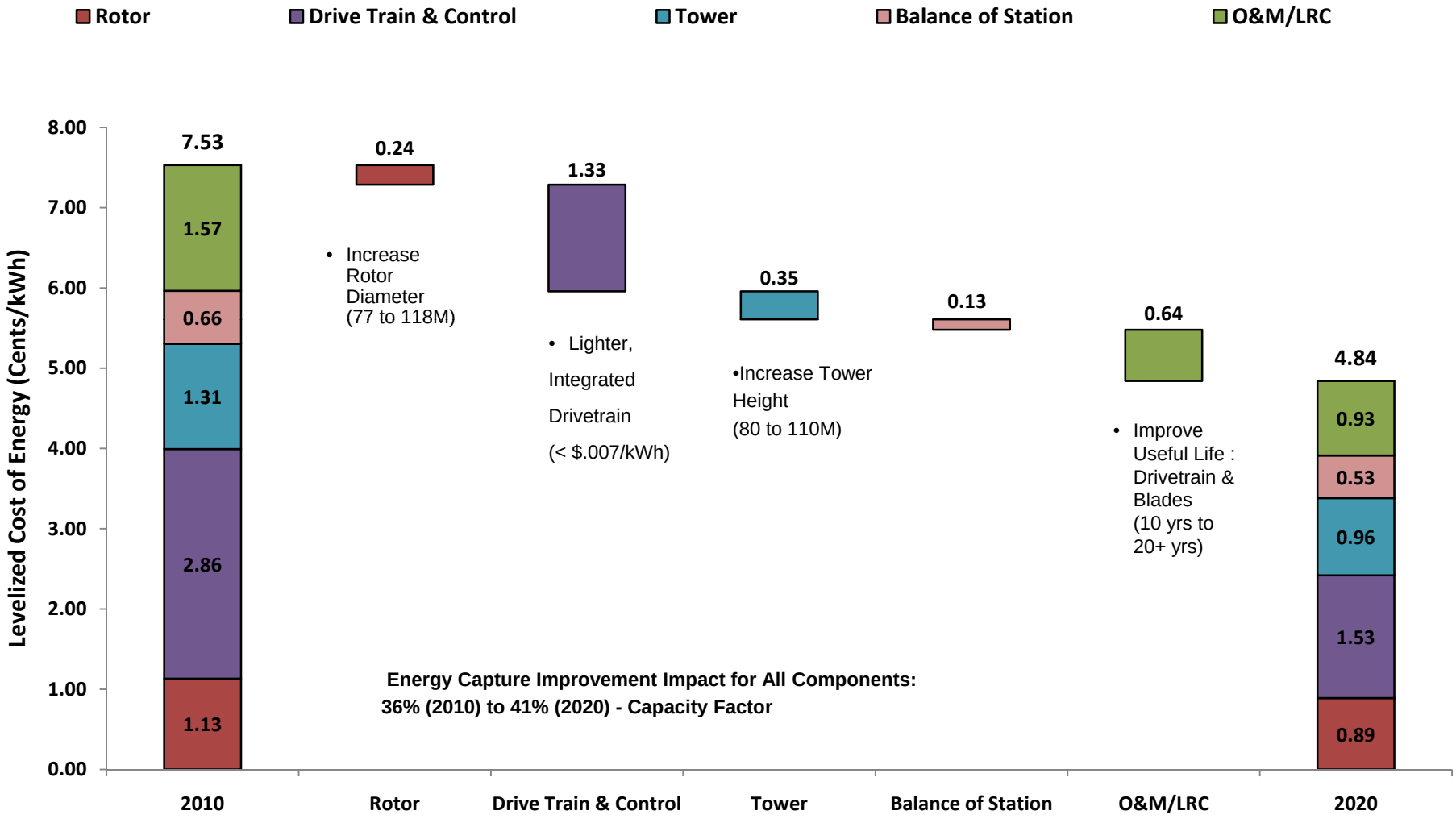
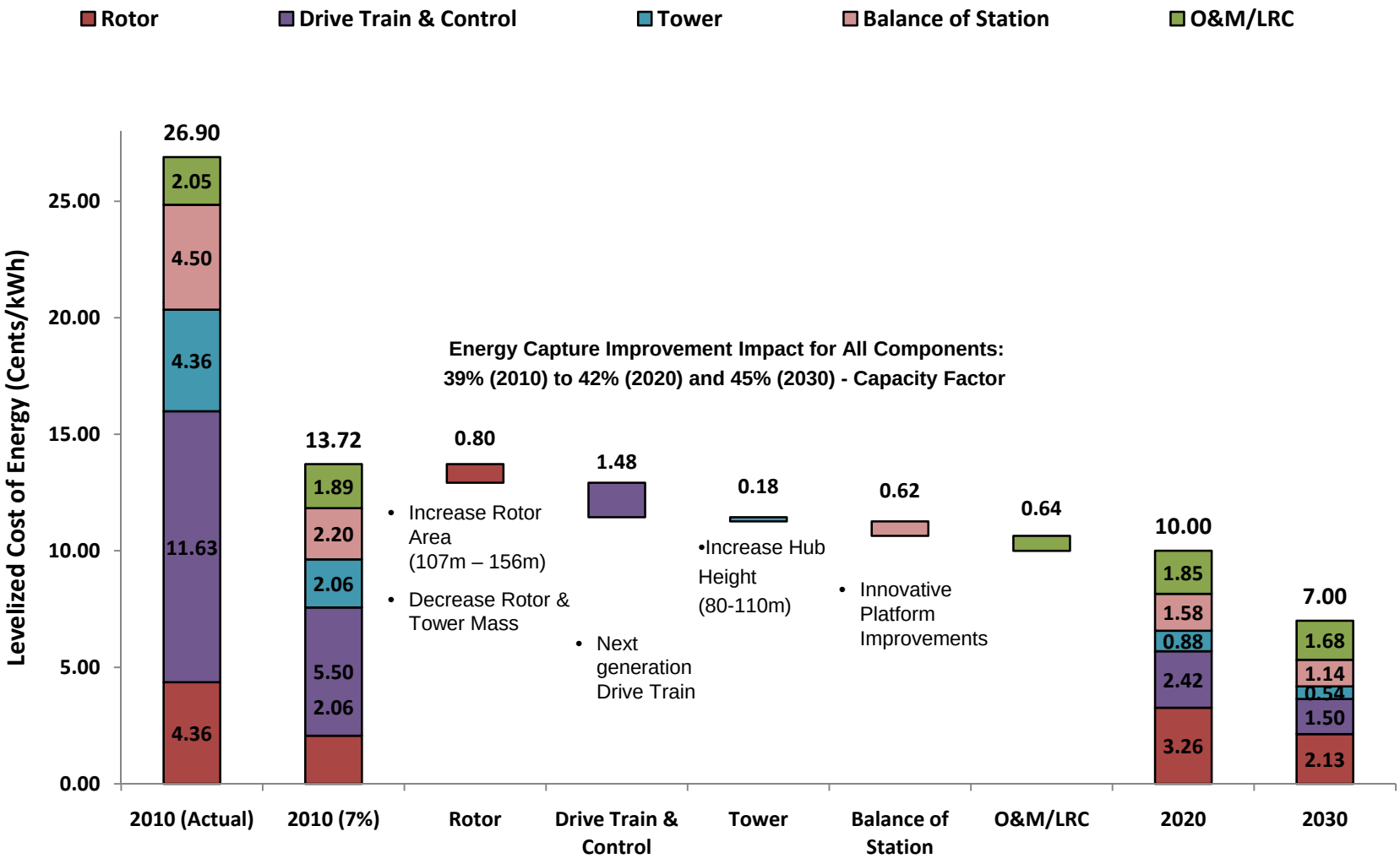


Cost of Energy Reduction Pathway: Offshore Wind



LCOE Reduction Pathway

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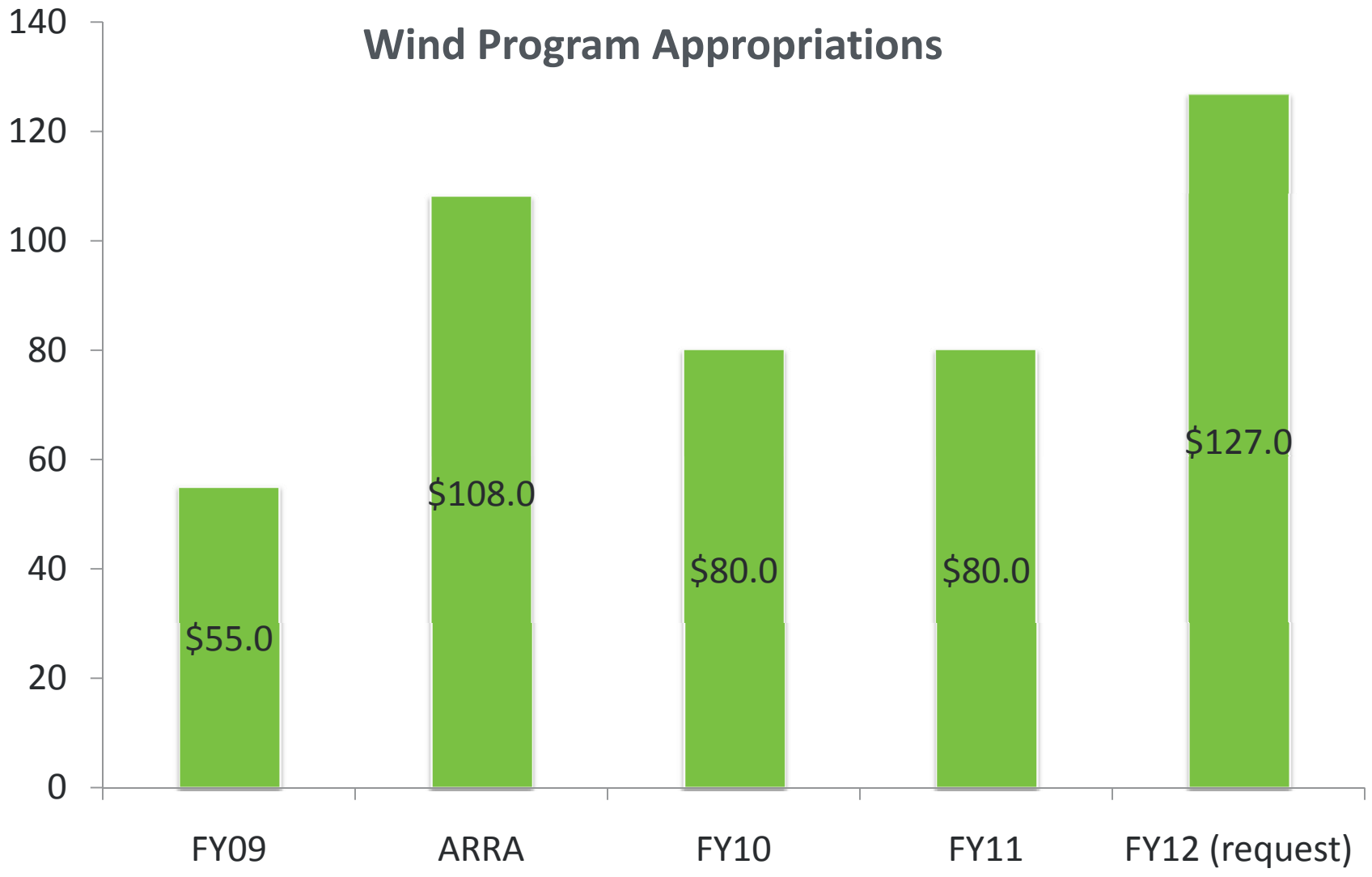
Major strategies for technology innovation, applicable to land and offshore wind plants

- Developing larger light weight turbine architectures that reduce overall mass (cost) and provide access to better resource (larger rotors, taller towers) and improved systems performance (capacity factor).
- Reducing integrated wind plant systems (energy) losses including power collection, grid interconnection, and large array effects
- Improving plant system performance including O&M and component reliability
- Demonstration of technology innovation to reduce risk and attract investment capital in innovative technologies – especially deep water offshore.

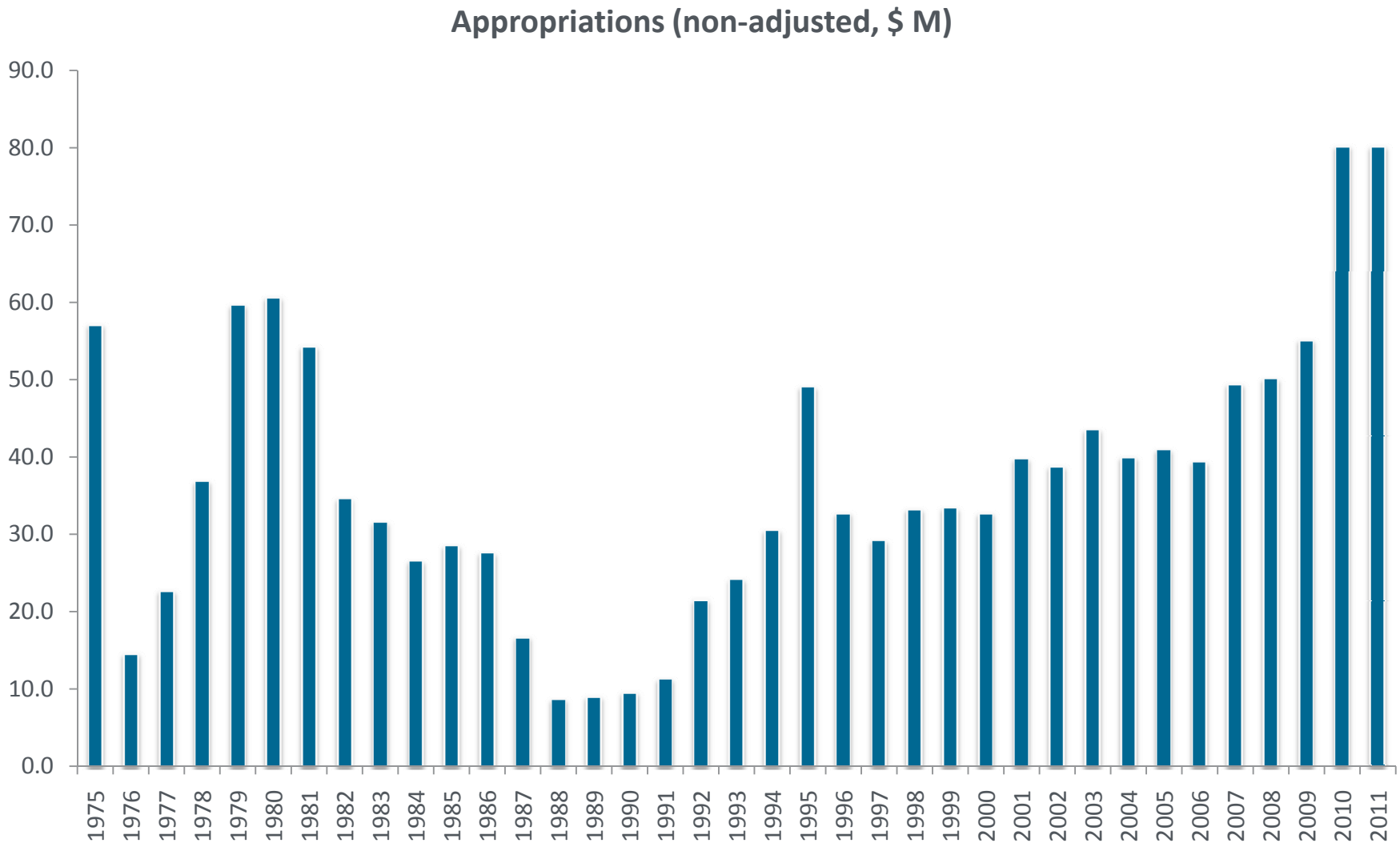
Associated R&D, modeling and analysis required to support innovation include:

- High Performance Computer Modeling of complex wind farms are essential to assess wind farm underperformance, define intra-array operating environments, quantify micro and macro climatology impacts, reduce failure rates and increase energy output through optimized siting.
- Systems level design of wind turbines and wind farms to optimize energy production and minimize cost from an integrated systems perspective
- Component material improvements (cost, strength, weight, fatigue) that facilitate turbine scaling and improve reliability.

Budget ($M)


Wind Program Appropriations
140
120
100
80
60
40
20
0
$55.0
$108.0
$80.0
$80.0
$127.0
FY09
ARRA
FY10
FY11
FY12 (request)

Wind Program Appropriations



Information Resources

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- 20% Wind Energy by 2030, July 2008.
- 2009 Wind Technologies Market Report, August 2010.
- A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States, February 2011.
- Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers, September 2010.

Technical Targets

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Performance Driver	Metric	Units	2010	2020	2030
1.0 Wind TURBINE Cost & Performance	**TCC/AEP**	**¢/kWh**	**1.78**	**1.37**	**1.39**
Rotor Swept Area - Increase rotor swept area while decreasing mass	Rotor Mass/Swept Area	kg/m^2		TBD	
Foundations and Support Structures	Cost/Installed kW	$/KW		TBD	
Drivetrain Weight and Integration	Up-tower mass/kW	kg/kW		TBD	
Power Electronics Efficiency - higher energy conversion at lower wind speeds	Power Electronics Cost/kW	$/kW		TBD	
2.0 Wind PLANT Cost & Performance	**BOS/AEP**	**$/kWh**	**0.86**	**0.69**	**0.46**
Wind Plant Performance Optimization	Wind Plant Capacity Factor	%	36%	41%	43%
Integrated System Cost Optimization	Rotor Mass/Swept Area	kg/m^2		TBD	
3.0 Wind Plant Reliability: reduce O&M costs and Levelized Replacement Costs	**(O&M + LRC)/AEP**	**$/kWh**	**1.57**	**0.93**	**0.78**
Increase Useful Life of Major Components	Useful Life (avg of Rotor & Drivetrain)	Years	7	14	21
Reduce O&M Costs	O&M Costs / Plant kW	$/kW		TBD	
4.0 Financing Costs: risk reduction activities	**Discount Rate**	**%**	**8%**	**7%**	**6%**
Technology Demonstration	# of offshore turbines deployed	#		TBD	
Wind Farm Siting, Permitting, and Construction Optimization	Contribution to discount rate	%	2%	1%	0%
5.0 Deployment Barriers	**GWs Delayed**	**GW**	**30**	**10**	**0**
Grid Integration and Transmission Access	TBD			TBD	
Wildlife and Environmental Constraints	GWs Delayed	GW		TBD	
Radar Interference Mitigation	GWs Delayed	GW		TBD	

Work Breakdown for Wind R&D

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Utility Scale Wind Plant

LCOE Levers

1.0 Wind Turbine Cost & Performance (TCC/AEP)

Rotor Swept Area

- *Innovative blade architectures*
- *High strength & stiffness materials*
- *Non-linear aeroelastic design tools*
- *Advanced control systems*
- *Faster tip speeds (reduced noise)*

Support Structure Design

- *Innovative tower architectures*
- *Advanced and hybrid materials*
- *Innovative substructure designs**

Drivetrain Weight and Design

- *Advanced platform architectures (e.g. superconducting, etc.)*
- *Non-linear integrated modeling*

Power Electronics Efficiency

- *Advanced medium/high voltage architectures*

2.0 Wind Plant Cost & Performance (BOS/AEP)

Wind Plant Energy Capture Optimization

- *Reduced wake and array losses*
- *Optimized micro-siting*
- *Improved resource prediction*
- *Advanced plant-level control strategies*

Wind Plant Cost Optimization

- *Reduced installation costs*
- *Reduced non-electrical BOS costs*
- *Reduced electrical BOS costs*
- *Advanced offshore infrastructure (harbors, ships, etc.)**

3.0 Wind Plant Reliability ((O&M+LRC)/AEP)

Major Component Useful Life

- *Rotor defect and failure characterization*
- *Drivetrain defect and failure characterization*
- *Blade manufacturing quality control*

O&M Cost Optimization

- *Condition-based monitoring*
- *Optimized servicing strategies*
- *Offshore O&M logistics**

4.0 Financing (Discount Rate)

Advanced Technology Demonstration

- *Advanced offshore technology (e.g. floating platforms)*
- *Geography-related challenges (e.g. Great Lakes, Gulf of Mexico, etc.)*

Siting, Permiting, and Construction Process Optimization

- *Streamlined and standardized project timelines*
- *Consistent local and national policy*

5.0 Deployment Barriers

Grid Integration and Access

- *Integration studies*
- *Interagency collaboration*

RadMitigationar Interference

- *Wind turbine technology solutions*
- *Interagency collaboration*

Wildlife and Environmental Constraints

- *Wildlife impact mitigation technologies and studies*
- *Environment alimpact mitigation technologies and studies*

Performance Drivers

- *Technology Pathways*