U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE's Wind & Water Power Program Overview

June 28, 2012

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Wind and Water Power Program

Administration & DOE Priorities

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White House
- Generate 80% of the nations' electricity from clean energy sources by 2035
- Reduce carbon emissions 80% by 2050
- Stimulate jobs and economic recovery through RE development

DOE
- Promote energy security through reliable, clean, and affordable energy
- Strengthening scientific discovery and economic competitiveness through science and technology innovation

EERE
- Invest in clean energy technologies that strengthen the economy, protect the environment, and reduce dependence on foreign oil

WWPP
- Improve the performance, lower the costs, and accelerate deployment of innovative wind and water power technologies

The ***mission*** of the Wind Power Program is to enable U.S. deployment of clean, affordable, reliable and domestic wind power to promote national security, economic growth, and environmental quality

Wind Program Portfolio
Transformational Technology Innovation

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The Wind Program performs **Research and Development of Transformational Technology Innovation** in three markets:

Land Based Utility Wind
- 1-5+ MW turbines
- R&D Focus: Next generation turbine cost reductions, improved energy capture & conversion at an "Integrated Wind Plant" level, advanced controls, extended useful life of components

Offshore Wind
- 3-10+ MW turbines
- R&D Focus: Floating platforms (access higher winds); integrated systems designs (reduce full plant LCOE); optimized O&M strategies (reduce costs, extend life); turbine innovations (less constraints than on land) including rotor, next generation drivetrain and control systems

Distributed Wind
- < 1 MW turbines, Grid connected on the customer side of the meter
- R&D Focus: Optimized for low Class 3/Class 2 wind speeds, very low maintenance, LCOE reduction to compete with retail

Wind Program focus is on transformational innovations that the Wind Industry cannot achieve on their own

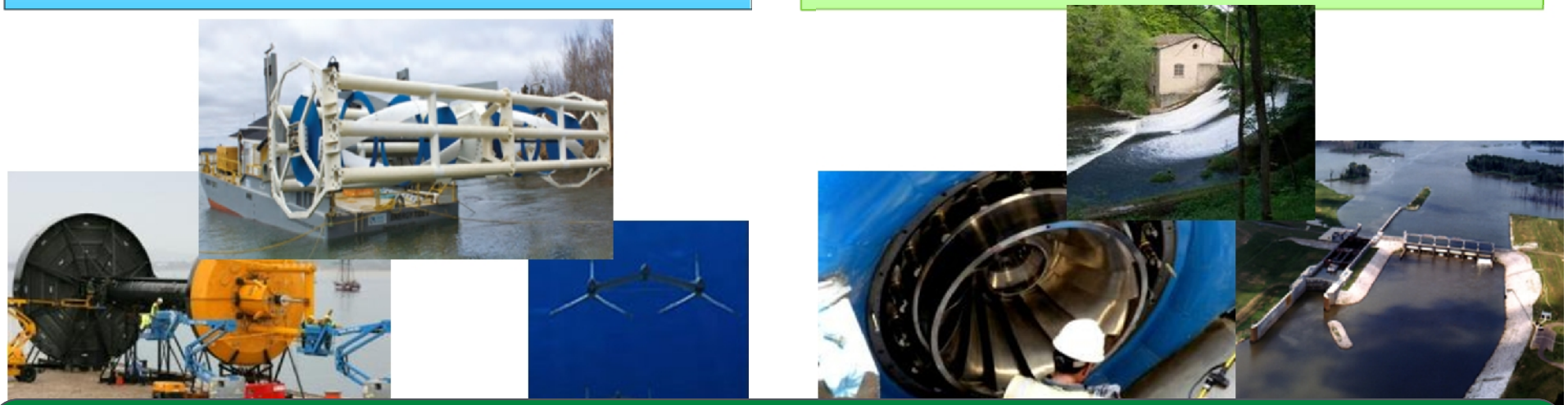
Water Power Program

Marine and Hydrokinetics (MHK)

Investigating a suite of renewable technologies that harness the energy from waves, tidal / ocean / river currents, and ocean thermal gradients (OTEC).

Conventional Hydropower (CH)

Improving technologies and processes for the efficiency, flexibility, and environmental performance of the existing hydropower fleet, and investigating opportunities for new hydropower development, and pumped storage hydropower



The **mission** of the Water Power Program is to research, test, and develop innovative technologies capable of generating renewable, environmentally responsible, and cost-effective electricity from water resources.

Wind Power Technology Evolution

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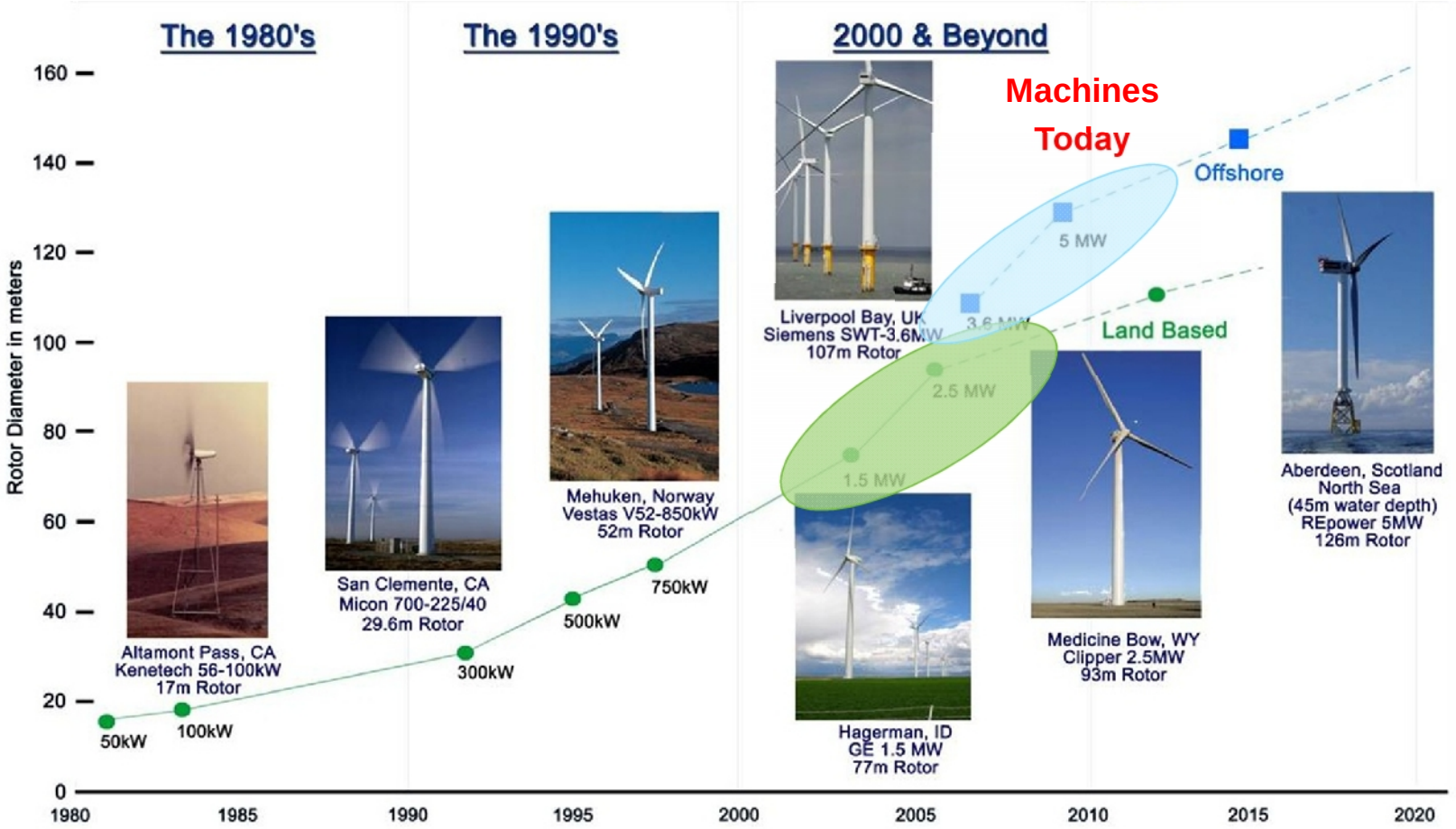

- **Land Based Technology > 2 MW; Turbine 50% Total Installation Cost**
- **Offshore Technology > 5 MW; Turbine 25% Total Installation Cost**
- **Land Based Turbine Size Constrained by Highway Transport**
- **Turbine Stiffness & Dynamic Coupling Driving Design Innovation**

Wind Technology major innovation shifts occurred at 100kw, 1.5MW, 3.5MW, beyond linear scaling. More paradigm shifts needed to achieve competitive parity with Natural Gas

MHK is much like the early Wind Industry

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Like the wind industry, early MHK designs exhibit vast technological variety. DOE investment will baseline costs and identify technology leaders and high-leverage R&D pathways.

MHK Major Decision Point: Technology Class Prioritization

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DOE can take lessons from the Wind industry and significant advances in computational capabilities to accelerate the identification of Wave technology class leader(s) before the end of the decade.

Wind Power
Total U.S. Wind Resource Potential

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		Land Based Wind			Offshore Shallow Water (< 30 meters)			Offshore Deep Water (> 30 meters)		
Wind Class (@ 80 meters)	Velocity Range (m/s)	Resource Potential (GW)	Capacity Factor (Weibull)	Quads (Quadrillion BTUs)	Resource Potential (GW)	Capacity Factor (Weibull)	Quads (Quadrillion BTUs)	Resource Potential (GW)	Capacity Factor (Weibull)	Quads (Quadrillion BTUs)
III	6.4 - 7.0	4186	30%	37.5						
IV	7.0 - 7.5	3544	35%	37.0	249	35%	2.6	292	35%	3.1
V	7.5 - 8.0	1109	40%	13.2	365	40%	4.4	505	40%	6.0
VI	8.0 - 8.8	64	42%	0.8	294	42%	3.7	712	42%	8.9
VII	8.8 - 11.9	16	45%	0.2	164	45%	2.2	1569	45%	21.1
Total :		**8919**		**88.8**	**1072**		**12.8**	**3078**		**39.1**

- **Total Addressable U.S. Wind Energy Potential** ≈ 141 Quads (13,000 GW equivalents)
- **Total U.S. Energy Use** ≈ 98 Quads (9,000 GW equivalents)
- **Total U.S. Electrical Energy Use** ≈ 13 Quads (1,200 GW equivalents)
- **20% by 2030 Goal** ≈ 3 Quads (300 GW equivalents)
- **Current U.S. Wind Contribution** ≈ 0.4 Quads (40 GW equivalents)

Source: NREL Wind Resource Database - Standard Version, April 2009

Significant SUSTAINABLE wind resource potential, greater than 10 times current total U.S. electricity consumption, supports high wind penetration scenarios

Marine and Hydrokinetics Resource Potential

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Marine and Hydrokinetics		Current Resource Estimates		23+ 2030
	Wave Energy	~400 GW	DOE, 2011*	19.5
	Tidal Current Energy	~60GW (>90% in Alaska)	DOE, 2011*	1.5
	Ocean Current Energy	1-2 GW	DOE, 1980 Updated DOE resource assessment underway	*TBD* *Ocean Current* resource has not yet been adequately characterized to formulate goals
	River Current Energy	~40 GW	NYU, 1986 Updated DOE resource assessment underway	2
	Ocean Thermal Energy	5 TW	U of HI, 2007 Updated DOE resource assessment underway	N/A

- Total Domestic Energy Use ≈ 98 Quads (9,300 MHK-GWeq)
- Total Electrical Energy Use ≈ 13 Quads (1,200 MHK-GWeq)
- **MHK Potential** > **5 Quads (>500 GW)**
- **Program Goal** **≈ .25 Quads (23 GW)**

*** Wave and Tidal assessment methodologies have been reviewed by a *National Academy of Sciences* panel of experts**

Initial estimates suggest significant addressable MHK resource potential, expanded resource assessments will further available energy from MHK.

Wind Program
LCOE and GW Goals

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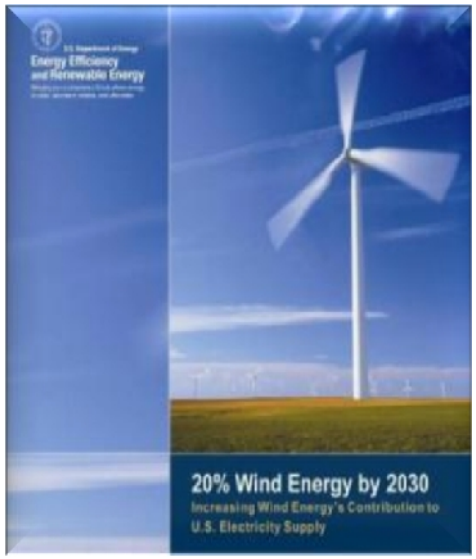
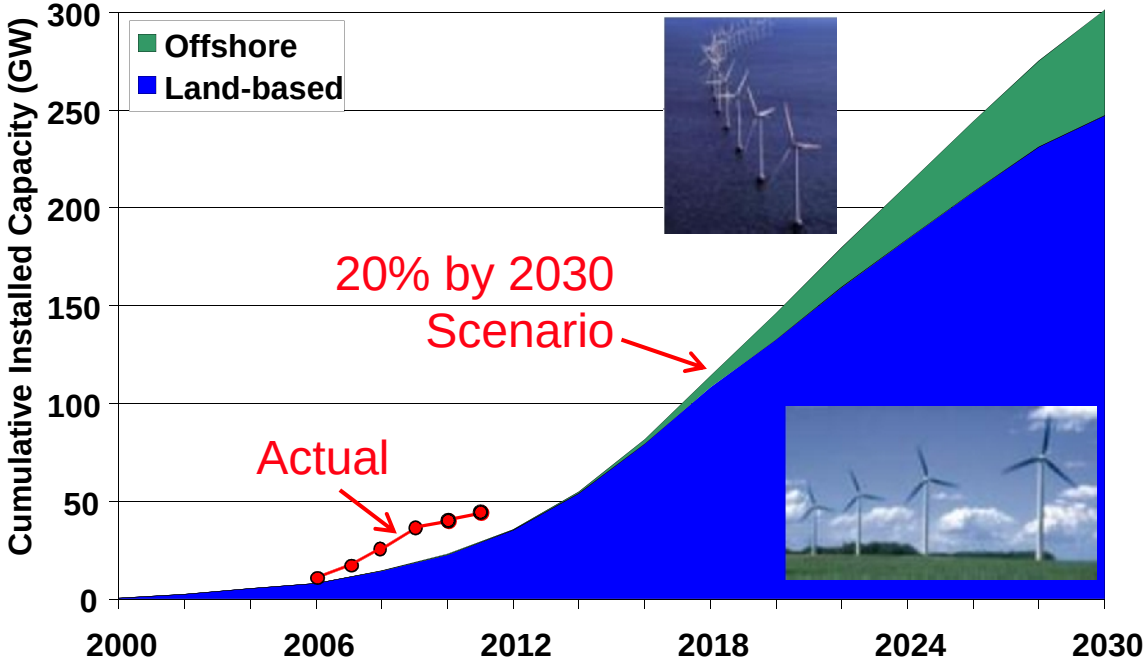


**Cumulative 2011 capacity includes 3,360 MW installed through Q3 2011 and assumes 33% of 8,482 MW under construction as of Q3 2011 in service by the end of 2011 for a total of 6,160 MW installed in 2011.*

20% Wind Scenario



Wind Program Goals	2010		2015		2020		2030	
Market Segment	**COE (¢/kWh)**	**GW**	**COE (¢/kWh)**	**GW**	**COE (¢/kWh)**	**GW**	**COE (¢/kWh)**	**GW**
Land-based Utility Target	8.2	40	6.5	75	4.8	125	4.2	250
Offshore Fixed-Bottom Target	25.3	0	23.3	0	16.7	10	13.6	54

Aggressive Wind LCOE and GW goals are achievable with anticipated Wind Program impacts

Water Power Program
LCOE and GW Goals

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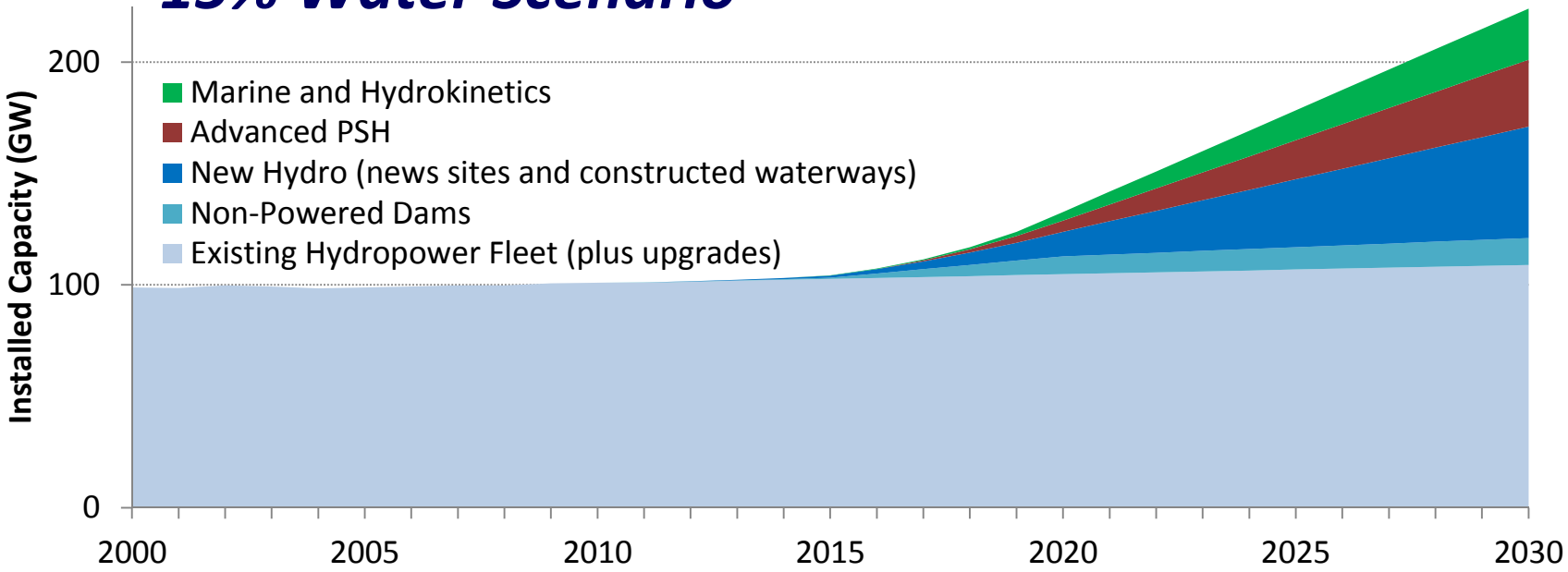
15% Water Scenario



	2010		2015		2020		2030	
Market Segment	**COE (¢/ kWh)**	**GW**	**COE (¢/ kWh)**	**GW**	**COE (¢/ kWh)**	**GW**	**COE (¢/ kWh)**	**GW**
MHK	40-60	0	25-40	0.05	10-20	4	6 (EERE Goal)	23
Advanced PSH	n/a	0	n/a	0	n/a	5	n/a	30
Low-head small hydro:	15	0	10	1	6	11	6	50
Non-Powered Dams	10	0	7	0.5	6	8	6	12
Existing Hydropower Fleet	n/a	101	n/a	103	n/a	105	n/a	109

Aggressive Water LCOE and GW goals are achievable with anticipated Water Program activities

Wind Program Value Added—Federal Role

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Wind – Unique Federal Role with Significant Value Added

EERE Wind Program Role

- **Significantly Increases Speed of Innovation:** Historical and current speed of wind industry technological innovation will not achieve deployment and fossil cost of energy parity goals
  - i.e. It took a decade for GE to adopt carbon hybrid blades: DOE program 2001
- **Interoffice, Interagency & Industry Collaboration to Solve Complex Market Barriers not Addressable by Industry**
  - DHS/DOD/FAA on Radar; DOI/BOEM on Wildlife, Technical Approval Guidelines and Offshore Wind Permitting; FERC and Office of Electricity on Wind Transmission Integration; Office of Science/NOAA on Resource Characterization and Energy Output Forecasting; DOI on siting and permitting
- **Operates National Wind Testing Platform which benefits entire U.S. Wind Industry**
  - Public access to National test facilities including new offshore wind test platform, sharing of test result information and evaluation of emerging technologies benefiting entire U.S. industry
- **Conducts Technology and System Validation to Increase Investor Certainty**
  - Critical for Offshore Wind market competitive financing
- **Leverages International Cooperation and Coordination**
  - IEA and International coordination to accelerate U.S. deployment (e.g. Offshore wind) and further refinement of industry codes and standards
  - Evaluation of “best practices” in designing and operating power systems with variable resources
- **Creates National Informational Databases and Shared Technology Platforms**
  - Historical Reliability databases for industry wide fault analysis, development of open source design tools

Unique Federal Role – Speed of shared Technology Innovation, National Testing platform, Complex Intra/Inter Agency coordination

Federal Role in Marine and Hydrokinetics

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EERE Water Program fulfills a unique and essential role in the development and advancement of a viable MHK industry:

- Serves as the technology development leader in the U.S. and internationally.
  - Cost-shared development, advancement and deployment of a wide range of innovative technologies
- Leader and facilitator of Interagency and international collaboration
  - Providing international leadership in standards development (TC-114) and data sharing (OES Annexes)
- Represents energy interests in inter-agency dialogue, information sharing, and permitting process coordination and resolution.
- Addressing market and environmental barriers that apply to all industry developers
  - Effectively lowering costs to individual developers, easing regulatory burdens, and speeding deployment
- Supports high-risk innovative technology development
  - Accelerating design and performance optimization, resulting in substantial, near-term cost of energy reductions
  - Sponsoring critical modeling with National lab expertise that cost-effectively improves technology design and testing protocols.
- Leverages investments and applies lessons learned in complimentary technologies
  - Identifying synergies with offshore wind issues to accelerate parallel development.
- Developing essential testing infrastructure and disciplined test protocols that are internationally accepted
  - Reducing costs to developers while speeding time to commercialization

Evolution of Wind Program Portfolio

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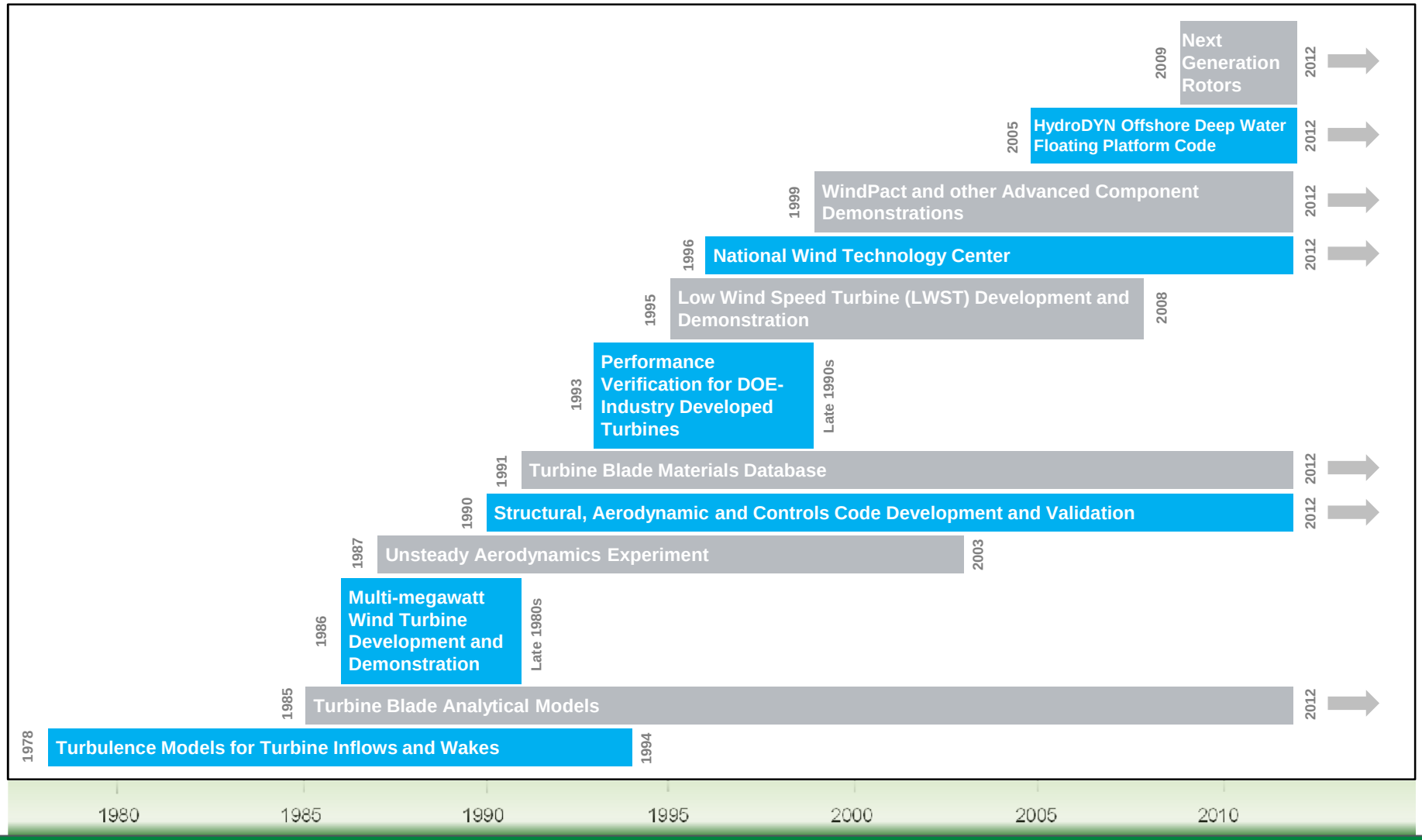

Over 30 years of demonstrated Program success

Wind Program
FY11 Key Accomplishments

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- **Offshore Wind**
  - Revitalized US offshore R&D sector through **41 offshore wind projects** to advance wind turbine design tools and hardware, improve information about U.S. offshore wind resources, and accelerate the deployment of offshore wind.
  - Initiated **six next-generation drivetrain research and development projects** focused on reducing the cost of wind energy by increasing component reliability, reducing drivetrain weight, and developing drivetrain designs that minimize the use of rare earth materials.
- **Advanced Turbine Controls**
  - Developed and demonstrated advanced turbine control algorithms that **reduce fatigue loads up to 40%**, as compared to the industry standard baseline.
- **Continuous Reliability Enhancement for Wind (CREW) Database**
  - Published **Wind Turbine Reliability Benchmark Report** for the U.S. Fleet, October 2011.
- **Massachusetts Wind Technology Testing Center (WTTC)**
  - Commissioned the **WTTC as the nation's first large wind blade test facility** with the capability to test blades up to 90 meters in length, longer than any other facility in the world and suitable for wind turbines up to 15 megawatts, as anticipated for Offshore.
- **Wind Forecasting**
  - Executed **DOE-NOAA MOU** for renewable resource characterization, with large-scale field forecasting project underway with two industry partners.
- **Radar**
  - **Instituted Interagency (DOD/DHS/FAA) Integrated Field Test and Evaluation** process to validate radar mitigation technologies.
- **Wind/Wildlife Siting Guidelines**
  - DOE input significantly **improved Fish and Wildlife Service proposed voluntary wind siting guidelines** to increase certainty for industry and protect sensitive wildlife.

FY 11 accomplishments critical for LCOE reductions and increased deployment

Wind Program: ARRA Project Funding Summary

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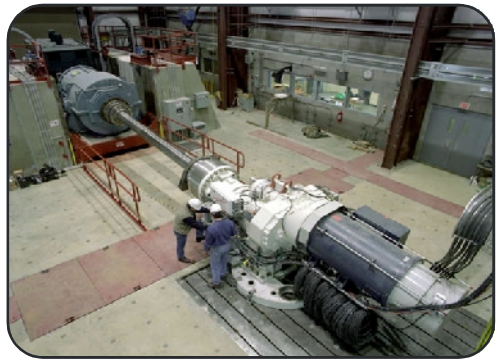
ARRA impact creating new wind test facilities:

- Large Wind Blade Test Facility
  Boston, MA - **$24.7M**
- Large Dynamometer Test Facility
  Charleston, SC - **$44.5M**
- NWTC Dynamometer Upgrade
  National Wind Technology Center (at NREL)
  Golden, CO - **$9.5M**
- University of Minnesota – Siemens 2.3 MW Turbine
  Minneapolis, MN - **$7.9M**
- Illinois Institute of Technology – GE 1.5 MW Turbine
  Chicago, IL- **$7.9M**
- University of Maine – 1-3 Offshore Floating Platforms
  Orono, ME - **$7.1M**



Testing facilities across the country lay foundation for nextgen technological innovation

State of the Industry - 2012

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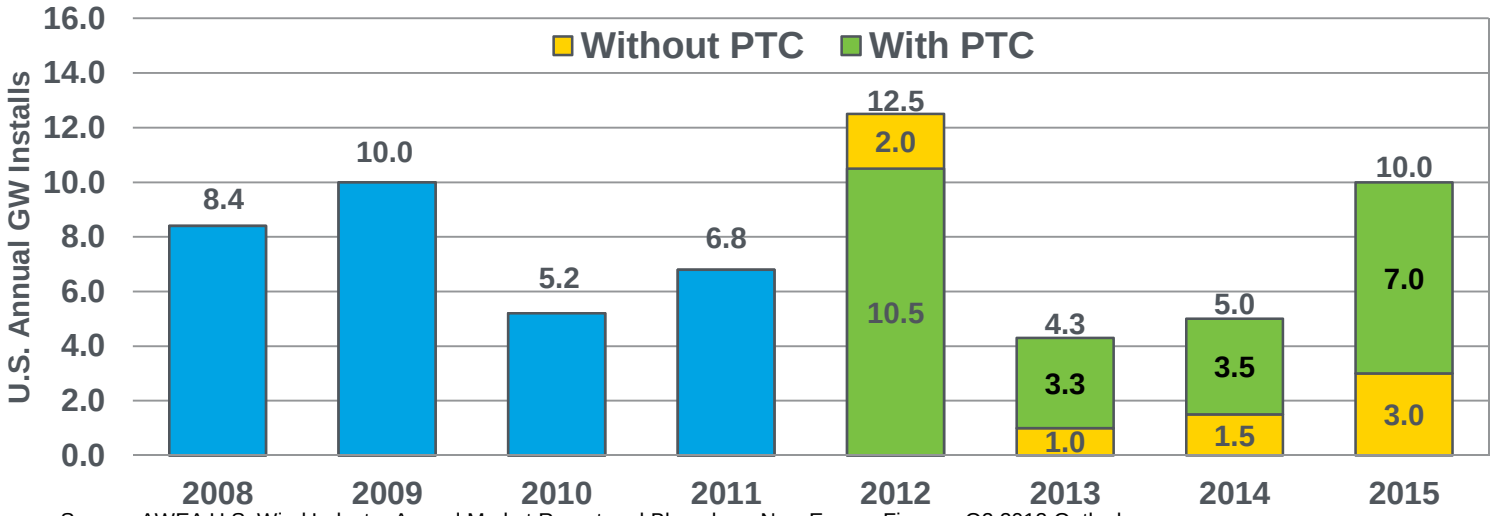
US Annual installs will peak in 2012 and then drop off precipitously due to PTC-uncertainty.



Source: AWEA U.S. Wind Industry Annual Market Report and Bloomberg New Energy Finance Q2 2012 Outlook

US Offshore wind significantly lags behind Europe and China

Source: H1 2012 Offshore Wind Market Outlook, Bloomberg New Energy Finance, 31 January 2012

OFFSHORE	Cumulative Capacity at 2011 YE	Additional Capacity Forecast 2012-2015*
Europe	3,256	10,448
China	338	3,835
Other	14	205
U.S.	0	250
Total	3,608 MW	14,738 MW

US Wind Industry facing significant uncertainty in U.S. policies

Wind Program Addressing Barriers

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	Barriers	Solutions	Program Activities
Technology Development	**Unsubsidized Wind LCOE is not "market competitive" with Natural Gas**	Target unsubsidized LCOE of 4.8-4.2/kWh (to offset transmission grid integration costs of 1.2-1.8/kWh) via improved turbine and wind plant efficiencies, cost effectively by FY 2020	INNOVATIONS: DRIVE TURBINE DESIGN AND PLANT DESIGN EFFICIENCIES
	Offshore Wind not "market competitive" with regional coastal pricing	Target unsubsidized Offshore LCOE < 9.3/kWh to enable regional competitive pricing	INNOVATIONS: DESIGN DEEPWATER SYSTEMS (PLATFORMS AND MARINE BASED TURBINES) TO ACCESS HIGH OFFSHORE WIND SPEEDS
	Distributed Wind not "market competitive" with regional retail rates	Target unsubsidized Distributed LCOE < 9.3/kWh to enable regional competitive pricing with retail rates	INNOVATIONS: REDESIGN 100KW-1MW DWT SYSTEMS WITH BEST DESIGNS FROM UTILITY SCALE
Market Acceleration	**Transmissions Barriers impacts to wind class (LCOE) and location. Perception that wind degrades grid system reliability**	Intra-Agency coordination with OE and FERC, and legislative policy to enable transmission capacity at high wind speed locations. Develop "frequency response", regulation support and voltage control capabilities	WIND TRANSMISSION AND INTEGRATION STUDIES, GRID TOOLS
	Market Barriers – Radar, Environmental, Permitting impacts to wind class and location	Produce and assemble new data to evaluate radar and environmental impacts. Identify key cost and time drivers for regulatory and permitting processes	RADAR AND ENVIRONMENTAL MITIGATION TECHNOLOGY DEVELOPMENT AND RESEARCH

125 GW deployed by 2020

GOAL:

Reduce Land COE to $0.048/kWh by 2020

Wind Program Priorities

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The Program seeks significant reductions in the Cost of Energy (LCOE) and rapidly accelerated Deployment. The offshore wind market is the primary focus of the Program, followed by the land-based and distributed wind markets.

Reduce Resource Uncertainty: • Improve wind power forecasting for utility operations • Increase precision of complex flow modeling for optimizing wind turbine design and plant operations	• Complete DOE-NOAA short term forecasting field project • Develop day ahead, multi day forecast R&D priorities • Validate current developmental complex flow models • Engage HPC assets for expanding model development
Grid Planning and Operations: • Facilitate/accelerate the development and adoption of successful strategies for planning and operating the power grid with variable generation	• High penetration integration studies • Improved utilization of existing transmission infrastructure • Reliability support using active power controls • Reserves impact analysis
Reduce Costs and Improve Performance: • Develop innovative and disruptive technologies • Reduce component and system level defects; • Characterize the effects of defects • Develop advanced installation and logistics strategies • Optimize plant infrastructure	• Develop advanced rotor and drivetrain architectures • Develop advanced active and passive control strategies • Investigate alternative materials and evaluate smart sensors for improved system health monitoring • Develop optimized micro-siting tools and plant level controls • Focused Offshore R&D and demonstrations
Reduce Siting & Permitting Barriers: • Accelerate/reduce the cost of project planning, siting and permitting • Coordinate gov't/industry Information Sharing • Develop cost effective wind radar and wildlife mitigation technologies	• Conduct baseline surveys and field assessments • Develop cost-effective wind radar mitigation technologies • Create Developer siting/permitting toolkit & mitigation menu
Leverage International Investments and Expertise: • Cooperative development of international standards • Share device performance data	• Participate in IEA Working Groups for standards development • Conduct cooperative research with European based laboratories (Risoe and ECN)

Every Wind Program Priority is linked to LCOE and GW Goals

Wind Program Strategic Backbone

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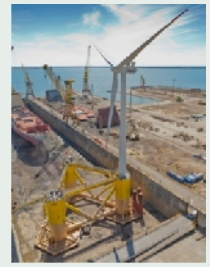
Establish a U.S. Offshore Wind Industry

Offshore System Development and Validation

- Improve financing terms for offshore wind plants through **offshore demonstration projects** and component testing
- Address offshore COE and reliability challenges through "cradle to grave" engineering including innovative turbine and foundation configurations, balance of system components and installation infrastructure
- Expand **open-source wind turbine design tool suite** to enable design and evaluation of next generation offshore turbines, both fixed and floating, leading to the most promising designs to lower system cost of energy



Market Barrier Removal

- Accelerate the siting and permitting process to reduce the cost of project planning and development
- Develop **cost effective wind radar and wildlife impact mitigation technologies**
- Facilitate government-government and government-industry cooperation and coordination
- Reduce Grid Integration costs through **wind integration studies, active controls analysis**, and Best Practices sharing

Optimizing Wind Plant Performance/Technology

Advanced Component Development

- Develop **advanced rotors, drivetrains**, support structures, and **prognostic health monitoring strategies**
- Investigate **active blade control**, **sensor technologies**, and control surfaces for enhanced energy capture
- Develop open-source wind turbine design tool suites for design and evaluation of wind plants and turbines

Wind Plant Performance Improvement

- **Reduce aerodynamics losses** resulting from turbulent inflow, wake interaction, and other complex flows
- Develop **HPC models** to improve wind forecasting and improve understanding of complex flow phenomena
- Investigate novel Integrated System Designs through systems engineering and analysis at the plant level

Wind Plant Reliability Improvement

- Improve the useful life of major components through gov't/university/industry **reliability collaboratives** (BRC & GRC)
- Develop advanced **offshore O&M strategies**, condition monitoring packages, and **sensor technology**
- Collect and report industry RAMS (Reliability, Availability, Maintainability, & Serviceability) data via the **CREW database**

Deep Water Modeling Requirements

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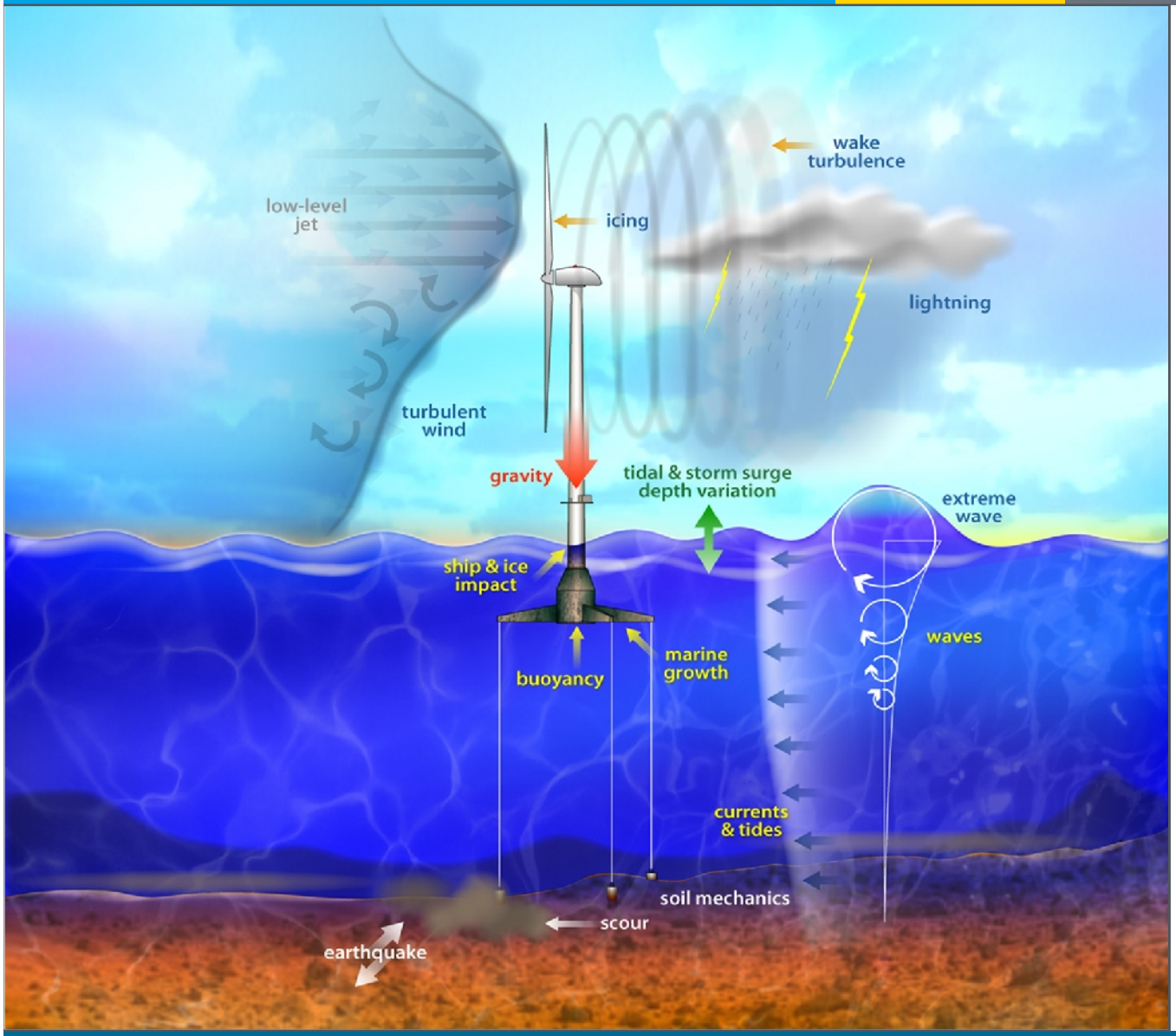

Fully coupled aero-hydro-servo-elastic interaction

- **Wind / Wave Interaction:**
  - discrete event prediction
  - turbulence effects
  - wave spectra
  - surface roughness
- **Aerodynamics:**
  - induction
  - rotational augmentation
  - skewed wake
  - dynamic stall
- **Hydrodynamics:**
  - scattering
  - radiation
  - hydrostatics
- **Structural dynamics:**
  - gravity / inertia
  - elasticity
  - foundations / moorings
- **Control system:**
  - yaw, torque, pitch

Offshore Wind Innovation and Demonstration

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54 GW at 7 c/kWh by 2030
10 GW at 10 c/kWh by 2020

Reduce Cost of Energy

Promote Responsible Deployment

Developing Innovative Technologies

Computational Tools

Turbine Design

Marine Systems Engineering

$34M

25 Projects

Removing Market Barriers

Siting and Permitting

Infrastructure

Resource Planning

$16.5M

22 Projects

Demonstrating Next-Generation Designs

Demonstration Project Partnerships

(Open FOA)

$180M

6 Projects

Wind Plant Underperformance - What are the Meteorological Challenges?

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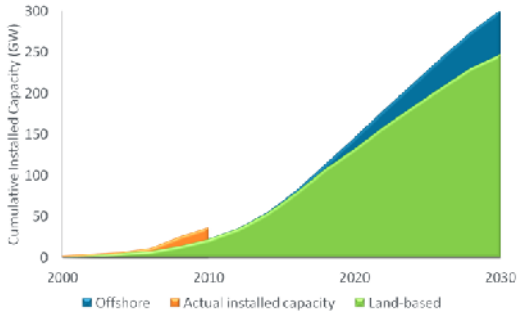
- Wind is the fuel

Under-performance
(10-15% under expected)

Reliability concerns

\+ Sub-par integration

Higher Costs of Energy



$4 - $6B in added costs to reach 20% by 2030 due to under-performance[1]

	10% Forecasting Improvement	20% Forecasting Improvement
14 % Wind Penetration	$140 M	$260 M
24% Wind Penetration	$500 M	$975 M

- Converting **Challenges** into **Innovations**

Addressing Challenges at all Scales

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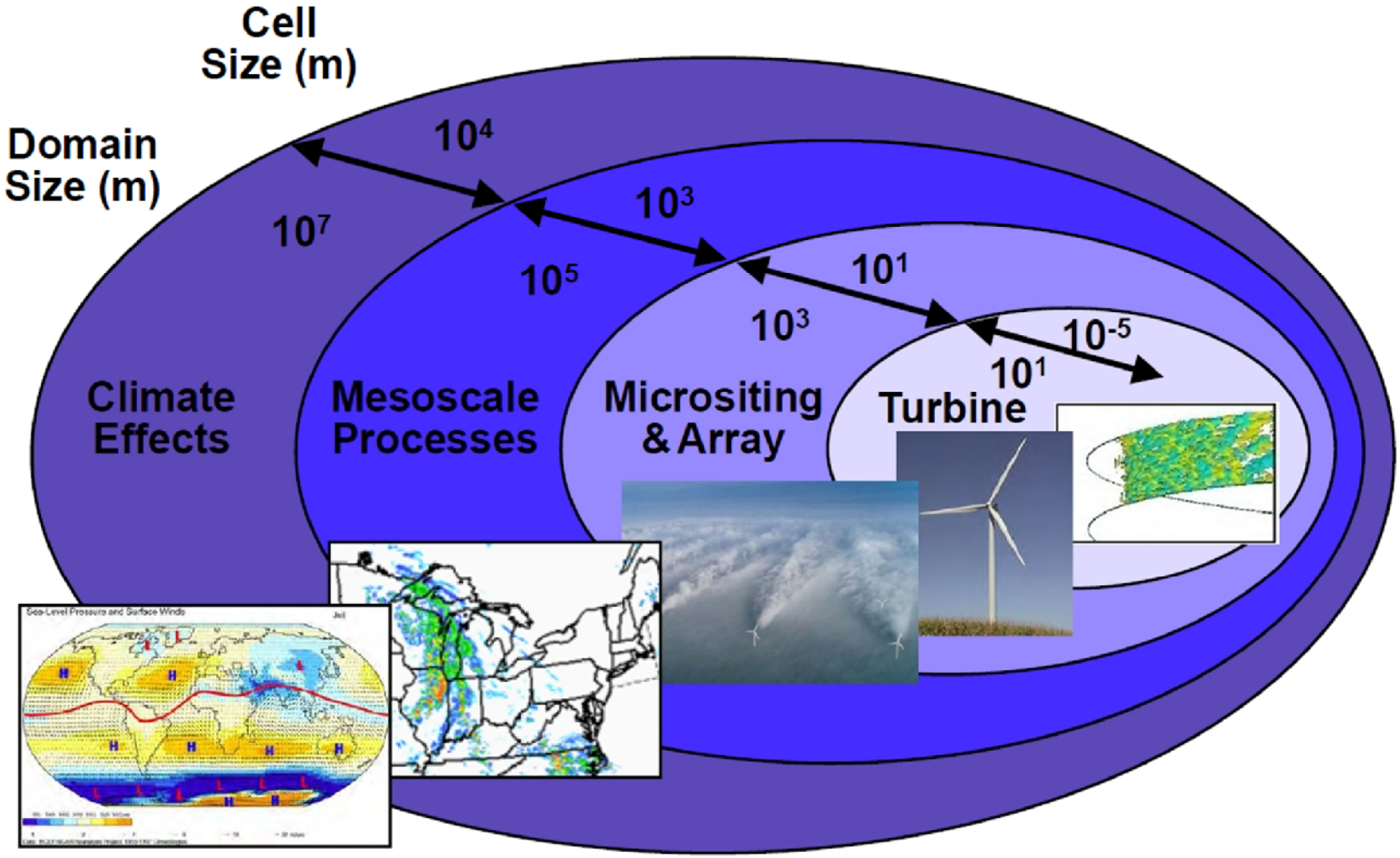
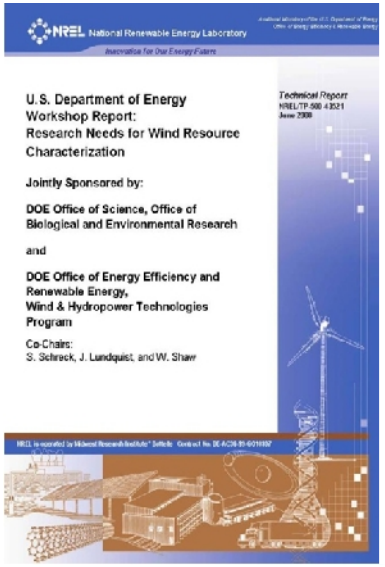


Wind Resource Characterization Needs

- **Resource assessment** for financial viability and optimized siting
- Wind turbine **inflow/turbulence modeling** to allow better turbine design
- **Wind plant array modeling** for effective power prediction
- **Data sets, models, and forecasting** for efficient power system operation
- **National observations network** serving weather-driven renewables
- **Climate change assessment** for wind resource impacts

Key Emphasis – Leveraging national weather enterprise capabilities



Wind Program
2020 Land Utility-Scale Wind Goals

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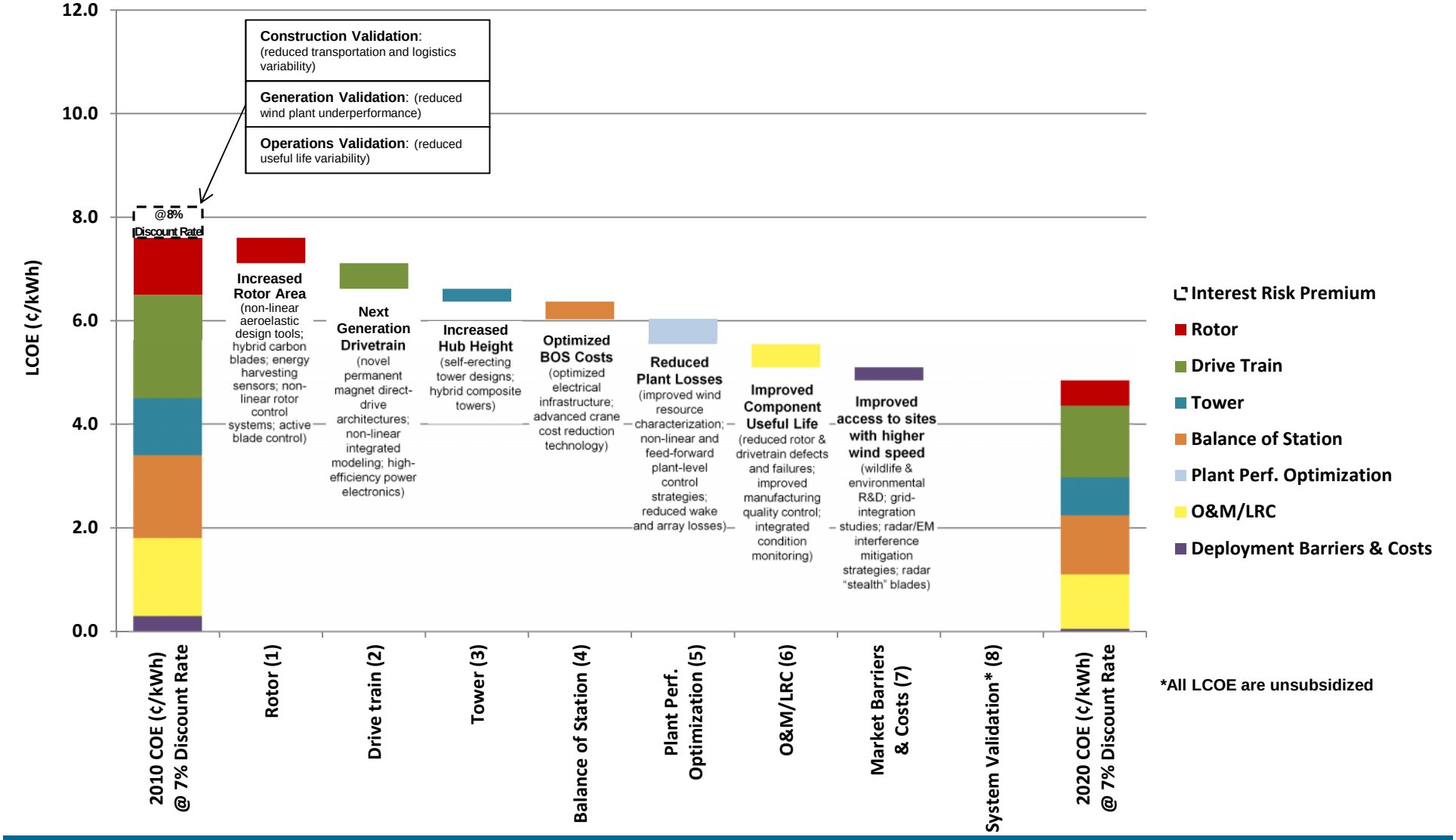
Land Utility-Scale Cost Reduction Cascade



*All LCOE are unsubsidized

Wind Program R&D Landscape
LCOE Impact Drivers

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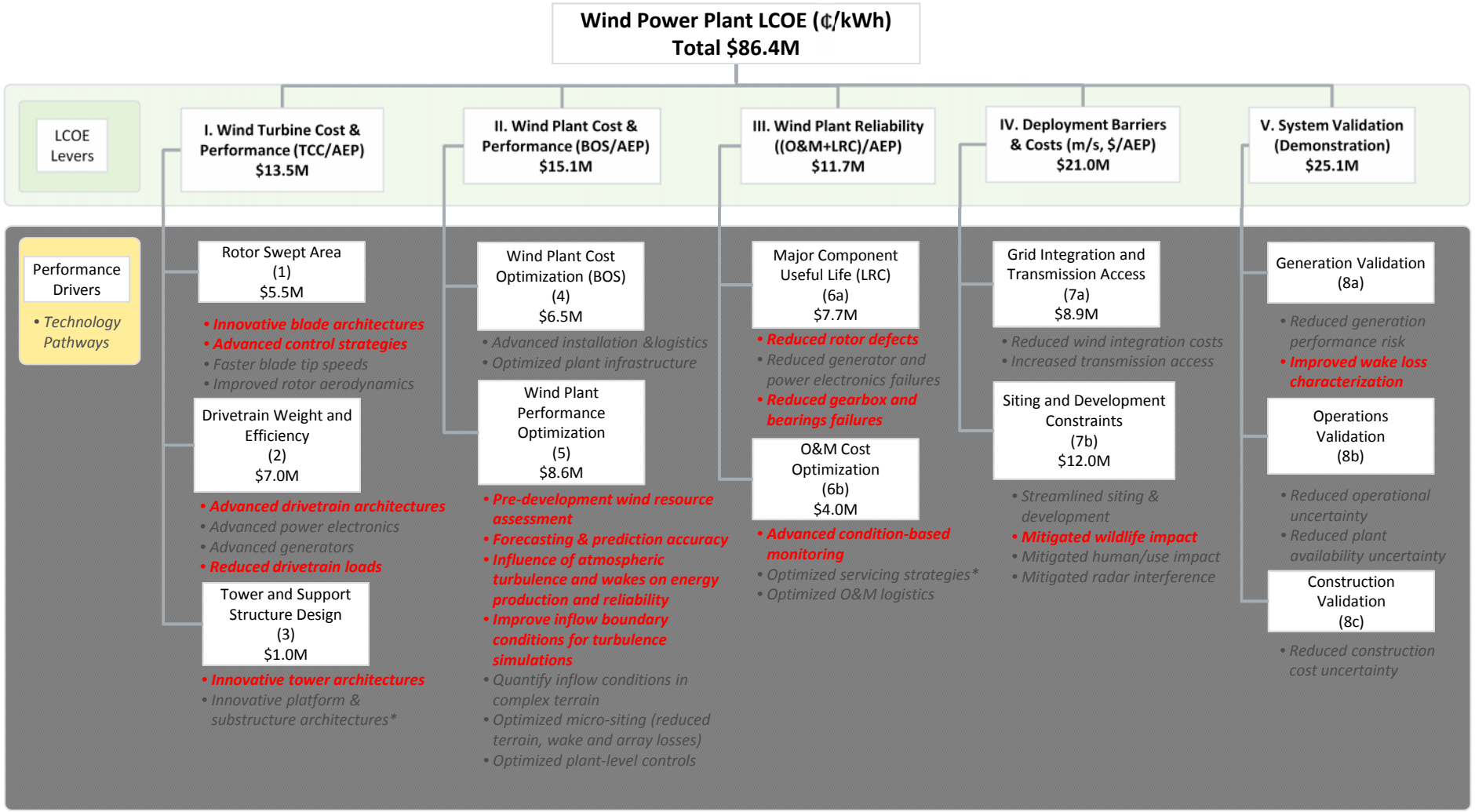

Wind Portfolio balanced to achieve both LCOE and GW targets

Wind Program R&D Landscape
Deployment Drivers

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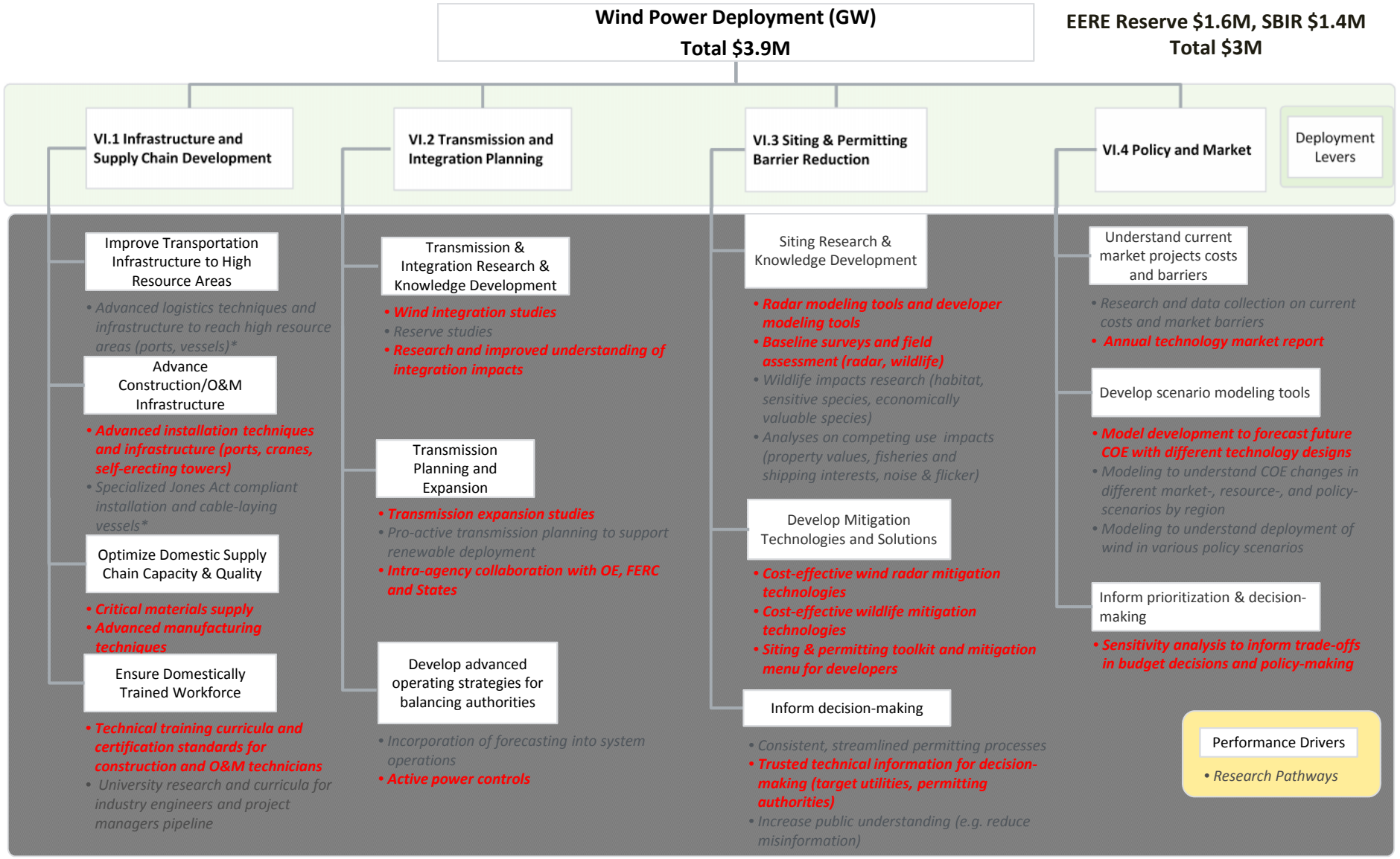

Wind Program
RDD&D Breakdown FY10-12

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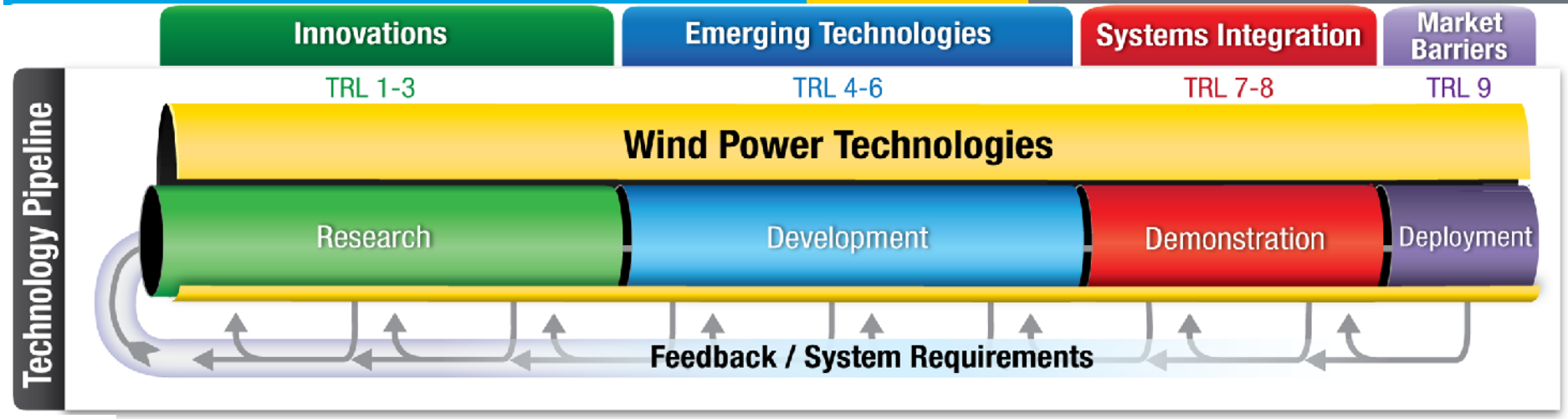

FY12 Budget	$28.0M	$29.7M	$24.1M	$11.5M	Total
% of Program Portfolio	30.1%	31.8%	25.8%	12.3%	$93.3
FY11 Budget	$35.1M	$30.6M	$0.9M	$13.4M	Total
% of Program Portfolio	43.9%	38.2%	1.1%	16.8%	$80.0
FY10 Budget	$36.4M	$32.3M	$0.6M	$10.7M	Total
% of Program Portfolio	45.5%	40.4%	0.7%	13.4%	$80.0

Water Power Program
FY12 RDD&D Breakdown

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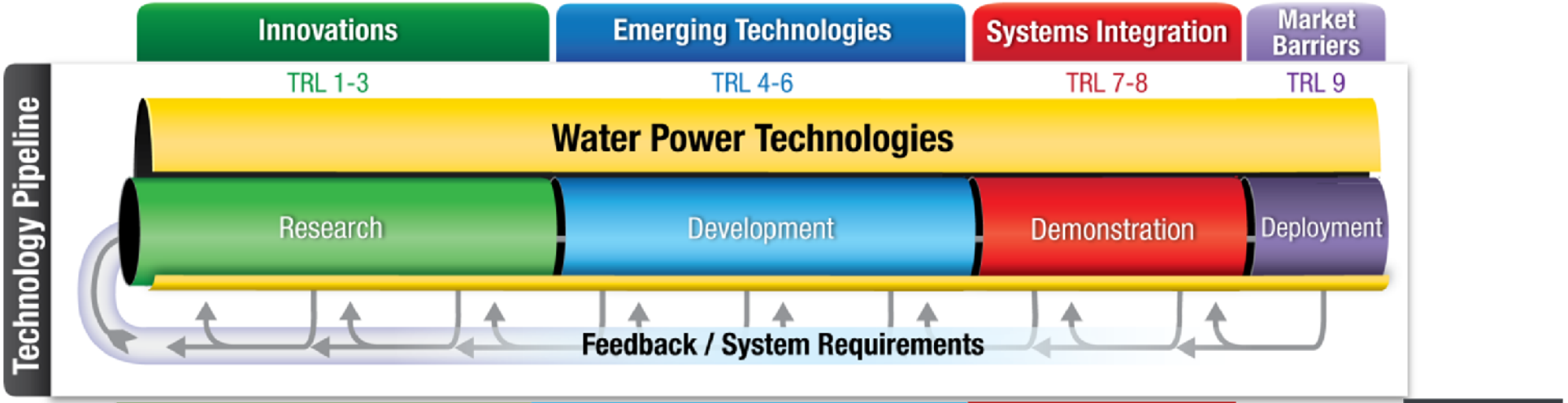

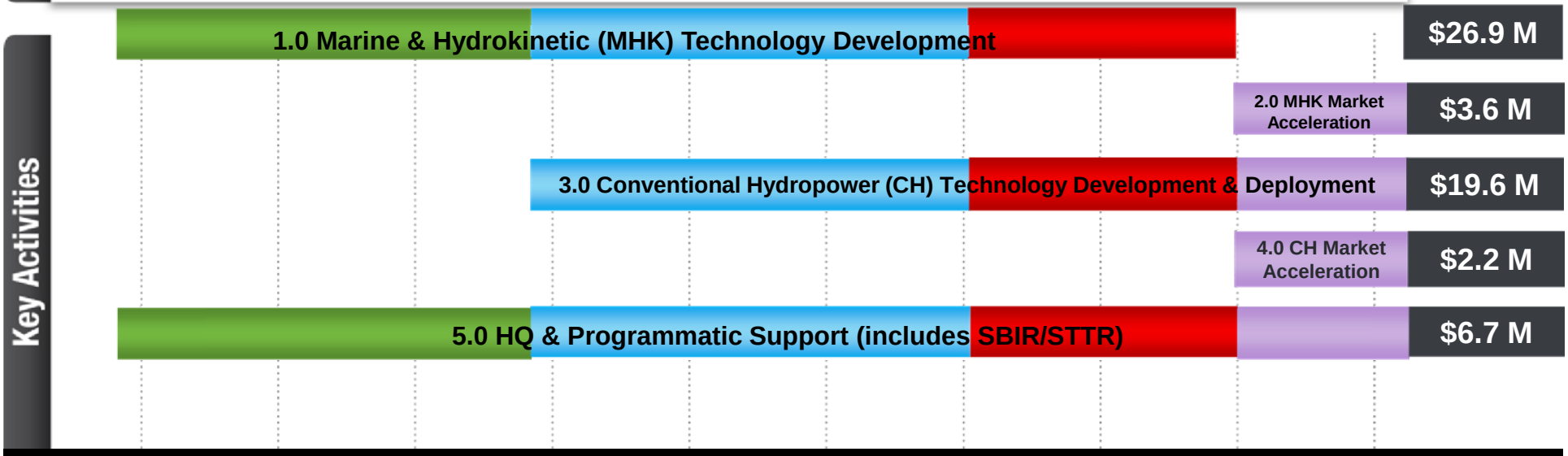

FY12 Budget	$4.6 M	$24.8 M	$20.9 M	$8.7 M	Total
% of Program Portfolio	8%	42%	35%	15%	$59M

Program Summary

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I. **High confidence that U.S. wind industry has infrastructure, U.S. supply chain, and investment funds available to achieve:**
   - Land utility LCOE goals (Natural Gas competitive parity)
   - GW goals (20% by 2030)
   - Related Jobs and Economic stimulation

II. **Solving wind transmission and market barrier bottlenecks will not only unleash backlog of wind projects (275 GW), but will significantly lower LCOE via access to high wind speed sites**

III. **Stable, long term US policies are needed to optimize wind financial investment**

IV. **The nation has vast MHK resources (500 GW) close to heavily populated coastal markets**

V. **High risk MHK technology development requires consistent federal government investment to mature; next generation designs will be a significant step towards cost-competitiveness**

VI. **Wind R&D investments and program expertise are accelerating MHK technology development**

VII. **Conventional hydropower and pumped storage are valuable assets for integrating large quantities of variable renewable energy**