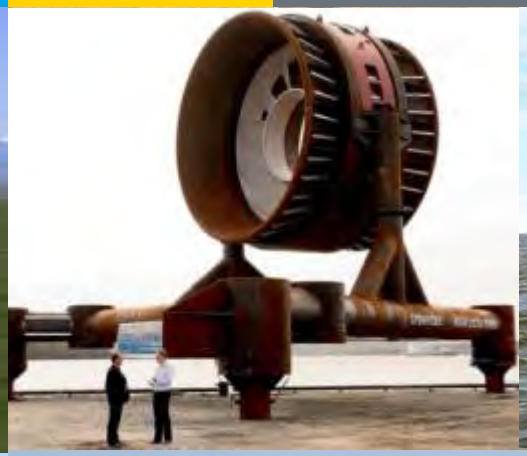
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Materials Challenges in Wind and Water Power Technologies

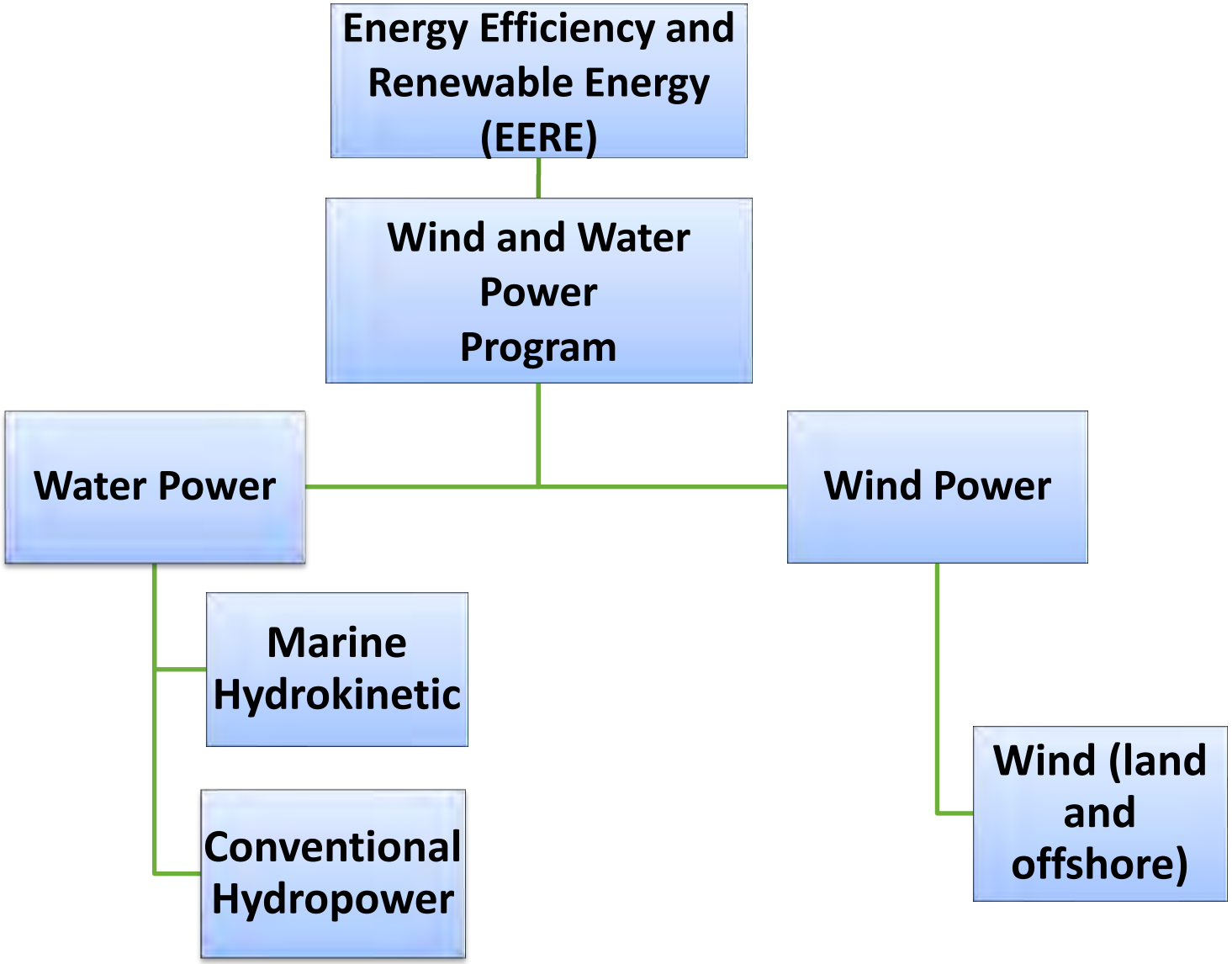
February, 2012

Megan McCluer &
Jim Ahlgrimm
Wind and Water Power Program
U.S. Department of Energy

Outline

- DOE Wind and Water Power Program
- Overview of Wind Technology
- Overview of Water Technology
- Materials Challenges
- Summary

Wind and Water Power Program Structure



Jose Zayas

Wind and Water Power Program Manager

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 and Water Power Program is to enable U.S. deployment of clean, affordable, reliable and domestic wind and water power to promote national security, economic growth, and environmental quality.

Wind and Water Deployment Scenarios

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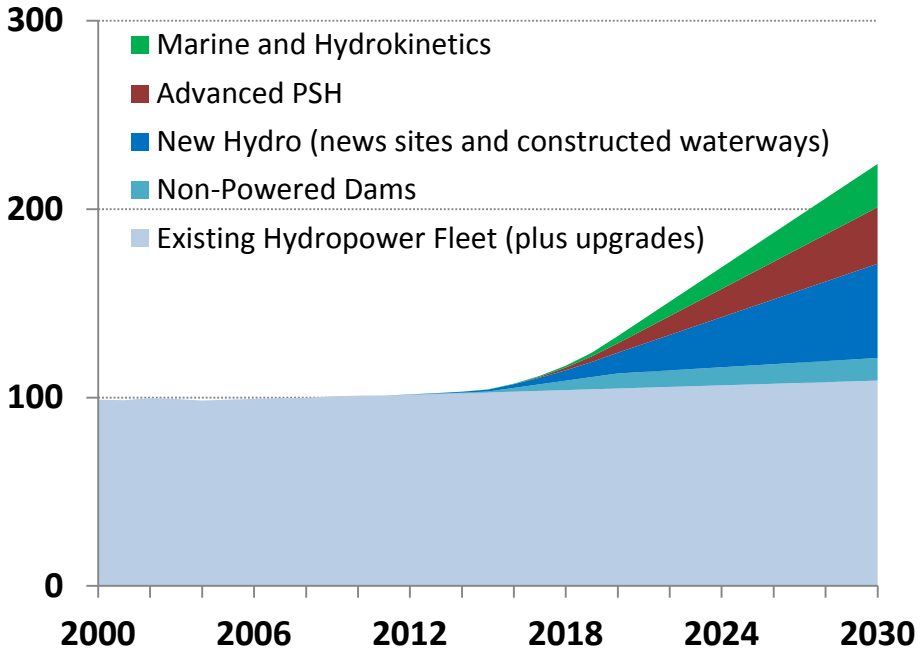
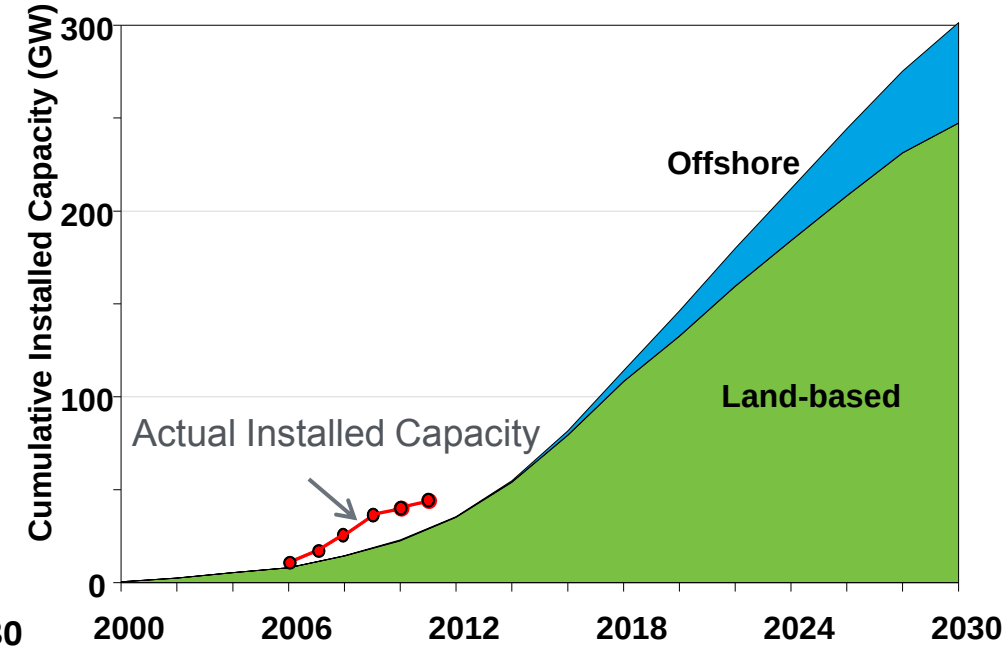
15% Water Scenario

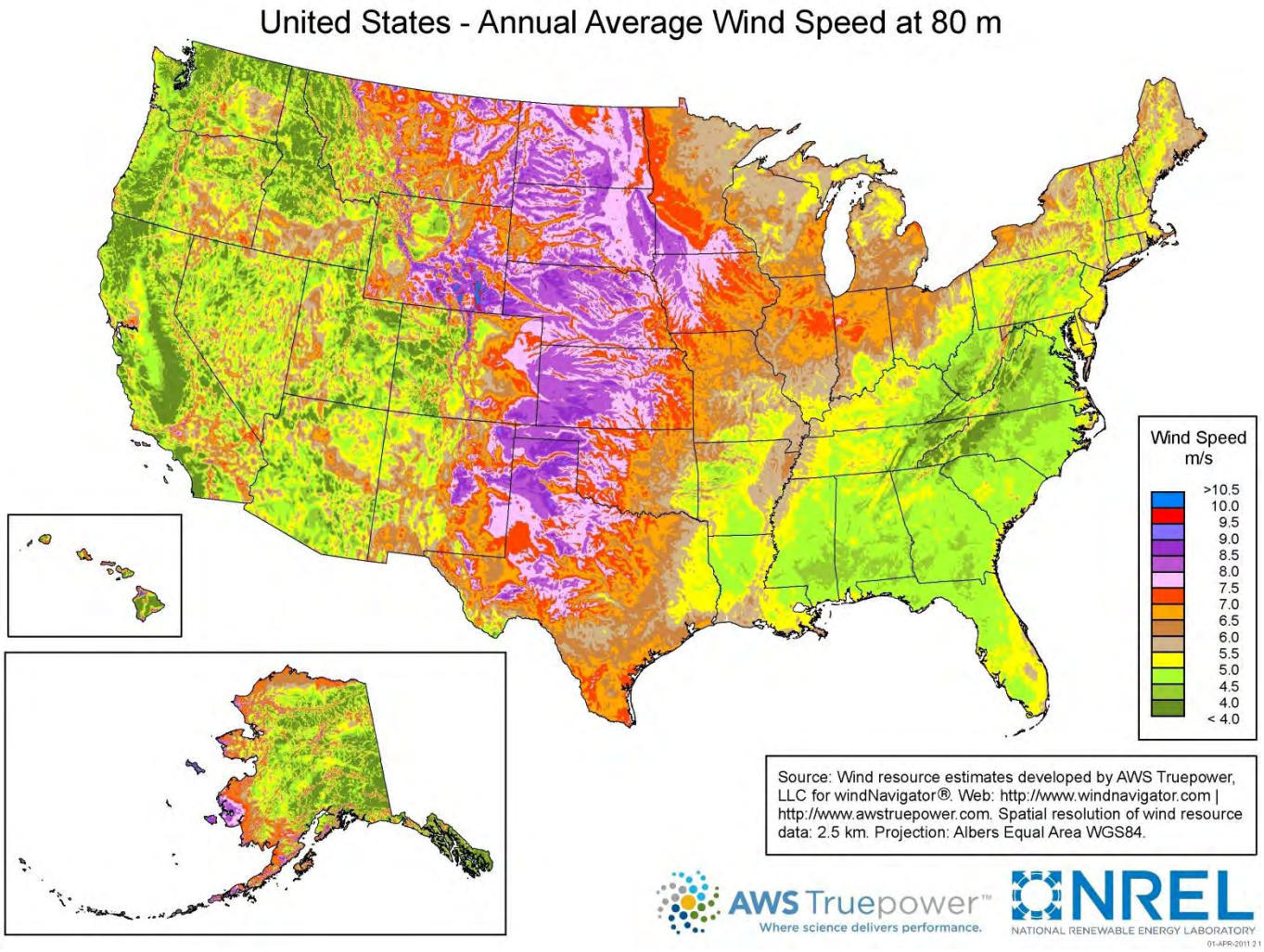


20% Wind Scenario



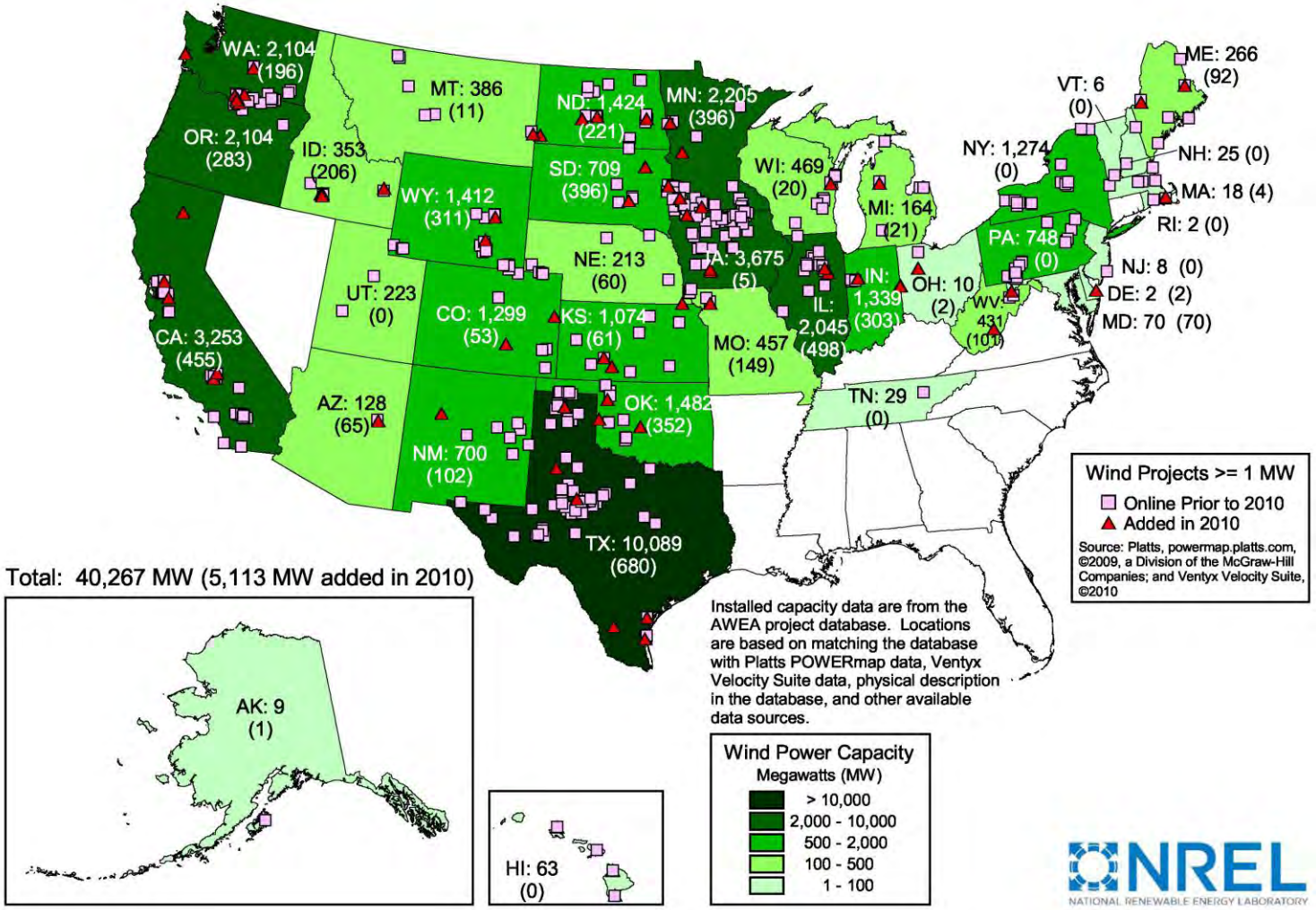
Large-scale deployment will require innovation, including materials R&D, to reduce the cost of energy to become competitive with traditional sources

Land Based Wind Energy

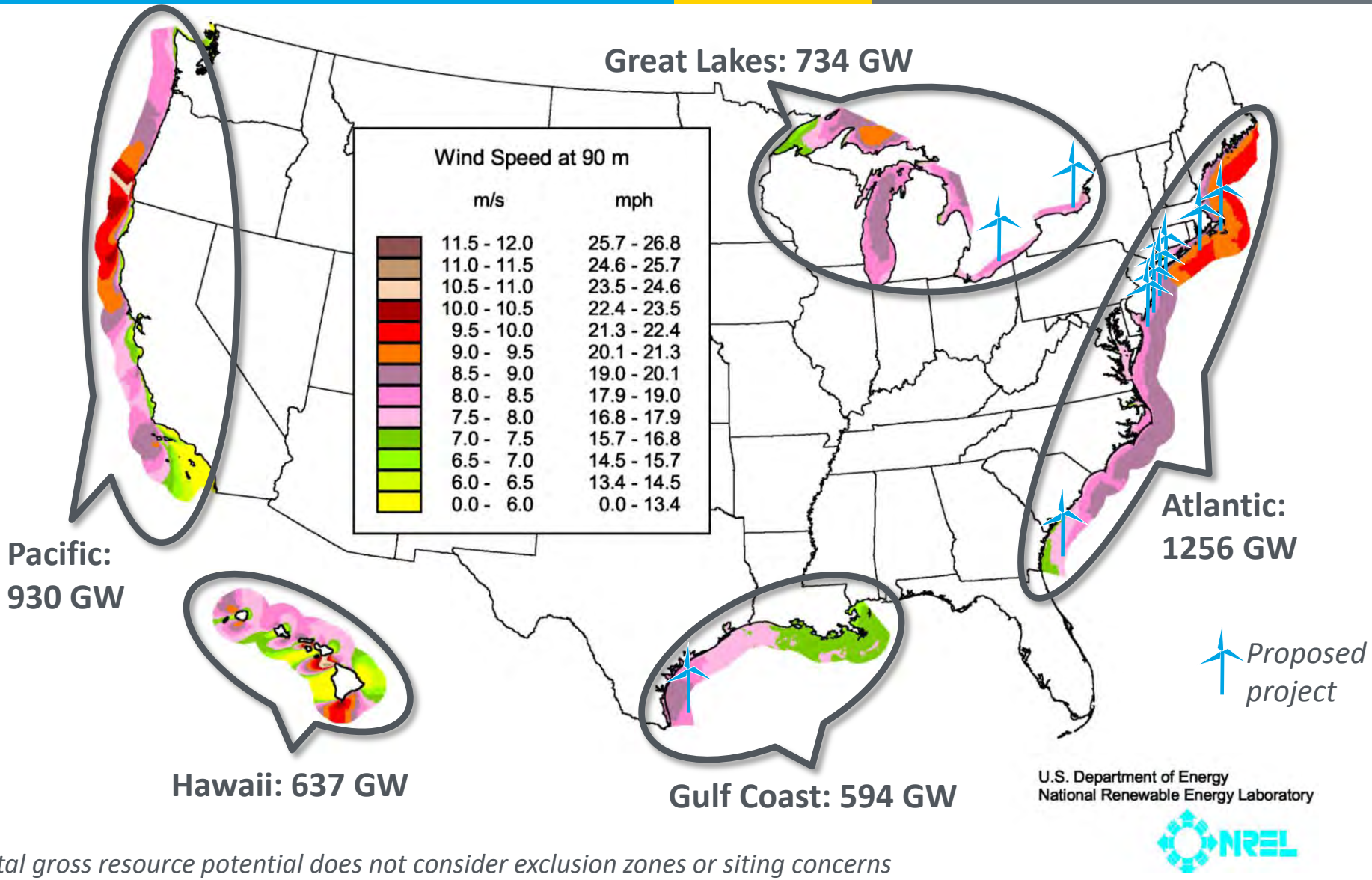


- 40 GW installed domestically
- 8,000 GW of economical land-based resource
- 4,000 GW of offshore resource
- Lack of transmission & siting barriers push developers to build in lower-quality wind regimes
  - ✓ decreasing capacity factor
  - ✓ increasing LCOE

Geographic Spread of Wind Power Projects in the United States

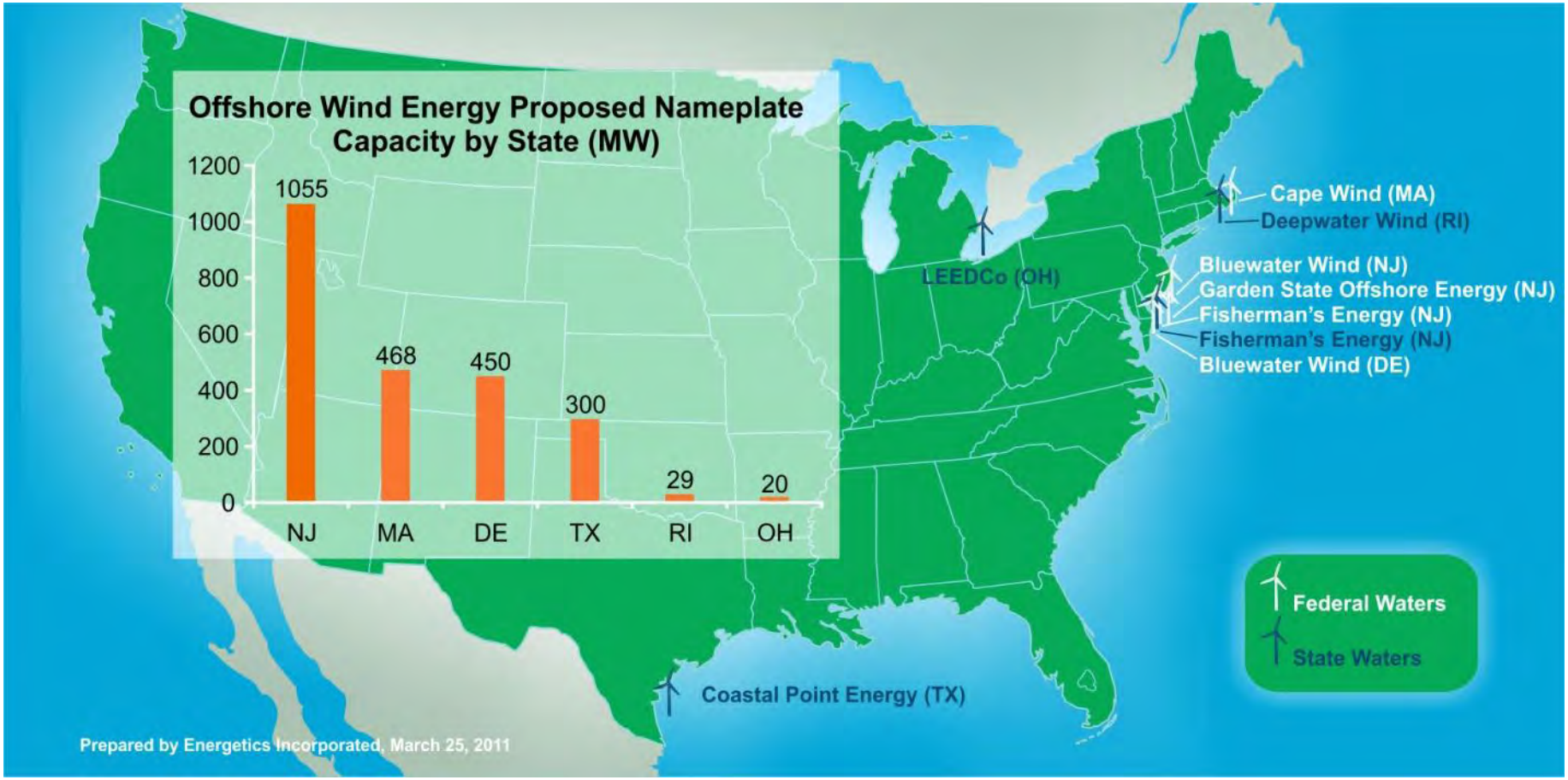


Offshore Wind Resources



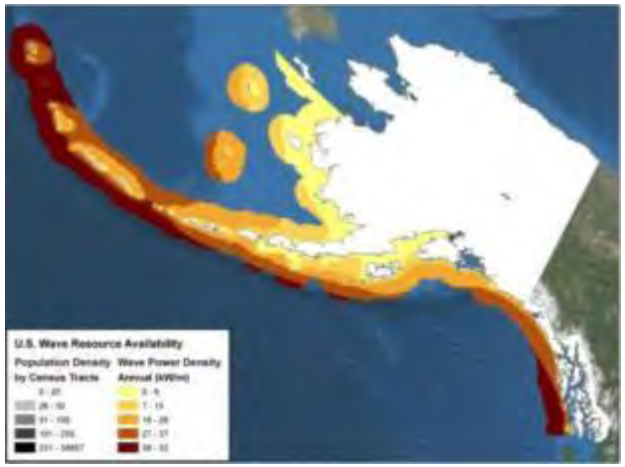
Total gross resource potential does not consider exclusion zones or siting concerns

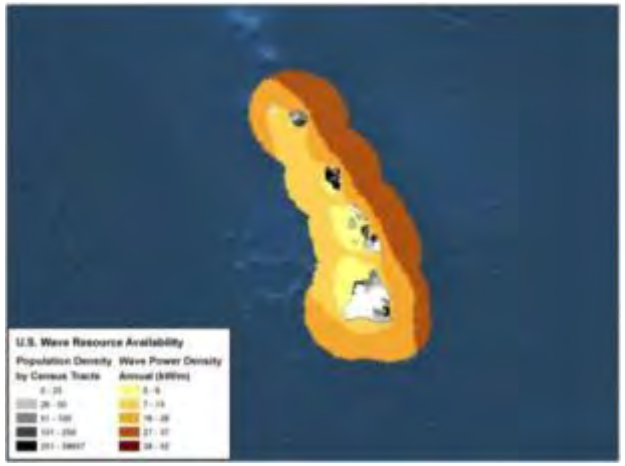
No Offshore Projects Have Been Built in the U.S., But 9 Projects Have Advanced Significantly in Permitting and Development

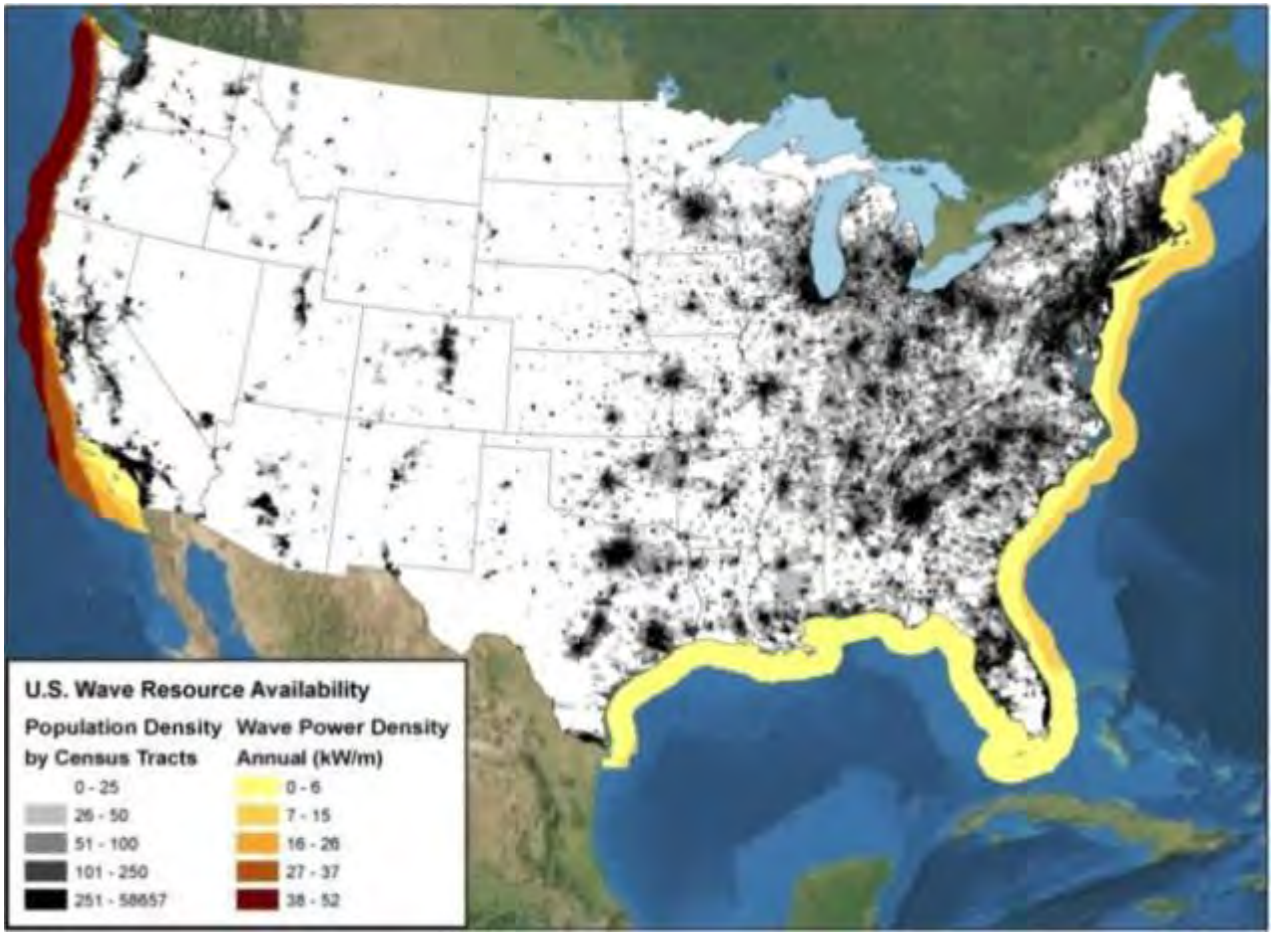


Marine and Hydrokinetics Wave Resource Assessment

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







900+ GW Gross Physical Potential

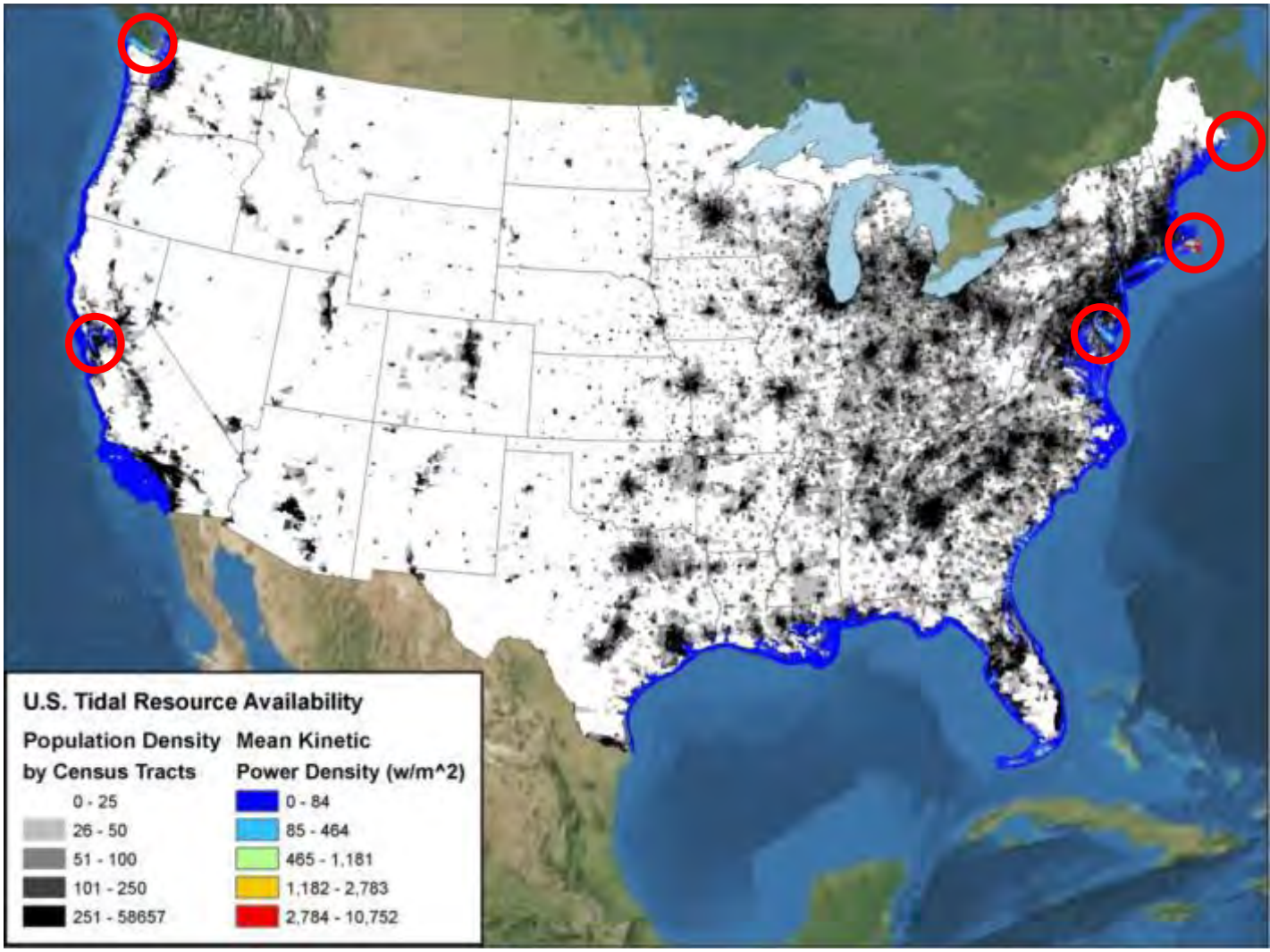
Wave Energy is the dominant MHK resource available to the United States

Marine and Hydrokinetics Tidal Resource

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

6 GW exist in close proximity to major coastal load centers

90% of the overall resource (**54 GW**) is in Alaska.



R&D Funding Opportunities

BUDGET	Wind	Water
FY 2012	$93M	$59M

Primary Funding Mechanisms:

- EERE funding: eere.energy.gov/financing

Additional DOE funding mechanisms:

- ARPA-E: arpa-e-foa.energy.gov
- Office of Science: www.er.doe.gov/grants
- Small Business Innovation Research (SBIR) science.energy.gov/sbir

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Wind Power Technology Segments

Small and Mid-sized Wind (<1MW)

Land-based Utility Wind Turbines

Offshore Wind

Improving reliability and performance of land-based systems and demonstrating innovative offshore technology.

Wind Technology Development

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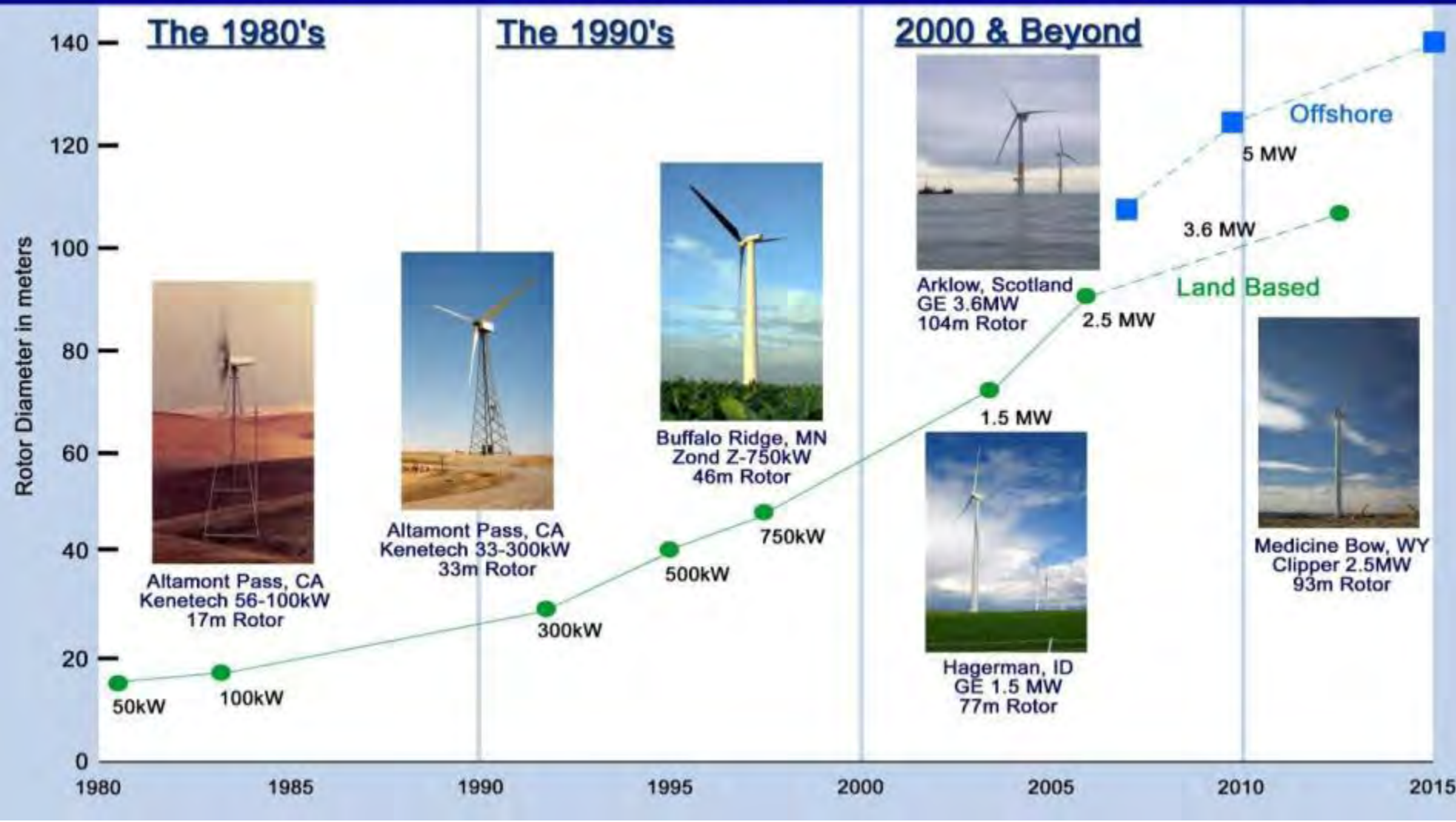
Evolution of U.S. Commercial Wind Technology



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Water Power Program
Marine and Hydrokinetics

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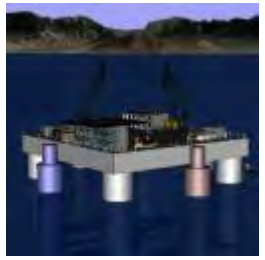
Wave | Tidal | Ocean Current | Instream Hydrokinetic | Ocean Thermal







A range of marine resources, each with its own set of unique characteristics and challenges…
A wide variety of technology types and device designs…
None yet mature nor optimized for performance

Why Pursue MHK Technologies?

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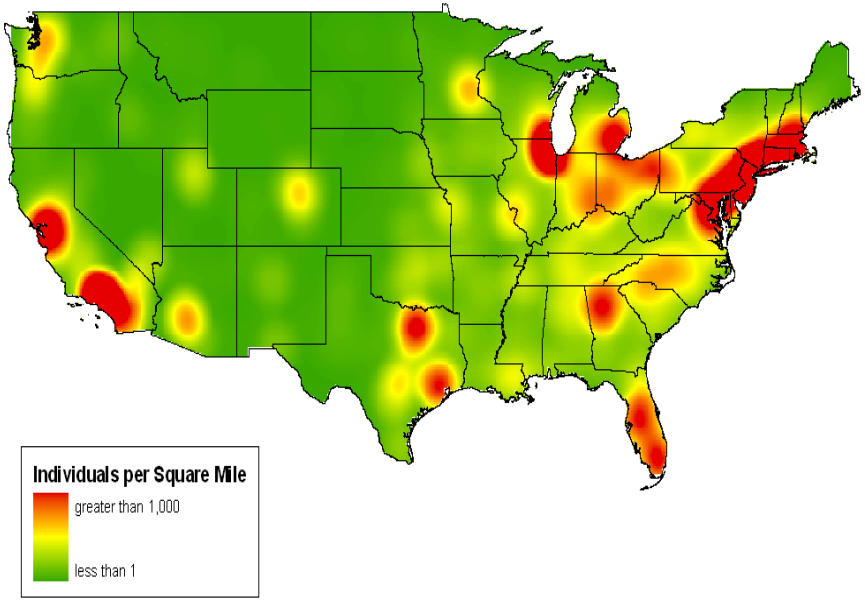
MHK resources are within close proximity to coastal load centers

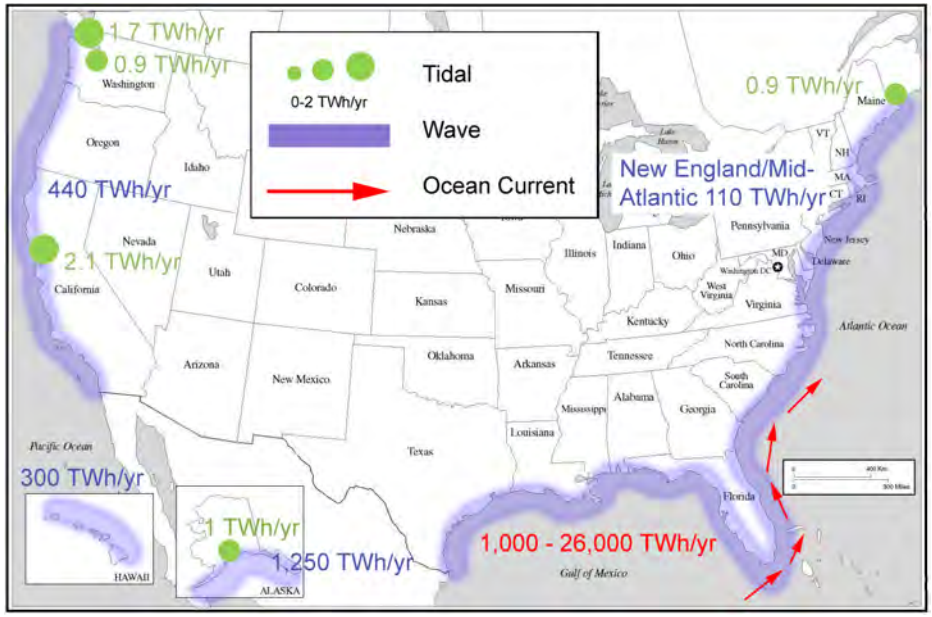
MHK resources are highly predictable , forecastable and vary slowly

MHK Technologies are taking advantage of wind's experience

Population Density of the Counterminous United States

U.S. Highest Population Areas



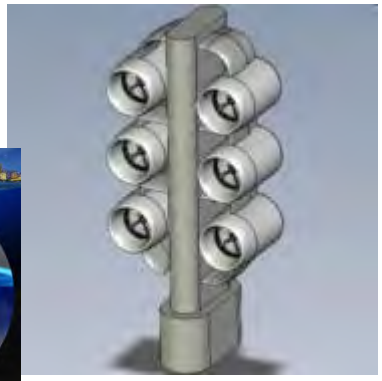


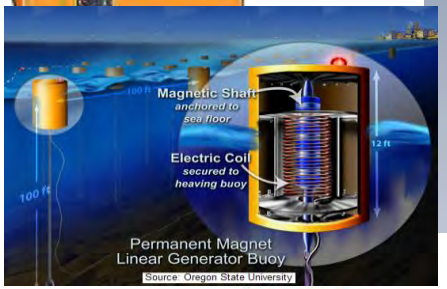
Graphic Credit: Bruce Bailey AWS Truewind

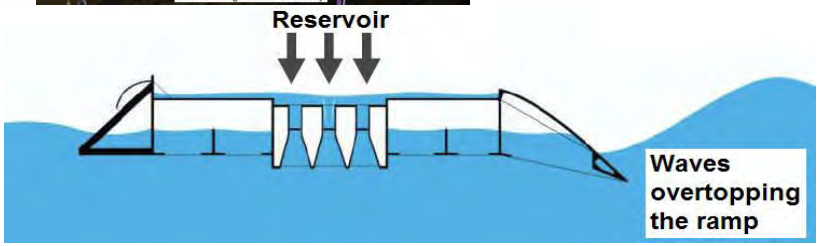
Marine and Hydrokinetic Technology Development and Variety

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

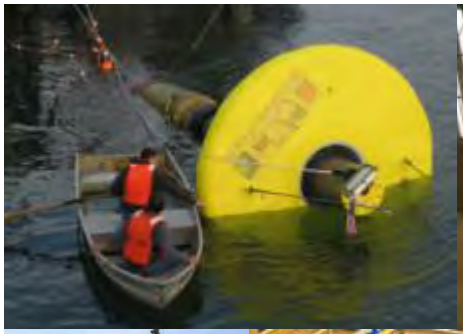
5-10 Years Ago

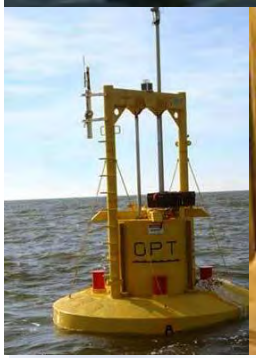


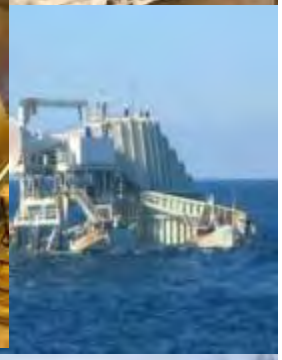




Ocean Energy Today







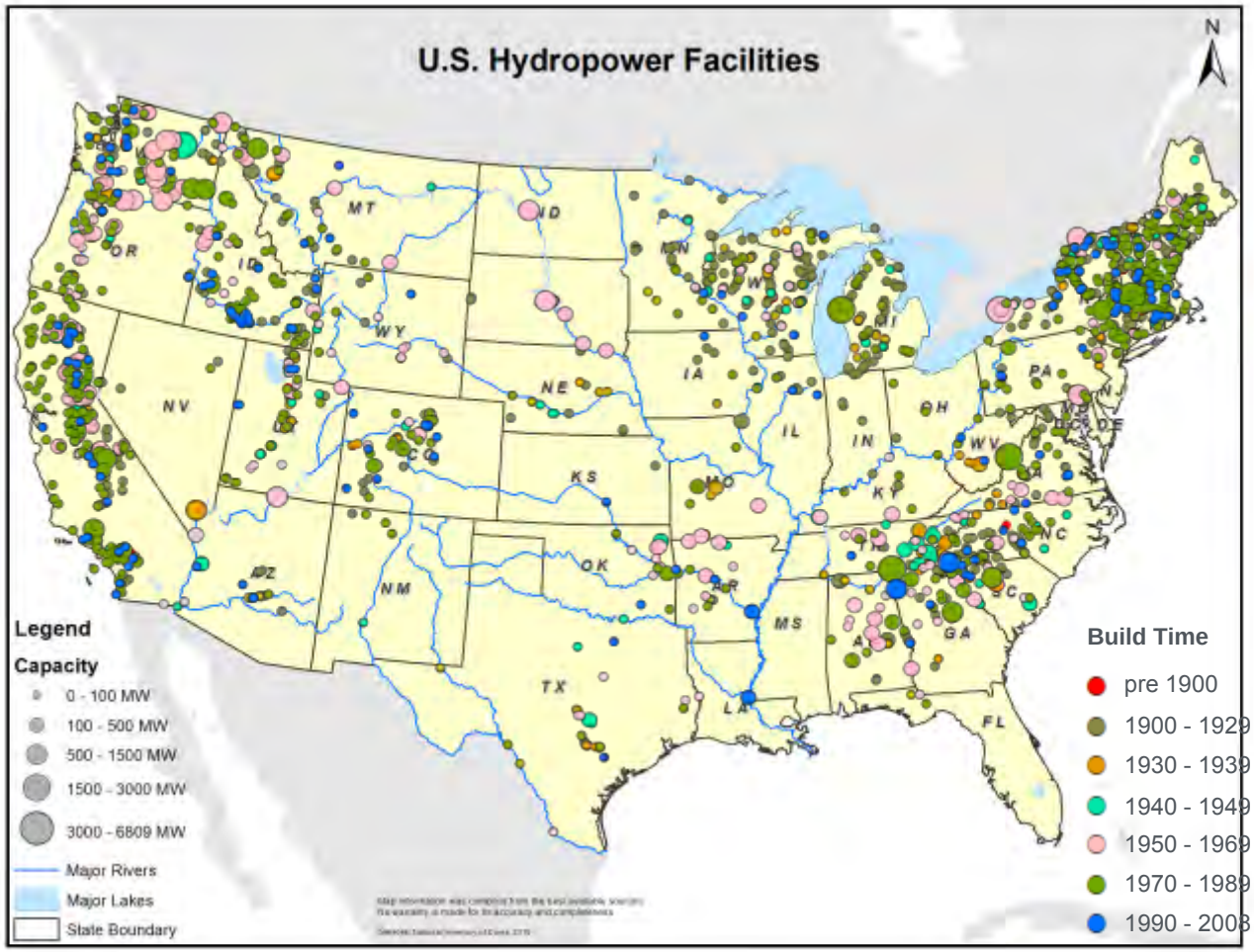
DOE-SPONSORED MHK PROJECTS AND TECHOLOGY READINESS LEVELS

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

	TRL 1-3	TRL 4-6	TRL 7-8	TRL 9
Wave • Point Absorber • Attenuator • OWC • Air Turbine	Resolute[1] M3 Wave PRINCIPLE Semprus SHIFT CONCEPTS NREC	wavebob Northwest Energy Innovations COLUMBIA POWER OPT OCEAN POWER TECHNOLO USSynthetic Atargis Energy Inc.	OPT OCEAN POWER TECHNOLO	
Current • Ocean • Tidal • In-Stream • Turbines • Gears / Generator	Whitestone Power & Communications DEHLSEN	FFP hmmh DEHLSEN VERDANT POWER SUNLIGHT PHOTONICS	orpc SNOHOMISH COUNTY PUD	
Power Transmission	BAYER FREE FLOW ENERGY	PRINCETON POWER SYSTEMS THOR Vortex Hydro Energy		
Moorings & Anchorage		orpc		
OTEC • Cold Water Pipe • Ht Ex	LOCKHEED MARTIN MAKAI OCEAN ENGINEERING	Scientific Solutions LOCKHEED MARTIN		

Conventional Hydropower
Installed US Capacity

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



United States:

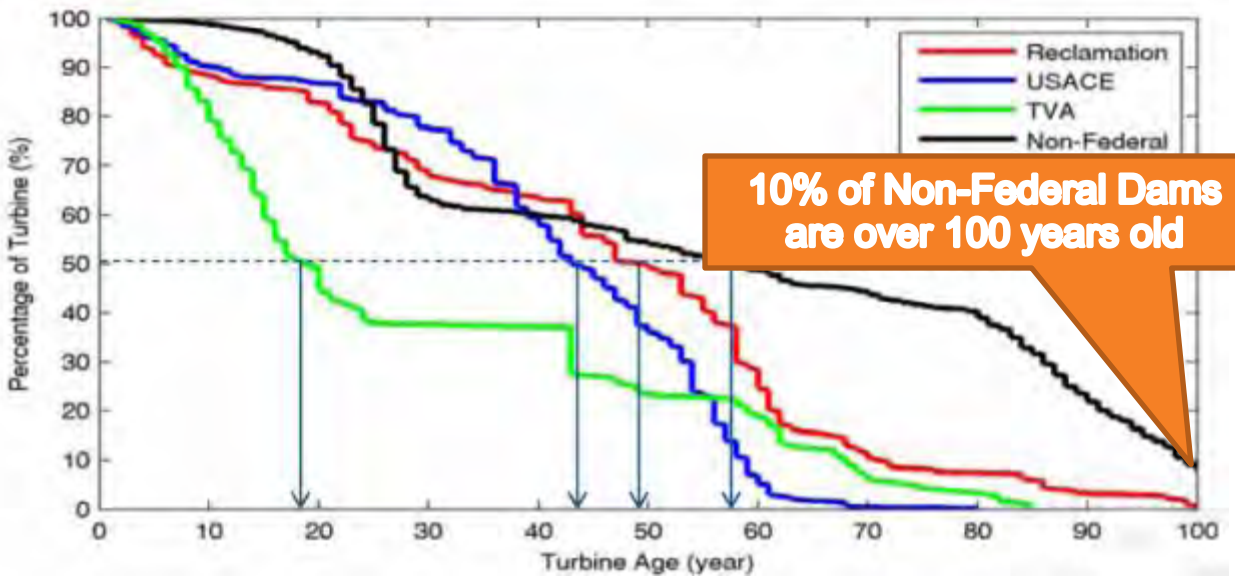
- 7% of Electric Production in 2009
- 78 GW Conventional Hydropower
- Of this, 1,101 plants <5 MW totaling 1.64 GW

Worldwide:

- 16% of Electric Production
- 723 GW

Hydropower is currently the nation's largest source of renewable energy, representing 7% of total US electricity production, and comprising 70% of all renewable energy generation.

Conventional Hydropower
Status of the Existing Fleet



The status of the existing fleet demonstrates the potential to modernize hydropower for additional capacity, flexibility and generation

	Median Ages	Older than 50 Years		Older than 75 Years	
Total US	53	52.5%	29.5 GW	36.8%	8.2 GW
Non-Federal	58	54.6%	18.4 GW	41.9%	8.1 GW
Reclamation	49	49.8%	4.1 GW	8.2%	.058 GW
Corps	44	37.2%	6.1 GW	0.3%	.002 GW
TVA	18	23.3%	0.8 GW	4.3%	.061 GW

Conventional Hydropower
Deployment Potential

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

Resource	Deployment Risk	Permitting Timeframe	Construction Timeframe	Deployment Potential
Additional generation from existing powerhouses	Low	1-2 years	1-3 Years	~16 GW
New generation from unpowered dam development	Low	1-3 years	2-4 Years	12.6 GW
New sustainable development	Medium to High	1-6 years	2-4 Years	~50 to 150+ GW
Advanced Pumped-Storage Development	High	2-6 years	3-6 Years	43 GW of Preliminary Permits
TOTAL POTENTIAL				120 to 220+ GW

Upgrades and unpowered dams can provide considerable new generation. New hydropower and advanced pumped storage opportunities are plentiful.

Advanced Hydropower Projects

- **Sustainable Small Hydropower**:
  - Nine projects, $5.8 million
  - Research, develop, and test low-head, small hydropower technologies
  - Non-powered dams or constructed waterways

- **Sustainable Pumped Storage Hydropower**:
  - Two projects, $6.8 million
  - Spur deployment of advanced pumped storage hydropower in the U.S.

- **Environmental Mitigation Technologies for Conventional Hydropower:**
  - Three projects, $2 million
  - Develop innovative hydropower technologies that will enhance environmental performance while increasing electricity generation, mitigating fish and habitat impacts and enhancing downstream water quality

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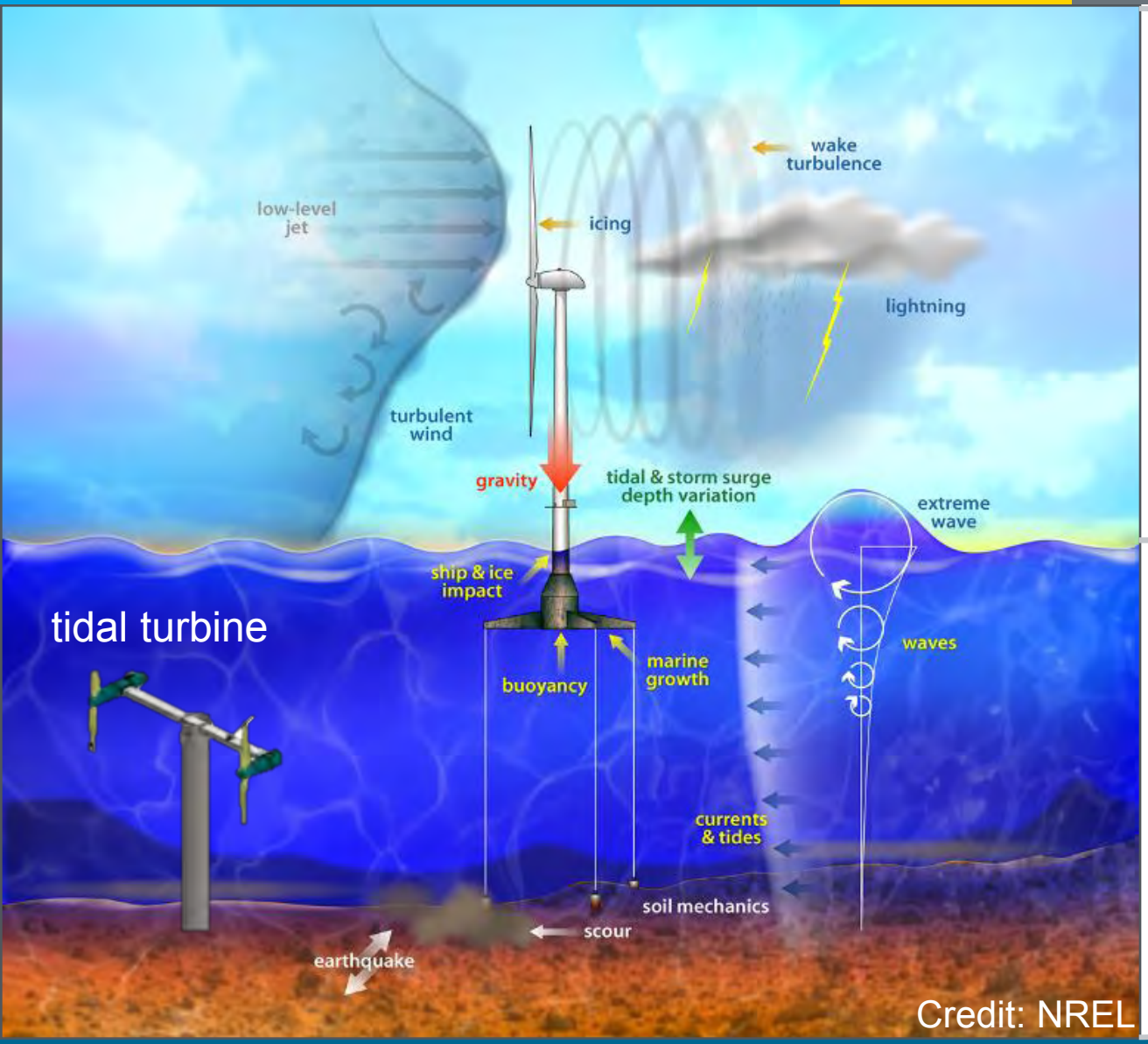
Environment Drives the Design

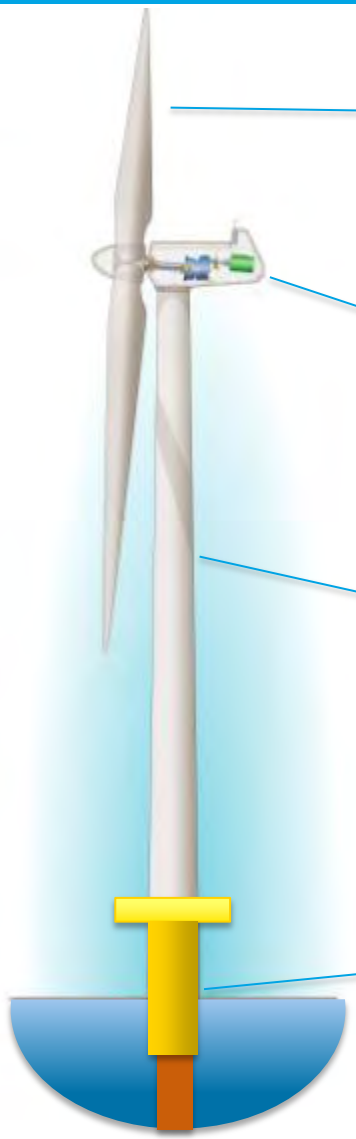


Land-Based Wind Turbines

Offshore Wind Turbine

MHK Devices

Wind / MHK major subsystems

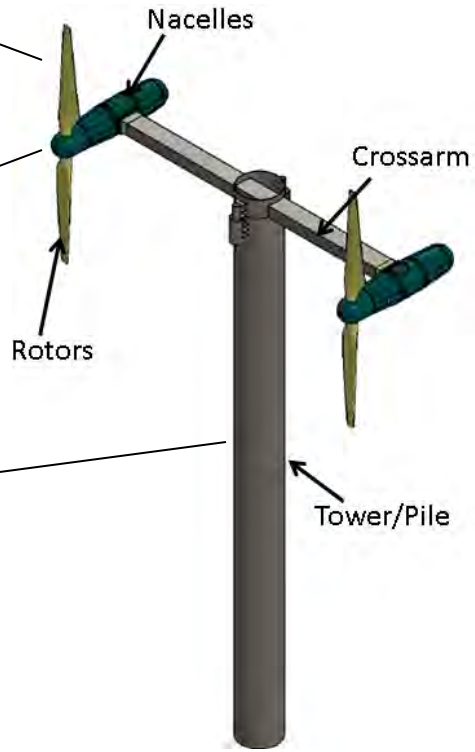


Rotor

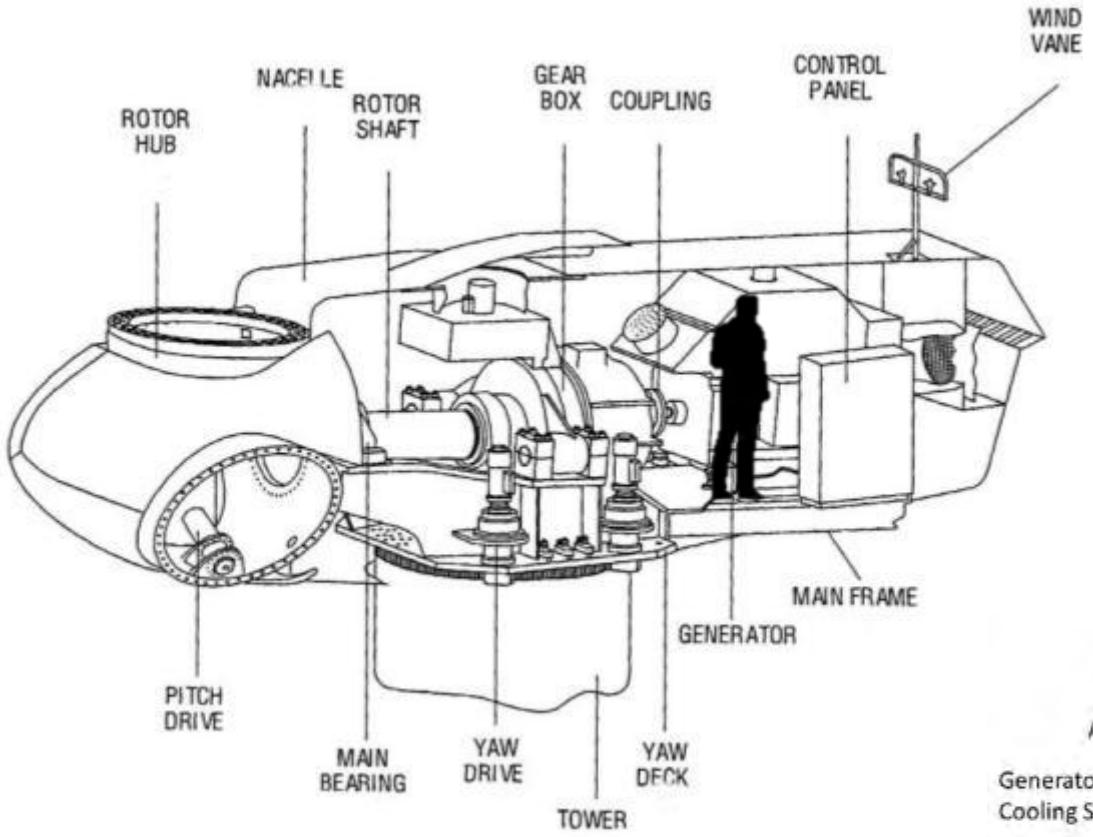
Nacelle

Tower

Foundation

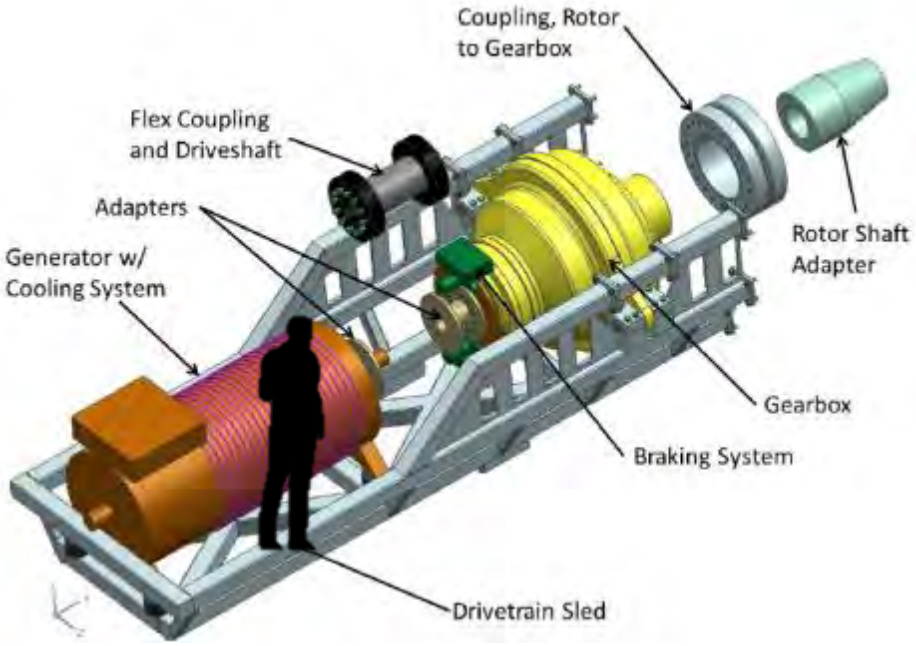


Component Terminology



Wind Turbines: Mature, more standardized topologies

MHK: Prototype stage, less standardized, wide variety topologies



Rotors – Challenges

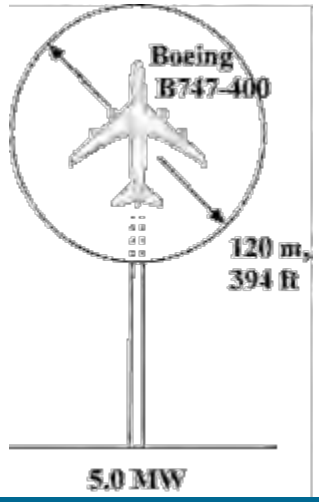
Challenges:

1) 2x rotor diameter → 4x energy capture → 8x mass

2) Origin and effects of defects in composites not well understood

Materials Opportunities:

- Stiffer materials to limit blade deflection
- Higher strength/weight ratio materials
- Material characterization from fiber up to full component



Typical Material Costs:
High End Military: ~$1000/lb
Aerospace: ~$100/lb
Wind turbine blades: ~$10/lb

Blade Reliability Collaborative

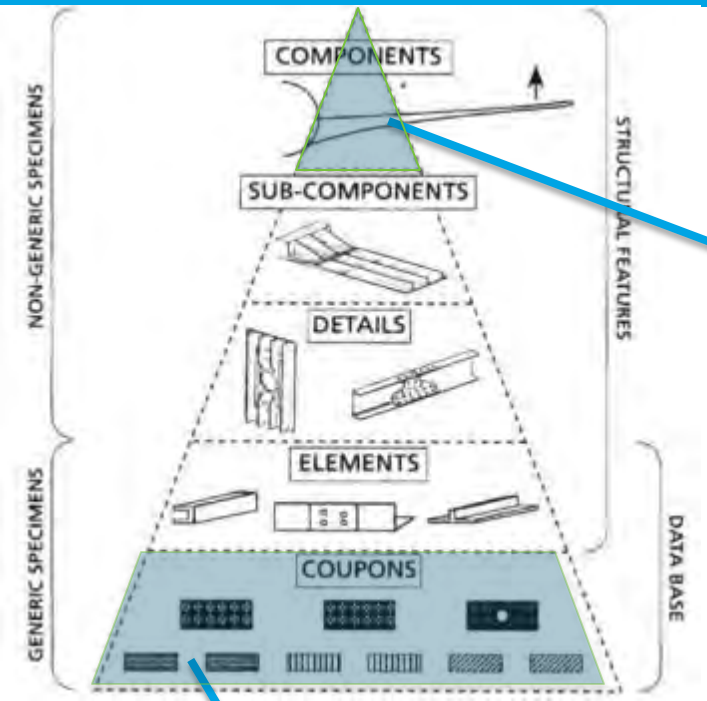
Industry collaborative lead by Sandia National Lab

windpower.sandia.gov

Major Activities	Goal
Root Cause Analysis	Document field failures and root cause analysis
Inspection Validation	Improve non destructive evaluation for manufacturing
Effects of Defects	Determine how flaws lead to failure
Analysis Evaluation	Improve ability of design tools to assess potential failure
Certification Testing	Evaluate certification testing to improve reliability

Will guide development of new materials and processes for blades

Rotors – R&D: Testing all scales



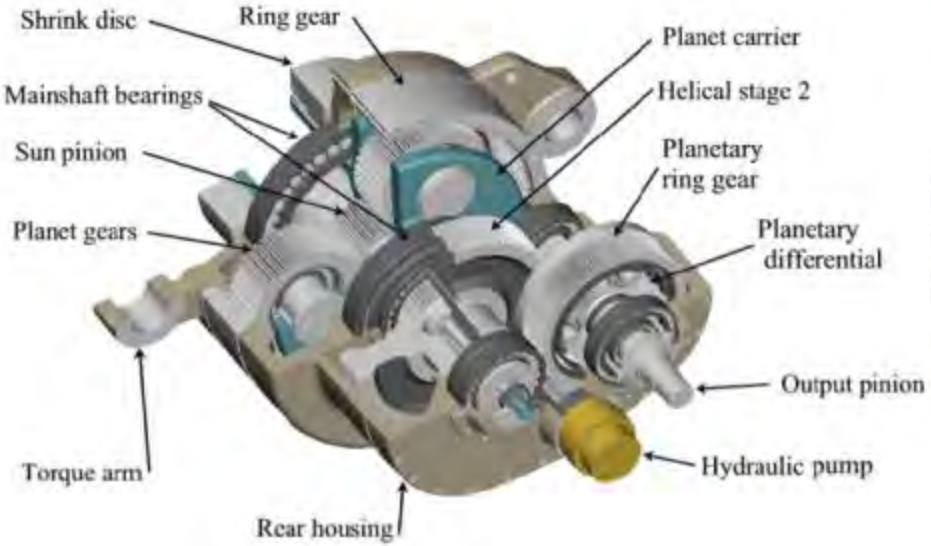
Massachusetts Large Blade Test Center

Sandia National Lab and Montana State University Composite materials testing
www.coe.montana.edu/composites/

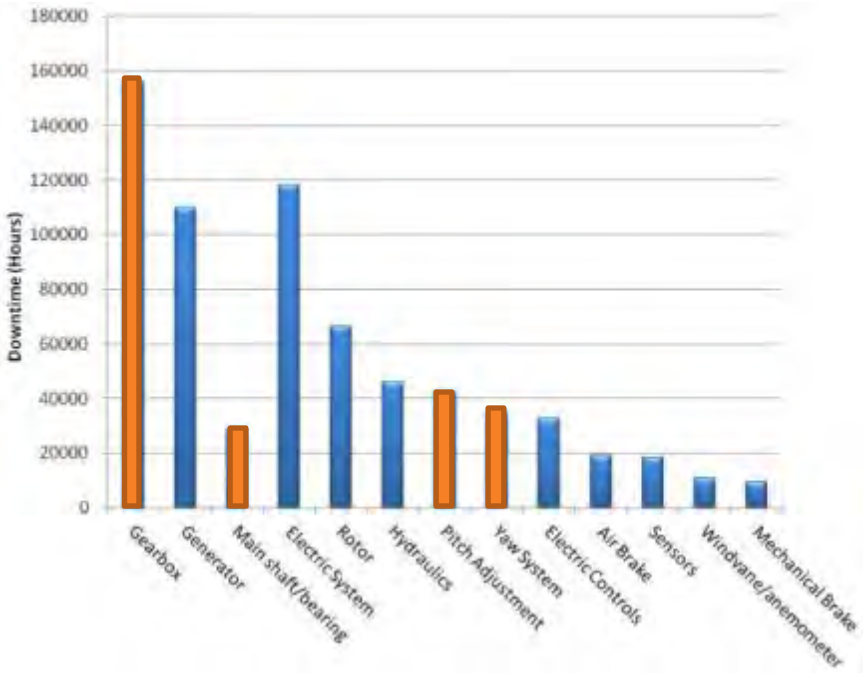
Bearings and Gears – Challenges

Challenges: Gearbox/pitch/yaw/bearings fail much earlier than design life leading to high maintenance costs.

Materials Opportunities: Root cause failure analysis, new lubricants and surface science.

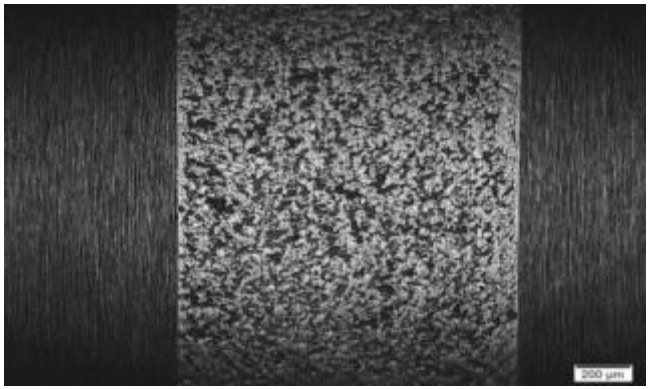


Conventional 3-stage gearbox model. WindPACT



Total Downtime by Wind Turbine Component. Windstats survey of 27,000 turbines.

Bearings and Gears – R&D

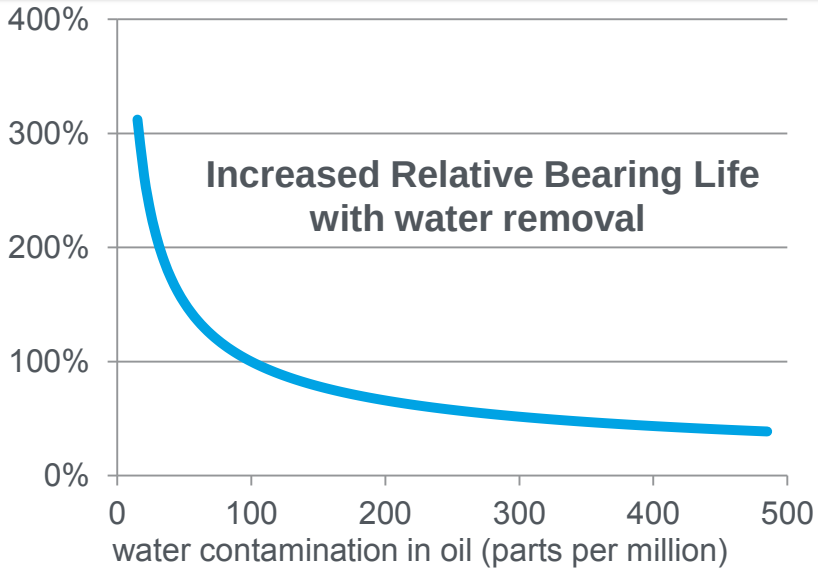


Micro-pitting of surface with conventional oil

1) Micro-pitting and wear reduction with advanced lubricants (Argonne National Lab)

Wear reduction with advanced lubrication system

2) Oil dehydrator for extended bearing life: Compact Membrane Systems LLC



Gearbox Reliability Collaborative – NREL:

Engages key representatives in the wind turbine gearbox supply chain to improve gearbox reliability and increase turbine uptime.

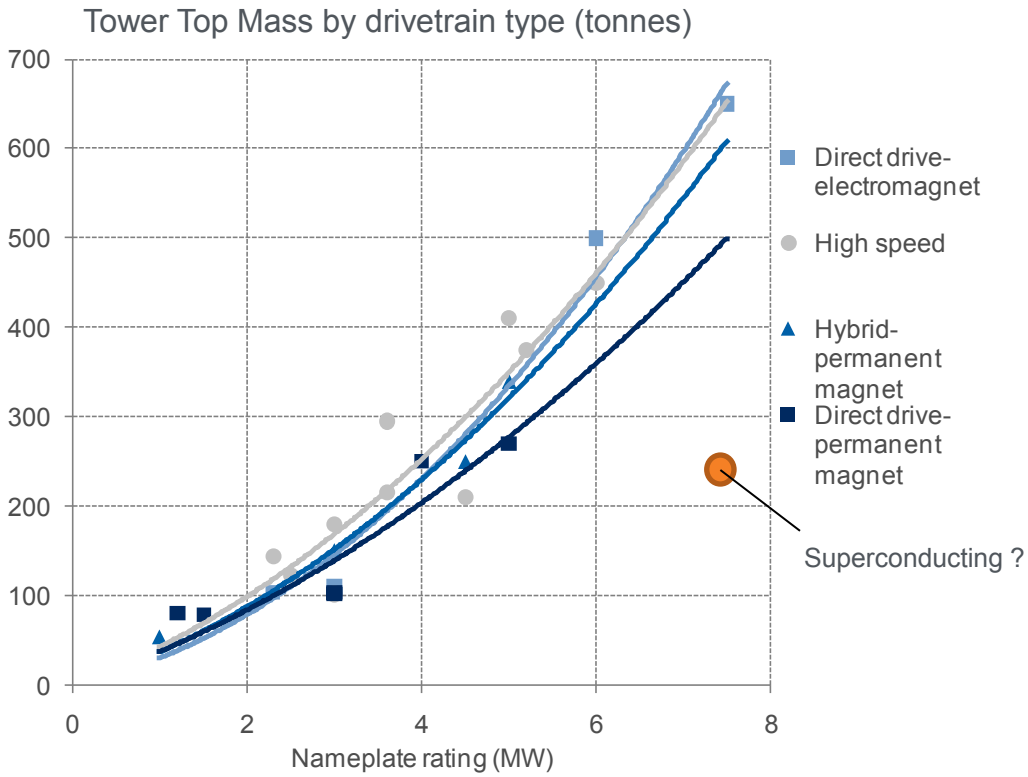
www.nrel.gov/wind/grc/

GRC Gearbox 1 high-speed stage displaying damage.

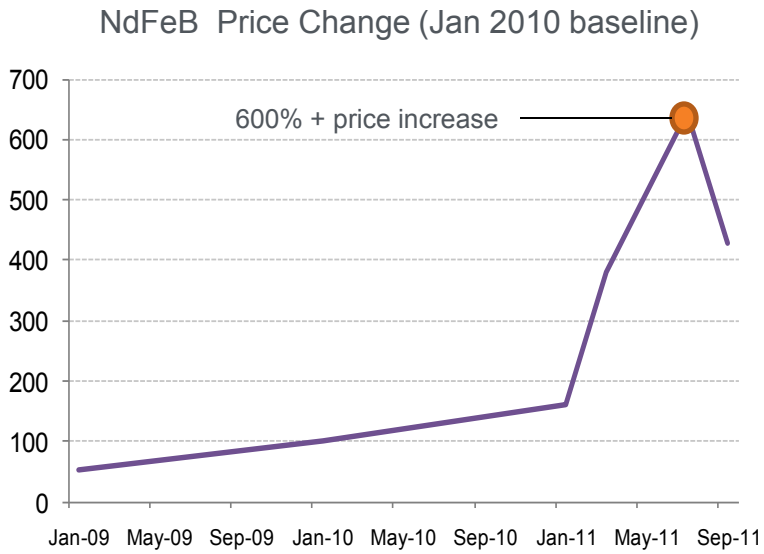
Generators – Challenges

Challenges: Reduce mass, magnet costs

Materials Opportunities: superconductors, rare earth magnet (NdFeB) alternatives



Source: Bloomberg New Energy Finance



Source: Bloomberg New Energy Finance

Generators – R&D

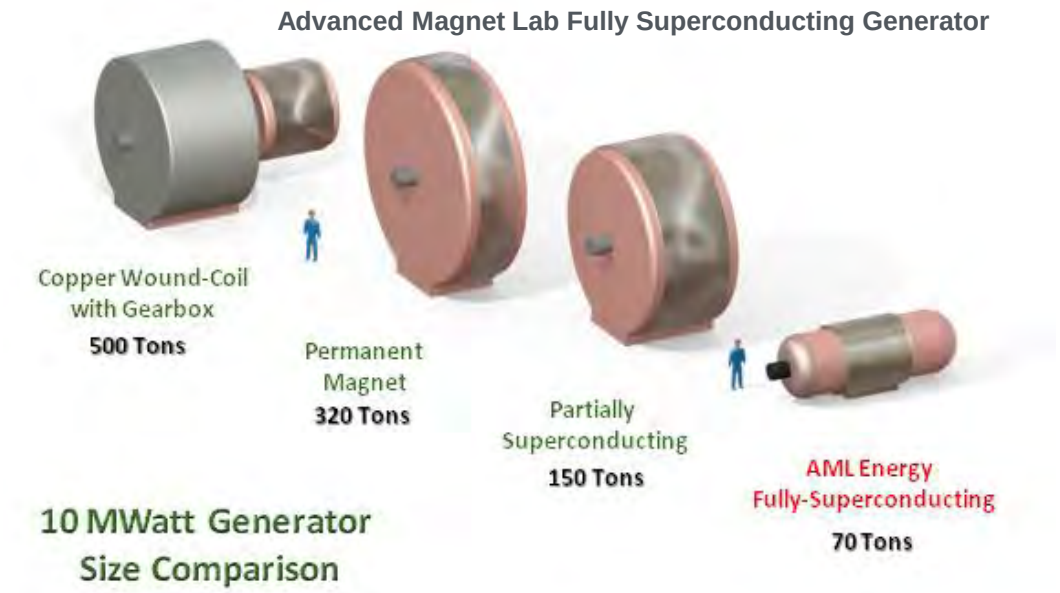
DOE Next Generation Drivetrain R&D ($7.5M):

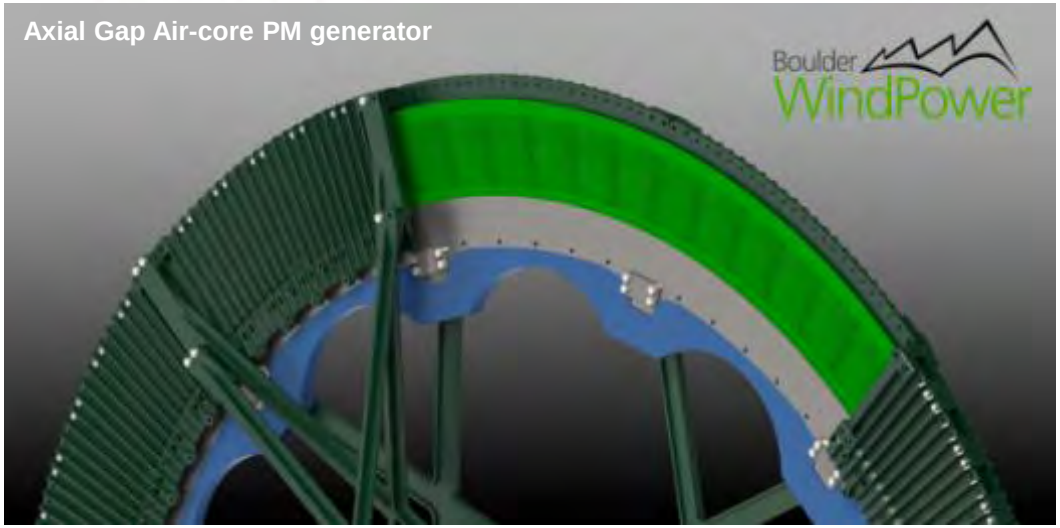
6 concepts for larger, more reliable and efficient drivetrains:

- Eaton
- Clipper
- GE Global Research
- Advanced Magnet Lab
- Boulder Windpower
- NREL

Generator concepts include:

- Superconducting
- Rare-earth magnet





Power Electronics – Challenges

Challenges: Harsh operational environment, increase power density, increase efficiency

Materials Opportunities: Semiconductor switches (SiC), magnetic transformer cores, thermal management

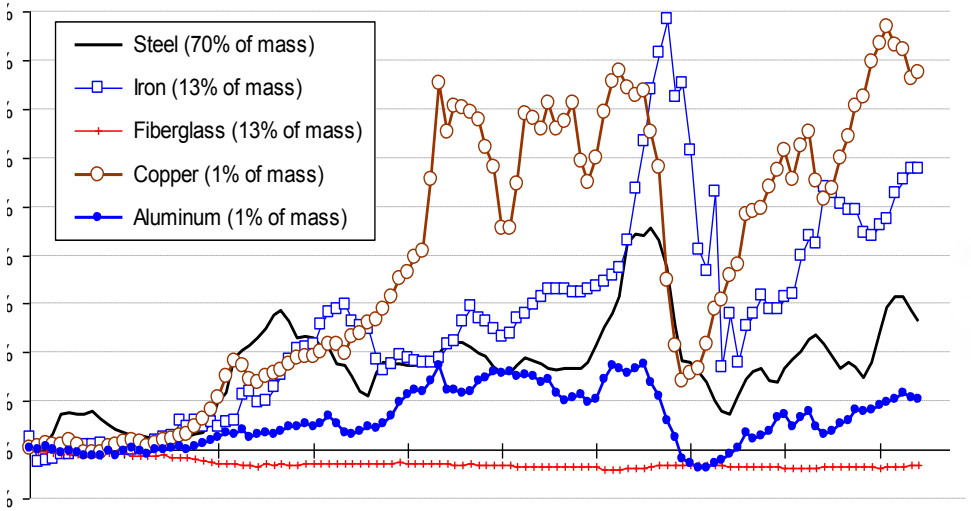
arpa-e.energy.gov/

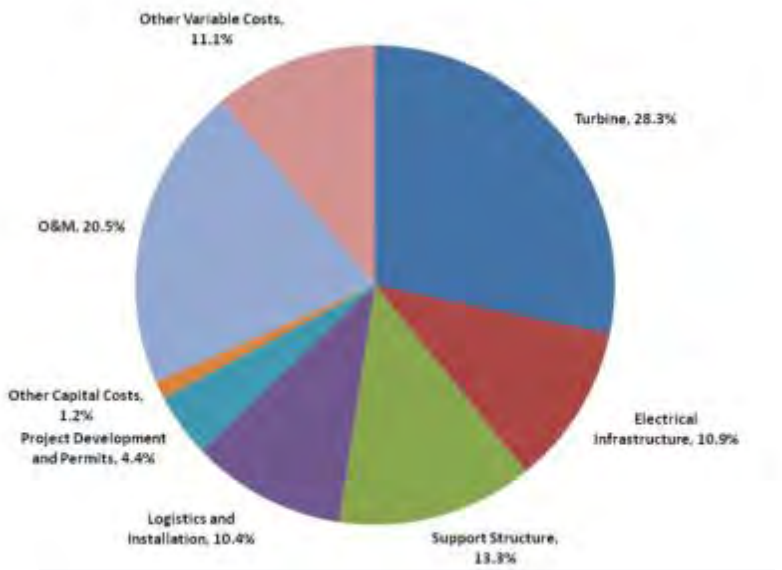
- **Agile Delivery of Electrical Power Technology (ADEPT)**
- **Rare Earth Alternatives in Critical Technologies(REACT)**

Structural Components - Challenges

Challenges: Increased weight/increased cost, commodity price swings, transportation logistics

Materials Opportunities: Light-weighting, alternative structural materials, on-site fabrication





Support Structure Offshore ~20% of total cost

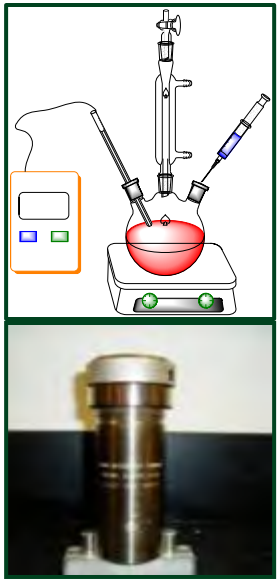
Source: M. Bolinger and R. Wiser. *Understanding Trends in Wind Turbine Prices Over the Past Decade*. LBNL. October 2011.

Coatings – Challenges

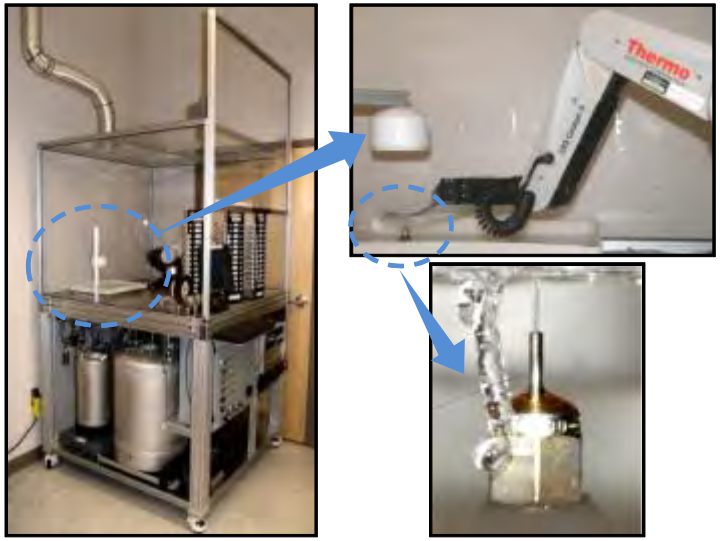
Challenge: Protection against environmental degradation of components (corrosion, biofouling, sediment fouling/erosion, cavitation, environmentally benign coatings)

Materials Opportunities:

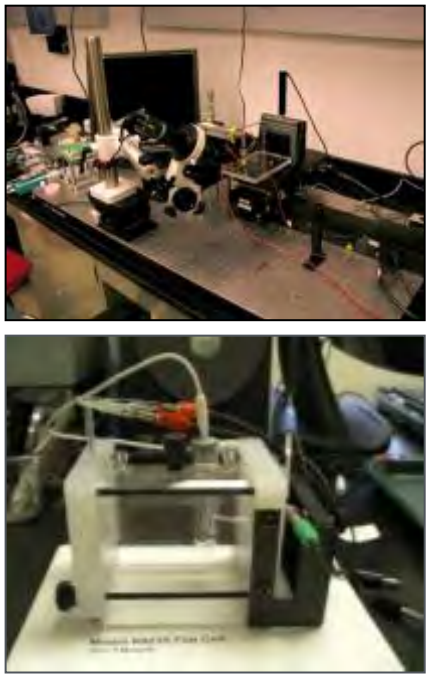
Novel Coatings Synthesis



Biofouling Testing



Corrosion/ Reliability Testing



Coatings – R&D: SNL Advanced Materials Lab

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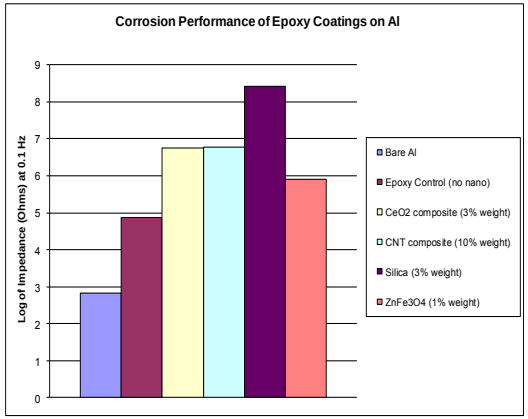
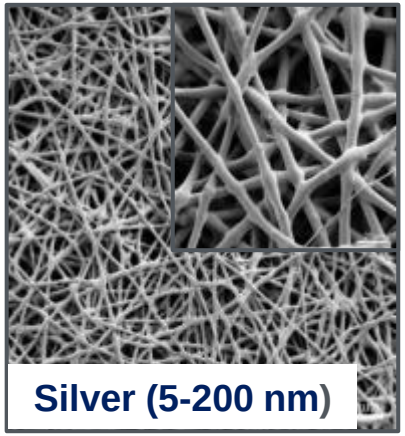
Coatings & Materials Performance Testing

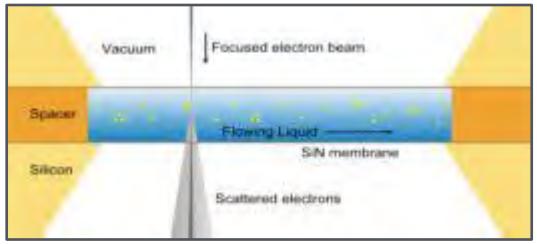
Anti-Corrosion Coatings



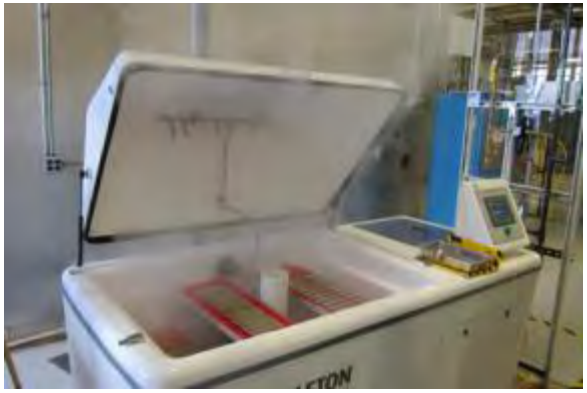
Anti-Biofouling Coatings



Microfluidic Mixing TEM Stage

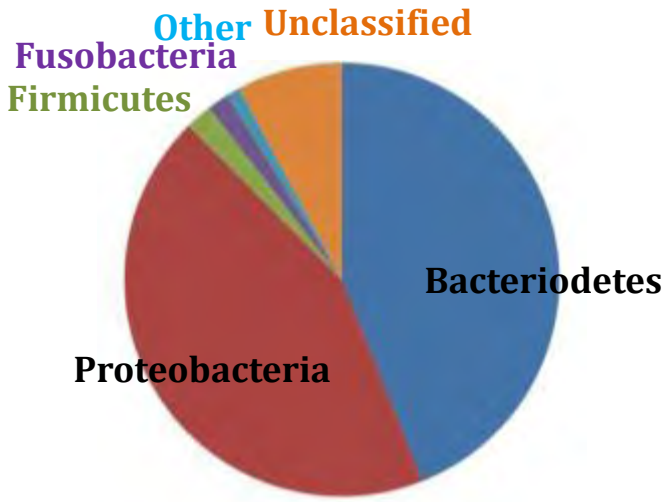


Salt Fog Testing



Industrial Support

Biofilm Characterization on Verdant Power Systems Deployed in East River

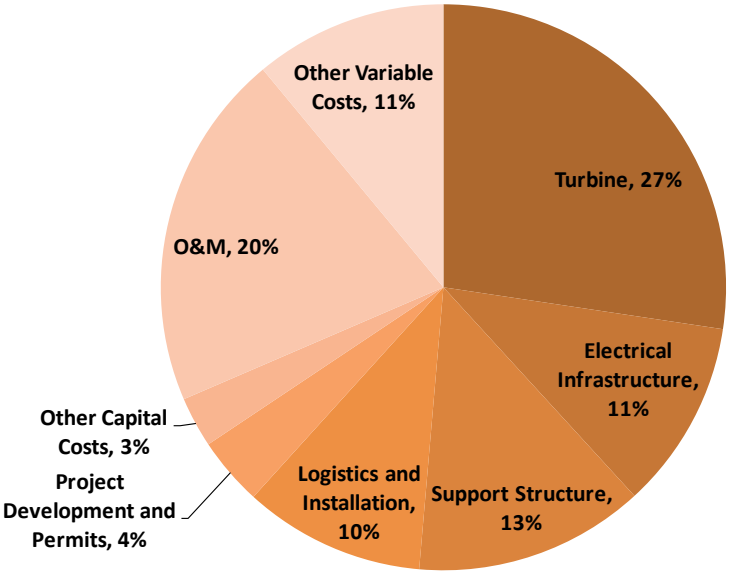


Outline

- DOE Wind and Water Power Program
- Overview of Wind Technology
- Overview of Water Technology
- Materials Challenges
- Summary

Major Challenge: Lower Cost of Energy

COE=



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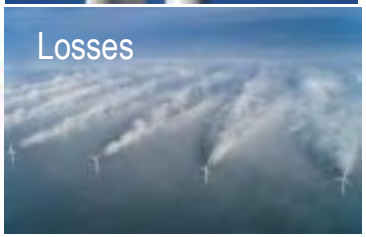
Lifetime Cost



Lifetime Energy Capture

kWh

Summary – Key Points

- Electricity is a commodity – Need to drive down **Cost of Energy**
- **Gigawatts deployed** – materials must be compatible with mass production
- Transfer materials developed in **complimentary industries** - optimize for unique wind and water operating conditions.

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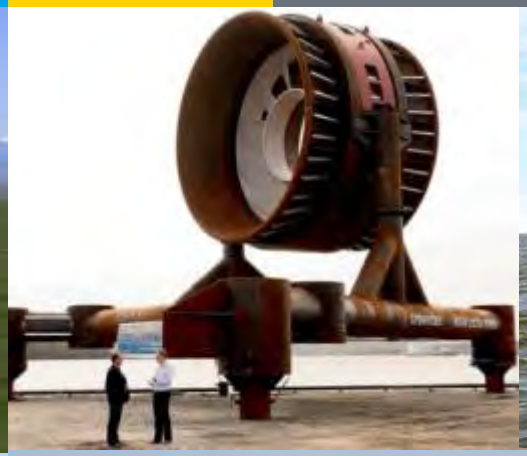

Thank You

water.energy.gov
wind.energy.gov