Offshore Renewable Energy R&D in the United States

By Bob Thresher, NREL Research Fellow

WavEC 2014 Transatlantic Seminar: Marine Renewable Energy
Lisbon, Portugal
9 October 2014
DOE Marine Hydrokinetic Strategic Objectives

- Prove technical credibility and optimize performance through **technology advancement and demonstration**
- Strengthen MHK device quality and rigor through comprehensive **testing infrastructure and instrumentation**
- Quantify operating conditions and reduce siting risk through **resource characterization**
- Boost investor confidence and reduce regulatory barriers through addressing a wide range of environmental and market barriers.

DOE aims to compress technology development timelines with the goal of **reducing the LCOE for MHK devices** to local coastal hurdle rates of 12-15 cents per kilowatt hour (kWh) by 2030.
U.S. Wave Energy Resource Maps

http://maps.nrel.gov/re_atlas
Wave Energy Simulator: WEC-Sim

WEC-Sim is a series of coupled code modules that run in concert to simulate WEC dynamics.

- Each module simulates a different physical phenomena.
- WEC-Sim is MATLAB/SimMechanics based and was released in open-source format in June, 2014 at GitHub through OpenEI: [http://en.openei.org/wiki/WEC-Sim](http://en.openei.org/wiki/WEC-Sim)
- WEC-Sim is being developed by NREL and Sandia and through code competitions.
Accomplishments & Progress

SimMechanics model

File structure

Input file

```matlab
% Simulation data
simu = simulationClass;
simu.simMechanicsFile = 'wecModel.slx';
simu.numWecBodies = 2;
simu.dt = 0.01;
simu.endTime = 1000

% Bodies
body(1) = bodyClass;
body(1).geom.file = ['geometry filesep 'flap.stl'];
body(1).setHydroData('wamit', ['wamit filesep
    oswec.out'], 1, simu);
body(1).setMass('user', 220e3);
body(1).setCg('user', [0 0 -14.28]);
body(1).momOfInertia = [147.85e6 42.04e6 106.00e6];

body(2) = bodyClass;
body(2).geom.file = ['geometry filesep 'frame.stl'];
body(2).setHydroData('wamit', ['wamit filesep
    oswec.out'], 2, simu);
body(2).setMass('wamit', simu);
body(2).setCg('wamit');
body(2).momOfInertia = [3.55e8 2.05e8 4.84e8];
body(2).setMooring('linear', ['mooring filesep
    frameMooring.m']);

% Set wave type and Run the simulation
waves = waveClass('irregular', 5, 8, simu);

% Run the simulation
wecSimDriver
```

http://en.openei.org/wiki/WEC-Sim
Power Performance Estimate

- Numerical Model: WEC-Sim
- Mechanical-to-Electrical conversion efficiency: 82%
- Capacity factor: 30%
- Averaged electrical power output: 108 kW
- Rated power: 360 kW
- Annual energy production: 882 kW
  - 98% transmission efficiency
  - 95% device availability
DOE Reference Model Project

The U.S. Department of Energy’s (DOE’s) Water Power Program established the Reference Model (RM) Project to:

• Gauge the status of the technology and its readiness and potential cost
• Identify areas where additional research could best be applied
• [http://energy.sandia.gov/?page_id=16794](http://energy.sandia.gov/?page_id=16794)

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**RM1**
Tidal Current Turbine

**RM2**
River Current Turbine

**RM3**
Wave Point Absorber

**RM4**
Ocean Current Turbine

**RM5** - Oscillating Surge Wave Energy Converter
NREL Design

**RM6** - Oscillating Water Column
Sandia design
Reference Model Project Modeling & Testing

Reference Model 1
Tidal Turbine

Reference Model 3
Point Absorber

Heave Response
Experimental versus CFD

Graph showing comparison between experimental and CFD data for Heave Response.
Sandia Technology R&D

High-Fidelity Simulation

Tidal Turbine
Device Design and Analysis
Performance and Acoustics Experimental Validation

Axial Velocity Variance (8cm)

WEC Arrays
Experimental Validation
Simulation

Oscillating Water Column
Dynamic Analysis

Reference Models
Design and Analysis

Materials and Coatings
Composite Material Water Absorption
Anti-Biofouling Effectiveness

Crystal Violet Absorbance (600nm)

Crystal Violet Absorbance (600nm)

- Control
- 258
- 1229A
- 1230A
- 1230B
- T2
- PU
- 700
- 900
Sandia Environmental Research

CEC Array Modeling
Cobscook Bay Array Optimization

WEC Array Modeling
Effects on Wave Propagation, Circulation, and Sediment Dynamics

Sediment Stability Maps
Erosion potential after 10 years

Acoustics Modeling
MHK Sound Generation and Propagation

HydroKinetic Turbines
Performance and Water Operations
**Challenge:** Organize & make available information on environmental effects of MHK development

**Approach:** Knowledge Management System, publically available & easily accessible

**Outcome:** Shared knowledge to accelerate siting & permitting

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**TETHYS**


Tethys is a database and knowledge management system that provides access to information and research pertaining to the potential environmental effects of marine and hydrokinetic (MHK) and offshore wind development. Tethys also hosts data from Annex IV, an international collaboration to gather information on MHK environmental research worldwide.

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Schematic of Tethys relationship with analysis tools (represented by ERES) & stakeholders

Courtesy of Jennifer States
PNNL MHK Environmental Research: Mitigating Risk to Endangered Species

Severity of Strike Analysis

- **Challenge:** Risk to SRKW from tidal turbines is a major barrier to permitting tidal power development in Puget Sound.

- **Technical Approach:** PNNL and Sandia National Laboratories modeled the forces caused by a turbine blade striking a SRKW and evaluated potential damage to the whale.

- **Outcome:** The models show that harm to the SRKW would be minimal or equivalent to a bruise. NOAA Fisheries is evaluating the information; Snohomish PUD has filed for a final license application with FERC.

Courtesy of Jennifer States
Administration of the Wave Energy Converter (WEC) Prize

WEC Prize competition will enable game-changing performance enhancements to WEC devices, and establish a pathway for sweeping cost reductions at a commercial scale.

MHK Demonstrations at the Navy Wave Energy Test Site

Testing, evaluation, and comparison of two close to full-scale wave energy conversion (WEC) systems at the Navy’s WETS.

To apply to these FOAs, Applicants must register with and submit application materials through: https://eere-Exchange.energy.gov
DOE Offshore Wind R&D

Two Critical Objectives

1) **Reducing the cost of energy** through technology development
2) **Reducing deployment timelines** and uncertainties

<table>
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<th>World-Class Test Facilities</th>
<th>Removing Market Barriers</th>
<th>Next Generation Drivetrain R&amp;D</th>
<th>Developing Innovative Technology</th>
<th>Demonstrate Next-Generation Designs</th>
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<tr>
<td>(ARRA Projects)</td>
<td>(Offshore FOA 1)</td>
<td>(Tech. Viability FOA)</td>
<td>(Offshore FOA 2)</td>
<td>(Offshore FOA 3)</td>
</tr>
<tr>
<td>Clemson 15 MW Dynamometer</td>
<td>Siting and Permitting</td>
<td>Aggressively Targets Key Cost</td>
<td>Computational Tools</td>
<td>Demonstration Project</td>
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<tr>
<td>Massachusetts Large Blade</td>
<td>Resource Planning</td>
<td>Components</td>
<td>Turbine Design</td>
<td>Partnerships with 50% Cost Share</td>
</tr>
<tr>
<td>Test Facility (to 90m)</td>
<td></td>
<td></td>
<td>Marine Systems Engineerin</td>
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Developed jointly by DOE and DOI

<table>
<thead>
<tr>
<th>Cost</th>
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<tr>
<td>$70M</td>
<td>$16.5M</td>
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<tr>
<td>$168M</td>
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U.S. Gross Offshore Wind Resource

4,150 GW
The Three Major Types of Floating Turbine Technologies

Spar

Semisubmersible

TLP

Illustration by Joshua Bauer, NREL
Offshore Wind Demonstration Projects

2013: 7 awards
$4M each for 50% planning, design & permitting

2014: Down-select to 3 projects Up to $47M each for construction; operational by 2017
Floating Foundations: Principle Power WindFloat

**Project Highlights**

- Semi-submersible foundation
- 16 nm off Coos Bay, Oregon in 1,200 ft of water (350 m)
- Five, 6-MW Siemens turbines
- No heavy-lift vessels required – quayside assembly, tow-out installation and tow-in O&M
- Mooring and anchors are pre-installed
- Dynamic electrical cable connecting turbines together
- Potential for mass production
- 2-MW WindFloat 1 off of Portugal since 2012
Introducing Atmosphere to Electrons (A2e)

A2e is a new, multi-year, multi-stakeholder DOE R&D initiative tasked with improving wind plant performance and mitigating risk and uncertainty to achieve substantial reductions in the cost of wind energy.

DOE Wind Program
- Federal Engagement & Oversight
- Integrated Program & Project Management
- Budgetary Control

National Labs & Universities
- Subject Matter Expertise
- Project Planning
- R&D Execution

Other Federal Agencies
- Leverage Strategic Programs
- Access to HPC Core Competencies
- Subject Matter Expertise
- Access to Facilities

Private Industry
- R&D Execution
- Operational Expertise
- End User Requirements
- Access to Operating Plants

Int’l Collaboration
- Coordinated & Collaborative Research Campaigns

Atmosphere to Electrons (A2e)

- DOE led partnership with National Laboratories, Other Federal Agencies, Universities, Industry, and International Stakeholders
- Integrated strategic research planning coordinated through lead National Labs & DOE
- Research conducted by appropriate organizations
High Definition Wind Plant Modeling

Simulator for Offshore Wind Farm Applications (SOWFA)

- Enables Optimum Wind Plant System Design Layout
- Understanding of Fatigue Loading Due to Wake Effects
- Understanding Deep Array Effects
- Enables Optimized Wind Plant Control

Scale: Mesoscale

Tools: WRF ← OpenFOAM ← FAST

SOWFA

Graphic Source: NREL
The National Wind Technology Center

- Turbine testing since 1977
- Leader in development of simulation tools and cost analyses
- Unique test facilities
  - Field testing
  - Controls turbines
  - Dynamometers
  - Controllable Grid Interface
  - Energy storage
- Approx. 130 staff on-site
- Budget approx. $30M
- Many CRADAs with industry & Gov.
- Implement DOE outreach, workforce and education activities
- Marine and Hydrokinetic Technologies
National Wind Technology Center Drivetrain Testing

Zond Z-750
GE 1.5 MW
Clipper (8 Gen)
Clipper (4 Gen)

Northern 1.5 MW
Northern 2.3 MW
GEC 1.5 MW
NREL/DOE GRC 1&2

Samsung 2.5 MW
Clipper Liberty
NREL/DOE GRC 3
GE 2.75 MW
Challenges / Innovations

Development of normative methods

Precision control

Dual axis testing

Resonant testing

Advanced blades

Sensing

Resonant Dual Axis Testing

Year

1990

1995

2000

2005

2010

2015

National Wind Technology Center Blade Testing
Thank You - Questions?

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