2014 WATER POWER PROGRAM PEER REVIEW

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

Compiled Presentations

February 24-28, 2014

Marine and Hydrokinetic Technologies

PR- 5A00-61854

Contents

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2014 Water Power Program Peer Review

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

Marine and Hydrokinetics Technologies Overview

Jose Zayas, Director
Wind and Water Power Technologies Office
February 24, 2014

White House & DOE Priorities

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

White House

- Generate 80% of the nations' electricity from clean energy sources by 2035
- Reduce carbon emissions 80% by 2050
- Lead the world in clean energy innovation, stimulate jobs and economic growth with a clean energy economy

DOE

- Ensure America's security and prosperity by addressing energy and environmental challenges through transformative science and technology solutions
- Maintain a vibrant U.S. effort in science and engineering as a cornerstone of economic prosperity

EERE

- Invest in clean energy technologies that strengthen the economy, protect the environment, and reduce dependence on foreign oil
- Increase U.S. competitiveness in the production of clean-energy materials and products

WWPTO

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

The ***mission*** of the Wind and Water Power Technologies Office 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.

Water Power Portfolio
Transformational Technology Innovation

WWPTO's Water Power Program performs research and development of transformational technology innovation in two markets:

Marine and Hydrokinetics (MHK)

- Wave, Tidal, Current & Instream Energy Technology
- Resource Characterization
- Environmental Performance and Market Barriers

Hydropower

- Existing Infrastructure
- Low-Impact New Development
- Pumped Storage Hydropower
- Environmental Performance and Market Barriers

Water Power Program Structure

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

Wind and Water Power Technologies Office
(WWPTO)
J. Zayas, Director

Water Power Technologies
M. Reed, Lead

Wind Power Technologies
M. Derby, Lead

Hydropower
M. Reed

Marine & Hydrokinetic (MHK)
A. LaBonte

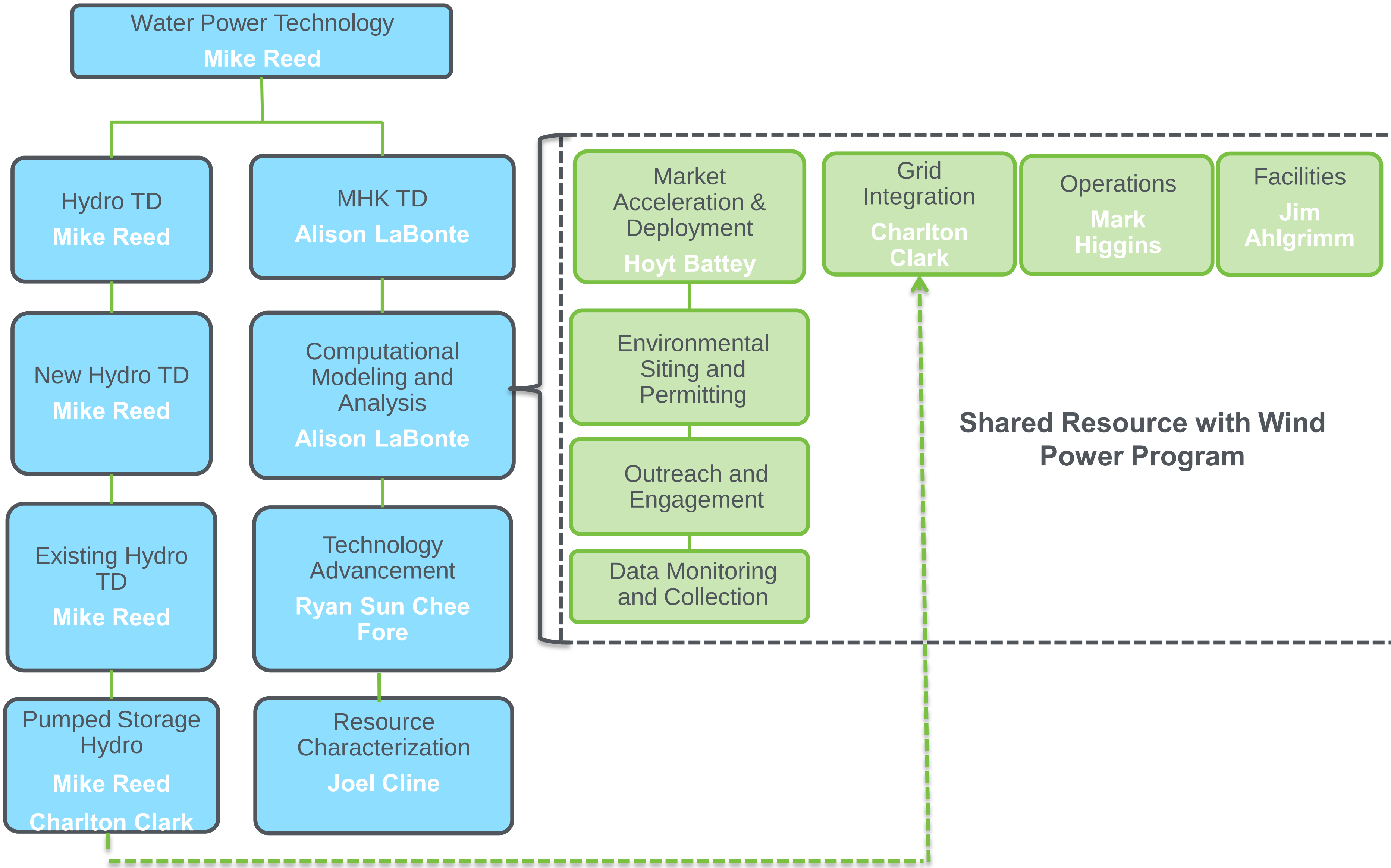
Land-based Wind

Offshore Wind

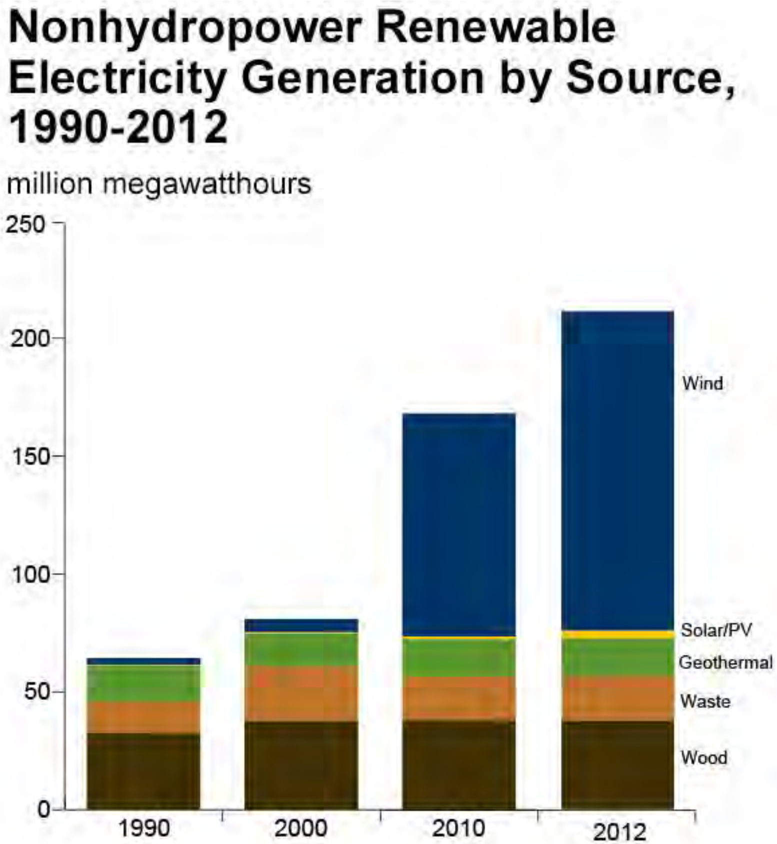
Distributed Wind

Cross Cutting Functions

Water Power Program Structure

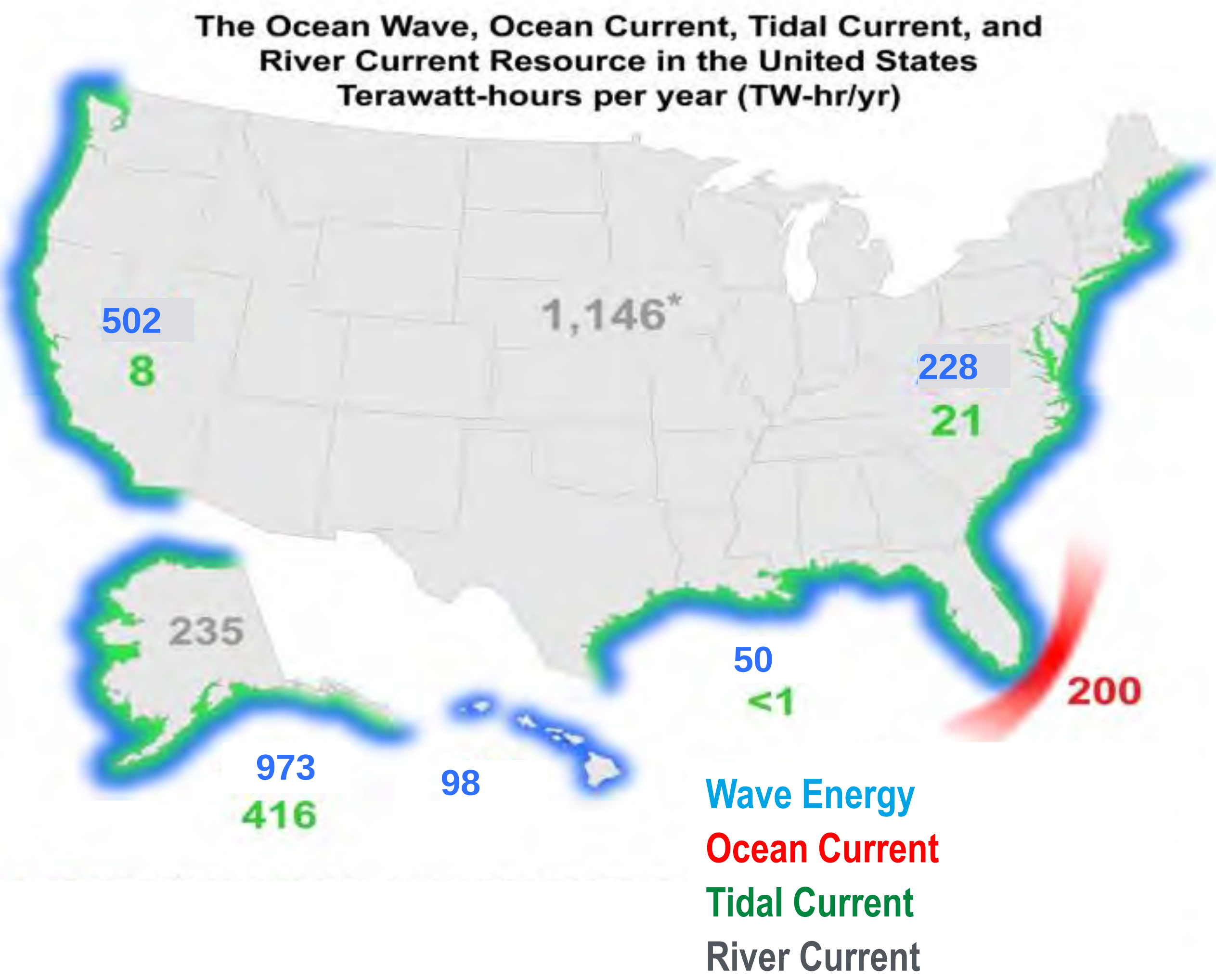


Marine and Hydrokinetics
A complex R&D role



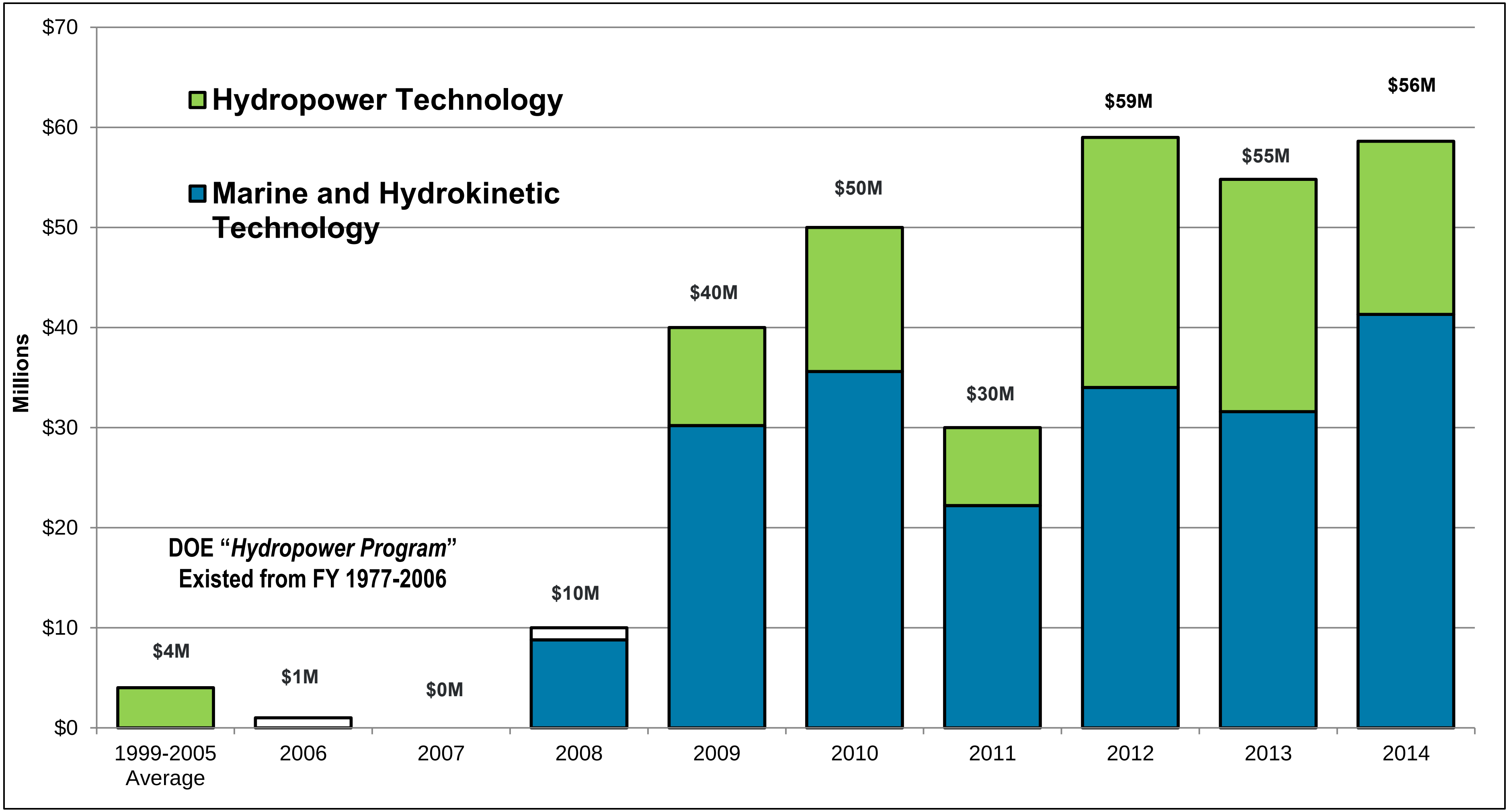
Source: U.S. Energy Information Administration, the *Electric Power Monthly* (March, 2013).

Despite a significant increase in renewables generation and a diverse set of viable MHK technologies, there are currently no commercial MHK technologies deployed in the United States.

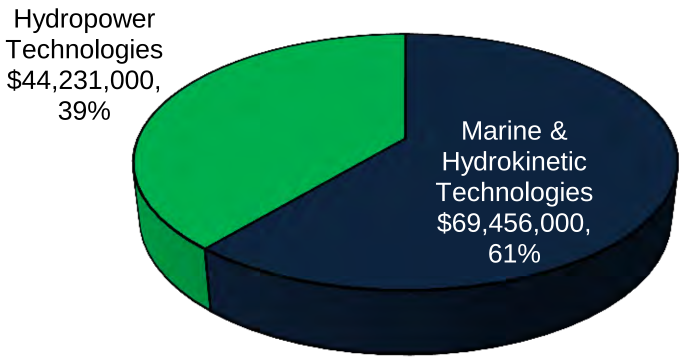


There is a vast amount of marine and hydrokinetic energy resources throughout major coastal and tidal zones in the United States.

Water Power Program Funding History



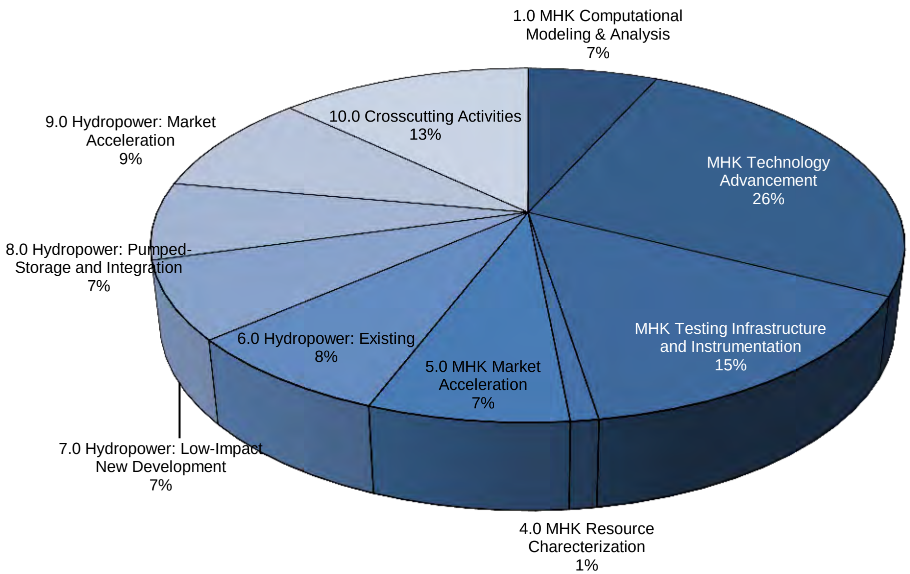
FY 2012 and FY 2013 Funding Appropriations



Subprogram	FY12 Enacted	FY13 Enacted	FY 2012 & FY 2013 Funding
Marine & Hydrokinetic Technologies	$34,000,000	$35,456,000	$69,456,000
Hydropower Technologies	$25,000,000	$19,231,000	$44,231,000
Water Power Technologies Office Summary	$59,000,000	$54,687,000	$113,687,000

Thrust Areas	FY12 Enacted	FY13 Enacted	FY 2012 & FY 2013 Funding
1.0 MHK Computational Modeling & Analysis	$3,738,000	$3,835,000	$7,573,000
2.0 MHK Technology Advancement	$13,172,535	$16,149,015	$29,321,550
3.0 MHK Testing Infrastructure and Instrumentation	$13,222,846	$3,884,909	$17,107,755
4.0 MHK Resource Characterization	$0	$1,150,000	$1,150,000
5.0 MHK Market Acceleration	$3,342,040	$4,909,900	$8,251,940
6.0 Hydropower: Existing	$2,934,000	$5,976,000	$8,910,000
7.0 Hydropower: Low-Impact New Development	$4,207,007	$3,866,127	$8,073,134
8.0 Hydropower: Pumped-Storage and Integration	$5,890,138	$2,146,000	$8,036,138
9.0 Hydropower: Market Acceleration	$5,230,228	$5,350,940	$10,581,168
10.0 Crosscutting Activities	$7,263,206	$7,419,109	$14,682,315
Water Power Technologies Office Summary	$59,000,000	$54,687,000	$113,687,000

FY 2012 and FY 2013 Funding Distribution by Thrust Area



Water Power Technologies Office Peer Reviewed Budget

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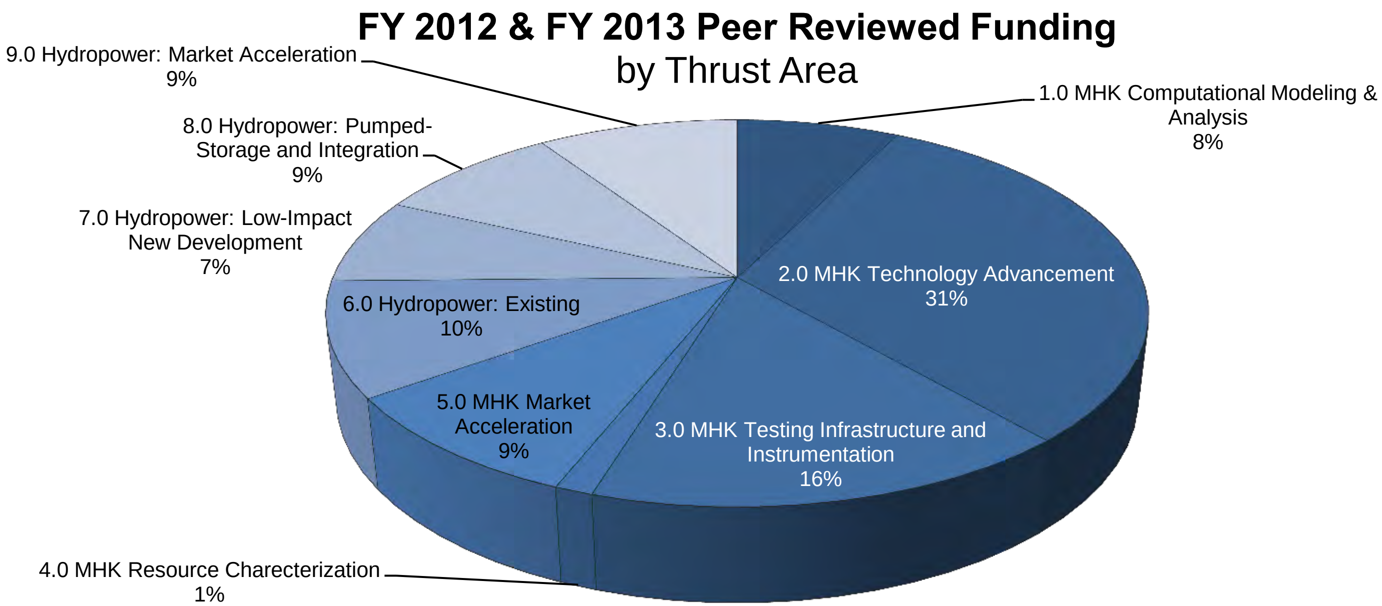

Thrust Areas	FY12 Funding	FY13 Funding	FY 2012 & FY 2013 Funding
1.0 MHK Computational Modeling & Analysis	$3,738,000	$3,160,000	$6,898,000
2.0 MHK Technology Advancement	$11,683,370	$16,149,015	$27,832,385
3.0 MHK Testing Infrastructure and Instrumentation	$10,742,846	$3,884,909	$14,627,755
4.0 MHK Resource Charecterization	$0	$1,150,000	$1,150,000
5.0 MHK Market Acceleration	$3,307,040	$4,899,900	$8,206,940
6.0 Hydropower: Existing	$2,934,000	$5,676,000	$8,610,000
7.0 Hydropower: Low-Impact New Development	$4,207,000	$2,250,000	$6,457,000
8.0 Hydropower: Pumped-Storage and Integration	$5,890,138	$1,946,000	$7,836,138
9.0 Hydropower: Market Acceleration	$3,455,014	$5,031,940	$8,486,954
10.0 Crosscutting Activities	$0	$0	$0
Water Power Technologies Office Summary	**$45,957,408**	**$44,147,764**	**$90,105,172**

79%
FY12 & FY13 Appropriations

DOE Unique Role in MHK

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WWPTO Unique Role in MHK Industry

Characterizing U.S. marine resources:

- Understanding the marine resources of the United States will provide industry stakeholders with the most relevant information for their business and/or performance predictions.
- Understanding loads associated with existing marine resources can inform design requirements and mitigate risk.

Providing industry with access to affordable testing infrastructure and instrumentation:

- Testing infrastructure for controlled and open testing will provide industry stakeholders with an opportunity to improve and validate designs and models.
- The development of robust device instrumentation will help industry more accurately monitor in-water device deployments.

Accelerating MHK markets:

- Through DOE funded R&D projects, WWPTO can ensure that MHK technologies are deployed and operated in a manner that is environmentally responsible.
- The MHK industry can learn from the experiences of wind and solar energy by addressing key environmental concerns early in the technology development phases.

Driving MHK technology advancement:

- By spurring innovation, DOE can encourage industry to develop ground-breaking solutions to current technology constraints in order to reduce risk and attract private investment.
- In providing access to open source codes and models, DOE can share knowledge and support device agnostic technologies that can accelerate and grow the industry.

WWPTO maximizes its federal allocations by investing in high impact areas that have broad impacts across the entire industry.

Marine and Hydrokinetics Opportunities and Goals

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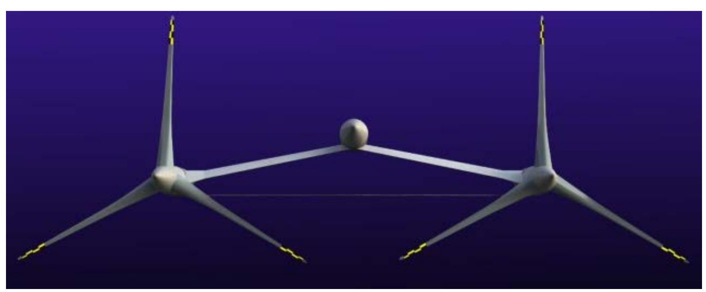
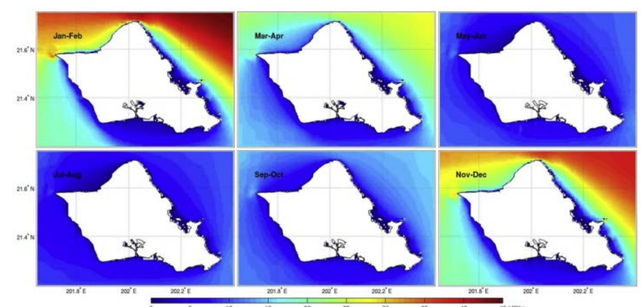
Opportunities		Goals
Technology Advancement & Demonstration	• Sector is young and prime for innovation • Clear data on cost and performance can drive progress	**Develop open source, fully validated MHK codes and collect technology performance and cost data through device demonstrations**
Market Acceleration & Deployment	• Uncertain environmental effects pose significant permitting and regulatory challenges • Disparate information sharing leads to poor access to best science available	**Support monitoring at deployed devices, develop and testing monitoring instrumentation, and engage with stakeholders and regulators**
Testing Infrastructure & Instrumentation	• Testing is expensive and instrumentation/sensors are limited • Domestic devices may lose competitive advantage in global markets	**Provide affordable access to facilities for testing at TRL 5 and above and develop robust instrumentation and sensors**
Resource Characterization	• Technical and business decision-making is hindered by a lack of resource data • Physical conditions will provide information on device loads	**Classify the U.S. MHK resource, disseminate resource data, and develop numerical modeling tools to predict loading conditions**

DOE Role: Resource Characterization

Resource (TWh/year)	U.S. (50 State) Theoretical Resource	U.S. (50 State) Technical Resource	Continental U.S. Technical Resource	Continental U.S. % U.S. 2050 Potential Generation
Wave Energy*	1851	899	359	7%
Tidal Current Energy**	445	222-334	15-22	0.3 – 0.4%
Ocean Current Energy***	200	45-163	45-163	1 – 3%
River Current Energy****	1381	120	100	2%
Total	3877	1286-1516	519-644	10 – 12%

State*	% State Generation Potential from Wave Energy
NC	0-3%
MA	0-10%
WA	9-22%
CA	13-29%
OR	58-84%
HI	Up to 96%
AK	Up to 100%





The program will emphasize wave energy technology development in future R&D funding, with focused support for tidal in key markets and regions.

DOE Role: MHK Technology Advancement

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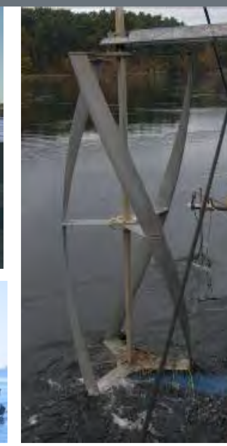

Technology Consideration	Wave	Tidal / Current
Technical Maturity (TRL)	Entire TRL range (2 through 8)	TRL 5 through 8
Risk Profile	Higher risk, longer term effort, higher rewards	Lower risk, early term rewards
State-of-the-Art Scale	Pilot system to single full-scale system	Single full-scale system to arrays
Knowledge Transfer	Capabilities leveraged from marine industries including the Navy, oil & gas and offshore wind	Capabilities leveraged from wind industry

Strategic Goals	• Develop critical testing infrastructure • Move to full-scale system demonstration • Develop numerical models	• Increase in-water operational hours • Move to array-scale demonstration • Validate numerical models

DOE Role: Device Testing and Demonstrations

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DOE Role: Market Acceleration and Deployment

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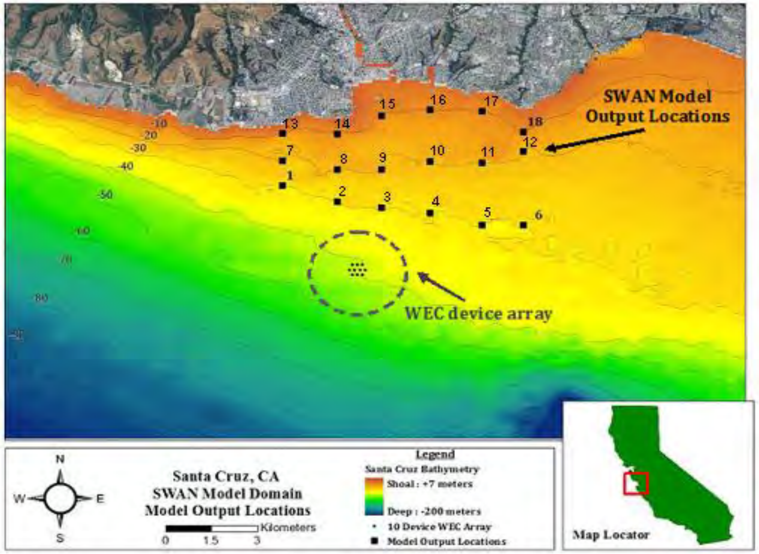
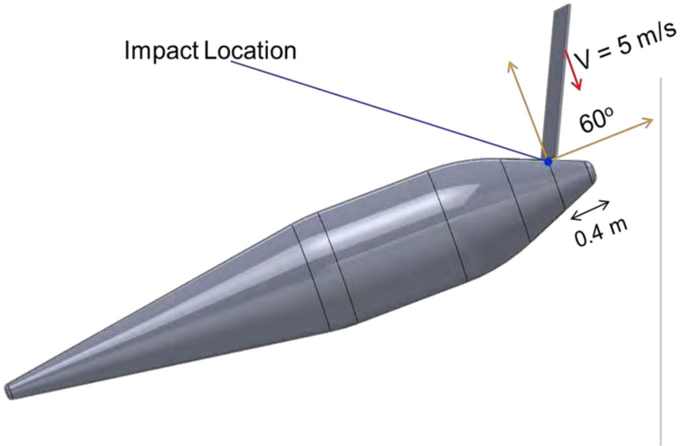
- Ensure that **rigorous data on environmental effects** are gathered to reduce uncertainty and risk current and future projects.
- Ensure that **affordable and effective tools and proven techniques** exist for environmental monitoring, and where necessary mitigation
- **Magnify the impact of environmental research** by actively disseminating information, ensuring that there is broad access to environmental effects data from around the world to ensure and that meta-analyses of the collective implications of these data have been conducted





Key MHK Accomplishments since 2011

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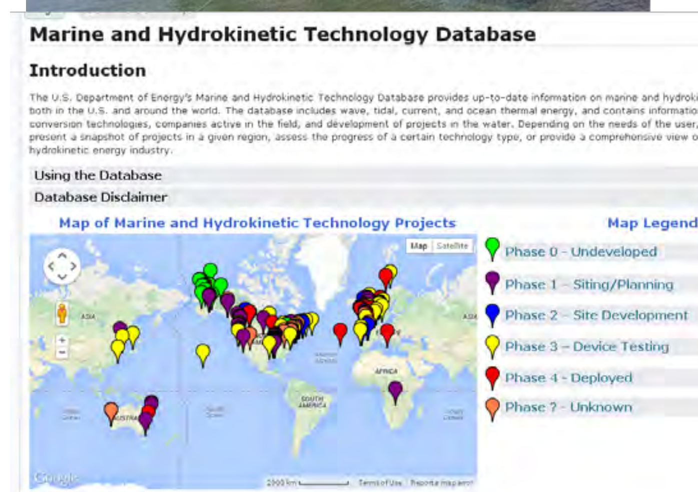
- ✓ Completed resource assessments for Wave, Tidal, Ocean & River Current
- ✓ Completed documents to inform strategy
  - ✓ Reference Models for four Devices
  - ✓ Cost Reduction Pathways for four devices
- ✓ Open water testing of 10 MHK devices and tank testing of 8 MHK devices from FY11-FY13
- ✓ Published guidance on standardized cost calculation
- ✓ Developed and disseminated MHK numerical tools
- ✓ Established a community wiki for Water Power on OpenEI



Marine and Hydrokinetics Activities and Peer Review Agenda

Activities		Agenda
Technology Advancement & Demonstration	• Reference models • Wave and tidal system and component development	**Monday, February 24** **Tuesday, February 25**
Market Acceleration & Deployment	• Acoustics experimentation • Environmental monitoring tool development and modeling • Habitat studies and strike analysis	**Wednesday, February 26**
Testing Infrastructure & Instrumentation	• National Marine Renewable Energy Centers • Standards development • Testing infrastructure and instrumentation	**Thursday, February 27**
Resource Characterization	• Flowfield characterization • Resource assessments	**Thursday, February 27**

MHK Summary

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- 2014 Water Power Peer Review will be a retrospective of work funded in FY12 and FY13
- FY12 and FY13 funded projects form the foundation of WWPTO's MHK strategy to:
  - Advance and demonstrate MHK technology
  - Develop instrumentation and testing infrastructure
  - Characterize U.S. marine resources
  - Address environmental and market barriers and
- DOE's investments have been and will continue to be tailored to support the emerging MHK sector.
- 2014 Water Peer Review Presentations will focus on how FY12 and FY13 funded projects provide the analytical basis for the future goals of WWPTO's MHK strategy.

2014 Water Power Program Peer Review

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Computational Modeling and Analysis

Wind and Water Power Technologies Office
Alison LaBonte
February 24, 2014

MHK Organizational Structure

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- Marine and Hydrokinetic Technologies
  - Computational Modeling and Analysis
  - Technology Advancement
  - Resource Characterization
  - Testing Infrastructure

Key Counterparts and Collaborators

- National Renewable Energy Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Industry
- National Marine Renewable Energy Centers

Water Power Program Key Objectives

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The 2014 Water Program Peer Review Agenda sessions will cover projects and activities in these priority areas:	
Advance the state of MHK technology	• Monday, 2/24 • Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26

Overview: Computational Modeling and Analysis

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Goals – Invest in open source MHK computational tools to aid industry prior to significant capital investment through early numerical assessment of device designs and performance, system and array optimization, and cost trade off analysis under operational and extreme conditions. Conduct performance and cost analysis to inform investment decisions.

Priorities – Provide Design Tools to Optimize MHK Systems

FY 14 Budget: $3.5M

DOE Unique Role – Provide leadership in leveraging national lab expertise and relationships with developers and universities to develop accepted, complete, and fully validated open source MHK design tools that would not otherwise be developed, and to foster and train MHK researcher and device developer code user communities.

MHK Budget
(FY 2012 – FY 2014)

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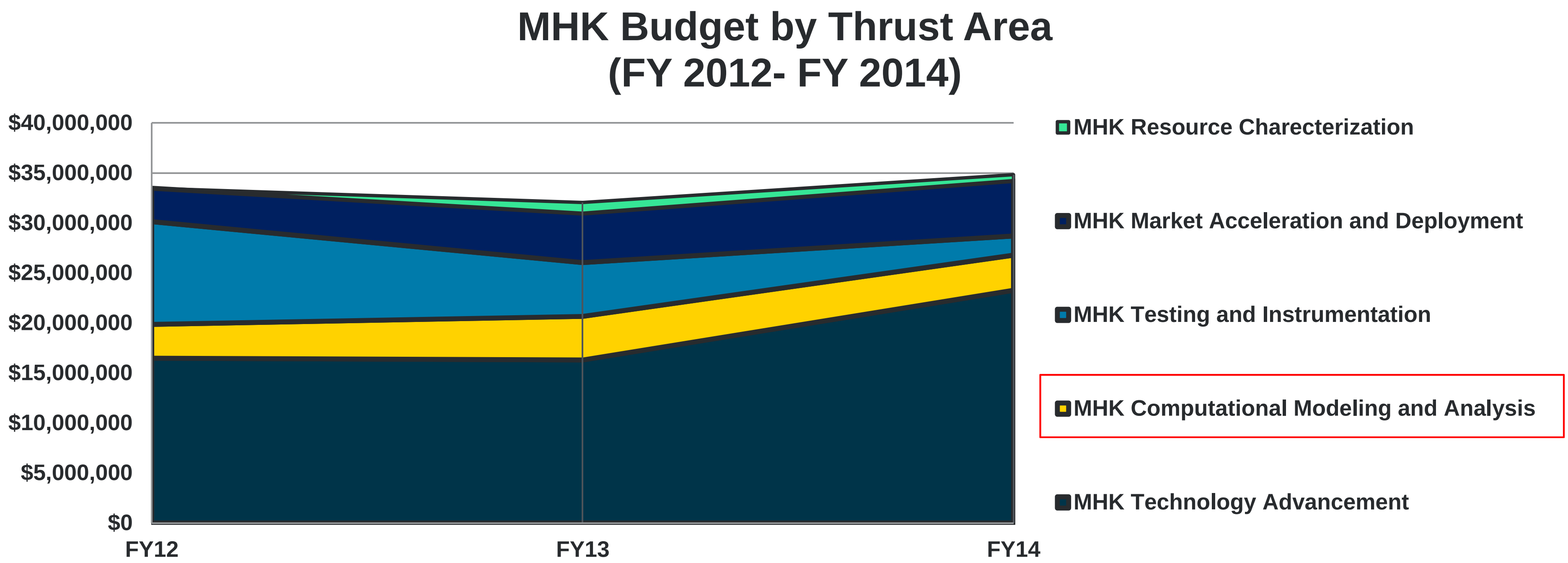

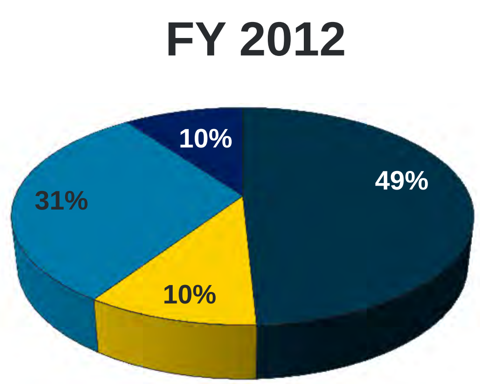

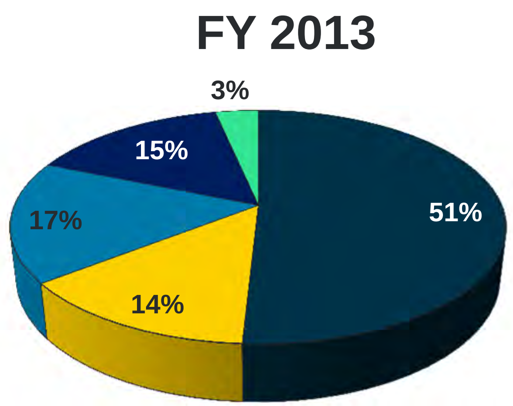

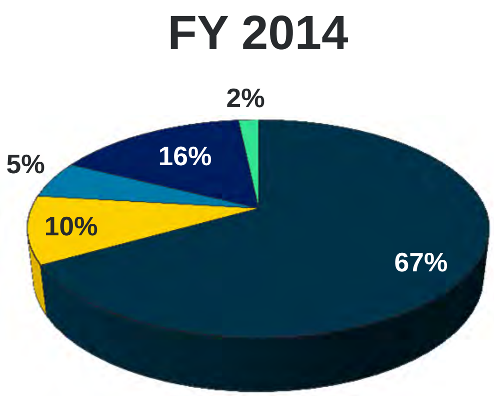

Main Elements of Computational Modeling and Analysis

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Technical Area	Key Projects/Activities
Provide design tools to optimize MHK systems	• Benchmark costs and cost reduction pathways • Wave Energy Converter Simulation • Advanced Controls Algorithms • Tidal Field measurement campaign

Priorities in FY12 and Beyond

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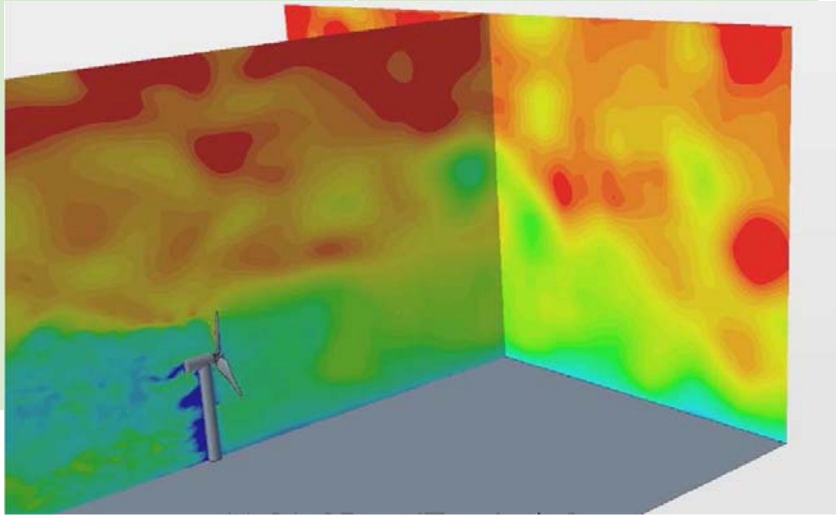
Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Key collaborators	Upcoming milestones
Provide Design Tools to Optimize MHK Systems	• Reduced effort in benchmark LCOE generation, intensified effort in LCOE actuals, and key cost reduction opportunities from industry partners • Greater incorporation of industry needs to guide development of codes • Strong focus on collaborative advancement of codes • Taper off on new Tidal code development; intensify advanced and open-source wave energy converter methods	NREL, SNL, PNNL, Industry, and Academia	• Tank Validated WEC-Sim and WEC controls algorithms • Development of extreme conditions procedure • Field Validated suite of tidal tools



Evolution of the CM&A Portfolio

2010 → 2012 → 2014 → 2020+

Analysis to Inform Investments

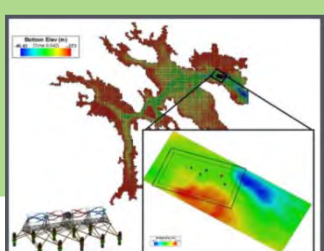
- Reference Model Development
- Developed benchmark resource data

- Identification of MHK Cost Reduction Pathways
- Published guidance for uniform reporting of LCOE

- Publish methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies
- Gather industry feedback on MHK Cost Reduction Pathways
- Collect quantitative information per the uniform cost reporting

Open Source Computational Tools

- Making design tools from Wind "MHK friendly"
- Modeling needs workshop



- International collaboration under Annex V
- Testing to Validate tidal MHK design tools in tanks and flumes
- Initial development and validation tests of Wave Energy Converter performance in the frequency domain

- Testing to validate tidal design tools through a field measurement campaign
- Testing to validate Wave Energy Converter time-domain simulation in wave tanks
- Community based numerical tool advancement
- Development of advance controls technology

- Application of high impact controls algorithms to double power production
- Use of field validated Wave and Current Energy Converter tools to optimize arrays of devices

Water Power Program Technology Transfer

Highly community / collaborative focused advancement

- Open-Source and Modular MHK Numerical Tools
- Online coding competition
- GitHub
- OpenEI

Open Data:

Standing up a data management system for MHK TD that will allow for public dissemination of data sets associated with code development and validation.

Water Power Reports

Links to technical reports and articles about the water power industry, specifically hydropower and marine and hydrokinetic energy.

Click to explore Water Power Reports:

- MHK Cost Reduction Pathway White Papers
  - Axial-Flow Turbine
  - Point Absorber
  - Attenuator
  - Floating Oscillating Water Column

Water Power Development Resources

Links to resources that should aid in the development of water power projects.

Click to explore Water Power Development Resources:

- MHK Numerical Tools:
  - The PyTurbSim tool
  - CACTUS – Code for Axial and Cross-flow Turbine Simulation

Water Power Community Forum

Provides users with a method for engaging in conversation about different water power topics of interest.
Click to be a part of the discussion

Water Power Program Questions for Peer Reviewers

- Do you see other federal R&D needs that are not currently being met?
- Do you agree with the DOE approach to pursue the advancement of codes as a collaborative community?
- Do you have suggestions for improved dissemination and collection of comments/feedback strategies from stakeholders on program products?
  - General comments on DOE's LCOE guidance
  - Feedback on our identified cost reduction pathways

Computational Modeling and Analysis Agenda Overview

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Subject Area	Time	Presenter	Topic
Computational Modeling & Analysis	2:15 PM	Vincent Neary, Sandia National Laboratories	Reference Models and Lifecycle Cost Analysis
	2:35 PM	Robert Thresher, National Renewable Energy Laboratory	
	2:50 PM	Simon Geerlofs, Pacific Northwest National Laboratory	
	3:15 PM	BREAK	
	3:35 PM	Michael Lawson, National Renewable Energy Laboratory	Wave Energy Converter Modeling Project
	3:45 PM	Kelley Ruehl, Sandia National Laboratories	
	4:05 PM	Andy LaMora, TopCoder	OpenWARP Coding Competition
	4:20 PM	Tim Crawford, Sandia National Laboratories	Advanced WEC Controls NEW
	4:35 PM	Robert Thresher, National Renewable Energy Laboratory	Tidal Device Field Measurement Campaign NEW
	4:45 PM	Marshall Richmond, Pacific Northwest National Laboratory	
	4:55 PM	Vincent Neary, Sandia National Laboratories	

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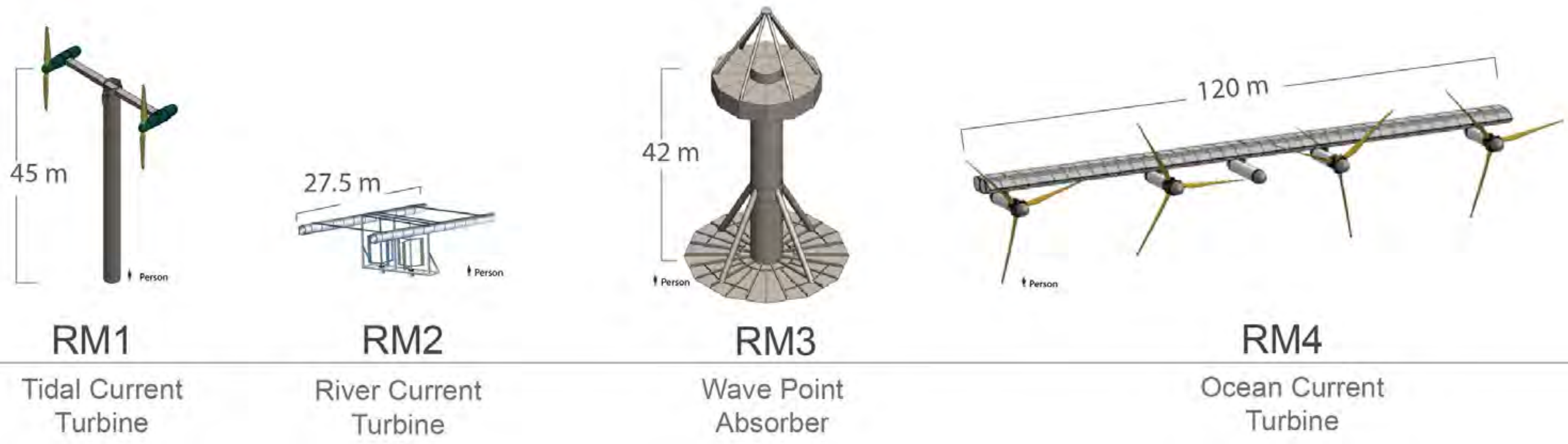

Reference Model Project and Lifecycle Cost Analysis

Vincent Neary
Sandia National Laboratories
vsneary@sandia.gov | 505 284 2199
February 24, 2014

Purpose & Objectives

Problem Statement: No non-propietary MHK devices for technical and economic evaluation.

Impact of Project:

- Methodology to evaluate technical and economic viability of MHK technologies
- Reference model (RM) point designs paired with resource sites for technical and economic assessment
  - Benchmarks for performance and costs, identifying key technical hurdles and cost drivers needing more focused study
  - Physical model data sets to document validation of open source design tools

This project aligns with the following DOE Program objectives and priorities:

Advance the state of MHK technology

Technical Approach

- Device point designs simple and robust (no cutting-edge innovation, TRL 3-4)
- Considered power and structural performance, power conversion chain (PCC) design, anchoring and mooring design, manufacturing and deployment, O&M, environmental compliance and costs
- Applied cost reduction curves to estimate levelized cost of energy (LCOE) for multiple-unit commercial scale array deployments

Point designs simple, robust and thorough

Accomplishments and Progress

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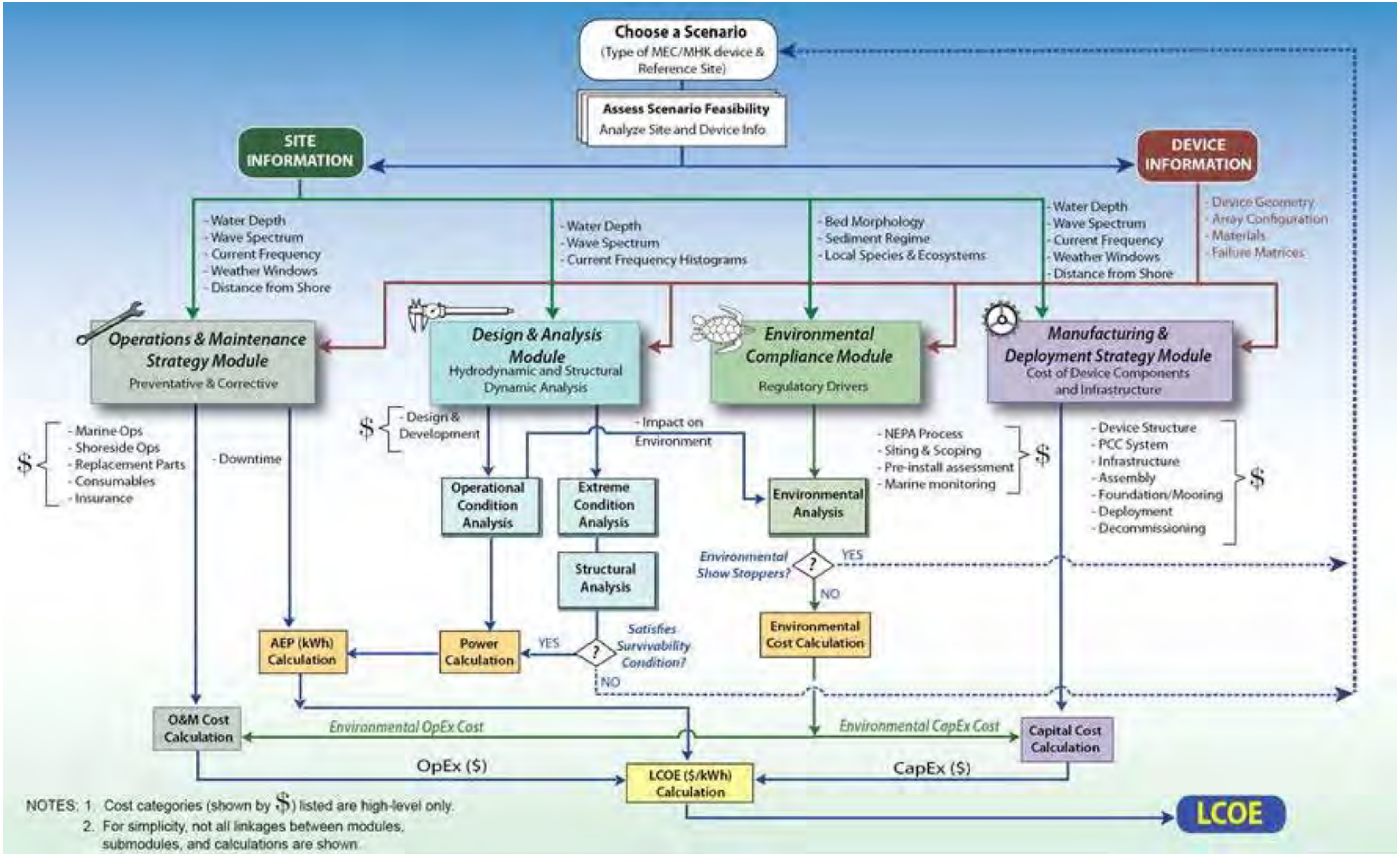

Open-source methodology for design, analysis, and LCOE estimation

Accomplishments and Progress

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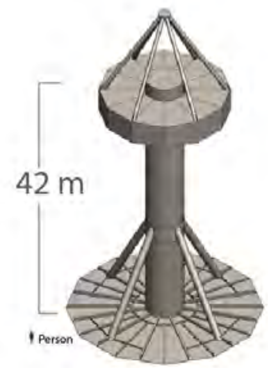
RM1

Tidal Current Turbine

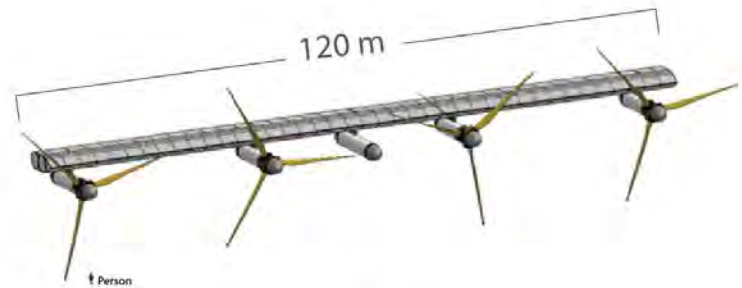
RM2

River Current Turbine



RM3

Wave Point Absorber



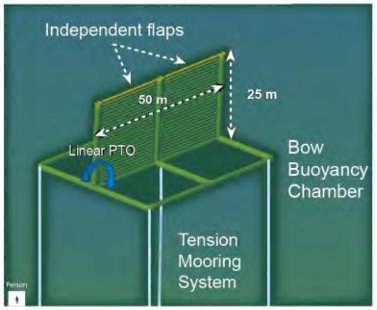
RM4

Ocean Current Turbine

Open source reference point designs paired with marine energy resource sites provide nonproprietary study objects for MHK R&D

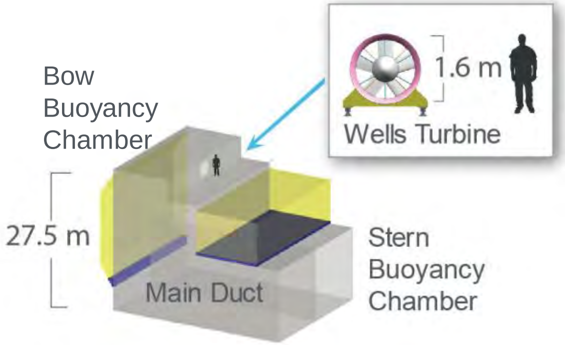
RM1, RM2, RM4 leveraged DOE wind research

No institutional knowledge to leverage for RM3, RM5, RM6



RM5

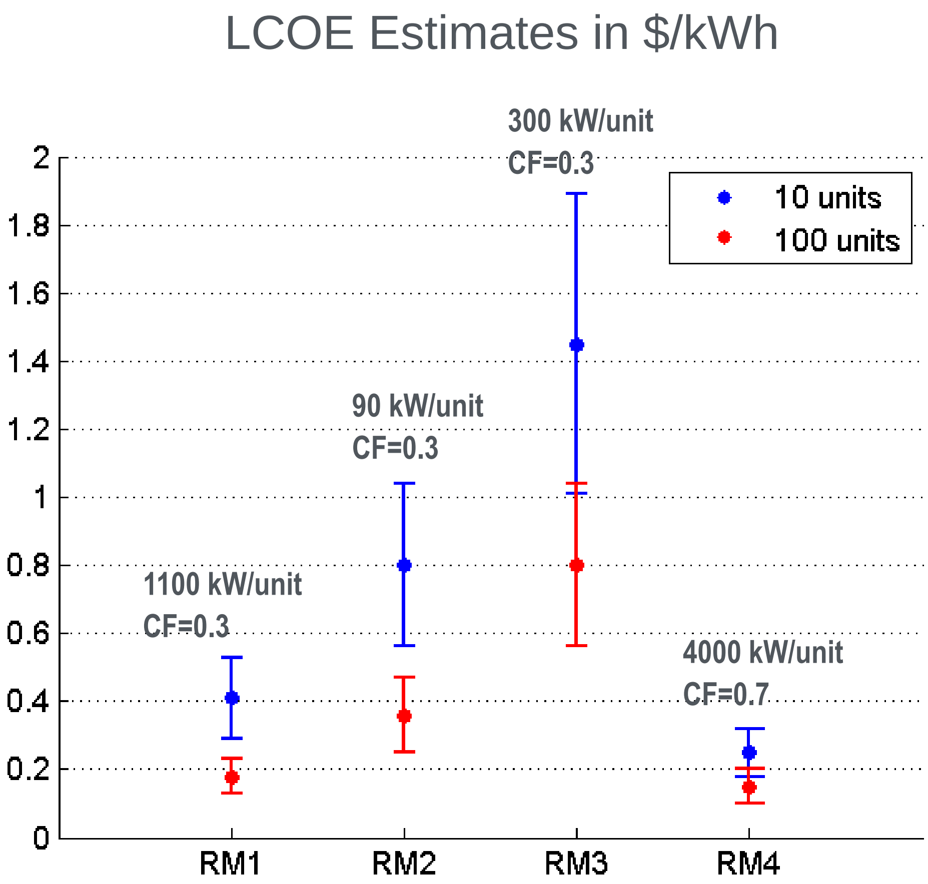
Surge Pitch Wave Energy Converter



RM6

Backward Bent Duct Buoy (BBDB)

Accomplishments and Progress



LCOE sensitive to installed capacity and capacity factor (CF)

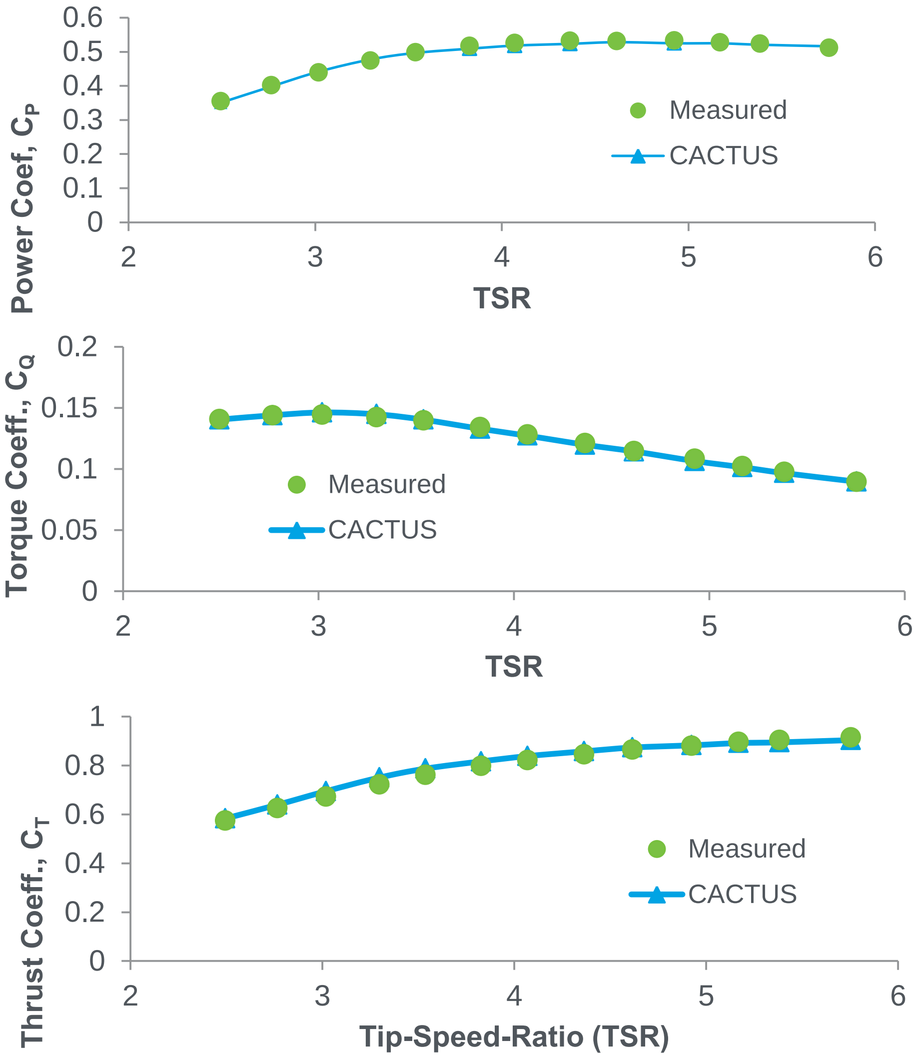
Significant LCOE reductions with project size

Power conversion chain (PCC) and structural components highest cost drivers all RMs

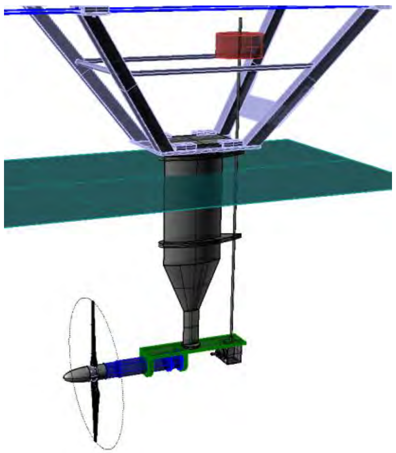
Mooring system and deployment costs for RM3 significant

Advanced controls critical for improving RM3 point absorber energy capture

Benchmarked LCOE, cost drivers and needs for technological innovation



Physical model data sets to document validation of open source design tools



Setup for the scaled RM1 tested at US Naval Academy (Luznik et al. 2012)

CACTUS web site (http://energy.sandia.gov/cactus)

Open-source design tools leveraged from wind can be used with confidence

RM2: river current turbine

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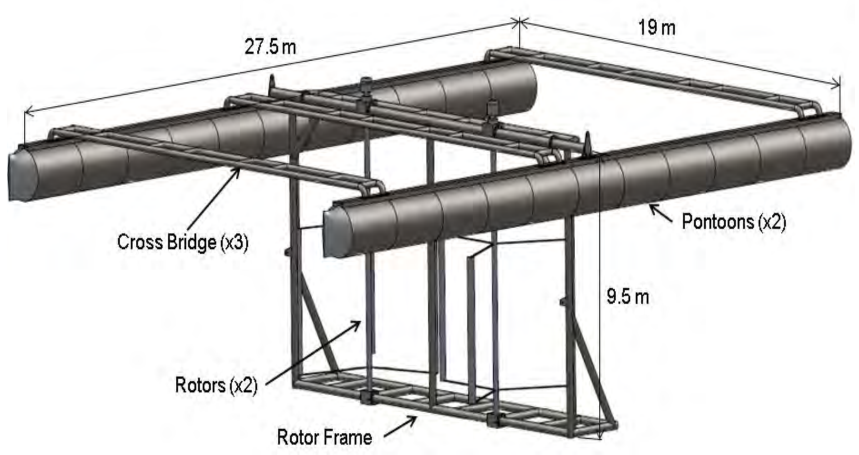
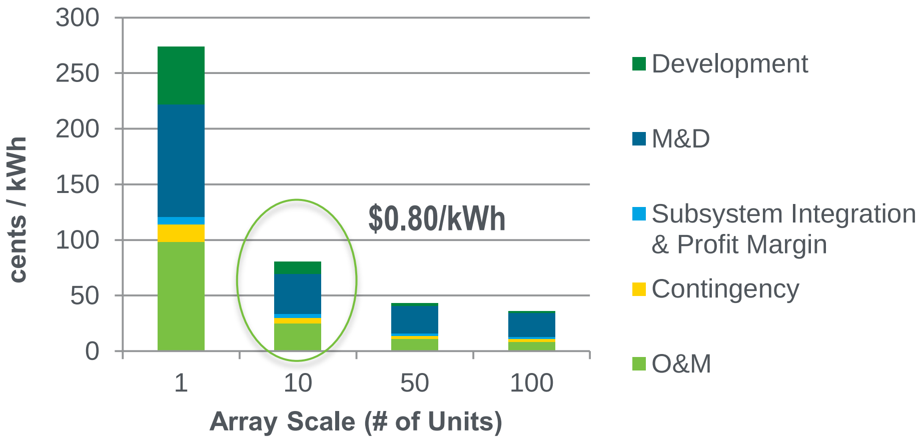
Power rating	100 kW (2x50 kW rotors)
Deployment location	Baton Rouge, LA
Rotor diameter	6.5 m
Capacity factor	0.3
Rotor power coefficient	0.38
Rotor type	Variable speed
Operational flow speeds	0.7 m/s – 2.6 m/s



LCOE estimates (100 kW/unit)



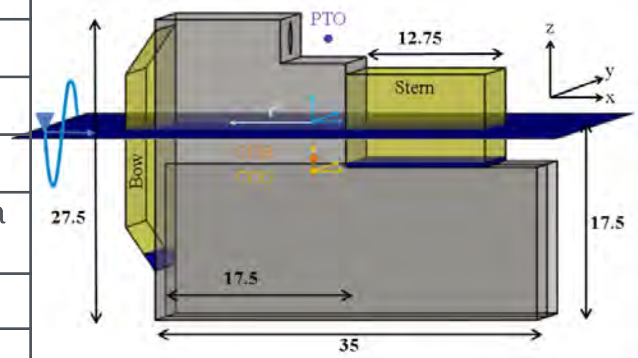
LCOE breakdown (10-unit array)

	cents/kWh	% of total LCOE
Development	11.0	13.7%
M&D	36.3	45.2%
Subsystem Integration & Profit Margin	3.0	3.7%
Contingency	5.0	6.3%
O&M	25.0	31.1%
Total	80.3	100.0%

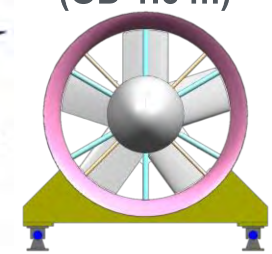
Detailed design geometries, performance specifications and cost breakdowns

RM6: Backward Bent Duct Buoy WEC (in progress)

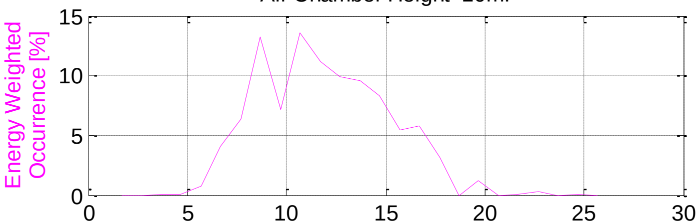
Description	Specification
Deployment depth	50 - 100 m
Mooring system	Spread Catenary (3 lines)
Absorbed Power (AAP)	208 kW
Power Conversion Chain	Fixed Pitch Wells Turbine coupled to a Variable Frequency Drive Generator
Delivered Power (AAP)	103 kW
Power Rating	373 kW
Array configuration	staggered



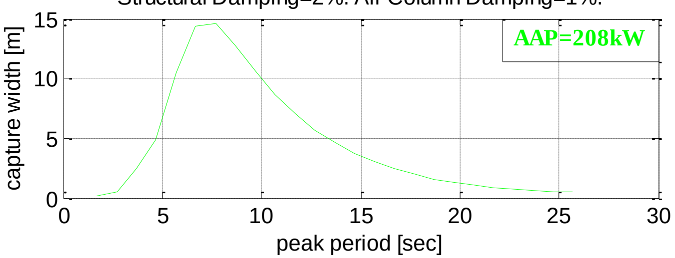
Wells Turbine Design (OD 1.6 m)

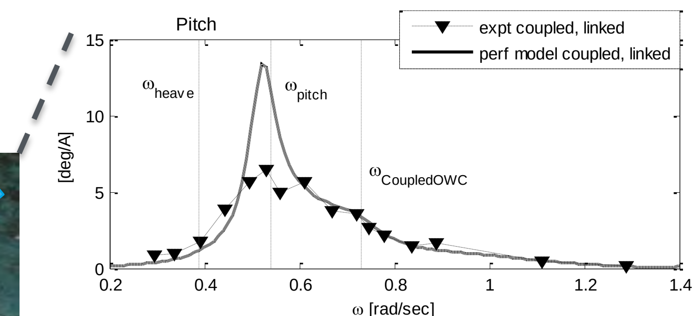


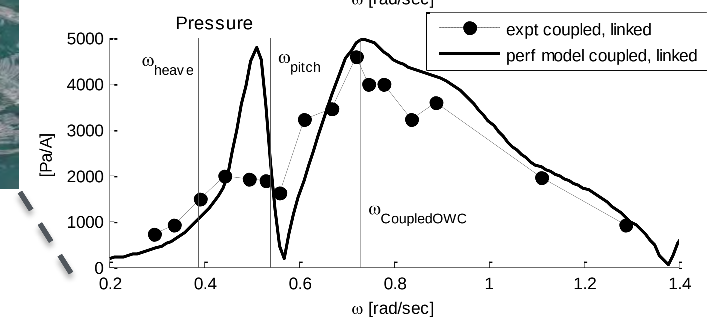
Comparing climate characteristics with capture characteristics of device.
Air Chamber Height=10m.



Structural Damping=2%. Air Column Damping=1%.







7 DOF model, experimentally validated, PCC optimization, sea state specific efficiency assessment

Project Plan & Schedule:

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Summary	
WBS Number or Agreement Number: 1.2.5 - 21373	1.1 (FY12) | 1.1.5 (FY13) | 1.2.3.1
Project Number: 1.2.5	
Agreement Number: 21373	21959

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Technical Support of Marine & Hydrokinetic Technology Industry Solicitation												
FY12Q1 Team meeting to select preliminary concept designs for RM4-6												
FY12Q2 Team meeting to finalize concept designs RM5-6												
FY12Q3 Draft report for RM4, 5 and 6 concept designs												
FY12Q4 Revise RM1 and RM2 reports												
FY13Q1 Report on RM3 point absorber												
FY13Q2 Reference model meeting												
FY13Q3 Submit RM1-4 report for review by DOE												
FY13Q4 Complete RM6 report												
Current work and future research												
FY14Q1 Verify RM6 performance model for selected device with HMRC test data												
FY14Q1 Launch RMP web site												
FY14Q2 Perform QA/QC on SAFL RM1 and RM2 sub-scale model tests												
FY14Q3 Complete HMRC and SAFL reports on scaled model experiments												
FY14Q3 Complete draft RM6 report												
FY14Q4 Submit final NREL RM5 report												
FY14Q4 Submit final RM6 report												

Comments

- Reference model project FY10 to FY14
- Ambitious project with over a dozen collaborators, challenges designing WEC reference models, estimating costs when no operational experience and delays at test facilities
- SNL staff redirected to other DOE priorities adversely affecting original schedules
- Changing collaborator roles delayed coordination in project completion

Ambitious project with multiple challenges & scheduling bottlenecks

Project Budget

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Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,826,000 $2,163,258 (with C/O)	n/a	$655,000 $1,291,666 (with C/O)	n/a	$0 $263,078 (C/O)	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$1,526,591	$753,588	$263,078

Approximately $700k funding annually over four years

Spending on track to complete RMP dissemination and RM6 design

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- **Sandia National Laboratories:** project lead, RM 2 and 6 lead
- **National Renewable Energy Laboratory:** RM 1, 3, 4 and 5 lead
- **Pacific Northwest National Laboratory:** environmental lead
- **Re Vision:** RM 1-4 economic analysis and design assistance
- **Penn State ARL:** RM 1, 2, 4, and 6 power-conversion-chain design and analysis
- **Oregon State University:** RM 3 power-conversion-chain design and analysis
- **SAFL**: RM 1 & 2 experimental testing
- **HMRC UCC**: RM 6 experimental testing

Communications and Technology Transfer:

- OpenEI link to SNL's Water Power Program RMP web site (http://energy.sandia.gov/rmp) RM project report, supplementary reports, SolidWorks geometry files, and experimental model validation data files
- CACTUS web site (http://energy.sandia.gov/cactus)
- Journal articles
- Conference publications and presentations

Communications and Technology Transfer (Continued):

Journal Articles

- Neary, V. S., B. Gunawan, and D.C. Sale. (2013). Turbulent inflow characteristics for hydrokinetic energy conversion in rivers. *Renewable and Sustainable Energy Reviews*, 26, 437-445.
- Neary, V. S., B. Gunawan, C. Hill, and L.P. Chamorro. (2013). Near and far field flow disturbances induced by model hydrokinetic turbine: ADV and ADP comparison. *Renewable Energy*. 60 (2013). 1-6.

Conference Proceedings

- Neary, V.S., Fontaine A.A. , Bachant P., Gunawan B., Wosnik M., Michelen C., Meyers R.J. and B. Straka (2013). US Department of Energy National Lab Activities in Marine Hydrokinetics: Scaled Model Testing of DOE Reference Turbines. *10th European Wave and Tidal Energy Conference*, Aalborg, Denmark, September 2-5, 2013.
- D. Bull and P. Jacob (2012), Methodology for creating nonaxisymmetric WECs to screen mooring designs using a Morison Equation approach, in *OCEANS '12.* Hampton Roads, VA, pp. 1 –9.
- D. Bull and E. Johnson (2013), Optimal Resistive Control Strategy for a Floating OWC Device, *11th EWTEC*, Aalborg, Denmark
- Fontaine et al. (2014), Optimization and Annual Average Power Predictions of a Backward Bent Duct Buoy Oscillating Water Column Device using the Wells Turbine, *Marine Energy Technology Symposium,* Seattle, Washington, April 15-18, 2014

Technical Reports

- Neary et al. (2014), Methodology for design and economic analysis of marine energy conversion (MEC) technologies, SAND2014-TBD.
- Barone M., Griffith T., Berg J. (2011), Reference Model 2: "Rev 0" rotor design. SAND2011-9306.
- Berg J.C. (2011), Extreme ocean wave conditions for northern California wave energy conversion device. SAND2011-9304.
- Neary, V. S. (2011). Reference inflow characterization for river resource reference model (RM2). ORNL/TM-2011/360.
- Neary, V.S., L.P. Chamorro, C. Hill, and B. Gunawan. (2012). Experimental test plan – DOE tidal and river reference turbines. ORNL/TM-2012/301.

Next Steps and Future Research

SNL FY14/Current research:

- Finalize RMP report for RM1-4
- Experimental verification of RM1 & RM2 at SAFL
- Complete RM6 model validation
- Complete RM6 design, economic analysis and final report

Proposed future research: No official work after FY14, but anticipate continued efforts maintaining SNL's RMP web site (http://energy.sandia.gov/rmp) as data clearing house for researchers and developers and open source design tools, e.g., CACTUS web site (http://energy.sandia.gov/cactus)

Water Power Peer Review

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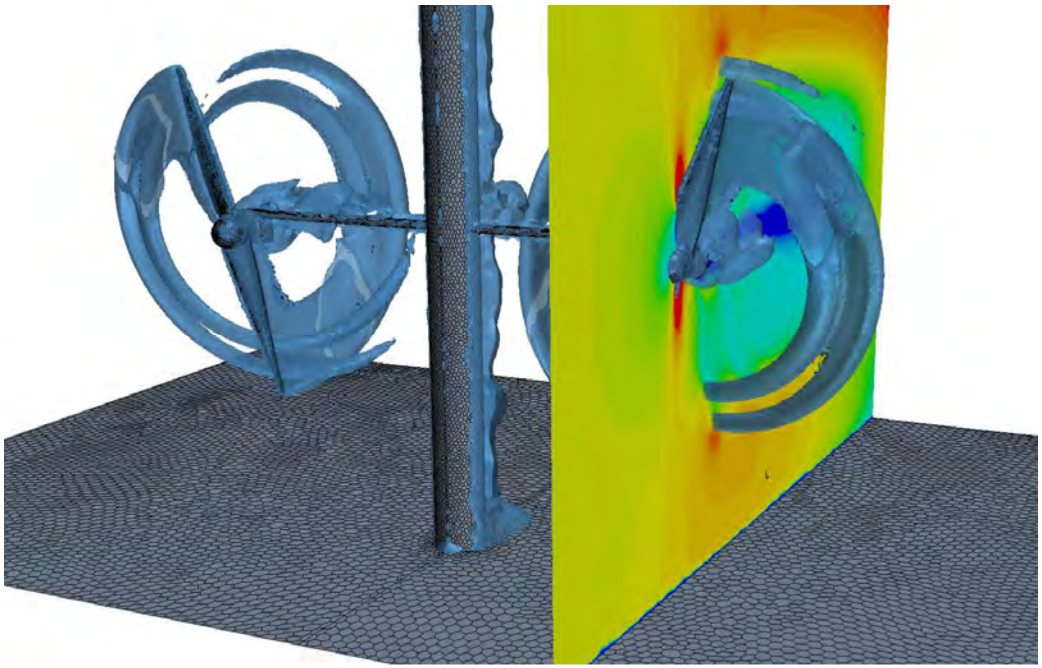

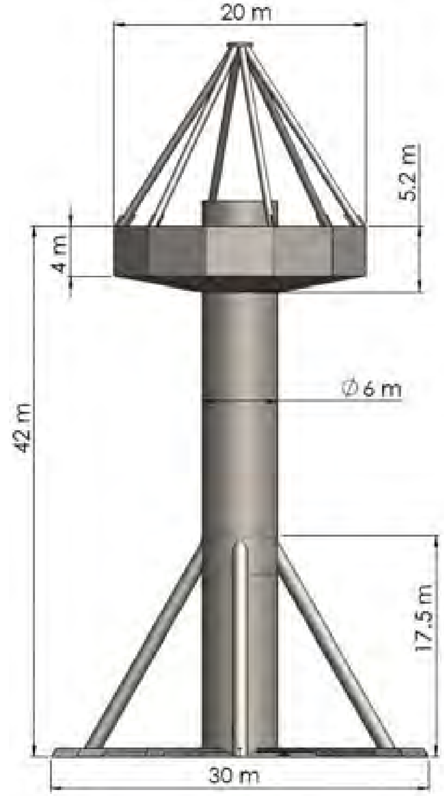

Reference Model Project and Lifecycle Cost Analysis

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NREL Research Fellow

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February 24, 2014

Purpose and Objectives

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Problem statement: A standard methodology is needed to evaluate the technical and economic viability of MHK technologies. To meet this need, the DOE Reference Model (RM) team developed a standardized device design and cost of energy estimation methodology and demonstrated its use by designing and analyzing 3 wave energy devices and 3 water current energy devices.

From FY12-FY14, NREL's role was the following on the various efforts:

- RM 1: Tidal current turbine – Design lead
- RM 3: Point absorber WEC – Design lead
- RM 4: Ocean current turbine – Design lead
- RM 5: Surge-pitch WEC – Design lead and LCOE analysis
- RM 6: OWC – LCOE analysis
- ReEDS modeling support for ReVision's wave energy lifecycle deployment study.

Purpose and Objectives

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Impact of project:

- Developed marine energy converter (MEC) reference resource sites representative of actual tidal, river, ocean current energy, and wave energy sites, thus enabling industry and the R&D community to benchmark new MEC designs and concepts using a standardized methodology
- Identifies key technical hurdles and cost-drivers needing more focused study
- Provides open-source reference technologies that researchers can use for physical model experiments to understand technologies and collect measurements for model validation

This project aligns with the following DOE Program objectives: To advance the state of MHK technology.

Technical Approach – Design Flowchart

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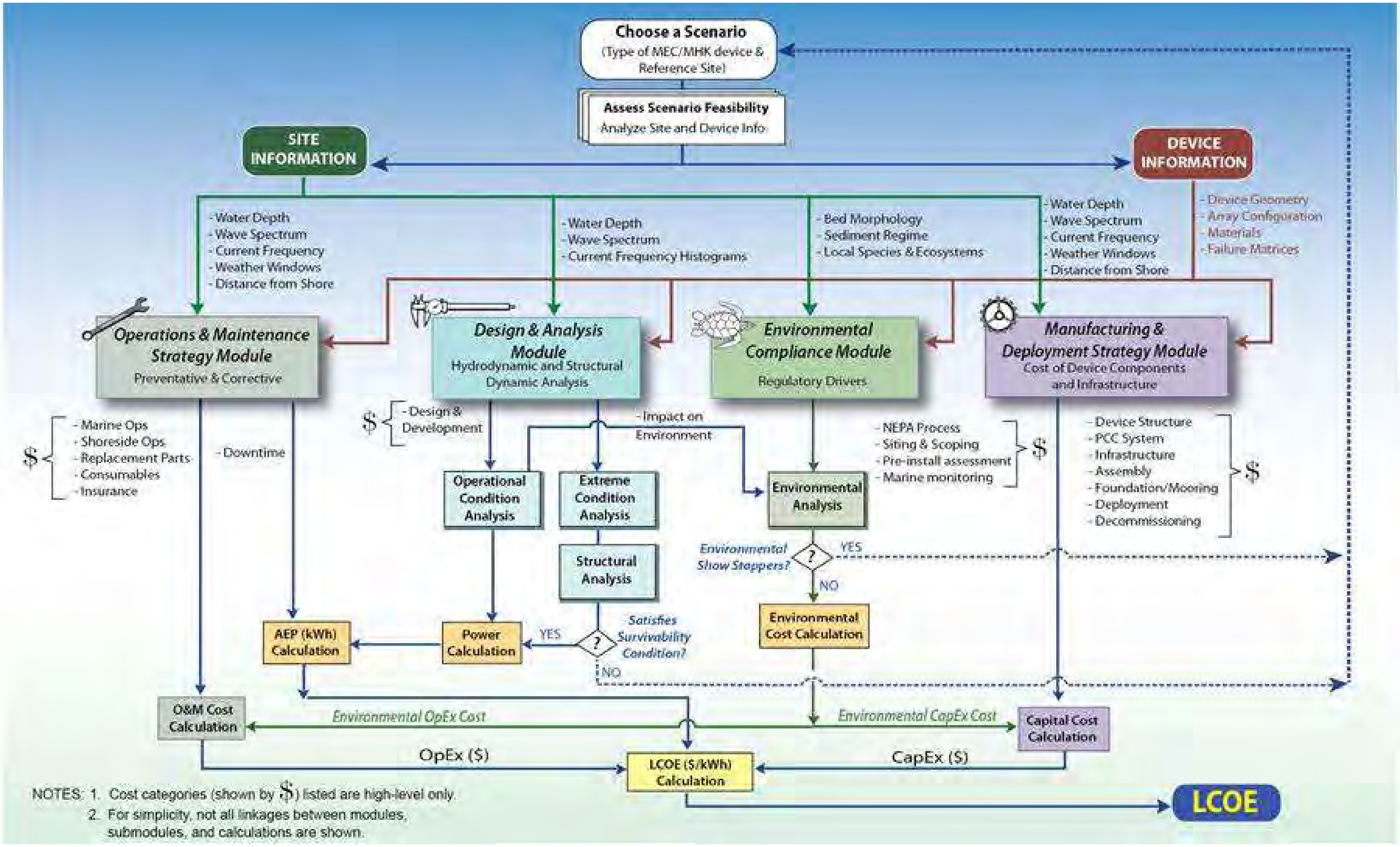

Figure 1. Flowchart showing the RM design methodology. High resolution version available at goo.gl/ZCpsli

Accomplishments and Progress

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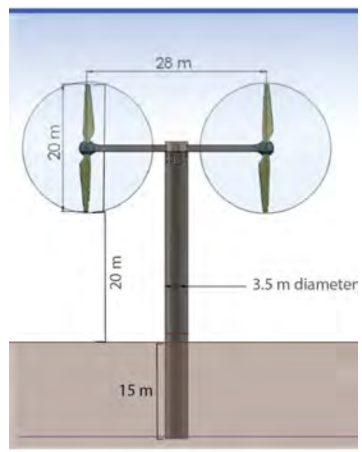
NREL led and completed the design and analysis of four RM devices:

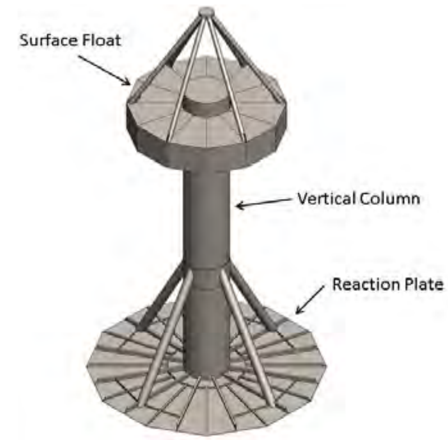
- RM1: Tidal current turbine (completed)
- RM3: Point absorber WEC (FY12-13)
- RM4: Ocean current turbine (FY12-13)
- RM5: Surge-pitch WEC (FY13-14).

NREL worked with SNL and PNNL to develop the RM design and economic analysis methodology.

RM1

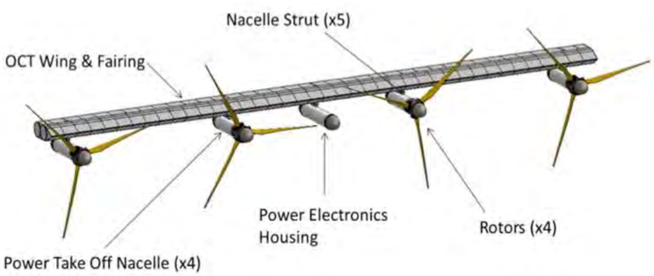


RM3

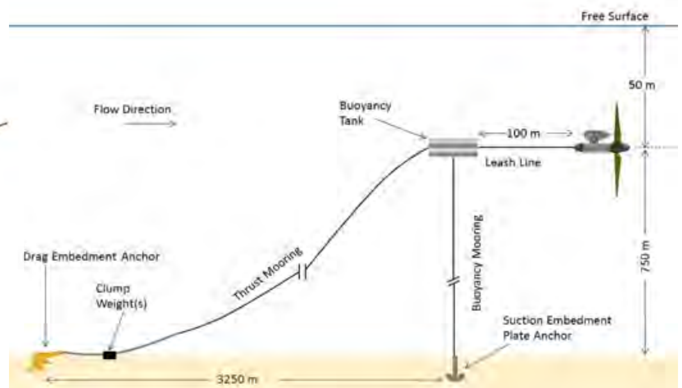


RM4

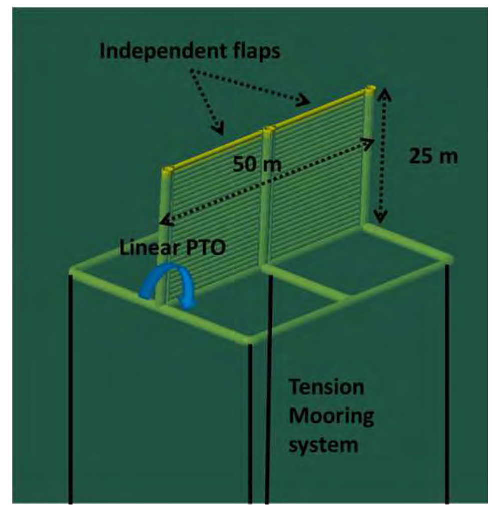
RM4 – isometric view



RM4 – side view



RM5



RM1: Tidal Current Turbine

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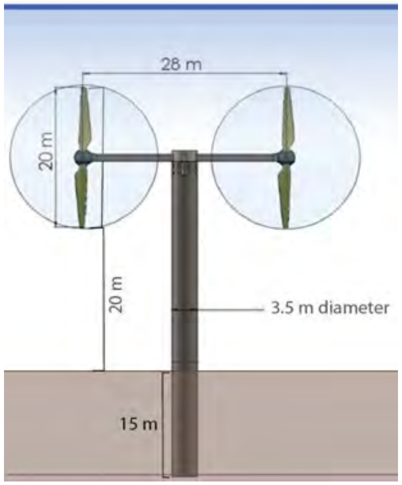
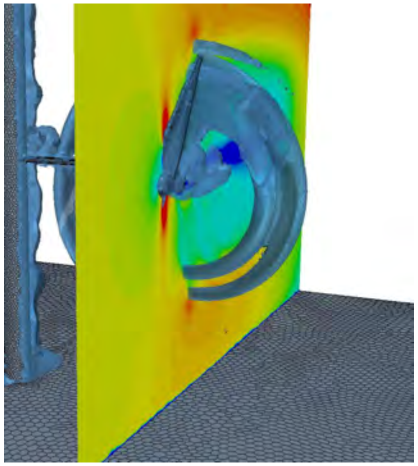
Power rating	1.1 MW (2x550 kW rotors)
Deployment location	Puget Sound, WA
Rotor diameter	20 m
Capacity factor	0.3
Rotor power coefficient	0.48
Rotor type	Variable speed, variable pitch
Operational flow speeds	0.5 m/s – 3 m/s

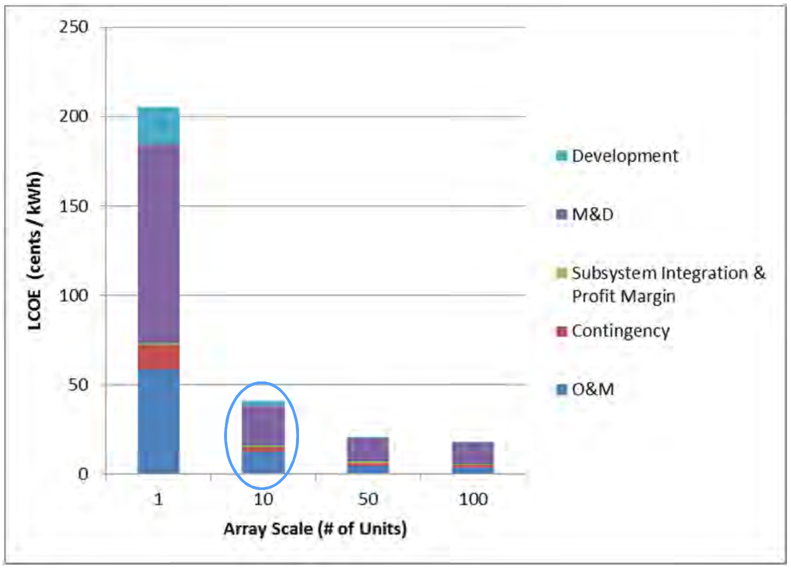
Device schematic



CFD analysis



LCOE estimates

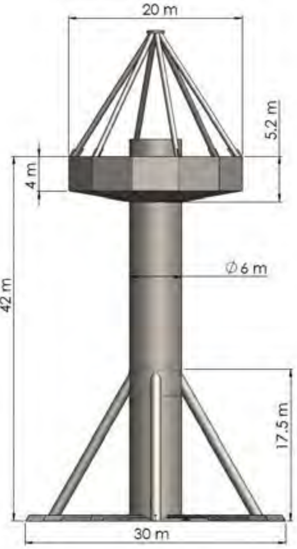


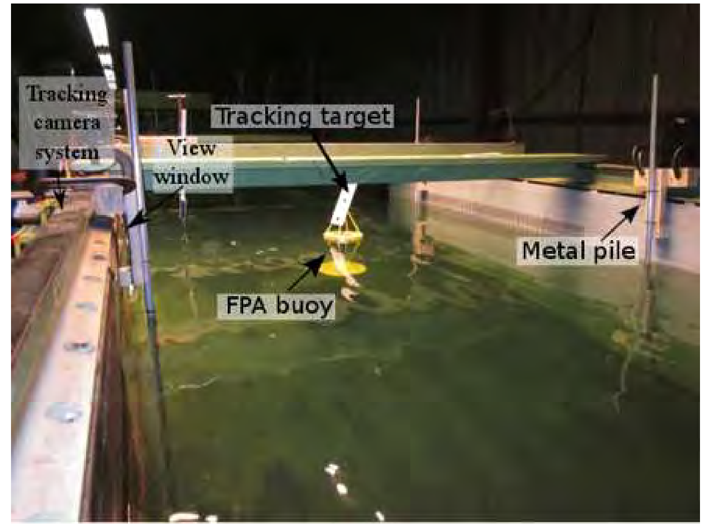
Cost breakdown for 10 units deployed

	cents / kWh	% of total LCOE
Development	3.1	7.7%
M&D	21.7	53.3%
Subsystem Integration & Profit Margin	1.1	2.6%
Contingency	2.6	6.4%
O&M	12.2	30.0%
Total	**40.7**	100.0%

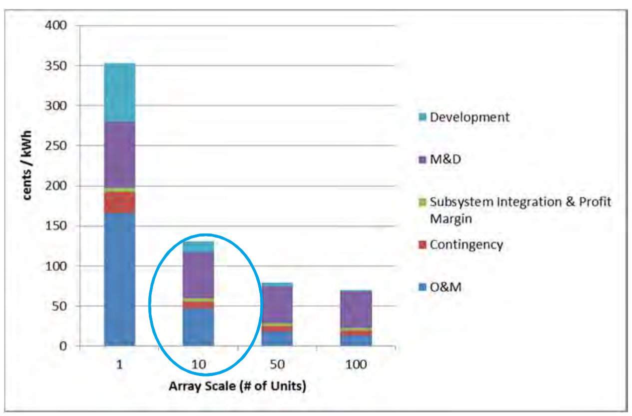
RM3: Two-body Point Absorber WEC

Description	Specification
Deployment depth	40 - 100 m
Mooring system	3-mooring line design
Rated power	286 kW (max power)
Float diameter	20 m
Operational sea states	Peak period = 5sec~18sec Sig. wave height = 0.75m~6m
Array configuration	Staggered with 30 float diameter separation





LCOE estimates



Cost breakdown for 10 units deployed

	cents/ kWh	% of total LCOE
Development	14.1	9.7%
M&D	71.1	49.0%
Subsystem Integration & Profit Margin	4.1	2.8%
Contingency	8.9	6.1%
O&M	47.0	32.4%
Total	**145.3**	100.0%

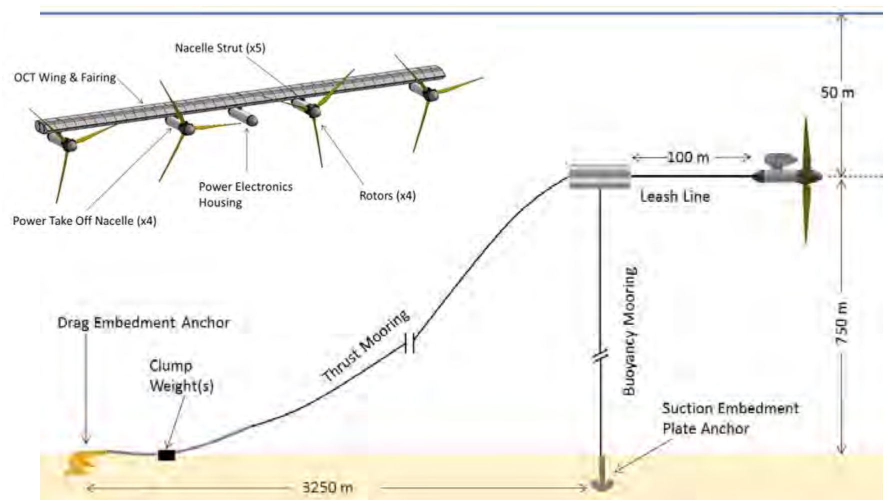
Power produced in operational sea states

Electrical Power Matrix

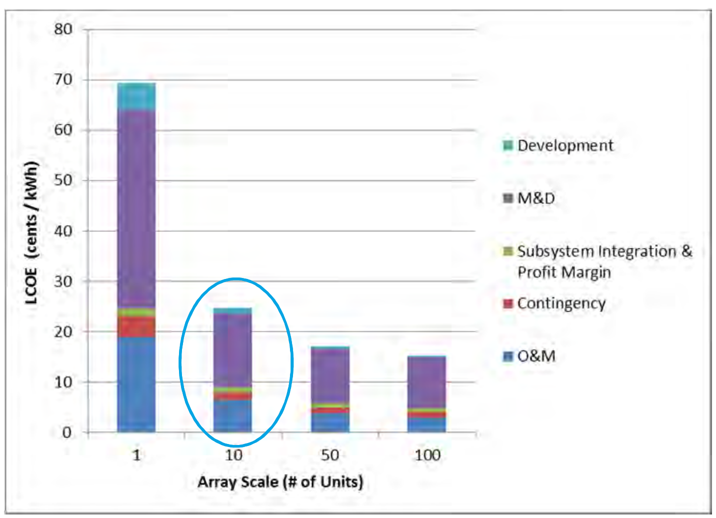
Hs \ Te	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5
0.25	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
0.75	3	5	7	9	10	10	9	7	6	5	4	3	3	2	2	2
1.25	9	15	20	25	27	26	23	20	17	14	11	9	8	6	5	4
1.75	18	29	40	48	52	50	45	38	32	27	22	18	15	12	10	8
2.25	29	48	65	79	84	81	72	62	52	43	35	29	24	20	16	14
2.75	43	71	97	116	123	118	106	91	77	63	52	43	35	29	24	20
3.25	60	98	134	161	169	162	145	125	105	87	71	59	48	40	33	28
3.75	80	130	178	211	222	212	190	164	138	114	94	77	63	52	44	37
4.25	102	167	227	268	281	268	241	207	174	144	119	97	80	67	55	47
4.75	128	207	281	286	286	286	286	255	214	178	146	120	99	82	69	58
5.25	155	252	286	286	286	286	286	286	258	214	176	145	120	99	83	70
5.75	186	286	286	286	286	286	286	286	286	254	209	172	142	118	99	83
6.25	219	286	286	286	286	286	286	286	286	286	244	201	166	138	115	97
6.75	255	286	286	286	286	286	286	286	286	286	282	232	192	160	134	112
7.25	286	286	286	286	286	286	286	286	286	286	286	266	220	183	153	129
7.75	286	286	286	286	286	286	286	286	286	286	286	286	249	207	173	146
8.25	286	286	286	286	286	286	286	286	286	286	286	286	280	233	195	164
8.75	286	286	286	286	286	286	286	286	286	286	286	286	286	260	218	184
9.25	286	286	286	286	286	286	286	286	286	286	286	286	286	286	242	204
9.75	286	286	286	286	286	286	286	286	286	286	286	286	286	286	267	226

RM4: Ocean Current Turbine

Power rating	4 MW (4x1 MW)
Deployment location	Miami, FL
Rotor diameter	33 m
Capacity factor	>0.7
Rotor power coefficient	0.48
Rotor type	Variable speed, variable pitch
Operational speeds	0.5 m/s – 3 m/s



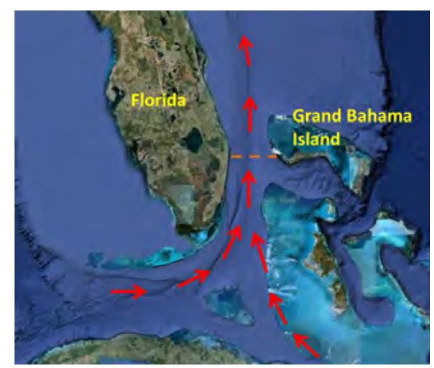
LCOE estimates



Cost breakdown for 10 units deployed

	cents/ kWh	% of total LCOE
Development	1.1	4.4%
M&D	14.6	59.2%
Subsystem Integration & Profit Margin	1.0	4.2%
Contingency	1.6	6.3%
O&M	6.4	25.9%
Total	**24.7**	100.0%

Deployment location



RM5: Surge-pitch WEC (in progress)

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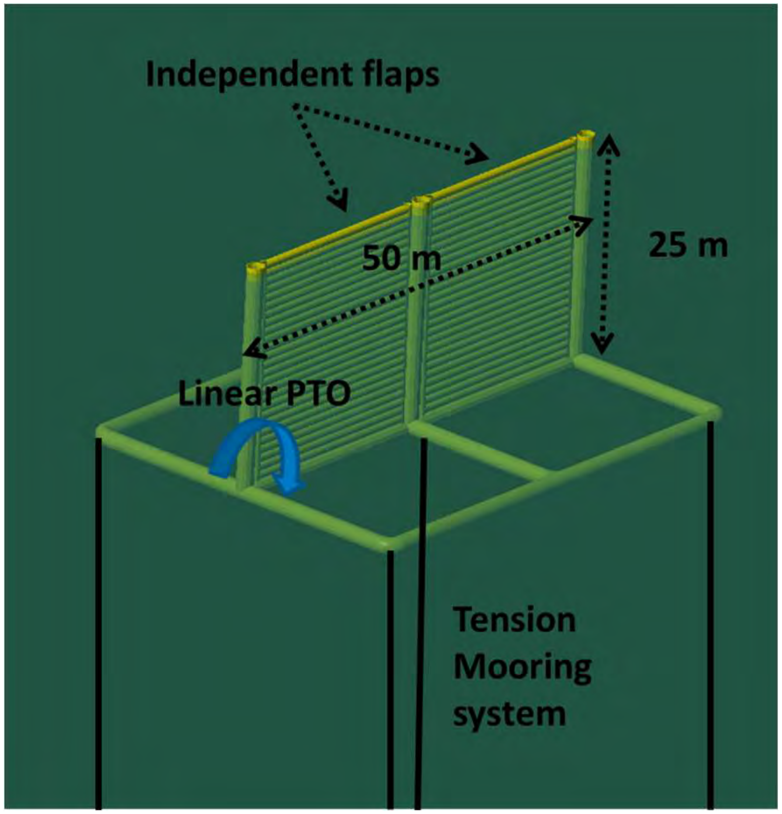
Description	Specification
Deployment depth	50 - 100 m
Mooring system	Tension leg
Rated power	TBD
Operational sea states	Peak period = 5sec~18sec Sig. wave height = 0.75m~6m
Array configuration	Can be deployed close together due to limited watch circle with tension leg mooring design

Power produced in operational sea states

Hs (kW)	Tp (sec) 5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.1
0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7	0.5	0.4	0.3	0.3	0.2
0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9	4.6	3.6	2.9	2.3	1.9
1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5	12.7	10.1	8.1	6.4	5.3
1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3	24.9	19.7	15.8	12.6	10.4
2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4	41.1	32.6	26.1	20.8	17.1
2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7	61.4	48.8	39.0	31.0	25.6
3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4	85.8	68.1	54.5	43.3	35.8
3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3	114.2	90.7	72.6	57.7	47.6
4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5	146.7	116.5	93.3	74.1	61.2
4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0	183.3	145.5	116.5	92.6	76.5
5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7	223.9	177.8	142.4	113.1	93.4

Preliminary design concept



Project Plan and Schedule:

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

Summary		Legend
WBS Number or Agreement Number 1.1.3.1		Work completed
Project Number		Active Task
Agreement Number 21372		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Reference Models and LCOE Analysis												
Q1 Milestone: Complete analaysis of data for Reference Model 3												
Q2 Milestone: Complete tools setup and test runs for Reference Models 4 and 5												
Q3 Milestone: Complete basic device design & analysis runs for simulating Ref Model 4												
Q4 Milestone: Participate in planning discussion on future Reference Models												
Q1 Milestone: Complete preliminary (TRL2) design of Ref Model surge device												
Q2 Milestone: Complete TRL3 design of Ref Model Surge Device												
Q3 Milestone: Update estimates of power generation performance for refined RM5												
Q4: Submit a draft report on the design and numerical modeling of surge device												
Q1: Submit vessel and mooring cost data summary spreadsheet												
Current work and future research												
Q2: Draft report describing methodology and results of Ref Model 6 LCOE analysis												
Q3: Draft Ref Model 5 report including design & performance analysis and baseline LCOE												
Q4: Document experimental data collected for RM3 project												

Project Budget

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$608k	n/a	$823k	n/a	$304k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$500K	$519K	$304k

- FY13 spending was lower than expected due to work on other DOE priorities
- FY14 project costs as of December 31st: $69k.

Research Integration and Collaboration

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

Partners, Subcontractors, and Collaborators:

- SNL: Overall RM project leader, RM 2 and 6 design leader
- NREL: Design leader RM 1, 3, 4 and 5 and cost estimation for RM 5 & 6, also ReEDS modeling support for ReVision's study entitled "The Future Potential of Wave Power in the United States"
- Pacific Northwest National Laboratory: Environmental evaluation and cost leader for all RM's
- ReVision: Economic analysis, design review, and structural design support RM 1 through 4
- Penn State ARL: Power-take-off design and analysis RM 1,2,4, and 6
- Oregon State University: Power-take-off design and analysis RM 3.

Communications and Technology Transfer:

- Comprehensive report and relevant data files are to be posted on the SNL RM website - http://energy.sandia.gov/?page_id=16798 and the OpenEI portal
- Two journal publications
- Conference publications and presentations as completed.

Communications and Technology Transfer (Continued):

Lawson, Mi. J.; Li, Y.; Sale, D. C. (2011). Development and Verification of a Computational Fluid Dynamics Model of a Horizontal-Axis Tidal Current Turbine. Paper No. OMAE2011-49863. ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2011), 19-24 June 2011, Rotterdam, The Netherlands. Volume 5: Ocean Space Utilization; Ocean Renewable Energy. New York, NY: American Society of Mechanical Engineers (ASME) pp. 711-720; NREL Report No. CP-5000-54326.http://dx.doi.org/10.1115/omae2011-49863

Bir, G. S.; Lawson, M. J.; Li, Y. (2011). Structural Design of a Horizontal-Axis Tidal Current Turbine Composite Blade. Paper No. OMAE2011-50063. ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2011), 19-24 June 2011, Rotterdam, The Netherlands. Volume 5: Ocean Space Utilization; Ocean Renewable Energy. New York, NY: American Society of Mechanical Engineers (ASME) pp. 797-808; NREL Report No. CP-5000-54299. http://dx.doi.org/10.1115/OMAE2011-50063

Yu, Y. H.; Li, Y. (2013). Reynolds-Averaged Navier-Stokes Simulation of the Heave Performance of a Two-Body Floating-Point Absorber Wave Energy System. Computers and Fluids. Vol. 73, 15 March 2013; pp. 104-114; NREL Report No. JA-5000-56139. http://dx.doi.org/10.1016/j.compfluid.2012.10.007

Yu, Y. H.; Li, Y. (2011). RANS Simulation of the Heave Response of a Two-Body Floating-Point Wave Absorber. Proceedings of the Twenty-First International Offshore and Polar Engineering Conference (ISOPE-2011), 19-24 June 2011, Maui, Hawaii. Cupertino, CA: International Society of Offshore and Polar Engineers pp. 565-571; NREL Report No. CP-5000-52959.

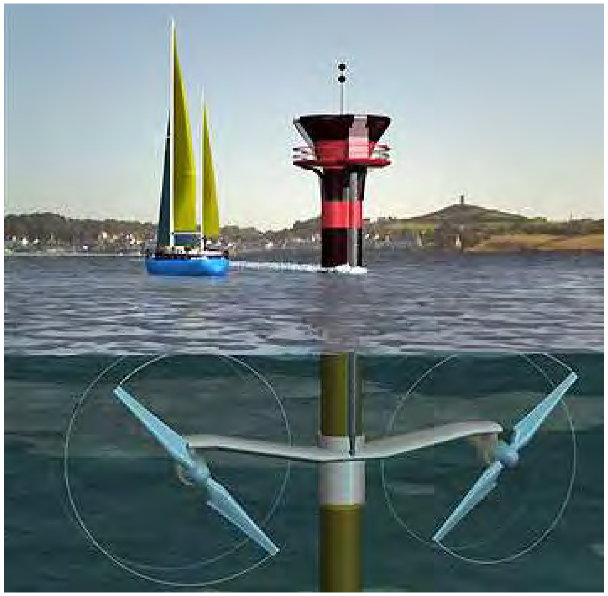
Next Steps and Future Research

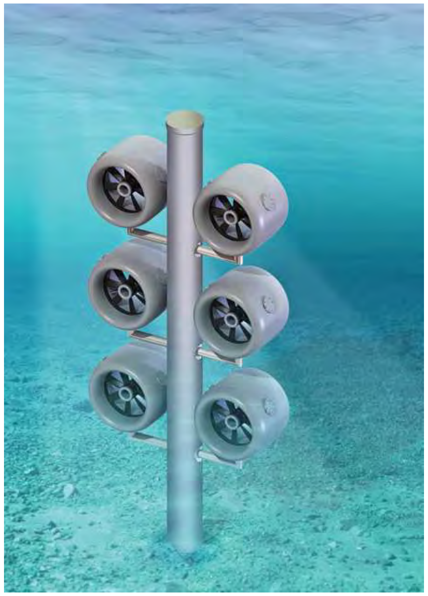
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

NREL FY14/current research:

- Complete report chapters for RM 1, 3, and 4
- Support SNL with review and integrated RM 1 – 4 report chapters
- Contribute to the final writing of the RM design and economic analysis methodology chapter
- Complete RM 5 design, economic analysis, and final report
- Complete economic analysis of RM 6.

Proposed future research: No research is planned on this project beyond FY14.





Reference Model

Technology Development

Andrea Copping

Pacific Northwest National Laboratory
andrea.copping@pnnl.gov (206) 528 3049
February 24 2014

Purpose & Objectives

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

Problem Statement:

- MHK development hindered by concerns about LCOE and uncertainties around environmental siting and permitting
- Need to understand contribution to LCOE from environmental requirements
- Need pathways for efficient environmental siting and permitting

Impact of Project:

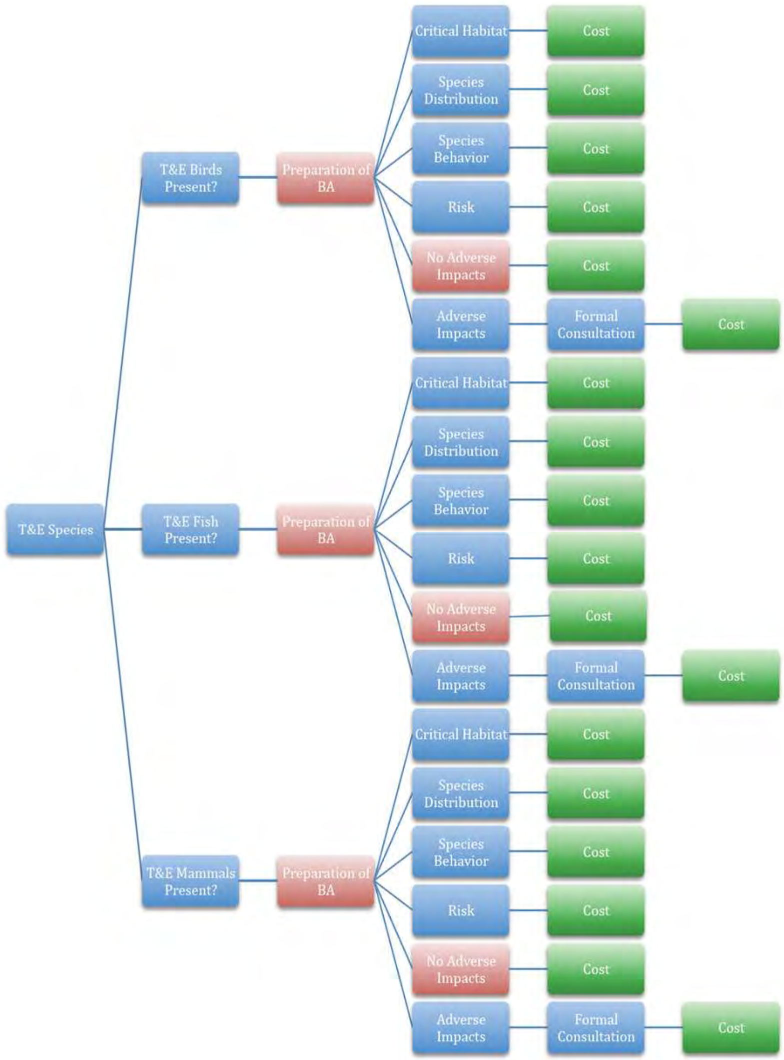
- Understand the contribution to LCOE from baseline assessments, post-installation monitoring, project documentation (NEPA and more)
- Determine efficient and effective pathways to gather environmental information that meet regulatory needs
- Share pathways with regulators and developers to accelerate siting and permitting processes

This project aligns with the following DOE Program objectives and priorities Advance the state of MHK technology *and* Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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

- **Define stressor/receptor relationships:** Environmental pathways and costing dependent on definition of each RM by RM engineering teams. Draft environmental work verified after final design and deployment plans completed by RM engineering teams.
- **Study needs driven by regulatory requirements:** The regulatory requirements for each type of RM, including location and potential aquatic animals and plants at risk was determined.



Technical Approach

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

- **Define types of studies that are likely:** Costs binned into three permitting phases:1) siting and scoping; 2) baseline (pre-installation) studies; and 3) post-installation monitoring, derived from regulatory requirements. Also costs of NEPA and other documentation.
- **Define environmental context for each RM:** Specific environmental requirements unique to each RM, its deployment location, and animals/habitats.
- **Scale costs:** Costs were applied for pilot (1-2 devices), small commercial (~10 devices), and large commercial (~100 devices) phases of development for each RM.
- **Costs account for**: ship days and equipment purchases; staff time for field monitoring; sample and data analysis; reporting and documentation for permitting.
- **Expert and Regulatory Review:** Peer review of pathways and costs by marine ecologists and MHK practitioners. Sharing of pathways (not costs) to regulatory agencies to get feedback on realism and appropriate application.

Accomplishments and Progress

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

- Environmental pathways and costs tailored to specific RMs, their deployment locations and environmental receptors completed for RMS 1-4. Draft pathways and costs for RM 5 (new) and 6.
- During course of project, PNNL provided guidance to engineering teams on environmental feasibility. Results in changes to some RMs, complete revision of RM5.
- Adjustments to pathways and costs after peer review boosted confidence in results.
- Interaction with regulatory agencies helped agencies understand effect of monitoring request on project costs

Project Plan & Schedule

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

Summary	
WBS # 1.2.5.6	
Project #59837	
Agreement #21374	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Reference Model												
Q1: Define environmental drivers for LCOE for three reference models												
Q2: Provide initial estimates for pilot developments for RMs 4, 5 and 6.												
Q3: Provide initial estimates for commercial developments for RMs 4, 5 and 6												
Q4: Finalize estimates for environmental studies and permitting requirements												
Q1: Final input to all costs and environmental pathways for RMs 1,2 and 3												
Q2: Report on draft environmental pathways and costs for RMs 5 and 6												
Q3: Final costs on environmental pathways and costs for RMs 5 and 6												
Q4: Final environmental pathways and costs for reference models 4.5, and 6												

Comments

Variances:

- Final environmental pathways and costs for RMs 5 and 6 will be completed, once the engineering teams have completed their work. Review of a final report incorporating the environmental information will be reviewed and augmented as necessary.

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$170K		$25K		$0	

- FY12 and FY13 funds were underspent, waiting for information from engineering teams to complete their work.
- 87% of the funds have been expended
- No other funding sources.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

- Project led by DOE WWPTO and SNL.
- Partner include: NREL, ORNL, Revision
- Peer review assistance from: University of Washington, Oregon State University, and HT Harvey and Associates.

Communications and Technology Transfer:

- Sharing of process and results at all Reference Model team meetings
- Presentation at GMREC FY12
- Outreach to regulatory agencies

Next Steps and Future Research

FY14/Current research:

- PNNL will complete RM work with verification of RMs 5 and 6, once the engineering teams finalize their work.
- Incorporation of environmental requirements material into a final report will also take place in FY14.

Proposed future research:

- RM project is proposed to be finished in FY14
- Future work could apply environmental pathways to a general process, potentially allowing acceleration of additional MHK projects undergoing siting and permitting

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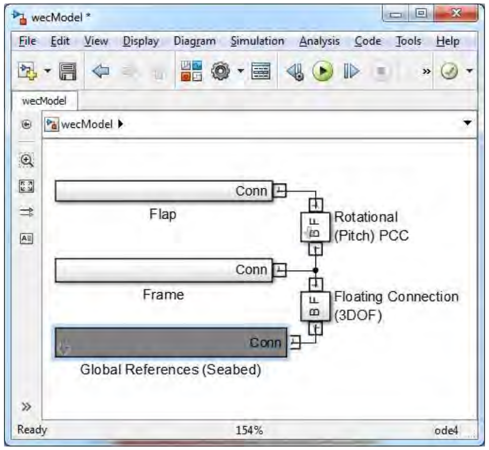
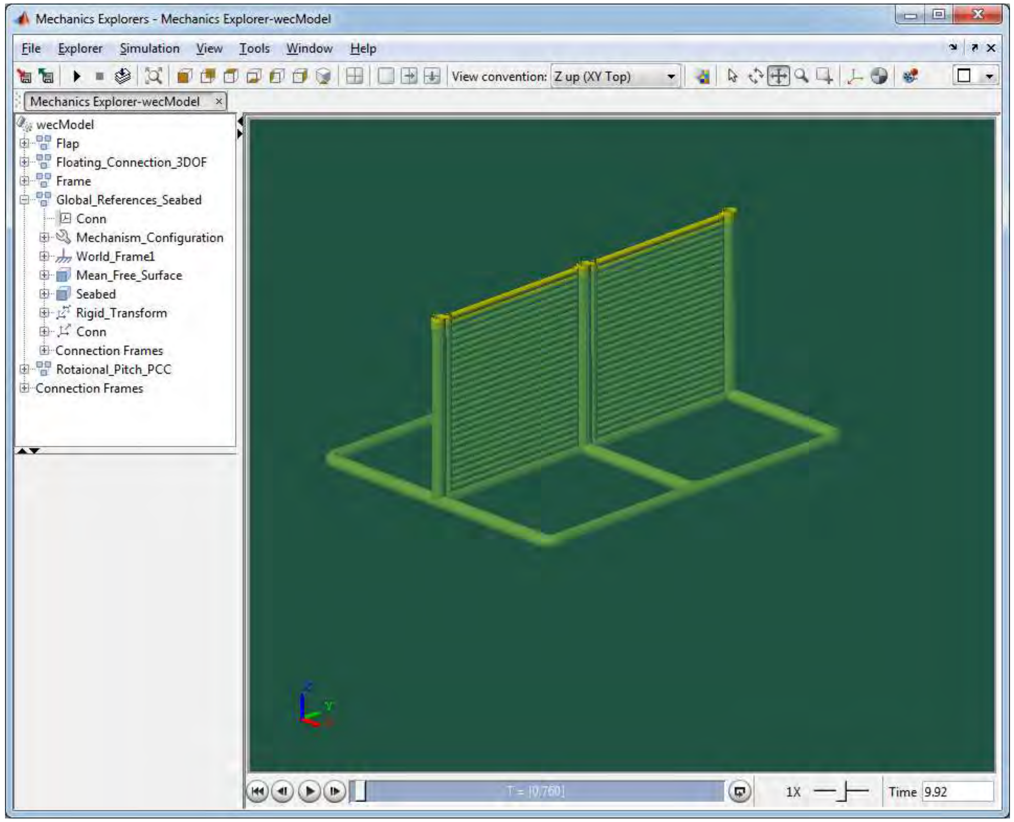


Hs (kW)	Tp (sec) 5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7
0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7
0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9
1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5
1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3
2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4
2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7
3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4
3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3
4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5
4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0
5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7



Wave Energy Converter Modeling

Michael Lawson

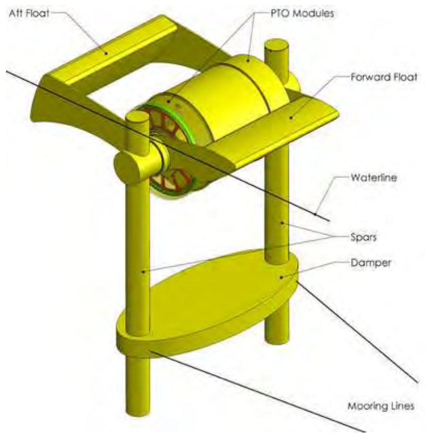
National Renewable Energy Laboratory

michael.lawson@nrel.gov | 303.384.7196

February 24th, 2014

Purpose & Objectives

Problem Statement: Designing reliable and cost-competitive WEC devices requires the ability to model device performance under operational and extreme conditions



Operational Conditions

Extreme Conditions

Existing numerical modeling tools cannot be customized for specific modeling needs

↓

A suite of open-source WEC design and analysis tools and modeling techniques is needed to accelerate the pace of WEC technology development

Images courtesy of Columbia Power Technologies

Purpose & Objectives

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

NREL and Sandia are working on two projects to develop a set of open-source WEC modeling tools that satisfy the needs of the wave energy community

WEC-Sim (FY13-FY15): Develop a device analysis and optimization software package to model WECs under operational conditions. FY13 tasks:

- Code development (in-house and code competitions)
- Code verification through code-to-code comparisons

Extreme events modeling objective (new in FY14): Study experimental and numerical methods for modeling WECs during extreme events → goal of identifying promising directions for FY15+ research

Impact of Project:

- Provide freely available and open-source WEC design, analysis, and optimization tools
- Reduce the cost barrier to WEC device development and help advance the industry towards commercial deployments

Alignment with DOE Priorities: WEC-Sim is the only open-source WEC simulation code under development world wide and this effort aligns with the DOE priority of **advancing the state of MHK technology**

Project Plan & Schedule

Summary	
WBS Number or Agreement Number	1.3.1.1 (FY13) & 1.1.1.1 (FY14)
Project Number	
Agreement Number	25674

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plar
Milestones & Deliverables (Actual)

Task / Event	FY2013 Q1	FY2013 Q2	FY2013 Q3	FY2013 Q4	FY2014 Q1	FY2014 Q2	FY2014 Q3	FY2014 Q4
Project Name: Wave Energy Converter Modeling								
Q1 Milestone: Deliver WEC-Sim modeling plan to DOE								
Q2 Milestone: Identify modules that will be developed using coding competitions								
Q2 Milestone: Develop Wave-Sim for incident wave conditions								
Q3 Milestone: Develop specifications for code competition to develop OpenBEM								
Q3 Milestone: Develop PTO-Sim for WEC power output								
Q4 Milestone: Complete Alpha version of WEC-Sim								
Q1 Milestone: Model a point absorber in WEC-Sim and post on project website								
Q2 Milestone: Release a mesh generation coding competition								
Current work and future research								
Q2 Milestone: Model a pitching device in WEC-Sim and post on project website								
Q3 Milestone: Complete Beta version of WEC-Sim								
Q3 Milestone: Hold an extreme events modeling workshop								
Q4 Milestone: Develop an experimental test plan for WEC-Sim validation								
Submit 2 OMAE conference papers on non-linear hydro and code-to-code								
Submit a METS conference paper on WEC-Sim verification and validation								
Hold the BEM code competition								

NREL Specific Milestones

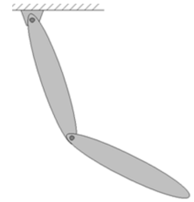
SNL Specific Milestones

Technical Approach

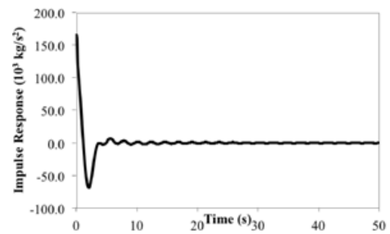
WEC device specification

Relevant numerical methods

WEC performance, motions, and loads

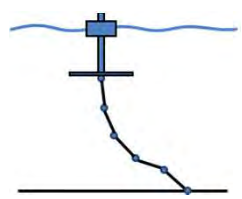


Multi-body dynamics



Potential flow hydrodynamics

Hs (kW)	Tp (sec) 5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7
0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7	0.5
0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9	4.6
1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5	12.7
1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3	24.9
2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4	41.1
2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7	61.4
3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4	85.8
3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3	114.2
4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5	146.7
4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0	183.3
5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7	223.9



PTO and mooring

Combine multi-body dynamics and potential flow numerical methods

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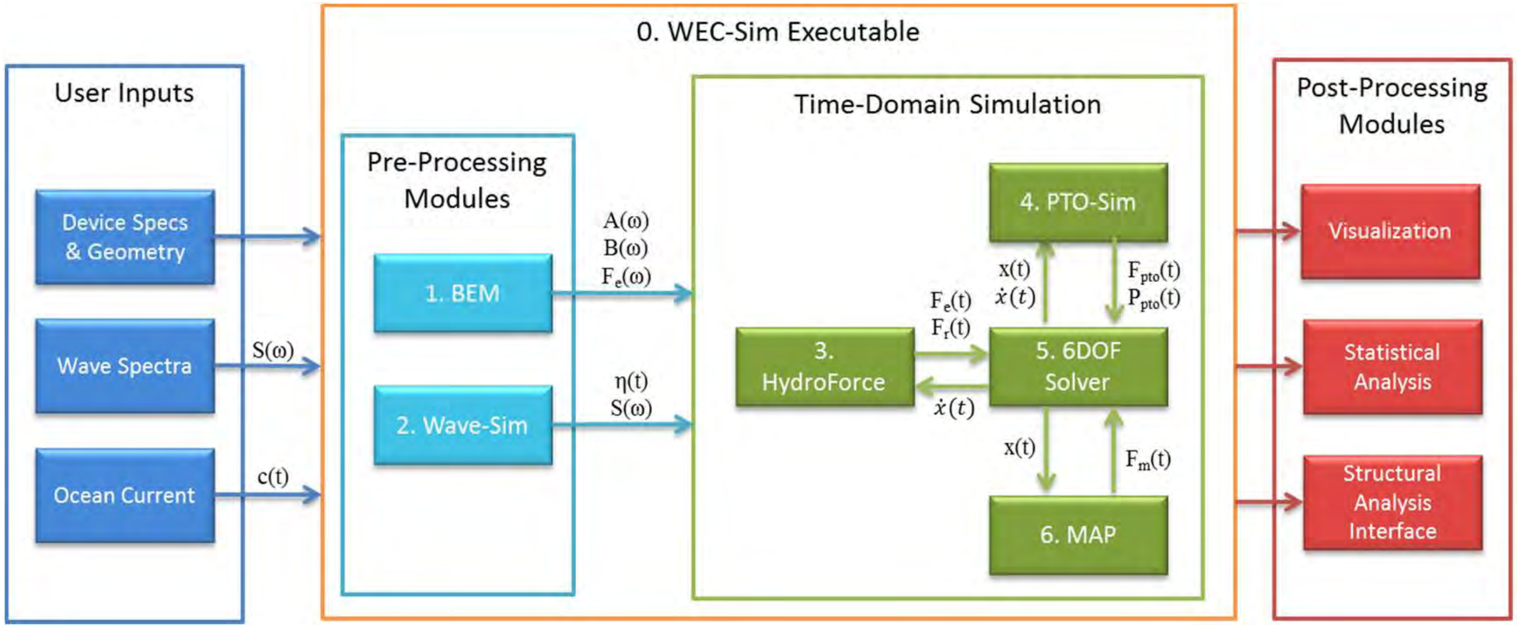


Each module simulates a different physical phenomena

Code is MATLAB/SimMechanics based and will be released in ***open-source*** format in Q3 FY14 at GitHub through OpenEI

Code is being developed ***in-house*** and through the use of ***code competitions***

WEC-Sim consists of coupled code modules that run in concert to simulate WEC dynamics

Accomplishments & Progress

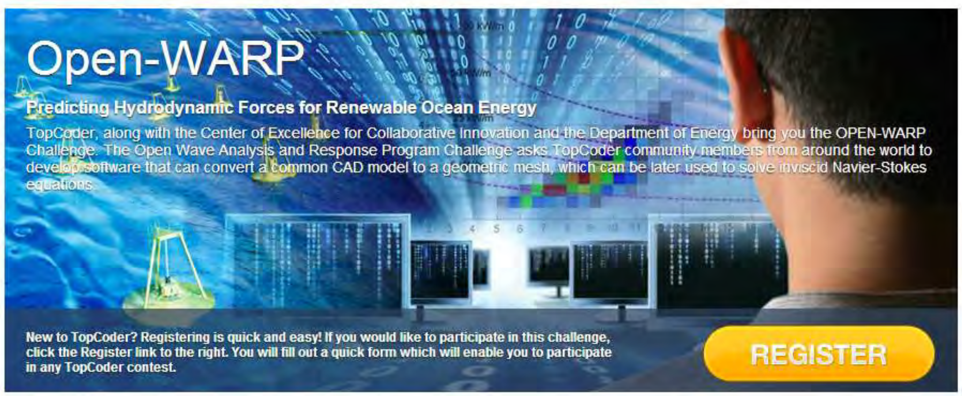
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Problem: WEC-Sim requires hydrodynamics coefficients from proprietary commercial BEM solvers → develop an open-source alternative to make the WEC-Sim package more accessible to users

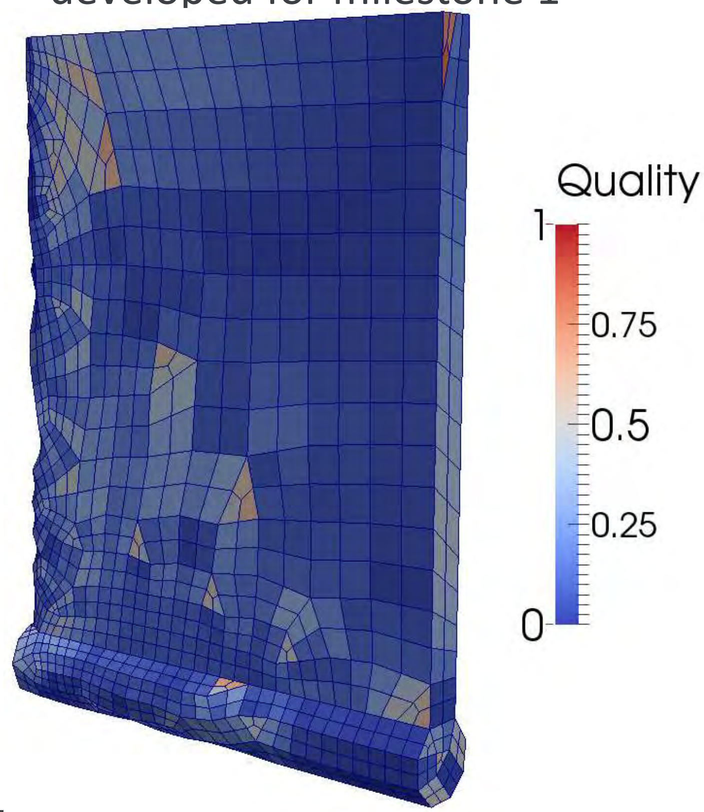
Leverage the world-wide TopCoder community to efficiently develop a BEM code

Q1 Milestone (complete): Develop a mesh generator
Q2 Milestone: Build on the Nemoh code (Ecole Centrale de Nantes) to create a fully functional BEM solver

Mesh of RM 5 device created using the mesh generator developed for milestone 1



http://www.topcoder.com/doe/



OpenWARP is a collaboration between NREL & DOE

Initiated a code competition to develop a boundary element method (BEM) code

Pre-processing
- Run WAMIT

↓

Set user inputs
- Wave conditions
- Simulation settings

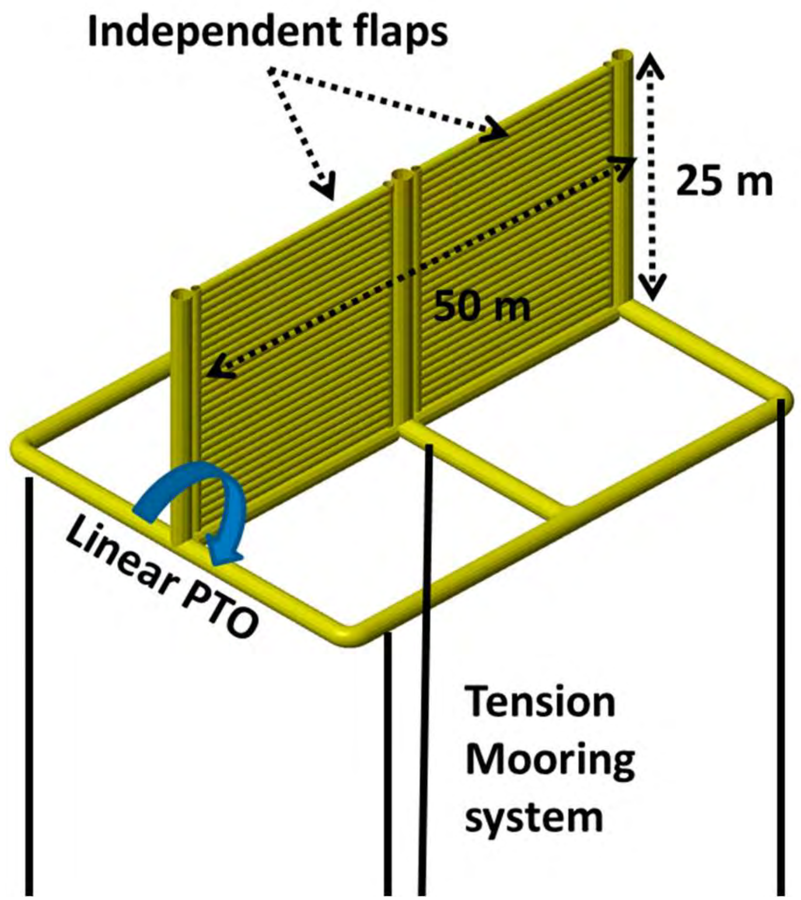
↓

Build SimMechanics model
- Use library of WEC components to build multi-body model of device
- Define geometry
- Define inertia properties

↓

Execute WEC-Sim code

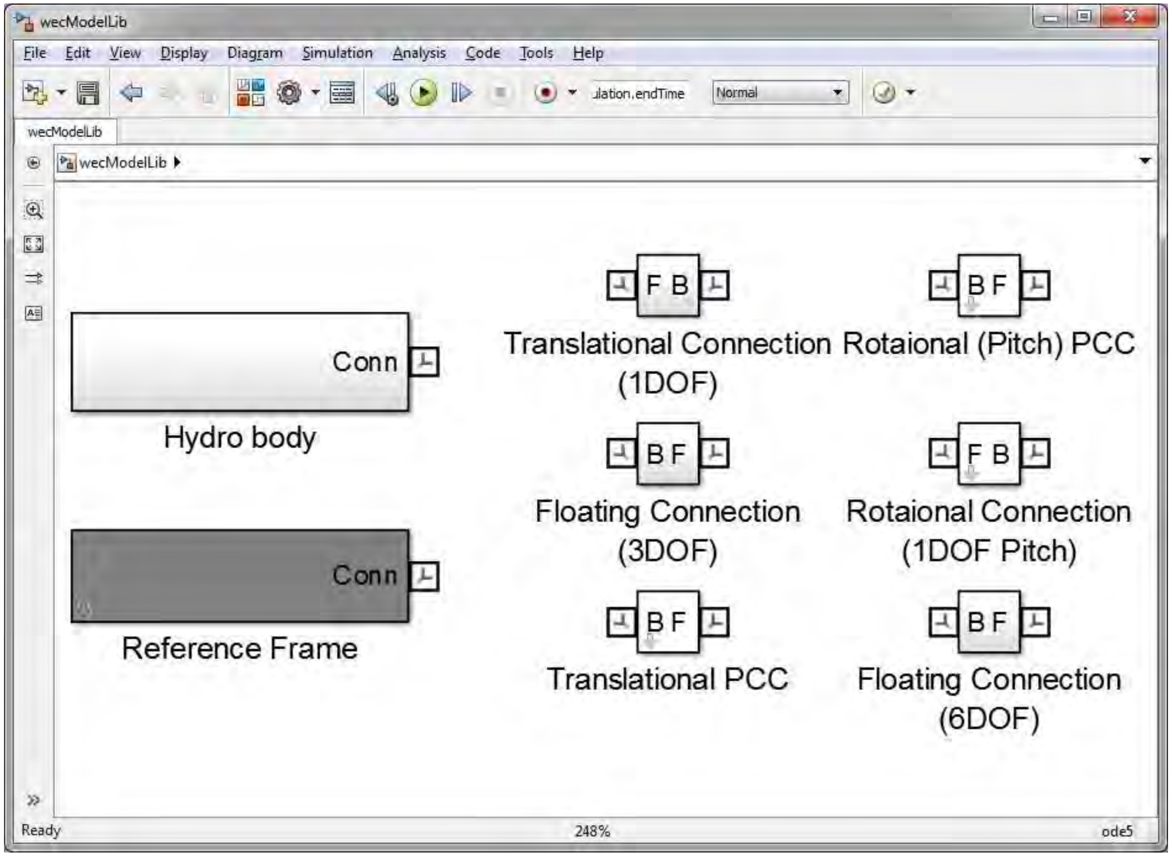
WEC-Sim was demonstrated to DOE using the RM5 pitching WEC



Code Demo: Simulating a floating pitch WEC with tension mooring

The WEC-Sim team built a "library" of common WEC components

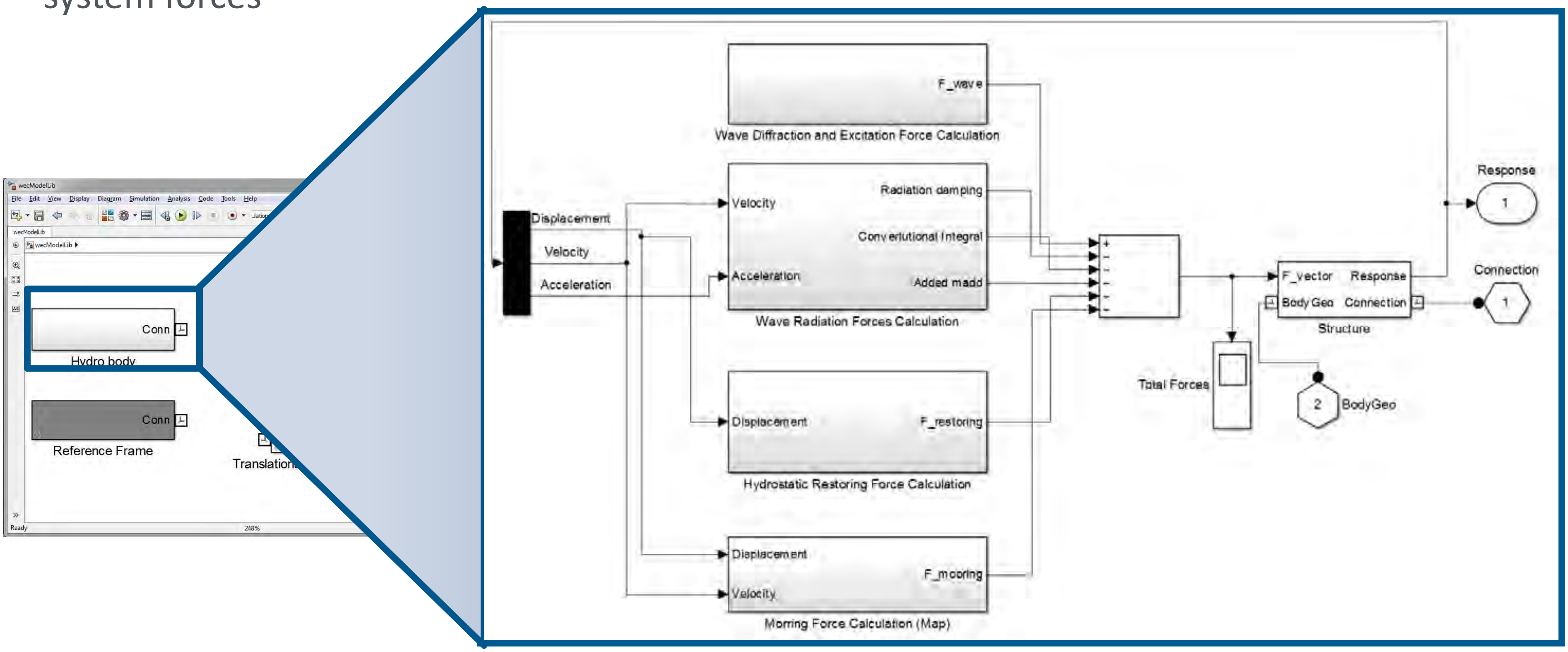
Users build WEC devices by using several components from the library shown below



A WEC-Sim model is created using the "WEC-Sim library"

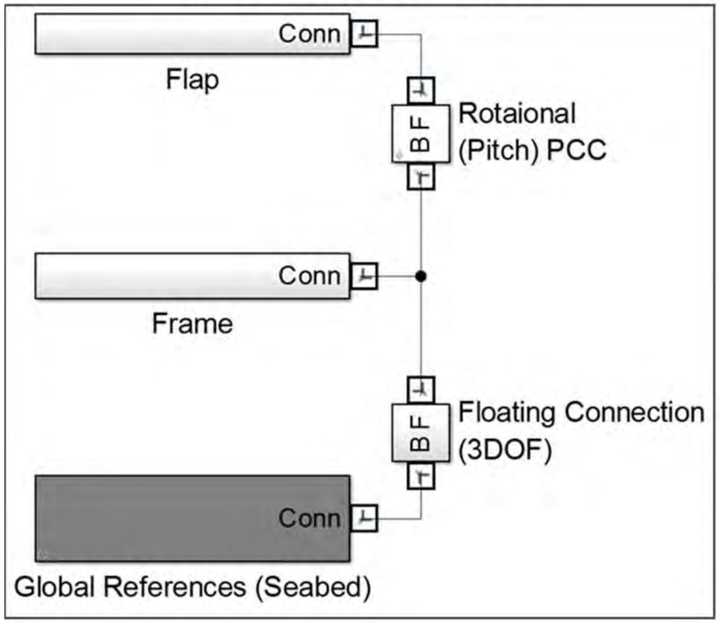
Each component in the WEC-Sim library models relevant WEC physics

For example, the “hydro body” block models hydrodynamic, hydrostatic, and mooring system forces

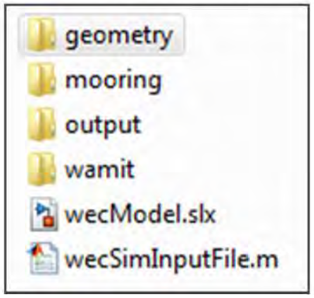


<u>The “hydro body” block models hydrodynamic, hydrostatic, and mooring system forces</u>

SimMechanics model



File structure

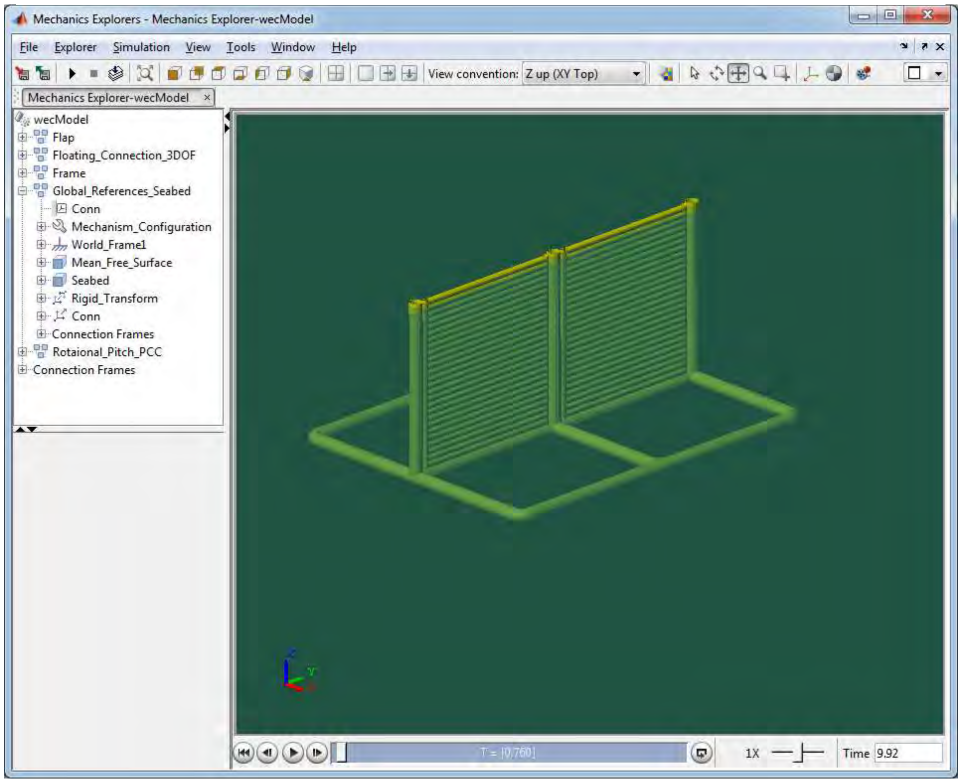


Input file

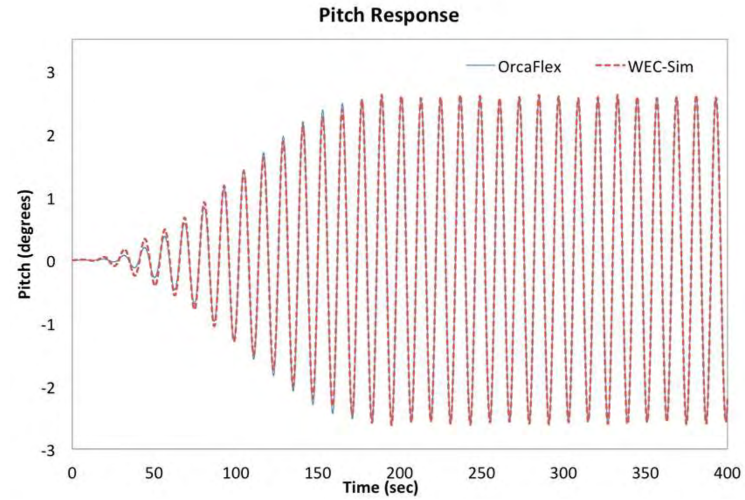
```
% Simulation data
simu = simulationClass;
simu.simMechanicsFile = 'wecModel.slx';
simu.numWecBodies = 2;
simu.dt = 0.01;
simu.endTime = 1000

% 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
```

Code Demo: Simulating a pitch WEC (DOE RM5) with tension mooring

WEC-Sim GUI and Simulation Visualization



Device motions



Device power matrix

Hs (kW)	Tp (sec) 5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7
0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7
0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9
1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5
1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3
2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4
2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7
3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4
3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3
4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5
4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0
5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7

Completed alpha version of WEC-Sim & DOE Demo in Q4 FY13

NREL Project Budget

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$700k	n/a	$1,100k	n/a	$1,350k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$0K	$556K	$1,013K

- $700k of funding was received in Q4 of FY12. This funding was part of the FY13 project budget
- $400k of funding received at the end of FY13 for FY14 work
- Current plans to preserve 25% in carryover per DOE guidance
- FY14 project costs as of December 31st: $121,877

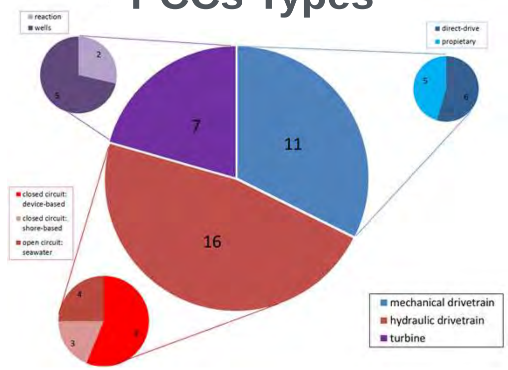
PTO-Sim

- WEC-Sim power performance module

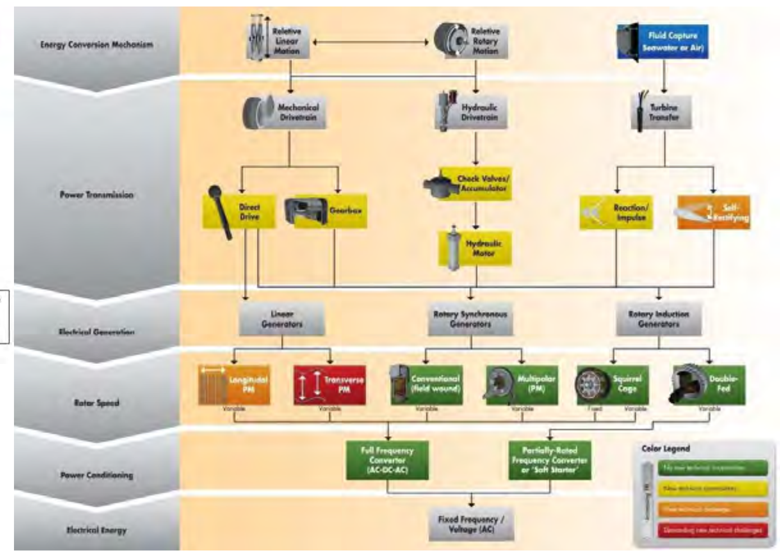
Milestones :

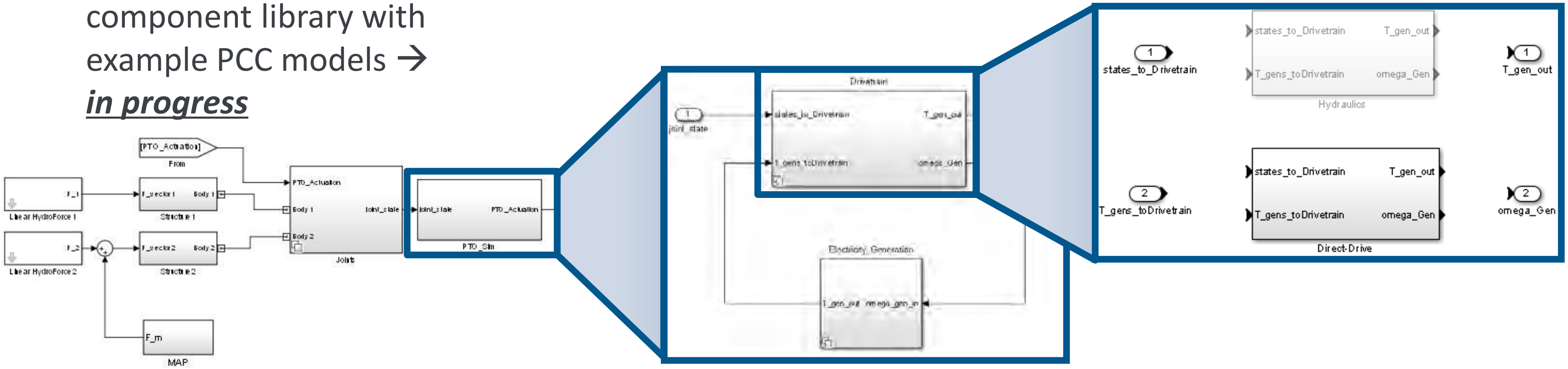
1. Literature review of TRL5+ Power Conversion Chains (PCC) → ***completed***
2. WEC-Sim Alpha version, PCCs modeled as linear damper → ***completed***
3. WEC-Sim Beta version, PCC component library with example PCC models → ***in progress***

PCCs Types



Power Conversion Chains

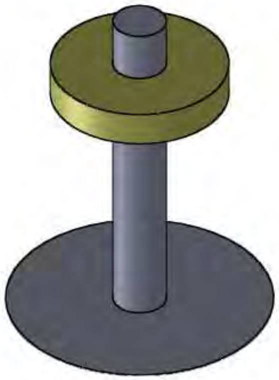


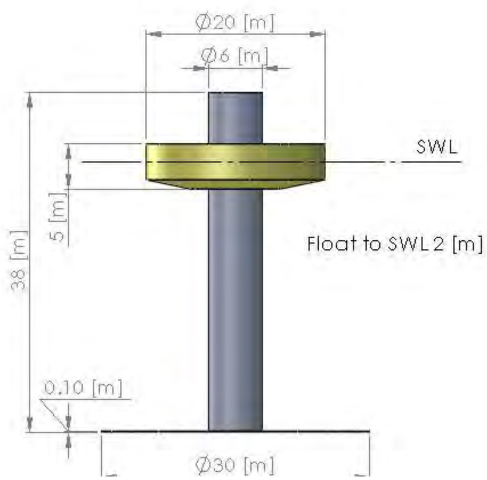


PTO-Sim (alpha version) Development by SNL

Accomplishments & Progress
(Presented by SNL)

Reference Model 3 (RM3) Point Absorber





Float				
CG (m)	Mass (tonne)	Moment of inertia (kgm^2)		
0	727	20907301	0	0
0		0	21306091	4304.8
-0.72		0	4305	37085481

Spar/Plate				
CG (m)	Mass (tonne)	Moment of inertia (kgm^2)		
0	878	94419614	0	0
0		0	94407091	217593
-21.3		0	217593	28542225

Tests performed:
- 1DOF code-to-code comparison
- 3DOF code-to-code comparison

Codes used:
- WEC-Sim
- WaveDyn
- AQWA
- OrcaFlex

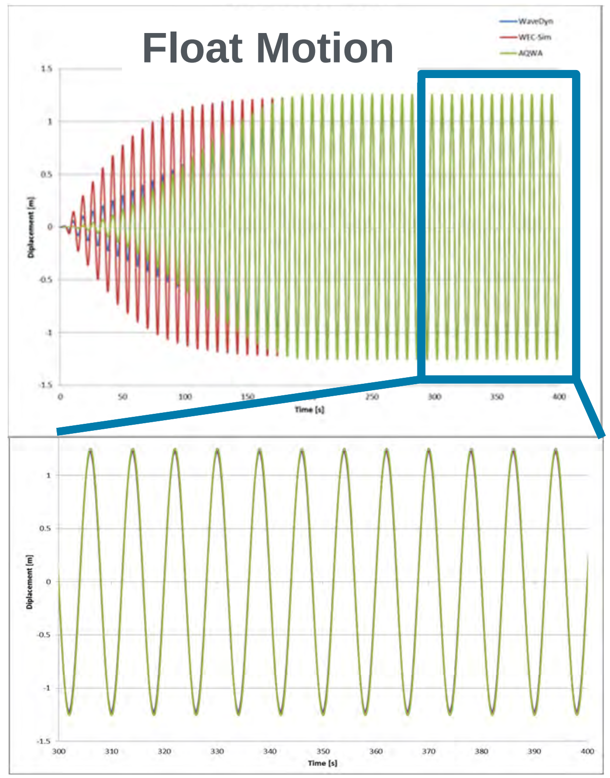
PTO:
- Modeled without damping
- Modeled with linear damper

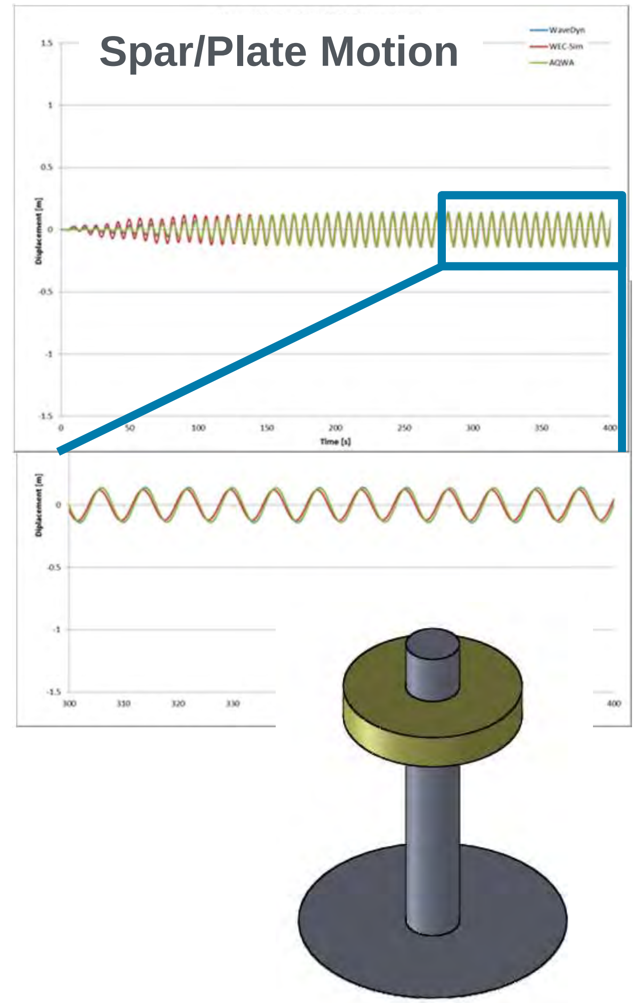
WEC-Sim Verification via Code-to-Code Comparison

Codes used:
- WEC-Sim
- WaveDyn
- AQWA

Degree of Freedom:
- Heave

Regular Wave:
- H = 2.5 [m]
- T = 8 [s]





Results
- Initial transients from wave "ramp function"
- Excellent agreement between WEC-Sim, WaveDyn, and AQWA

Completed 1DOF Code-to-Code Comparison without PTO

Accomplishments & Progress
(Presented by SNL)

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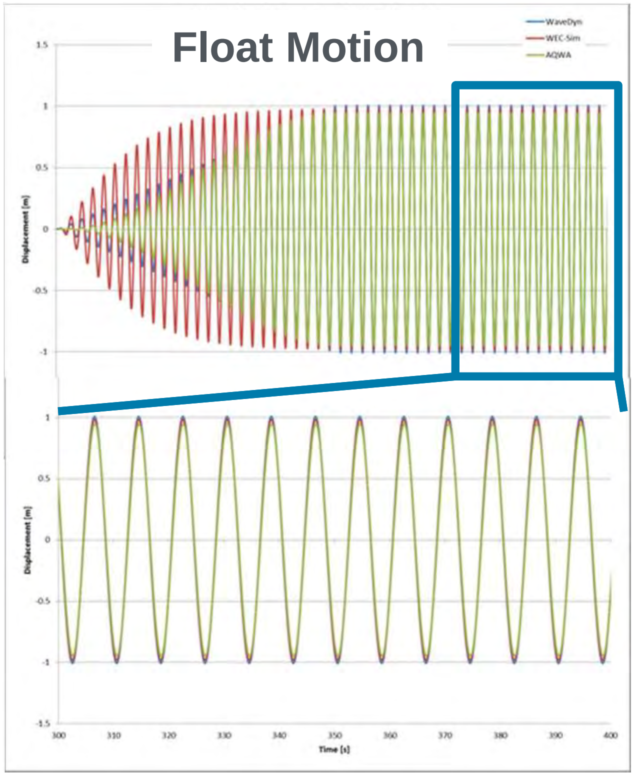
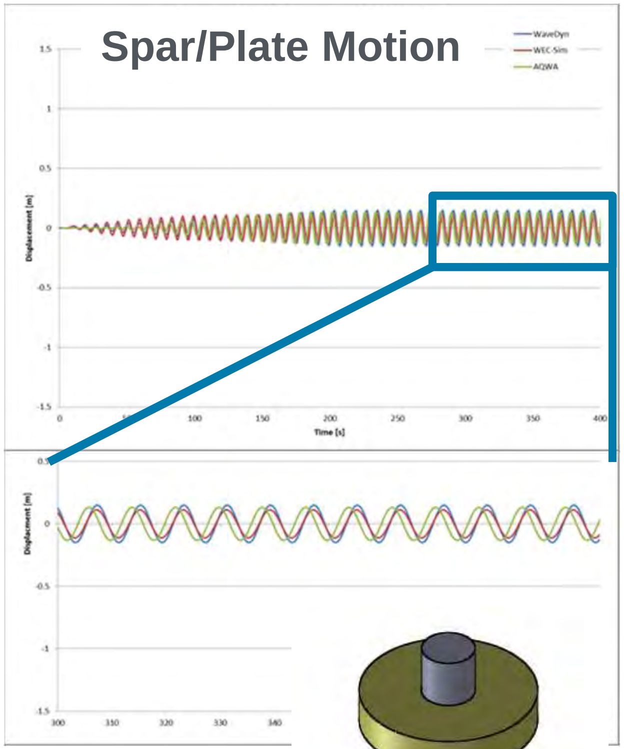
Codes used:
- WEC-Sim
- WaveDyn
- AQWA

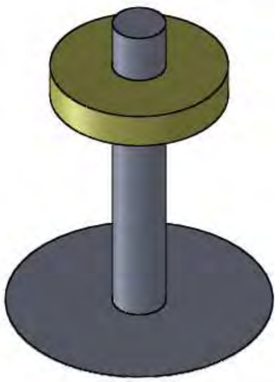
Degree of Freedom:
- Heave

Regular Wave:
- H = 2.5 [m]
- T = 8 [s]
- C_{PTO} = 1200 [kN-s/m]





Results
- Initial transients from wave "ramp function"
- Excellent agreement between WEC-Sim, WaveDyn, and AQWA



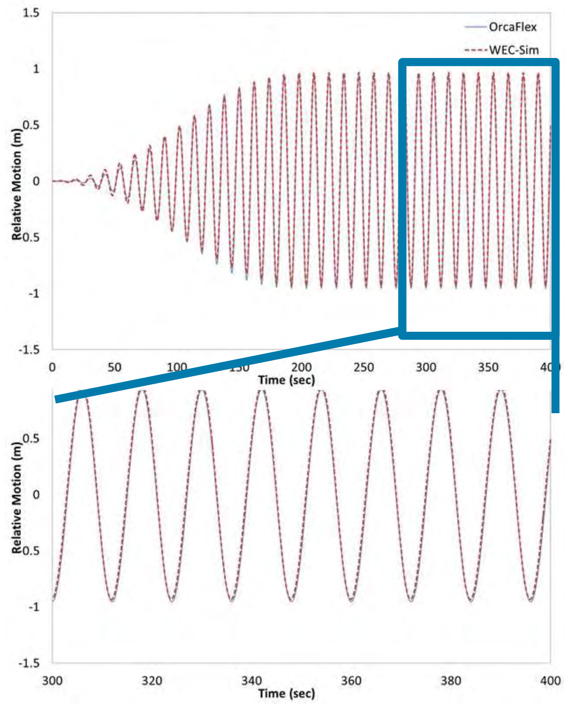
Completed 1DOF Code-to-Code Comparison w/PTO

Codes used:
- WEC-Sim
- OrcaFlex
- AQWA

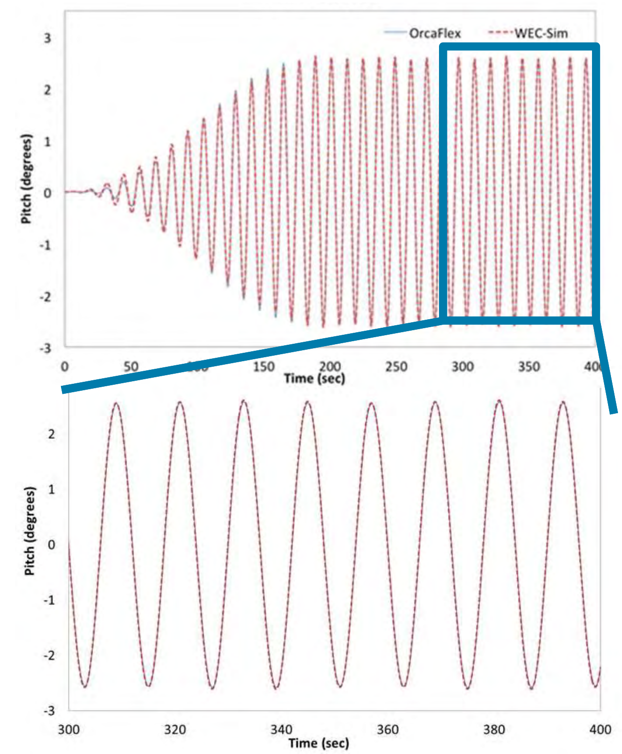
Degrees of Freedom:
- Heave, pitch and surge

Regular Wave:
- H = 2.5 [m]
- T = 12 [s]

Relative Heave Motion



Pitch Motion



Results:
- Initial transients from wave “ramp function”
- Excellent agreement between OrcaFlex and WEC-Sim
- Difficulty simulating 3DOF with WaveDyn and AQWA

Completed 3DOF Code-to-Code Comparison w/o PTO

Accomplishments & Progress
(Presented by SNL)

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Major Project Accomplishments:

- Completed the WEC-Sim Modeling Plan in collaboration with DOE HQ and NREL to outline the 3 year project objectives, milestones and schedule.
- Established a GitHub code repository for the WEC-Sim project that is used by the WEC-Sim team to collaborate on WEC-Sim's code development and application.
- Developed the structure of the WEC-Sim code in the first year of the project in a modular structure, and uploaded a functional pre-alpha release to the GitHub repository.
- Completed the alpha version of WEC-Sim and demonstrated its functionality via a Webinar to DOE HQ at the end of FY13
- Applied the WEC-Sim code to model RM3, the heaving point absorber WEC developed by the Reference Model Project.
- Applied the WEC-Sim code to model RM5, the pitching WEC developed by the Reference Model Project.
- Verified the code's functionality by modeling the RM3 device in WEC-Sim, and via a code-to-code comparison using the commercial codes WaveDyn, AQWA and OrcaFlex.

Project Status:

All WEC modeling tasks are currently on schedule

SNL Project Budget
(Presented by SNL)

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

Project Funding History

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0K	N/A	$300K	N/A	$1025K	N/A

Budget Notes

– FY13 Budget, all $300K of funding was received in Q4 of FY12
– FY14 Budget, $200K of funding was received in Q4 of FY13

Project Spending

– FY14 project costs as of December 31st = $63K
  - Funding reflects both WEC-Sim and EEM projects
  - SNL wave modeling project staff ramp up in FY14

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$0K	$174K	$882K

Research Integration & Collaboration *(Presented by SNL)*

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Multi-Lab Collaboration:

WEC-Sim: NREL and SNL
Extreme Events Modeling: SNL and NREL
In-person team meetings every 2-3 months
Weekly telecon and/or email interaction

Communications and Technology Transfer:

This work has been disseminated through papers, presentations, and workshops.

- WEC-Sim publication and two presentations at 2013 METS in Washington, D.C.
- WEC-Sim presentation at IEA OES Annex V workshop in Edinburgh, Scotland
- WEC-Sim publication and presentation at ISOPE 2013 in Anchorage, AK
- Upcoming papers in 2014 at GMREC/METS and OMAE

GitHub is used for WEC-Sim development and distribution:

- WEC-Sim will be publically available in Q3 FY14 at github.com/NREL/WEC-Sim, on OpenEI, the NREL codes webpage, and the SNL codes webpage

WEC-Sim user outreach and training planned for WEC developers and research institutions

Next Steps and Future Research
(Presented by SNL)

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WEC-Sim FY14/Current Research:
- Code-to-code comparisons for WEC-Sim verification
- Complete Beta version of WEC-Sim for public release
- Develop a test plan for WEC-Sim experimental validation

WEC-Sim Future Research:
- Evaluate the pros/cons of moving to a fully open-source code
- Apply WEC-Sim to model a third WEC device
- Plan and perform experimental wave tank tests for WEC-Sim validation

Sandia National Laboratories

NREL

Extreme Events Modeling (EEM)

NREL and SNL are working to develop a procedure for modeling WECs during extreme events

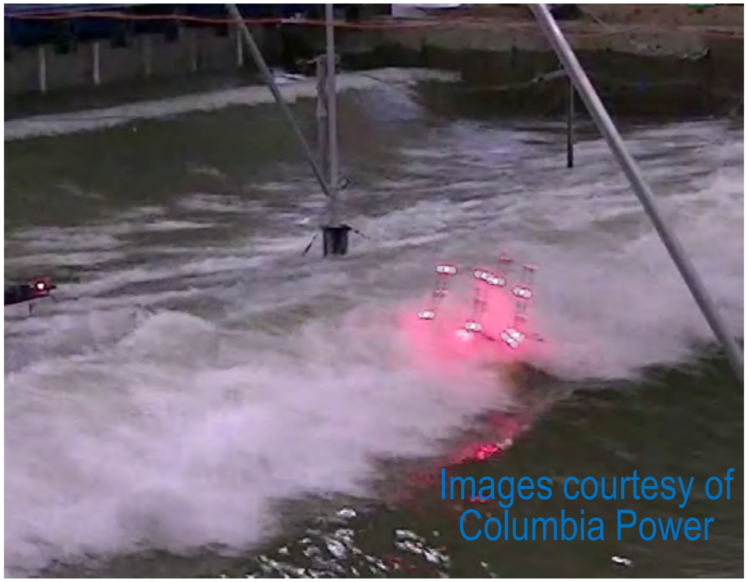
FY14 Milestones

Literature review: Perform a literature review to understand state of the art methods

Workshop: Hold a technical workshop with 20-30 experts from offshore wind, oil and gas, shipping, and MHK industries with the goal of identifying best practices and areas where research is needed to improve numerical and experimental predictive methods

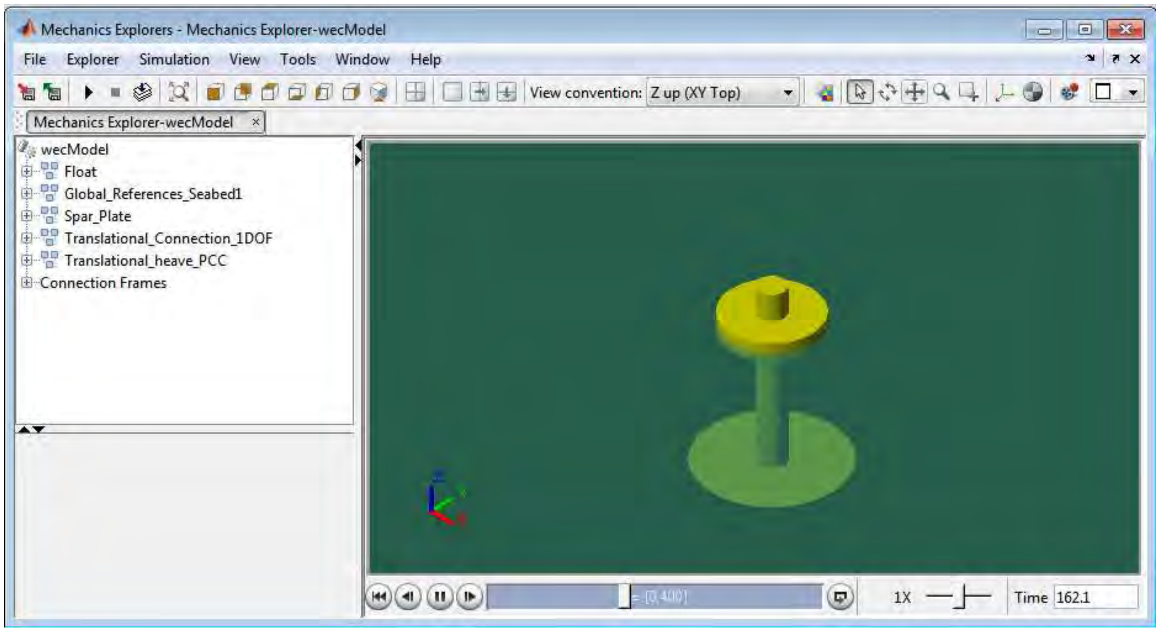
↓

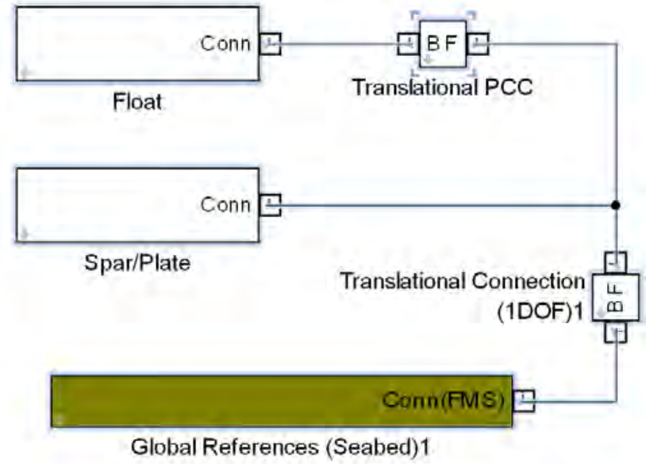
Use results to direct future WEC extreme events experimental and numerical modeling efforts

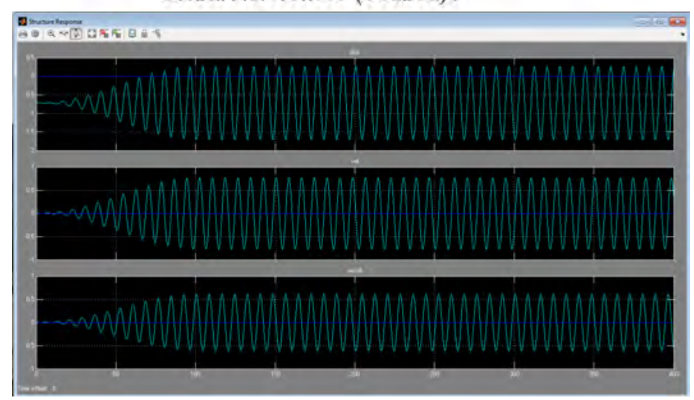


Images courtesy of Columbia Power

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







Wave Energy Converter Modeling

Kelley Ruehl

Sandia National Laboratories

kmruehl@sandia.gov | 505.284.8724

Monday 2/24/2014

Purpose & Objectives

(Presented by NREL)

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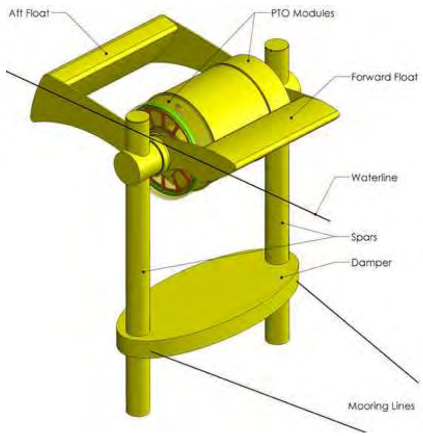
Problem Statement: Designing reliable and cost-competitive WEC devices requires the ability to model device performance under operational and extreme conditions



Operational Conditions

Extreme Conditions

Existing numerical modeling tools cannot be customized for specific modeling needs

A suite of open-source WEC design and analysis tools and modeling techniques is needed to accelerate the pace of WEC technology development

Images courtesy of Columbia Power Technologies

Purpose & Objectives
(Presented by NREL)

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

NREL and Sandia are working on two projects to develop a set of open-source WEC modeling tools that satisfy the needs of the wave energy community

WEC-Sim (FY13-FY15): Develop a device analysis and optimization software package to model WECs under operational conditions. FY13 tasks:

- Code development (in-house and code competitions)
- Code verification through code-to-code comparisons

Extreme events modeling objective (new in FY14): Study experimental and numerical methods for modeling WECs during extreme events → goal of identifying promising directions for FY15+ research

Impact of Project:

- Provide freely available and open-source WEC design, analysis, and optimization tools
- Reduce the cost barrier to WEC device development and help advance the industry towards commercial deployments

Alignment with DOE Priorities: WEC-Sim is the only open-source WEC simulation code under development world wide and this effort aligns with the DOE priority of **advancing the state of MHK technology**

Project Plan & Schedule
(Presented by NREL)

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

Summary	
WBS Number or Agreement Number	1.3.1.1 (FY13) & 1.1.1.1 (FY14)
Project Number	
Agreement Number	25674

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2013 Q1	FY2013 Q2	FY2013 Q3	FY2013 Q4	FY2014 Q1	FY2014 Q2	FY2014 Q3	FY2014 Q4
Project Name: Wave Energy Converter Modeling								
Q1 Milestone: Deliver WEC-Sim modeling plan to DOE								
Q2 Milestone: Identify modules that will be developed using coding competitions								
Q2 Milestone: Develop Wave-Sim for incident wave conditions								
Q3 Milestone: Develop specifications for code competition to develop OpenBEM								
Q3 Milestone: Develop PTO-Sim for WEC power output								
Q4 Milestone: Complete Alpha version of WEC-Sim								
Q1 Milestone: Model a point absorber in WEC-Sim and post on project website								
Q2 Milestone: Release a mesh generation coding competition								
Current work and future research								
Q2 Milestone: Model a pitching device in WEC-Sim and post on project website								
Q3 Milestone: Complete Beta version of WEC-Sim								
Q3 Milestone: Hold an extreme events modeling workshop								
Q4 Milestone: Develop an experimental test plan for WEC-Sim validation								
Submit 2 OMAE conference papers on non-linear hydro and code-to-code								
Submit a METS conference paper on WEC-Sim verification and validation								
Hold the BEM code competition								

NREL Specific Milestones

SNL Specific Milestones

Technical Approach
(Presented by NREL)

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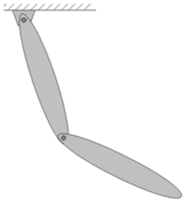
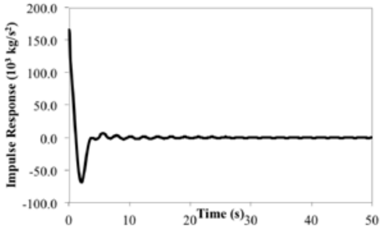
WEC device specification

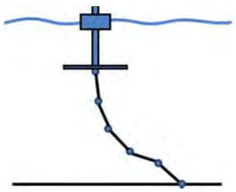
Relevant numerical methods



Multi-body dynamics



Potential flow hydrodynamics



PTO and mooring

WEC performance, motions, and loads

		Tp (sec)								
		5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7
Hs (kW)	0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7	0.5
	0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9	4.6
	1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5	12.7
	1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3	24.9
	2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4	41.1
	2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7	61.4
	3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4	85.8
	3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3	114.2
	4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5	146.7
	4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0	183.3
	5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7	223.9

Combine multi-body dynamics and potential flow numerical methods

Technical Approach
(Presented by NREL)

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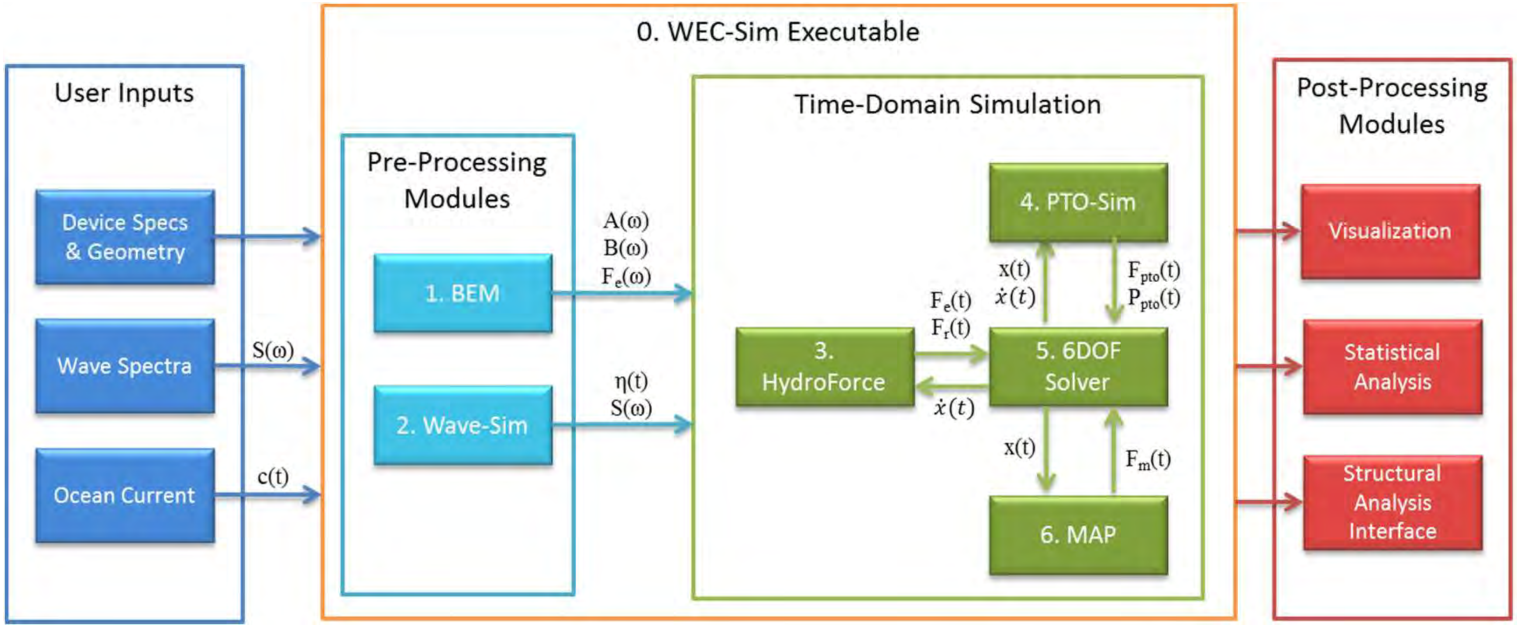


Each module simulates a different physical phenomena

Code is MATLAB/SimMechanics based and will be released in ***open-source*** format in Q3 FY14 at GitHub through OpenEI

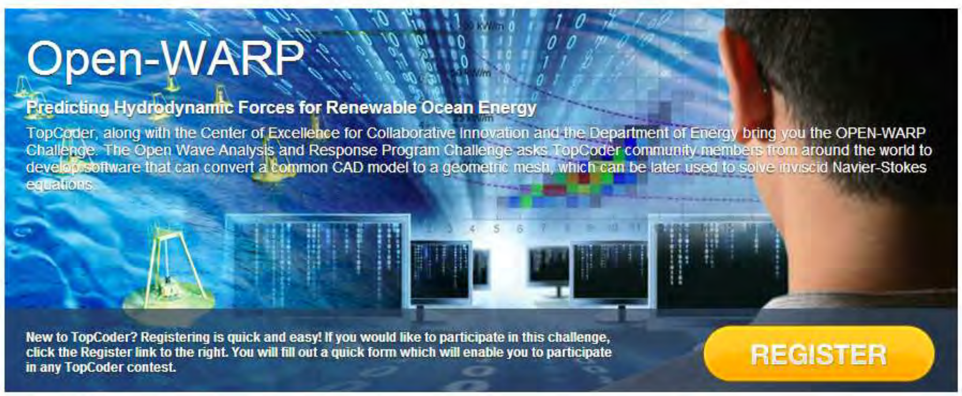
Code is being developed ***in-house*** and through the use of ***code competitions***

WEC-Sim consists of coupled code modules that run in concert to simulate WEC dynamics

Problem: WEC-Sim requires hydrodynamics coefficients from proprietary commercial BEM solvers → develop an open-source alternative to make the WEC-Sim package more accessible to users

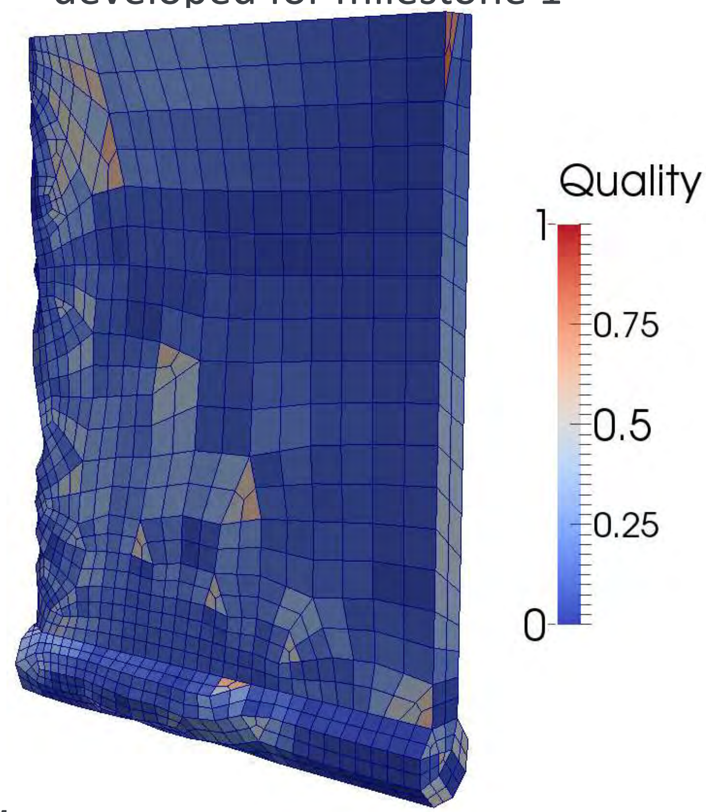
Leverage the world-wide TopCoder community to efficiently develop a BEM code

Q1 Milestone (complete): Develop a mesh generator
Q2 Milestone: Build on the Nemoh code (Ecole Centrale de Nantes) to create a fully functional BEM solver



http://www.topcoder.com/doe/

Mesh of RM 5 device created using the mesh generator developed for milestone 1



OpenWARP is a collaboration between NREL & DOE

Initiated a code competition to develop a boundary element method (BEM) code

Accomplishments & Progress
(Presented by NREL)

Pre-processing
- Run WAMIT

↓

Set user inputs
- Wave conditions
- Simulation settings

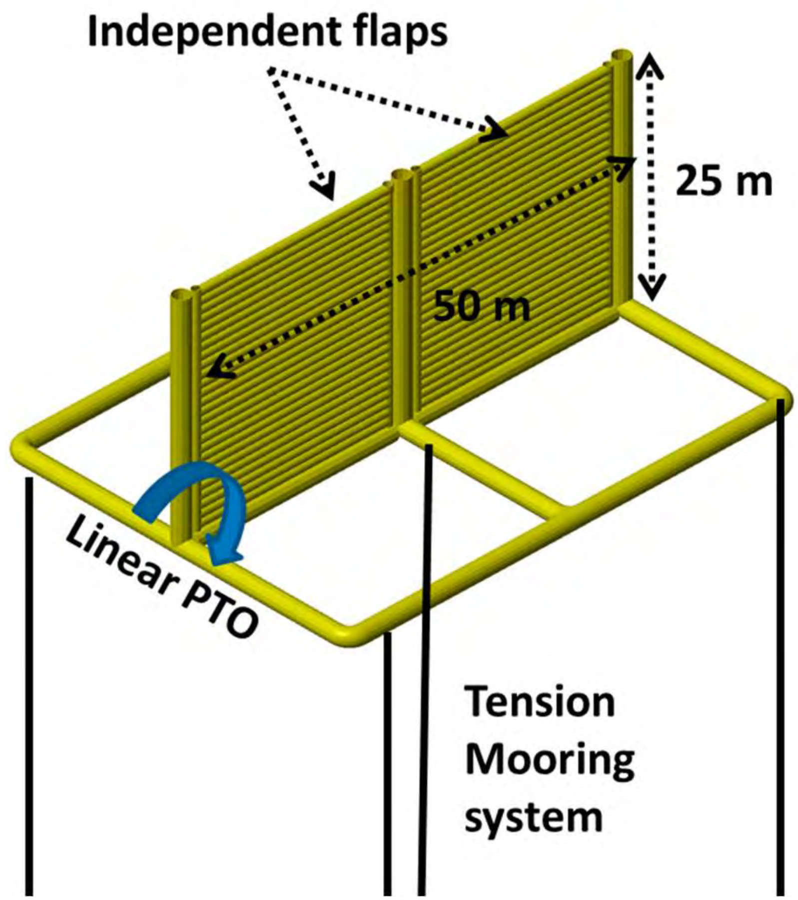
↓

Build SimMechanics model
- Use library of WEC components to build multi-body model of device
- Define geometry
- Define inertia properties

↓

Execute WEC-Sim code

WEC-Sim was demonstrated to DOE using the RM5 pitching WEC



Code Demo: Simulating a floating pitch WEC with tension mooring

Accomplishments & Progress
(Presented by NREL)

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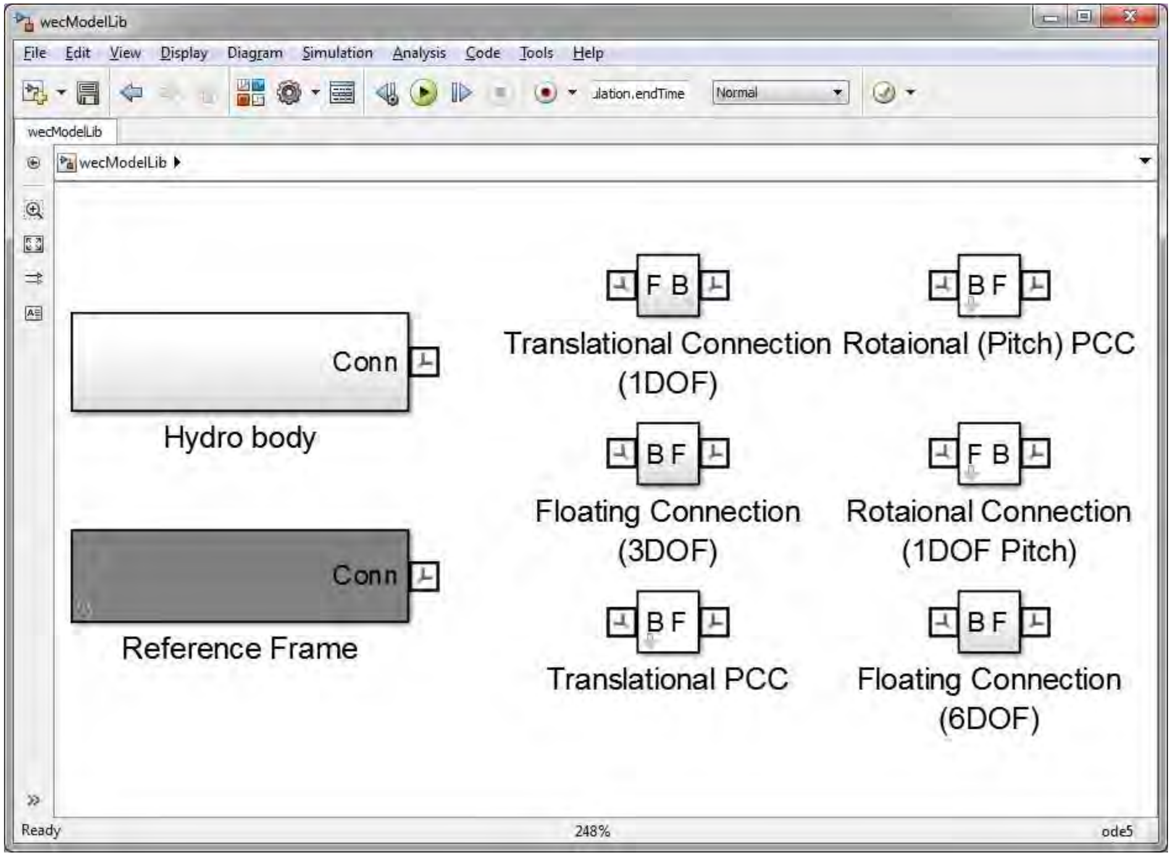
The WEC-Sim team built a “library” of common WEC components

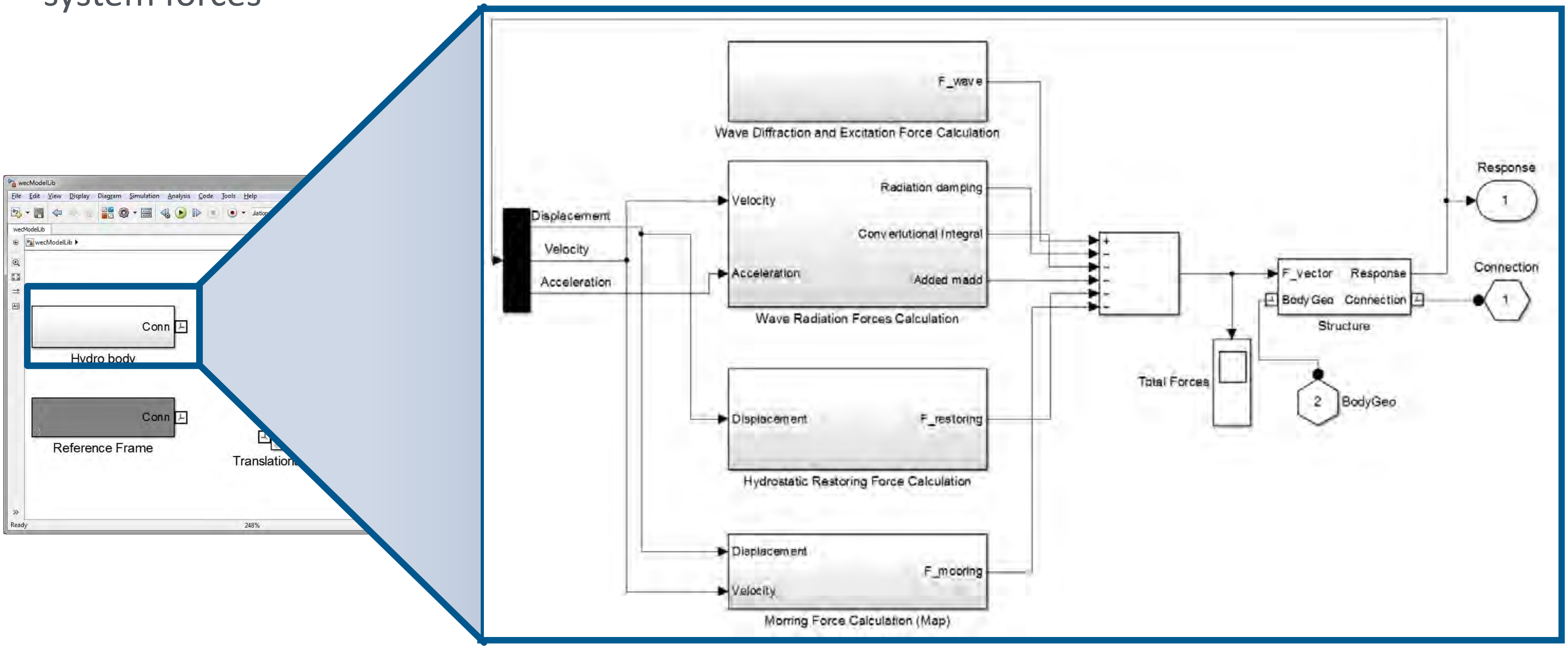
Users build WEC devices by using several components from the library shown below



A WEC-Sim model is created using the “WEC-Sim library”

Each component in the WEC-Sim library models relevant WEC physics

For example, the “hydro body” block models hydrodynamic, hydrostatic, and mooring system forces



The “hydro body” block models hydrodynamic, hydrostatic, and mooring system forces

Accomplishments & Progress
(Presented by NREL)

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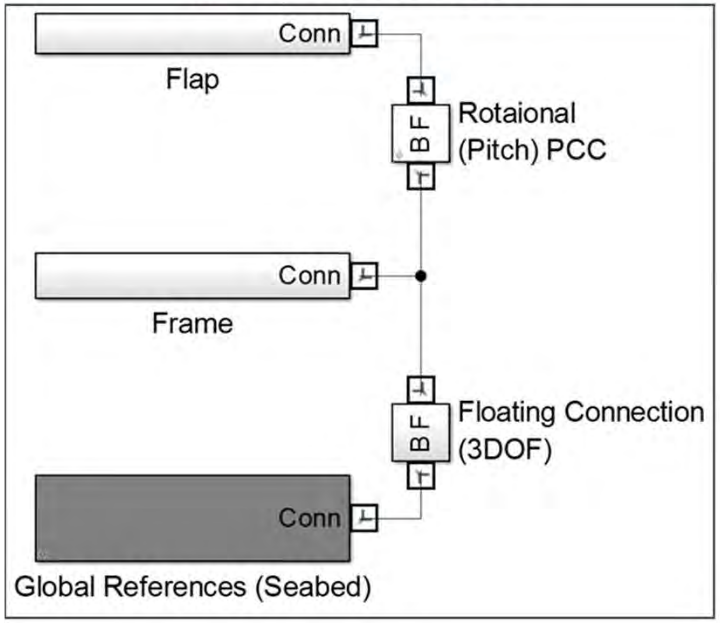
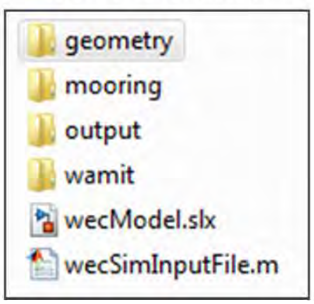
SimMechanics model



File structure



Input file

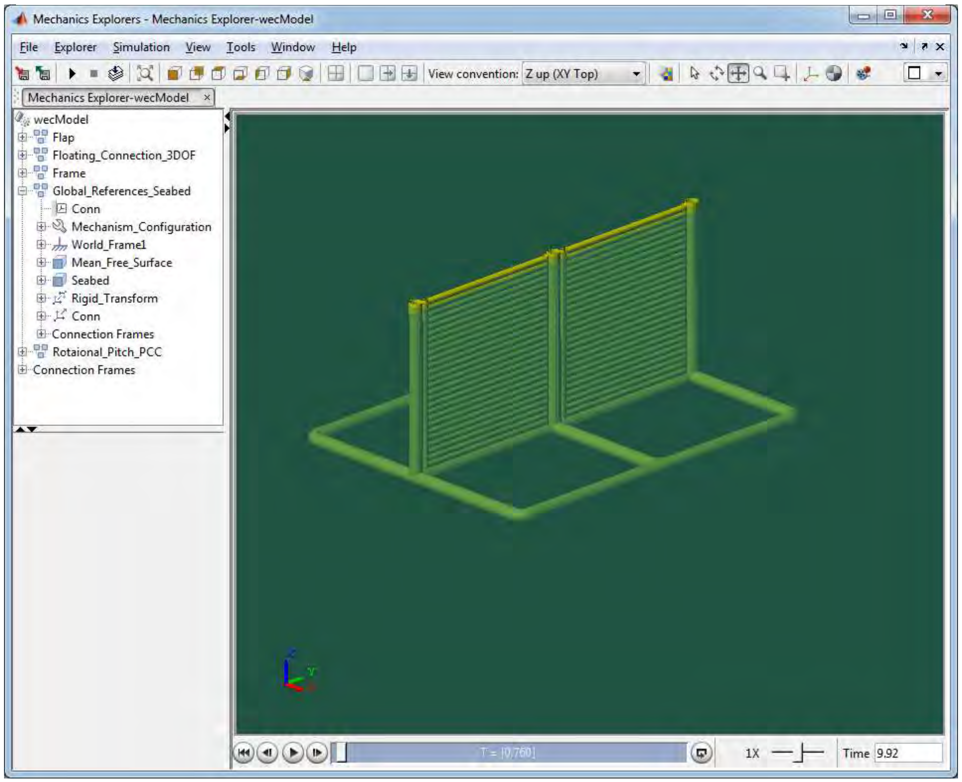
```
% Simulation data
simu = simulationClass;
simu.simMechanicsFile = 'wecModel.slx';
simu.numWecBodies = 2;
simu.dt = 0.01;
simu.endTime = 1000

% 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
```

Code Demo: Simulating a pitch WEC (DOE RM5) with tension mooring

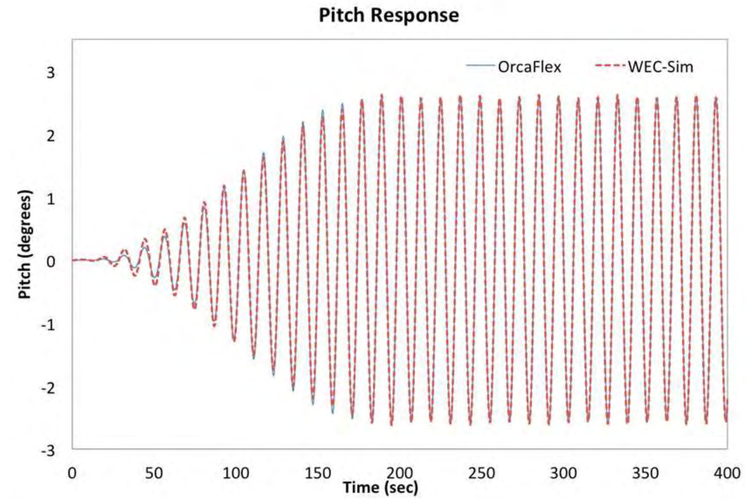
Accomplishments & Progress
(Presented by NREL)

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

WEC-Sim GUI and Simulation Visualization



Device motions



Device power matrix

Hs (kW)	Tp (sec) 5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7
0.25	2.9	3.1	2.6	2.2	1.5	1.2	0.8	0.7
0.75	26.3	27.5	23.1	19.7	13.5	10.5	7.6	5.9
1.25	73.2	76.3	64.3	54.9	37.5	29.1	21.0	16.5
1.75	143.4	149.5	126.0	107.5	73.5	57.0	41.2	32.3
2.25	237.1	247.1	208.3	177.7	121.5	94.3	68.1	53.4
2.75	354.2	369.1	311.2	265.5	181.6	140.9	101.8	79.7
3.25	494.7	515.6	434.6	370.8	253.6	196.7	142.1	111.4
3.75	658.7	686.4	578.6	493.7	337.6	261.9	189.2	148.3
4.25	846.1	881.6	743.1	634.1	433.6	336.4	243.1	190.5
4.75	1056.9	1101.3	928.3	792.0	541.7	420.3	303.6	238.0
5.25	1291.2	1345.3	1133.9	967.5	661.7	513.4	370.9	290.7

Completed alpha version of WEC-Sim & DOE Demo in Q4 FY13

NREL Project Budget
(Presented by NREL)

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$700k	n/a	$1,100k	n/a	$1,350k	n/a

Project Spending

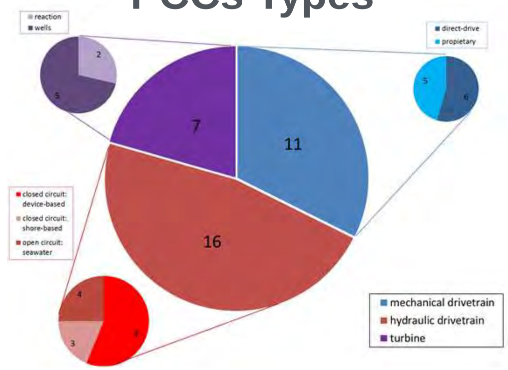
Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$0K	$556K	$1,013K

- $700k of funding was received in Q4 of FY12. This funding was part of the FY13 project budget
- $400k of funding received at the end of FY13 for FY14 work
- Current plans to preserve 25% in carryover per DOE guidance
- FY14 project costs as of December 31st: $121,877

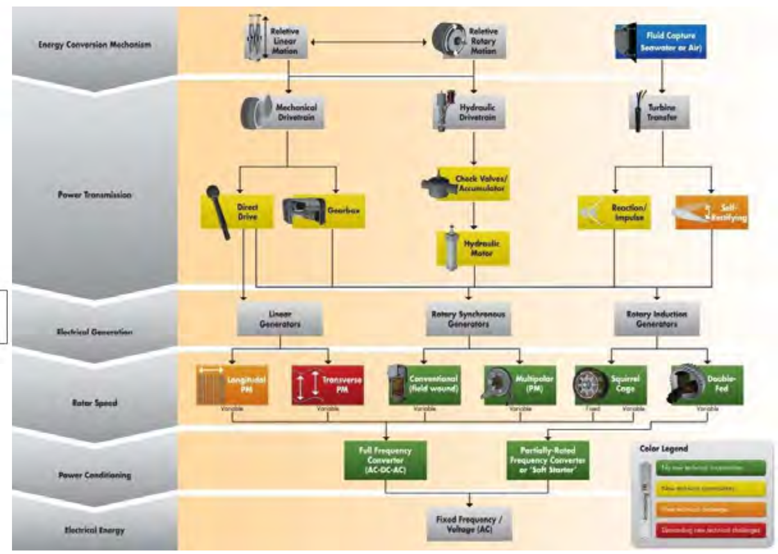
PTO-Sim
- WEC-Sim power performance module

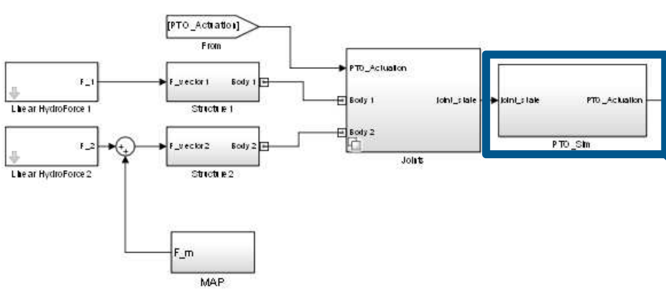
Milestones :
1. Literature review of TRL5+ Power Conversion Chains (PCC) → ***completed***
2. WEC-Sim Alpha version, PCCs modeled as linear damper → ***completed***
3. WEC-Sim Beta version, PCC component library with example PCC models → ***in progress***

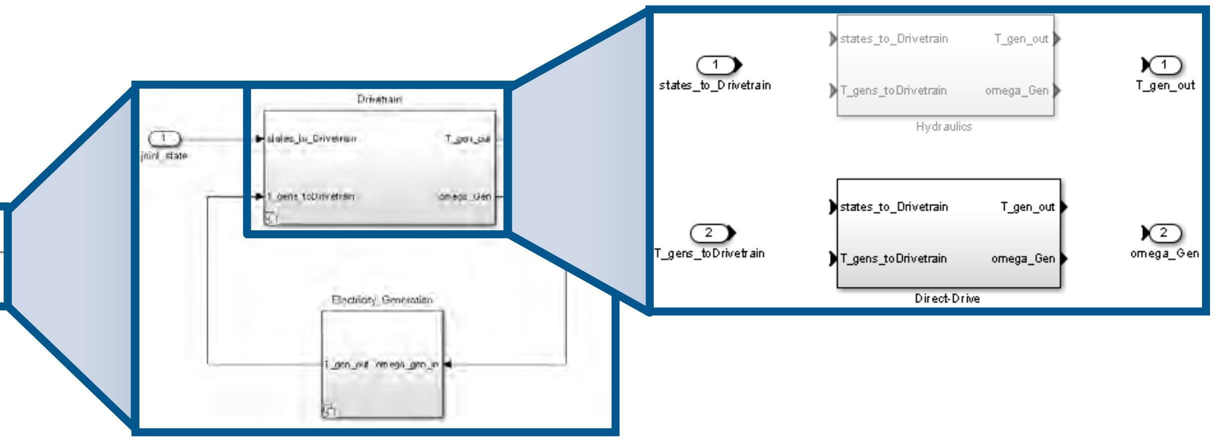
PCCs Types



Power Conversion Chains





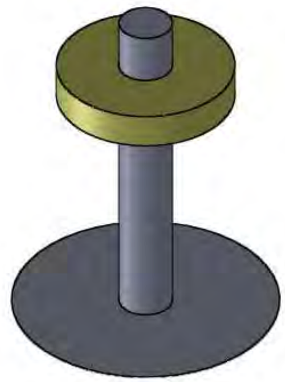


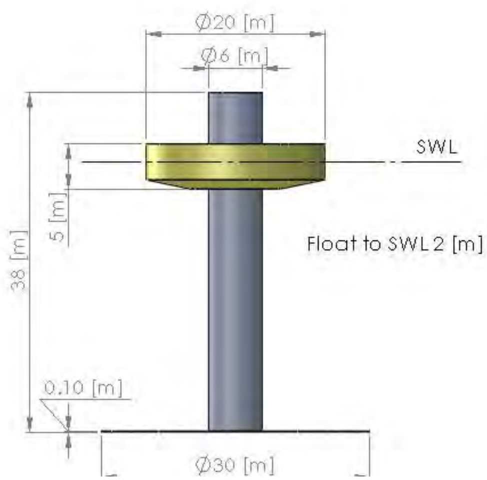
PTO-Sim (alpha version) Development by SNL

Accomplishments & Progress

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

Reference Model 3 (RM3) Point Absorber





Float				
CG (m)	Mass (tonne)	Moment of inertia (kgm^2)		
0	727	20907301	0	0
0		0	21306091	4304.8
-0.72		0	4305	37085481

Spar/Plate				
CG (m)	Mass (tonne)	Moment of inertia (kgm^2)		
0	878	94419614	0	0
0		0	94407091	217593
-21.3		0	217593	28542225

Tests performed:
- 1DOF code-to-code comparison
- 3DOF code-to-code comparison

Codes used:
- WEC-Sim
- WaveDyn
- AQWA
- OrcaFlex

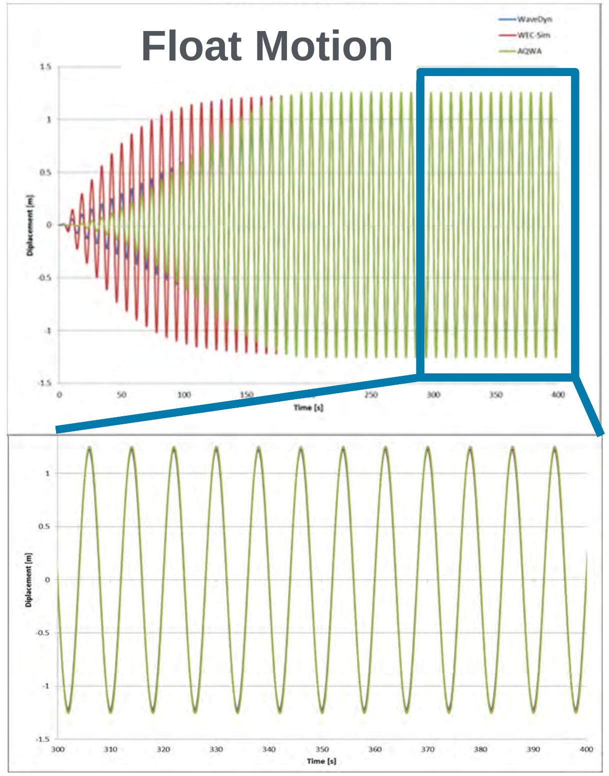
PTO:
- Modeled without damping
- Modeled with linear damper

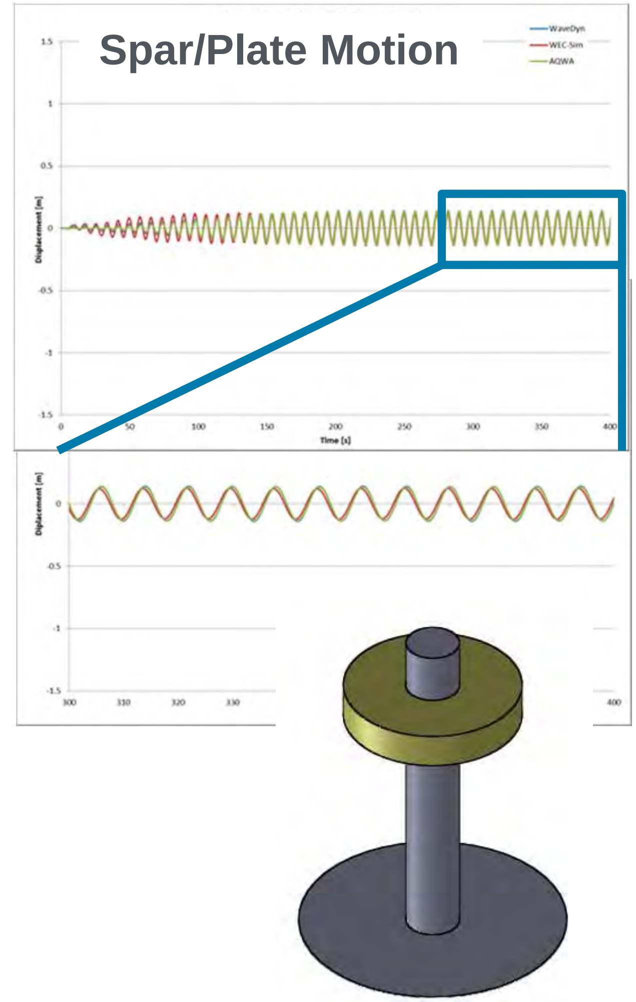
WEC-Sim Verification via Code-to-Code Comparison

Codes used:
- WEC-Sim
- WaveDyn
- AQWA

Degree of Freedom:
- Heave

Regular Wave:
- H = 2.5 [m]
- T = 8 [s]





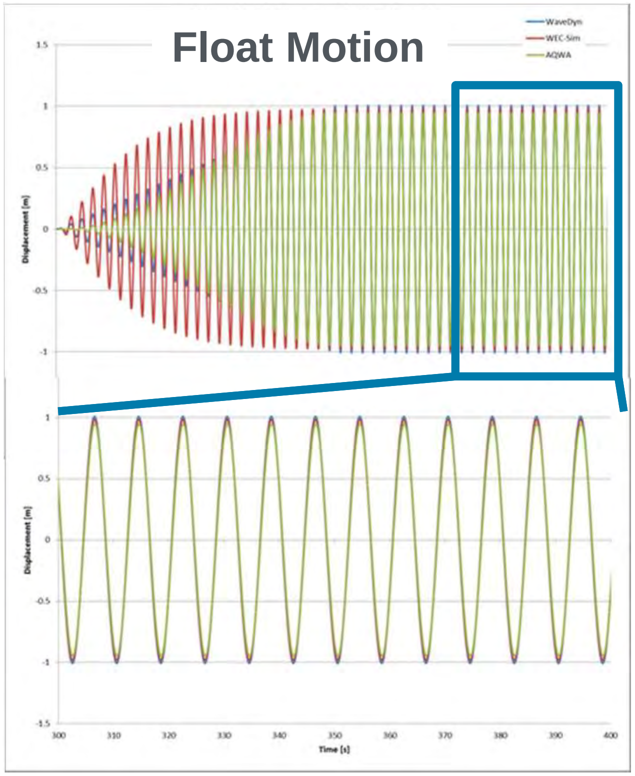
Results
- Initial transients from wave "ramp function"
- Excellent agreement between WEC-Sim, WaveDyn, and AQWA

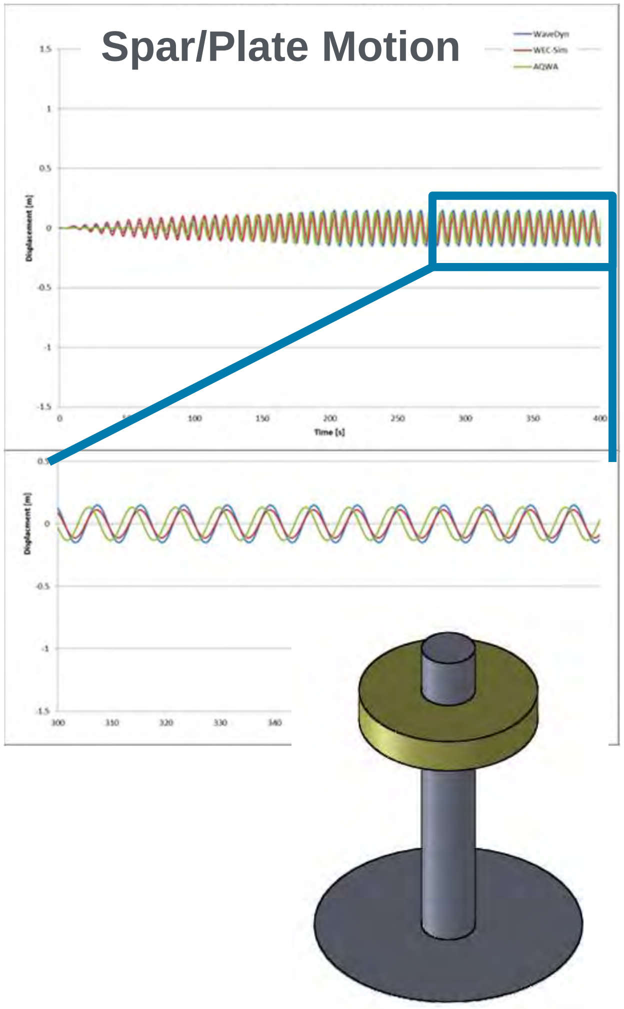
Completed 1DOF Code-to-Code Comparison without PTO

Codes used:
- WEC-Sim
- WaveDyn
- AQWA

Degree of Freedom:
- Heave

Regular Wave:
- H = 2.5 [m]
- T = 8 [s]
- C_{PTO} = 1200 [kN-s/m]





Results
- Initial transients from wave "ramp function"
- Excellent agreement between WEC-Sim, WaveDyn, and AQWA

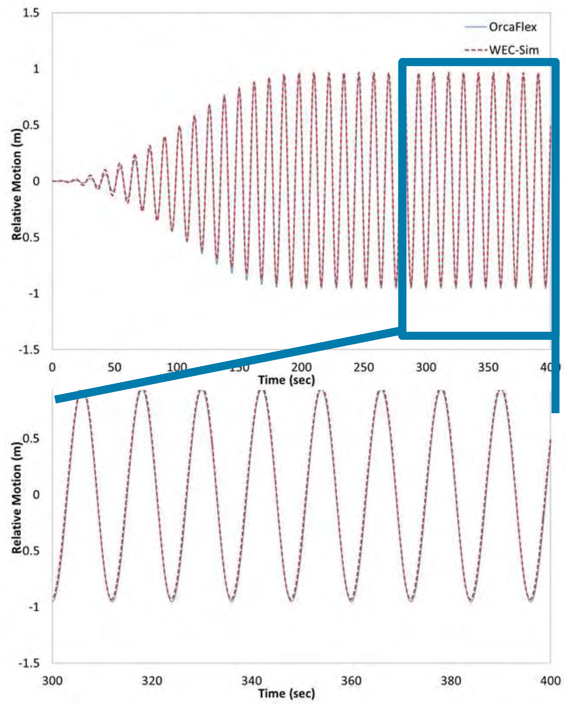
Completed 1DOF Code-to-Code Comparison w/PTO

Codes used:
- WEC-Sim
- OrcaFlex
- AQWA

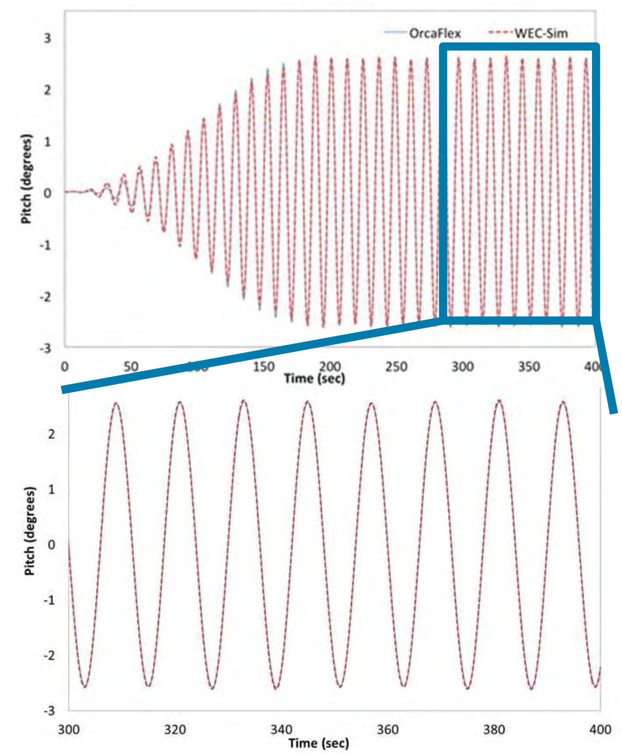
Degrees of Freedom:
- Heave, pitch and surge

Regular Wave:
- H = 2.5 [m]
- T = 12 [s]

Relative Heave Motion



Pitch Motion



Results:
- Initial transients from wave “ramp function”
- Excellent agreement between OrcaFlex and WEC-Sim
- Difficulty simulating 3DOF with WaveDyn and AQWA

Completed 3DOF Code-to-Code Comparison w/o PTO

Major Project Accomplishments:

- Completed the WEC-Sim Modeling Plan in collaboration with DOE HQ and NREL to outline the 3 year project objectives, milestones and schedule.
- Established a GitHub code repository for the WEC-Sim project that is used by the WEC-Sim team to collaborate on WEC-Sim's code development and application.
- Developed the structure of the WEC-Sim code in the first year of the project in a modular structure, and uploaded a functional pre-alpha release to the GitHub repository.
- Completed the alpha version of WEC-Sim and demonstrated its functionality via a Webinar to DOE HQ at the end of FY13
- Applied the WEC-Sim code to model RM3, the heaving point absorber WEC developed by the Reference Model Project.
- Applied the WEC-Sim code to model RM5, the pitching WEC developed by the Reference Model Project.
- Verified the code's functionality by modeling the RM3 device in WEC-Sim, and via a code-to-code comparison using the commercial codes WaveDyn, AQWA and OrcaFlex.

Project Status:

All WEC modeling tasks are currently on schedule

SNL Project Budget

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

Project Funding History

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0K	N/A	$300K	N/A	$1025K	N/A

Budget Notes

– FY13 Budget, all $300K of funding was received in Q4 of FY12
– FY14 Budget, $200K of funding was received in Q4 of FY13

Project Spending

– FY14 project costs as of December 31st = $63K
  - Funding reflects both WEC-Sim and EEM projects
  - SNL wave modeling project staff ramp up in FY14

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$0K	$174K	$882K

Multi-Lab Collaboration:

WEC-Sim: NREL and SNL

Extreme Events Modeling: SNL and NREL

In-person team meetings every 2-3 months

Weekly telecon and/or email interaction

Communications and Technology Transfer:

This work has been disseminated through papers, presentations, and workshops.

- WEC-Sim publication and two presentations at 2013 METS in Washington, D.C.
- WEC-Sim presentation at IEA OES Annex V workshop in Edinburgh, Scotland
- WEC-Sim publication and presentation at ISOPE 2013 in Anchorage, AK
- Upcoming papers in 2014 at GMREC/METS and OMAE

GitHub is used for WEC-Sim development and distribution:

- WEC-Sim will be publically available in Q3 FY14 at github.com/NREL/WEC-Sim, on OpenEI, the NREL codes webpage, and the SNL codes webpage

WEC-Sim user outreach and training planned for WEC developers and research institutions

Next Steps and Future Research

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

WEC-Sim FY14/Current Research:

- Code-to-code comparisons for WEC-Sim verification
- Complete Beta version of WEC-Sim for public release
- Develop a test plan for WEC-Sim experimental validation

WEC-Sim Future Research:

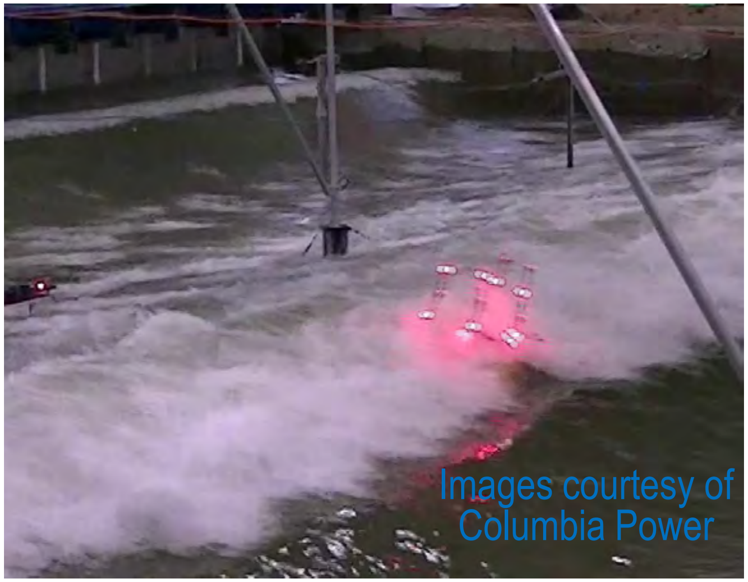
- Evaluate the pros/cons of moving to a fully open-source code
- Apply WEC-Sim to model a third WEC device
- Plan and perform experimental wave tank tests for WEC-Sim validation

Sandia National Laboratories

NREL

Extreme Events Modeling (EEM)

NREL and SNL are working to develop a procedure for modeling WECs during extreme events



FY14 Milestones

Literature review: Perform a literature review to understand state of the art methods

Workshop: Hold a technical workshop with 20-30 experts from offshore wind, oil and gas, shipping, and MHK industries with the goal of identifying best practices and areas where research is needed to improve numerical and experimental predictive methods

↓

Use results to direct future WEC extreme events experimental and numerical modeling efforts

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

Open-WARP (Wave Analysis and Response Program):

Predicting Hydrodynamic Forces for Renewable Ocean Energy

(with contests!)

OpenWARP Challenge

Andy LaMora

Appirio Topcoder

alamora@appirio.com | (917) 312-7406

February 24 2014

Purpose & Objectives

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

Problem Statement: Develop an open source version of the BEM code (OpenBEM) for use in the WEC-Sim simulation code.

Impact of Project: Removing the need to purchase a commercial BEM code will significantly reduce the cost of using WEC-Sim. The commercial BEM code is the most expensive part of the WEC-Sim code.

This project aligns with the following DOE Program objectives and priorities

MHK
- Advance the state of MHK technology
- Develop key MHK testing infrastructure, instrumentation, and/or standards

Hydropower
- Advance new hydropower systems and/or components for demonstration or deployment
- Optimize existing hydropower technology, flexibility, and/or operations

Technical Approach

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OpenWARP is executed with Contests

- DOE has an IAA with NASA's Center of Excellence for Collaborative Innovation
- COECI engages Harvard to study the technology of Crowdsourcing
- Harvard facilitates contest production through TopCoder
- TopCoder decomposes projects ("challenges") into atomized contests.
- Contests are outcome based: many may play, but only successful outcomes pass, and only winners earn.
- The TopCoder Community of Competitors includes both software developopment and algorithm/mathematics professionals

Many ways to build BEM: Use contests to discover them

- Suitable Open Source packages may exist
- TopCoder competitors can build from scratch
- A hybrid of both may be best

Technical Approach

Contests (on TopCoder) are very effective for…

- Finding solutions, not proposals (competitions produce results that meet your screening criteria)
- Sourcing useful new solutions from outside the target discipline
  - Particularly effective in data science
  - And in "ideation"
- Reducing prototype and development costs

And are less effective for…

- White papers
- Anything that has to be mailed in a box

The OpenWARP Challenge is designed to these opportunities and constraints.

Managing Projects of Atomized Contests

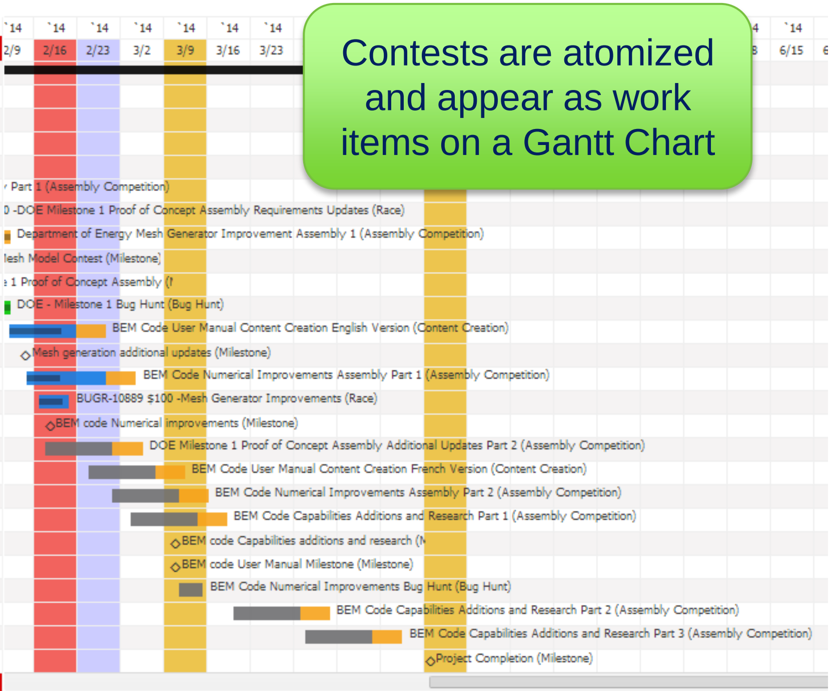
Game Plan Gantt Chart Hide Left Panel

Batch Edit Exp

Drafts	Scheduled	Active	Finished	Cancelled
7/$31,012.50	0/$0.00	1/$5,610.00	5/$8,496.66	0/$0.00

	Challenge Type	Duration	% Comp.	Start	FR End	APR End
- DOE OpenWARP		192 Days	43%	10/16/13	2/24/14	4/25/14
BUGR-9821 $100 - minisite for the Department of Energy project - wo...	Race	12 Days	100%	10/16/13	10/27/13	10/27/13
DOE Open-WARP Software Copilot Opportunity	Copilot Posting	15 Days	100%	10/25/13	11/7/13	11/7/13
BUGR-9886 $50 - minisite for the Department of Energy project (part...	Race	5 Days	100%	10/25/13	10/29/13	10/29/13
DOE Open-WARP Software Copilot Opportunity	Copilot Posting	8 Days	100%	11/18/13	11/25/13	11/25/13
DOE Milestone 1 Proof of Concept Assembly Part 1	Assembly Competition	12 Days	100%	12/26/13	1/6/14	1/6/14
BUGR-10483 $450 -DOE Milestone 1 Proof of Concept Assembly Requirem...	Race	14 Days	100%	1/16/14	1/29/14	1/29/14
Department of Energy Mesh Generator Improvement Assembly 1	Assembly Competition	18 Days	100%	1/29/14	2/10/14	2/15/14
DOE - CAD to Mesh Model Contest	Milestone	-	100%	1/29/14	1/29/14	1/29/14
DOE Milestone 1 Proof of Concept Assembly	Milestone	-		1/31/14	1/31/14	1/31/14
DOE - Milestone 1 Bug Hunt	Bug Hunt	4 Days	100%	2/12/14	2/15/14	2/15/14
BEM Code User Manual Content Creation English Version	Content Creation	17 Days	54%	2/15/14	2/26/14	3/3/14
Mesh generation additional updates	Milestone	-		2/17/14	2/17/14	2/17/14
BEM Code Numerical Improvements Assembly Part 1	Assembly Competition	19 Days	30%	2/18/14	3/3/14	3/8/14
BUGR-10889 $100 -Mesh Generator Improvements	Race	6 Days	79%	2/20/14	2/25/14	2/25/14
BEM code Numerical improvements	Milestone	-		2/21/14	2/21/14	2/21/14
DOE Milestone 1 Proof of Concept Assembly Additional Updates Part 2	Assembly Competition	17 Days		2/21/14	3/4/14	3/9/14
BEM Code User Manual Content Creation French Version	Content Creation	17 Days		2/28/14	3/11/14	3/16/14
BEM Code Numerical Improvements Assembly Part 2	Assembly Competition	17 Days		3/4/14	3/15/14	3/20/14
BEM Code Capabilities Additions and Research Part 1	Assembly Competition	17 Days		3/7/14	3/18/14	3/23/14
BEM code Capabilities additions and research	Milestone	-		3/14/14	3/14/14	3/14/14
BEM code User Manual Milestone	Milestone	-		3/14/14	3/14/14	3/14/14
BEM Code Numerical Improvements Bug Hunt	Bug Hunt	5 Days		3/15/14	3/19/14	3/19/14
BEM Code Capabilities Additions and Research Part 2	Assembly Competition	17 Days		3/24/14	4/4/14	4/9/14
BEM Code Capabilities Additions and Research Part 3	Assembly Competition	17 Days		4/5/14	4/16/14	4/21/14
Project Completion	Milestone	-		4/25/14	4/25/14	4/25/14

Time scale : Day Week Month Quarter Hide Time Milestone



Accomplishments

- NEMOH: Collaboration with ECN to facilitate release under Apache 2.
  - Supplies a significant portion of the most challenging requirements
  - Competitors are able to “bootstrap” solutions with NEMOH
  - May allow greater focus on downstream usability
- First Mesh Generation contest produced very good results

Timeline

- ~2 weeks behind on in-process targets
- On time for Milestone 1 (Mesh Generator)
- Milestone 2 on-time (but untested)

Awards and Recognition

Topcoder Members Awarded to date after 5 Contests:

Contest Type	# of Members
Unique Registrants	87
Unique Submissions	7
Winners To Date	4

Project Plan & Schedule

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

Summary			Legend
WBS Number or Agreement Number			Work completed
Project Number			Active Task
Agreement Number			Milestones & Deliverables (Original Plan)
			Milestones & Deliverables (Actual)

	FY2013				FY2014				FY2015			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: OpenWARP												
Q1 Milestone: Launch												
Q2 Milestone: Complete Mesh Generator												
Q3 Milestone: Complete Integrated Math Package												
Q3 Milestone: Go, No-go for Phase 2												

Comments

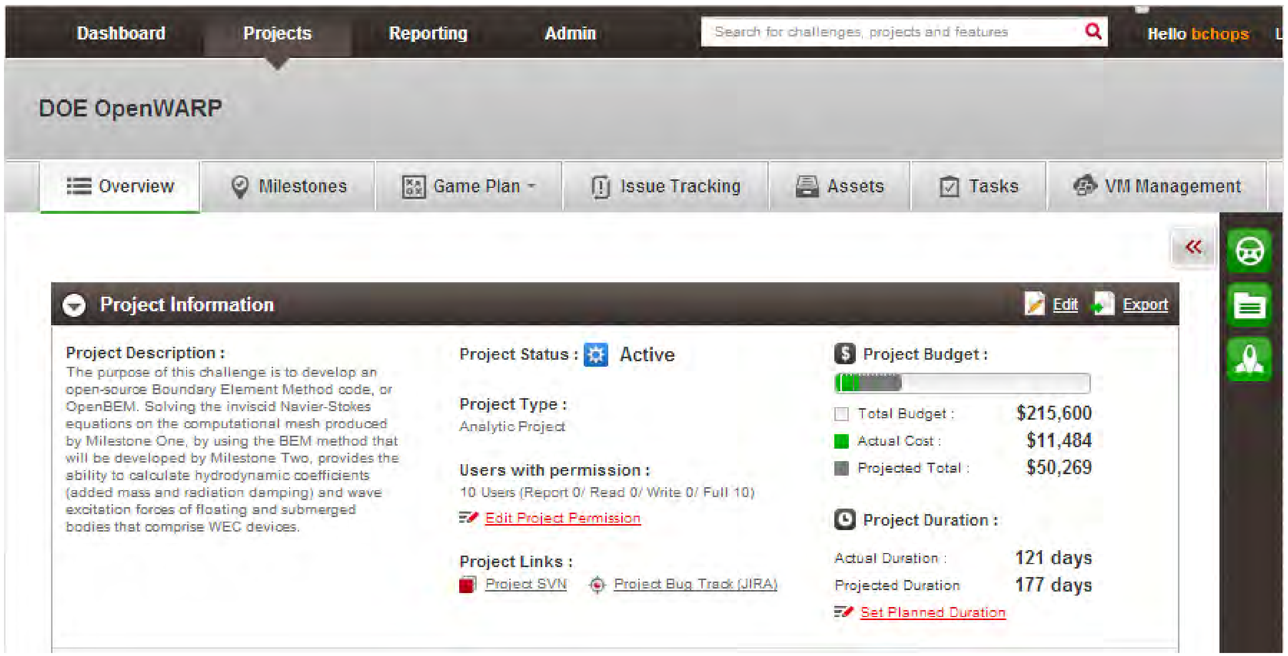
- Initiated: 9/1/2013. Planned Completion: 7/1/2014
- Currently on-time
- July 2014: Go, no-go decision on Phase Two (optimization, productization)

Project Budget

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

Budget History

Project Management on TopCoder Cockpit



- Use of NEMOH is expected to reduce math development costs
- Approximately 25% of the build budget has been committed

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

- DOE (Michael Lawson, Brooke White, Alison LaBonte, et al)
- NASA Center of Excellence for Collaborative Innovation
- Harvard University (Dr. Rinat Sergeev - Data Science)
- TopCoder (Ashley Thomas, Rashid Sial - PMs)
- The 87 TopCoder members who have participated to date.

Communications and Technology Transfer:

- After only 5 contests, 87 participants new to WEC have learned about the technology and library. 7 members have attempted implementation.
- This challenge served as the catalyst to bring NEMOH forward with an Open Source license that is friendly for business use.

Next Steps and Future Research

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

FY14/Current research:

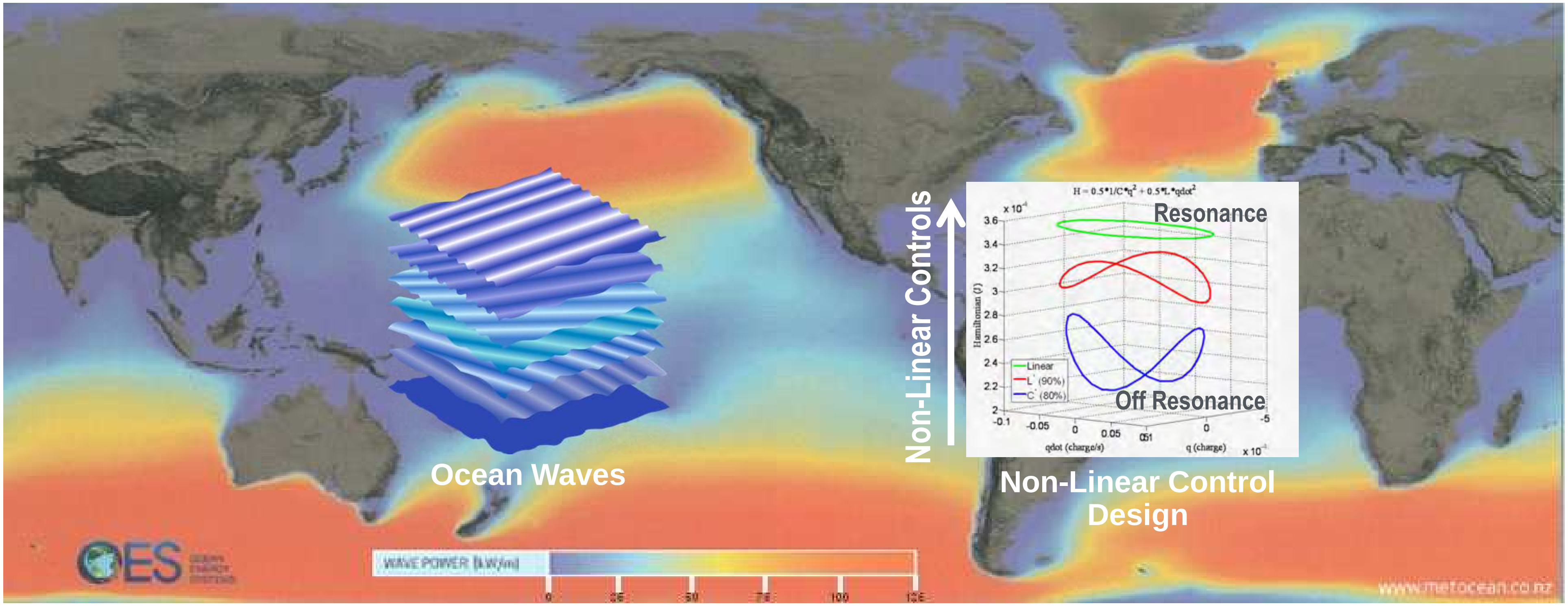
- Complete the Mesh Generator
- Fill gaps in the math package
- Package and document OpenWEC for general use

Proposed future research:

- Optimize OpenWEC for outstanding performance
- Develop an easy-to-use, dashboard style GUI

Water Power Peer Review

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



New Project: Advanced WEC Controls

Computational Modeling & Analysis

Tim Crawford
Sandia National Laboratories
tjcrawf@sandia.gov
(505) 844 2949
24 Feb 2014

Purpose & Objectives

Problem Statement: The LCOE of WEC devices is too high compared to other forms of power generation. To enable significant market penetration, the LCOE of WEC devices must be significantly reduced.

Impact of Project: Demonstrate a *50% reduction* in calculated *LCOE* of resonant WECs through fundamentally changing their power conversion characteristics with broadly applicable advanced control strategies.

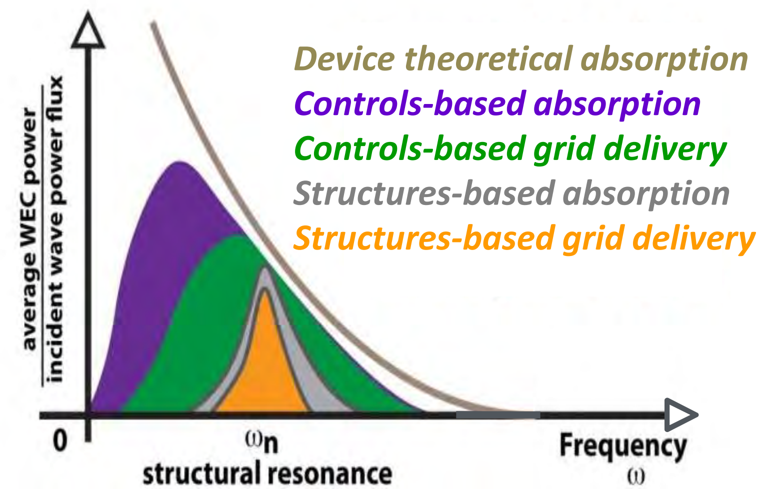
This project aligns with the following DOE Program objectives and priorities: Advance the state of MHK technology

Technical Approach

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

The ocean is **spatially, temporally, and energetically** variable.

Program to expand the narrow band over which resonant WECs currently produce power by extending the structurally defined phase matched absorption to a real-time *controls-based* phase matched absorption.



Representative Capture Widths of a Point Absorber

Systematically introduce complexities in numerical tools and the complimentary verification and validation experiments

Evaluate multiple control strategies to increase applicability of work to multiple resonant architectures and identify comparative metrics

Leverage advanced controls expertise from past DOD/DARPA projects to address inherent nonlinearities of WECs

Technical Approach

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

Performance Model
Numerical Tools
Experimental Validation

Wave Foreknowledge Model
Numerical Tools
Experimental Validation

Control Algorithms
Numerical Tools
Experimental Validation

Closed Loop Real-Time Demonstration

Scaled Experimental Validation

Comprehensive/quantitative approach versus point solution

- Multiple control strategies
- Valid for multiple device designs
- Valid for multiple power conversion chains
- Applying linearized and *nonlinear* controls
- Validation under many scenarios
- Publically available results and tools versus proprietary
- Applicable to whole industry, not specific design

12.2-million-gallon tank in Carderock, West Bethesda, MD
Naval Surface Warfare Center

Systematic approach of validation testing will result in realistic and proven tools

Project Plan & Schedule

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

Summary	Legend	
WBS Number: 1.1.1.4		Work completed
Project Number: 21848		Active Task
Agreement Number: 26923		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Advanced WEC Controls								
FY13 Q4 Milestone: Develop Research Plan								
FY14 Q1 Milestone: Recommendation of Wave Tank to include specifications								
FY14 Q2 Milestone: Provide evaluation framework of control strategies								
FY14 Q3 Milstones: Complete alpha version of performance model								
FY14 Q4 Milestone: Provide test plan for validation wave tank test								
Current work and future research								
Physical scaled model design & fabrication								
Performance model development								
Initial selection of control strategies								

Comments

- Overall projected timeline: July 2013 to March 2018
- 1st Go/no-go decision point: ability to show 100% improvement in absorbed power on performance model, March 2015

Program on track according to schedule submitted to DOE

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$50K	$0	$816,650	$0

- FY13 Q4:
  - Developed and submitted Advanced WEC Controls Research Plan to DOE
- FY14 Q1: 14% ($114K) expenditure, as of end of Q1.
  - Project is more heavily loaded mid and end of year in preparation of physical scaled model build, performance model development and initial controls work, as reflected in the Gantt Chart

Program on track according to Spend Plan submitted to DOE

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: Wave tank partner has been recommended to DOE. Other partner involvement is on-going, focusing on experimentation and wave foreknowledge.

Communications & Technology Transfer: As the project progresses, conclusions will be presented to the DOE Team/Tech Leads and Industry Stakeholders, through DOE/SNL public portals and in publications & conference proceedings. Sites such as DOE's OpenEI, DOE & SNL newsletters and websites, along with direct technical outreach will be utilized. Ultimate goal is to publically release the data sets and codes behind the numerical tools for the enhancement of the water power industry.

Technical collaboration and outreach is a priority and all means of communication available will be utilized

Next Steps and Future Research

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

FY14/Current research:

The first stage of the project focuses on the fundamentals of the multi-year project: the WEC performance model, the WEC design, wave tank selection, and initial control strategy evaluation. A scaled device and performance model will be validated in Q1 of FY15.

FY14 Milestones:

Q1: Recommendation of the most appropriate wave tank
Q2: Control strategies presented in an evaluation framework.
Q3: Alpha version of the performance model exhibited.
Q4: Test plan for the first stage delivered.

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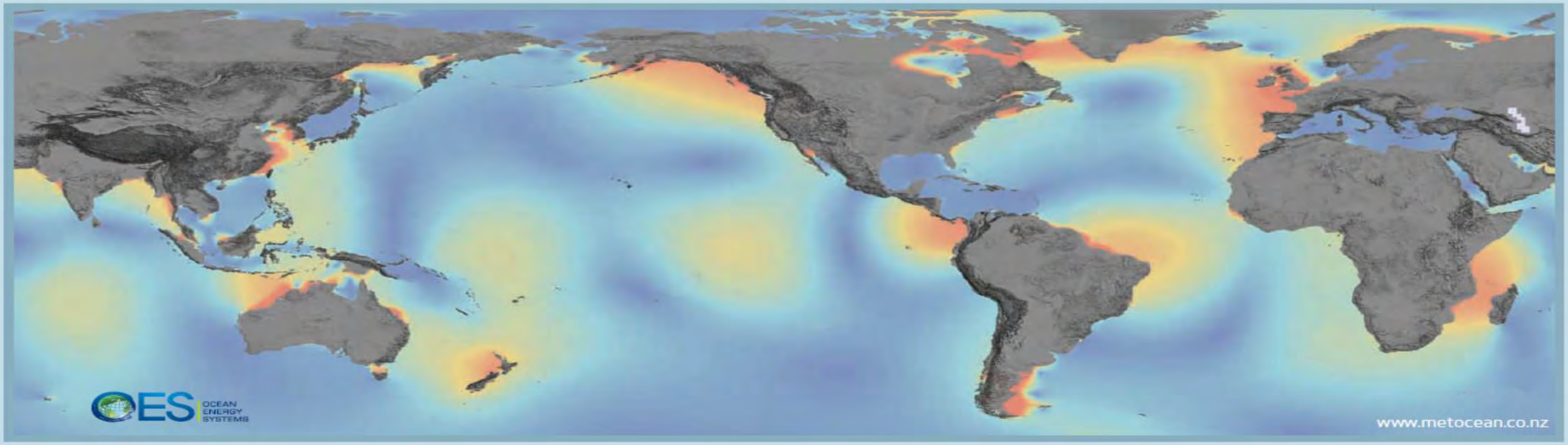

Tidal Range

Tidal range energy is potential energy derived by height changes in sea level, caused by the gravitational attraction of the moon, the sun and other astronomical bodies on oceanic water bodies. The effects of these tides are complex and most major oceans and seas have internal tidal systems.

The rise and fall of the tide (range) offers the opportunity to trap a high tide, delay its fall behind a barrage or fence, and then exhaust the potential energy before the next tidal cycle.

The map shows the global pattern of the M2 tidal constituent, the principal lunar semidiurnal component. Note that the range is usually significantly amplified nearshore, so that tidal ranges may reach as much as 17 m in the Bay of Fundy (eastern Canada).

The worldwide theoretical power of tidal power (including tidal currents) has been estimated at around 1,200 TWh / year [8].

[8] World Energy Council, 2010.

Tidal Research: Model Development and Field Measurement Campaign

Bob Thresher
NREL Research Fellow
Robert.Thresher@nrel.gov
February 25, 2014

Purpose & Objectives

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

Problem Statement: The marine hydrokinetic industry and the Department of Energy's Water Power Program needs performance and load simulation tools, and in depth field measurements to validate these tools, so that the commercial viability, performance, and reliability of marine current turbines can be accurately predicted.

Impact of Project:

- The project will provide the needed open source simulation tools for tidal, river and ocean devices.
- The project will also take field measurements which can be used to validate the simulation tools being developed under program sponsorship. Validation of the performance and dynamic simulation tools will further both the industry's confidence in the tools and their use, as well as the market's confidence in MHK technology's performance, reliability and durability.

This project aligns with the following DOE Program objectives and priorities:

- To Advance the state of MHK technology

Technical Approach

Technical approach: To address the problem, Sandia, Pacific Northwest National Lab and NREL have developed open source current device simulation tools (HARP_OPT, HydroFAST, CACTUS) based on existing wind turbine models, and initiated the planning of a comprehensive experimental measurement campaign to measure performance, loads, and flow characteristics for current devices.

Key Issues to be Addressed:

1. The numerical simulation tools used to simulate performance, loads, structural dynamics, and turbulence response need to be validated with experimental measurements from sub- and full-scale experiments.
2. Comprehensive physical model experiments (e.g., Sandia turbine experiment in the ARL water tunnel) and the full-scale open-water field measurement campaign (FMC) measures the power curve and dynamic responses such as: torque, tower moments, blade root loads, the blade spanwise section loadings, turbulence inflow, as well as wake velocities.
3. The FMC provides the first full-scale field measurements for the spanwise blade load distribution using fiber Bragg grating (BFG) sensors, and in-situ wake measurements.

Concept Sketch for the Field Measurement Campaign

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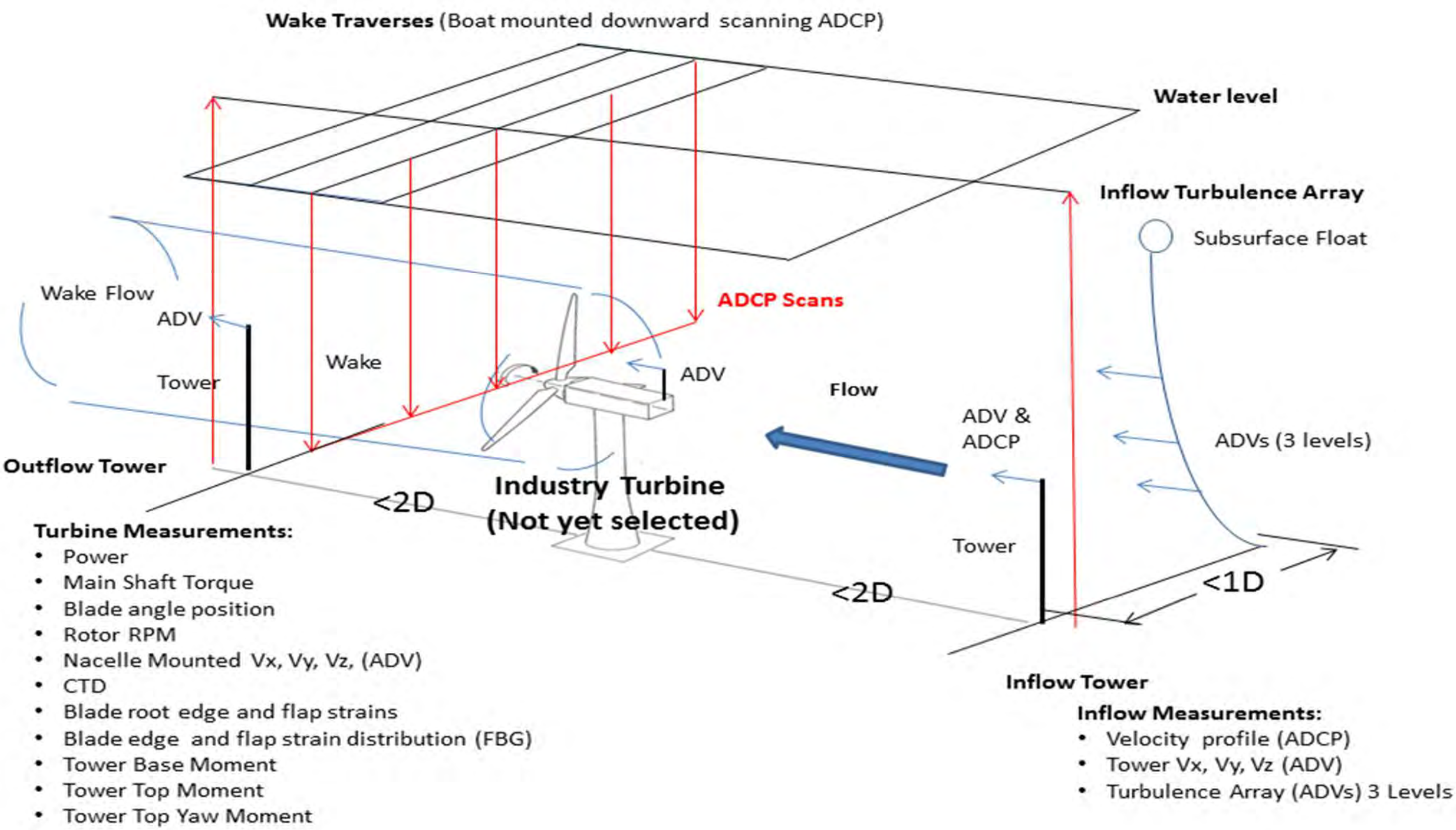

Project Plan & Schedule

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

Summary
WBS Number or Agreement Number 1.1.2.1
Project Number
Agreement Number 26494

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plar
Milestones & Deliverables (Actual)

Task / Event	FY2013 Q4 (Jul - Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Tidal Device Field Measurement Campaign to Validate Tools					
Q4 Milestone: Hold project kickoff meeting					
Q1 Milestone: Complete draft test plan					
Q2 Milestone: Release beta version of HydroFAST					
Q3 Milestone: Select Test Turbine (Agree upon test plan, joint work statement, NDA					
Q4 Milestone: Adapt instrumentation system for test turbine with live sensors					
Q4 Milestone: Deliver technical report or presentation to DOE					
Current work and future research					

Comments

- Field Measurement Campaign project initiated during the summer of 2013
- HydoFast simulation model development initiated in FY2012, and development has been delayed to work on other DOE Priorities in FY2013
- Test turbine criteria and options are under study
- Actual testing tentatively planned for FY2015

Project Budget

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$350k	n/a	$573k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY13	Spend Plan FY14
$1.6k	$390k

- Received $350k at the end of FY13, spending was minimal
- Current plans to preserve 25% carryover per DOE guidance
- Project costs as of December 31st: $13k

Research Integration & Collaboration

FMC Team:

1. Industry Partner – (Test Turbine Pending Negotiations)
2. Sandia National Laboratories - (responsible for the FBG blade measurements and related data system)
3. Pacific Northwest National Laboratories – (wake measurements)
4. National Renewable Energy Laboratory – (Test coordination, MOIS data acquisition system and turbulent inflow measurements)

Communications and Technology Transfer:

1. Open source codes, related documentation, and nonproprietary test results are to be made available on OpenEI.org at http://en.openei.org/wiki/Gateway:Water_Power
2. Topical project reports will be available on contributing team members' websites and selected project results will be presented at national and international conferences.

Current Research Outline

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FY14 and FY15 research plans

1. Complete draft test plan in Q1, FY14
2. Release beta version of HydroFAST in Q2. (HARP_OPT previously released in 2012)
3. Select test turbine in Q3, FY14
4. Develop and finalize the FMC test plan in Q3. (FY14 test plan, joint work statement, NDAs/CRADAs, etc.)
5. Final instrumentation system for testing DAS with live sensors in Q4, FY14
6. Technical review of final plans with DOE in Q4, FY14
7. Integrate and check instrumentation on the test turbine in Q1, FY15
8. Perform test campaign (two month campaign) in Q2, FY15
9. Retrieve test turbine (TBD)
10. Data analysis and reporting in Q3 – Q4, FY15

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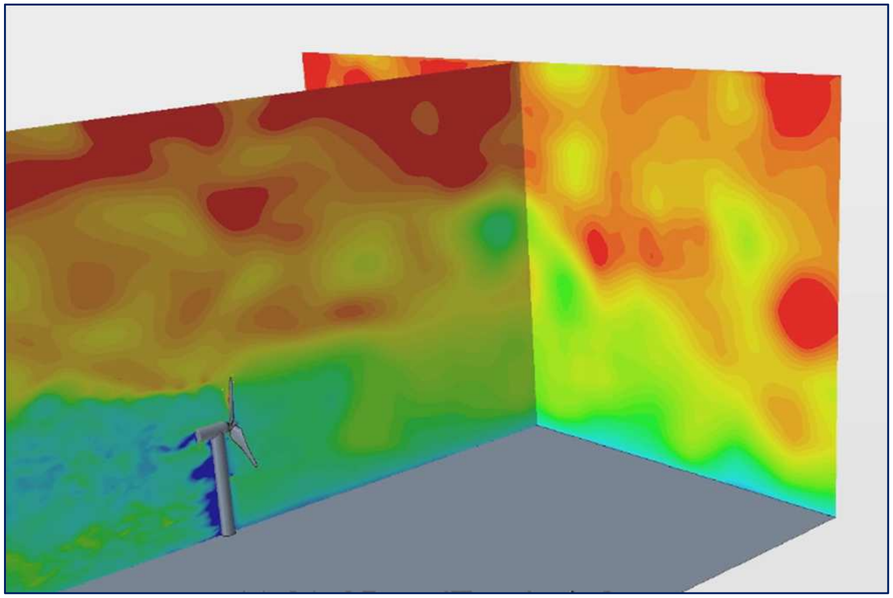

Tidal Device Research:
Field Measurement Campaign to Validate Modeling Tools

Marshall Richmond
Pacific Northwest National Laboratory
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February 24, 2014

Purpose & Objectives

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

Problem Statement: Wake recovery and inflow measurements for a full-scale tidal turbine are needed to validate design modeling and array placement tools

Impact of Project: The FMC project will provide a comprehensive set of field measurements of velocity distributions around an operating tidal turbine for use in model validation

This project aligns with the following DOE Program objectives and priorities:

- Advance the state of MHK technology
- Develop key MHK testing infrastructure, instrumentation, and/or standards

Technical Approach

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

- Test Requirements and Instrumentation Plan
- Site and Turbine Specific Test Plan
  - Site specific issues, logistics, local marine services
- Instrumentation Package Design
  - Bottom tripod with upward looking ADCPs upstream and downstream of the turbine
  - Additional ADCPs (short term lease) for increased spatial coverage
  - Shipboard mobile ADCP traverses
  - CTD casts to characterize vertical density profile
- Shakedown testing in the Columbia River
  - Use a bridge pier wake to test instrumentation and data analysis methods
- Perform FMC measurements at turbine test site

Technical Approach: Wake and Inflow Velocities

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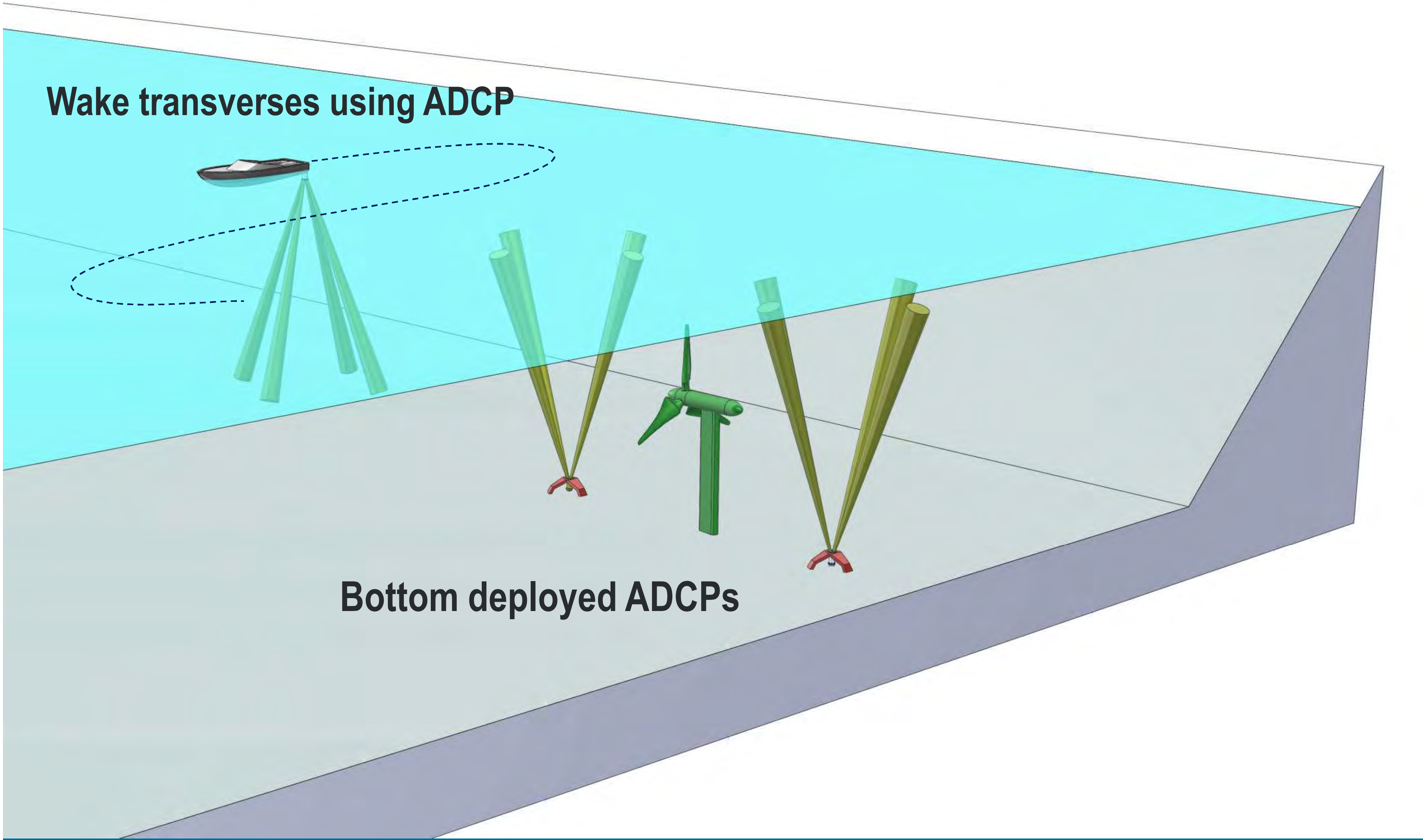

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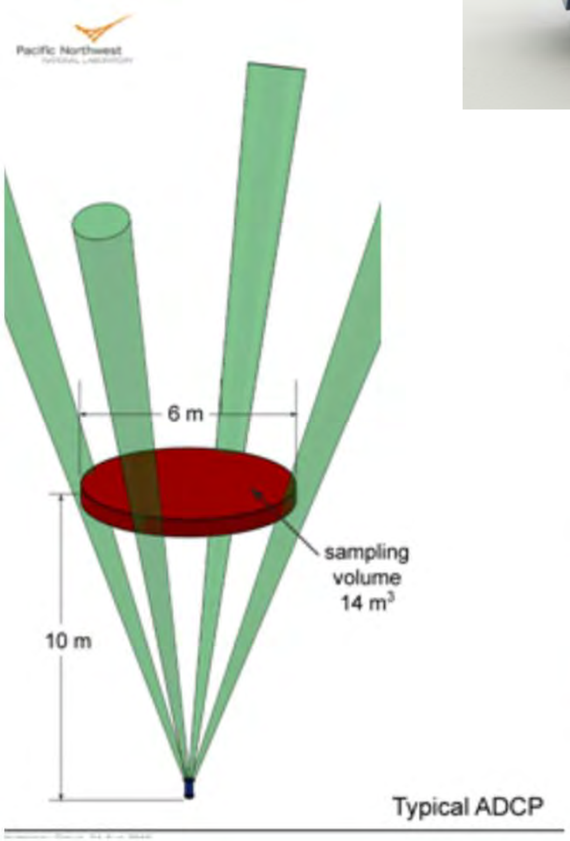
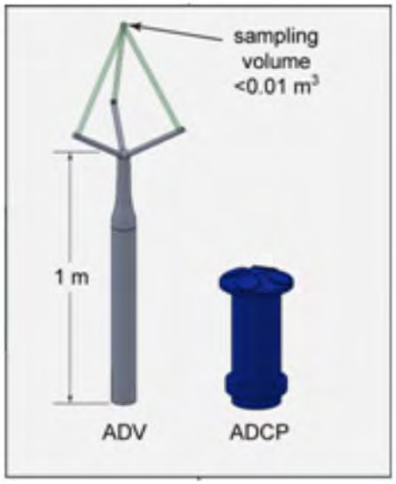
ADCP unit

(RD instruments)





ADCP unit in tripod

Technical Approach: Example data products

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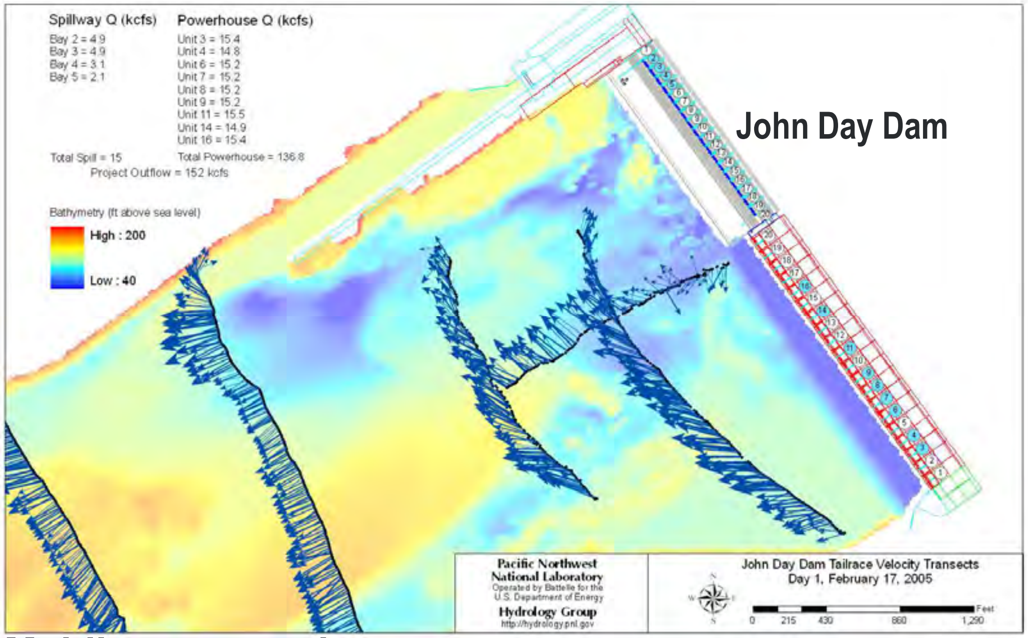
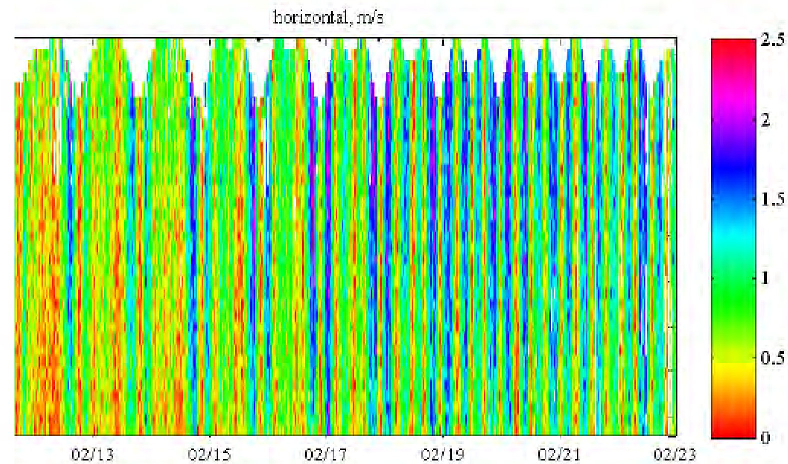
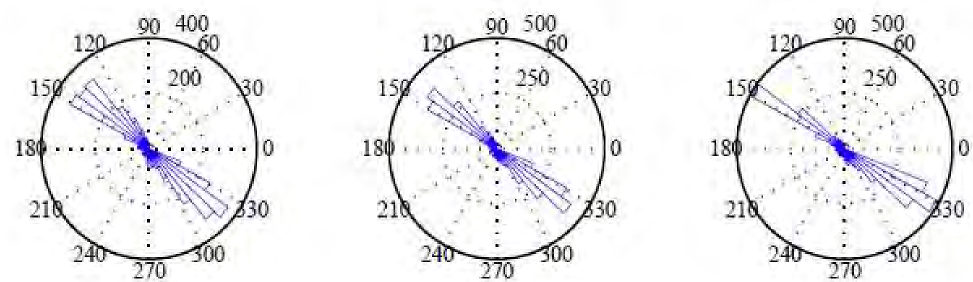


Mobile traverse data (example - downstream of a hydropower dam)

Horizontal velocity depth profile (bottom deployed ADCP)



Velocity direction at different depths



5 m | 10 m | 15 m

Project Plan & Schedule

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

Summary		Legend
WBS Number or Agreement Number 1.1.2.1		Work completed
Project Number		Active Task
Agreement Number 26494		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2013 Q4 (Jul - Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)	FY2015 Q1 (Octt-Dec)
Project Name: Tidal Device Field Measurement Campaign to Validate Tools						
Q4 Milestone: Hold project kickoff meeting	◆					
Q1 Milestone: Complete draft test plan		◆				
Q2 Milestone: Develop a detailed test plan for the turbine testing			◆			
Q3 Milestone: Assemble the instrumentation system and conduct shakedown testing				◆		
Q4 Milestone: Instrumentation ready for delivery at the test turbine site					◆	

Comments

- Field measurement campaign project initiated in September 2013
- Site and turbine selection to be done in FY2014
- Measurements at turbine field site scheduled for FY2015

Project Budget

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

PNNL - Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$200K	n/a	$350k (150k in FY 14 funds, 200k in FY 13 carryover)	n/a

- Received $200K at the end of FY2013
- FY2014 spent to date is approximately 20%

Partners, Subcontractors, and Collaborators: FMC Team:

1. Industry Partner – (Test Turbine and Site Pending Negotiations)
2. National Renewable Energy Laboratory – (Test coordination, DAS and turbulent inflow measurements)
3. Sandia National Laboratories - (responsible for the FBG blade measurements and related data system)
4. Pacific Northwest National Laboratory – (wake measurements)
5. University Collaborators – University of Washington

Communications and Technology Transfer:

1. Nonproprietary test data will made available via a website.
2. Topical project reports will be available on contributing team members websites and selected project results will be presented at national and international conferences.
3. Results will be submitted to peer-reviewed journals.

FY14 and FY15 Research Plans:

1. Complete draft test plan in FY14-Q1
2. Select industry partner and test turbine FY14-Q2
3. Shakedown testing in the Columbia River FY14-Q3
4. Develop and finalize the FMC test plan in FY14-Q3. (test plan, joint work statement, NDAs/CRADAs, etc.)
5. Final instrumentation system for testing DAS with live sensors in FY14-Q4
6. Technical review of final plans with DOE in FY14-Q4
7. Integrate and check instrumentation on the test turbine FY15-Q1
8. Perform test campaign (two month campaign) FY15 Q2
9. Retrieve test turbine and instrumentation (TBD)
10. Data analysis and reporting FY15 Q3 – Q4

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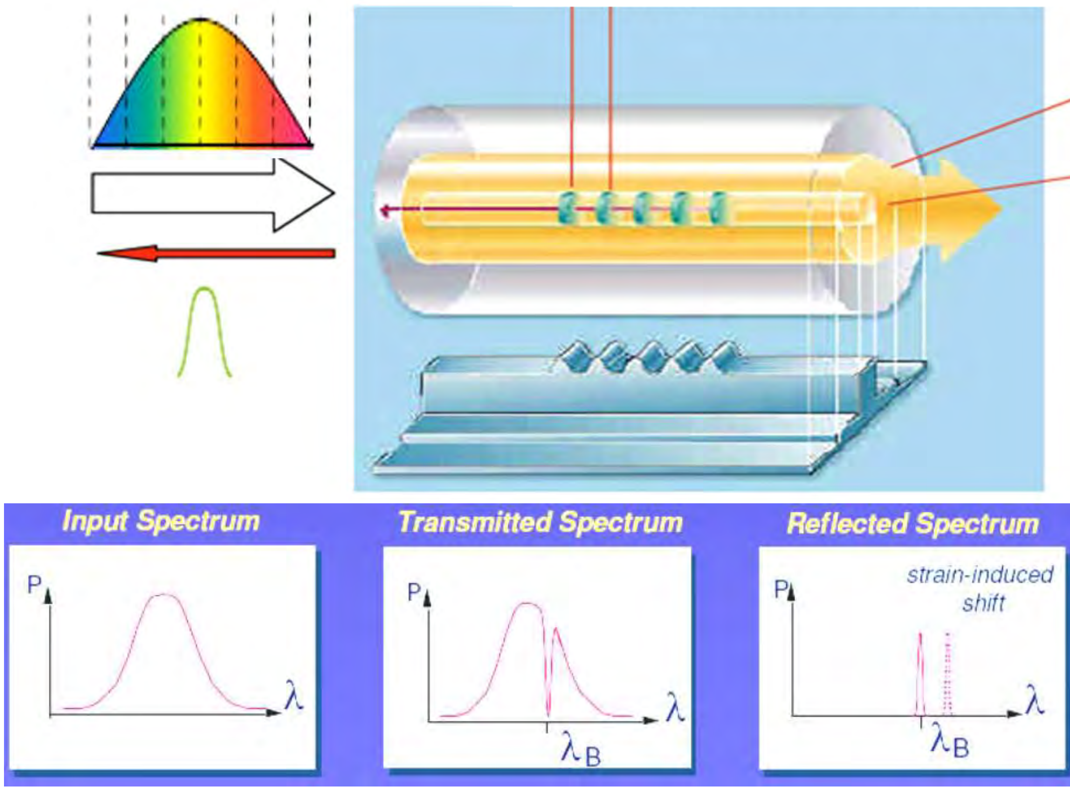


New Project: Tidal device field measurement campaign to validate tools includes upkeep of tools for industry use

Vincent Neary

Sandia National Laboratories

vsneary@sandia.gov 505 284 2199

February 24, 2014

Purpose & Objectives

Problem Statement: Comprehensive in-situ blade load distribution measurements are needed to make significant improvements in tidal turbine rotor design

Impact of Project: The field measurement campaign (FMC) provides first full-scale field measurements for spanwise blade load distribution using fiber Bragg grating (FBG) sensors

This project aligns with the following DOE Program objectives and priorities to provide state of the art:

Advance the state of MHK technology

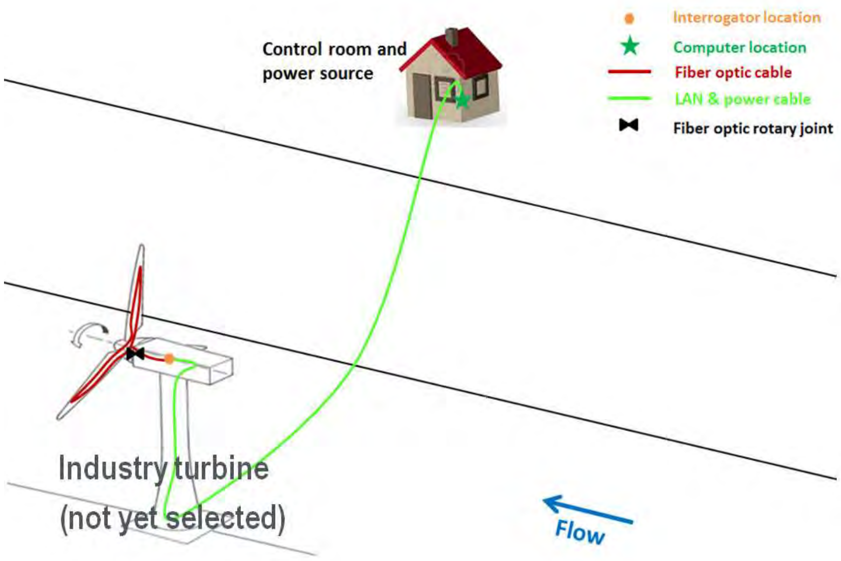
- Improve and optimize design based on analysis of rotor blade structural response to steady and unsteady hydrodynamics and related blade forces
- Validate modeling tools and verify technology performance

Develop key MHK testing infrastructure, instrumentation, and/or standards

- Demonstrate use of novel instrumentation, i.e., FBG sensors in seawater, and instrumentation integration

Technical Approach

1. Design FBG instrumentation system based on turbine type and site condition
2. Bench top testing and calibration
3. System integration
   – FBG system integration with NREL's data acquisition (DAQ) system and other measurement instruments
   – System testing at NWTC, NREL
4. Test turbine dry testing
   – FBG sensor installation at blade root, various blade span lengths, and possibly tower bottom to measure thrust
   – Integrate redundant FBG system to the blade for backup and results verification
   – Testing data acquisition system (DAS) with live sensors
5. Perform FMC ~2 months



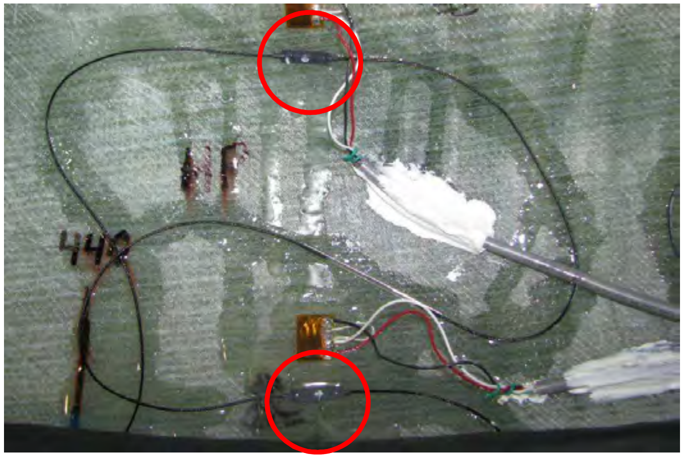
Os3200 strain sensor

Technical Approach

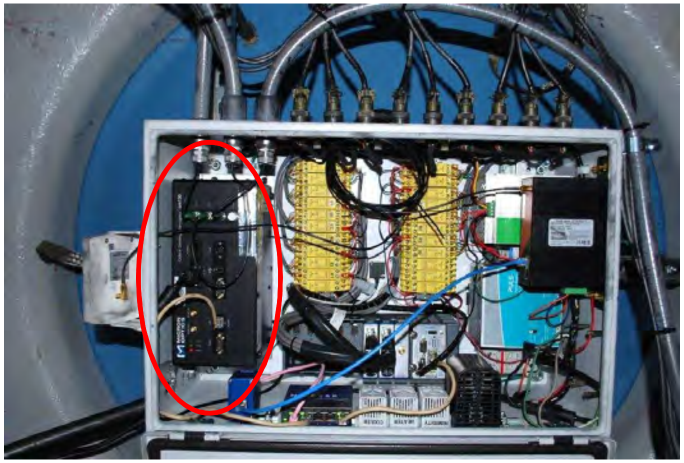
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Sandia's Wind Power Group: Installation of FBG sensors on a wind turbine blade

Sensor installation during blade manufacturing



Sensors surface-mounted using epoxy



FBG interrogator and other instruments installed at turbine nacelle

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number 1.1.2.1	
Project Number 21849	
Agreement Number 26493	

Legend	
(light blue)	Work completed
(blue)	Active Task
◆ (grey)	Milestones & Deliverables (Original Plan)
◆ (black)	Milestones & Deliverables (Actual)

	FY2013	FY2014			
Task / Event	Q4 (Jul - Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Tidal Device Field Measurement Campaign to Validate Tools					
Q4 Milestone: Hold project kickoff meeting	Work completed ◆				
Q1 Milestone: Complete draft test plan		Work completed ◆			
Q2 Milestone: Bench top testing; Select test turbine			◆		
Q3 Milestone: Develop FMC test plan				◆	
Q4 Milestone: Final FBG system for testing DAS					◆
Q4 Milestone: Deliver technical report or presentation to DOE					◆
Current work and future research					

Comments

- Project initiated Summer 2013
- Actual testing tentatively scheduled for FY2015
- Industrial partner has yet to be identified

Project Budget

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

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$450,000	n/a	$225,000	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY13	Spend Plan FY14
$6.5K	$400K

- Received $450k at the end of FY13, spending was minimal
- Received $225k in FY14, project costs $64k as of December 31st
- Q1 spending low, but will increase significantly in subsequent quarters to accomplish FBG system assembly and testing

FMC Team:

1. Industry Partner – test turbine pending negotiations
2. National Renewable Energy Laboratory – test coordination, DAS and turbulent inflow characterization
3. Sandia National Laboratories - responsible for the fiber optic blade measurements and turbulent inflow characterization
4. Pacific Northwest Laboratories – wake measurements

Communications and Technology Transfer:

1. Data at SNL's *MHK Technology* SharePoint site,
2. Topical SNL project reports at SNL's Water Power Publications website, http://energy.sandia.gov/?page_id=834
3. Selected project results disseminated at national and international conferences
   a. Marine Energy Technology Symposium, Global Marine Renewable Energy Conference, April 2016
   b. 6th International Conference on Ocean Energy, September 2016
4. Peer reviewed journal publication submitted Q1, FY16: *Renewable Energy* or *International Journal of Marine Energy*

FY14 and FY15 research plans

1. Completed FBG system test plan, FY14, Q1
2. Bench top testing. FY14, Q2
3. Select industry partner and test turbine, FY14, Q2
4. Develop FMC test plan, FY14, Q3
5. Final FBG system for testing DAS, FY14, Q4
6. Technical review of final plans with DOE, FY14, Q4
7. Integrate/check instrumentation on test turbine FY15 Q1
8. Perform test campaign (two month campaign) FY15 Q2
9. Retrieve test turbine (TBD)
10. Data analysis and reporting FY15 Q3 – Q4

2014 Water Power Program Peer Review

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

Technology Advancement

Wind and Water Power Technologies Office
Alison LaBonte and
Ryan Sun Chee Fore
February 25, 2014

MHK Organizational Structure

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

Marine and Hydrokinetic Technologies

- Computational Modeling and Analysis
- Technology Advancement
- Resource Characterization
- Testing Infrastructure

Key Counterparts and Collaborators

- National Renewable Energy Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Industry
- National Marine Renewable Energy Centers

Water Power Program Key Objectives

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

The 2014 Water Program Peer Review Agenda sessions will cover projects and activities in these priority areas:	
★ Advance the state of MHK technology	• Monday, 2/24 • Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26

Overview: Technology Advancement

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

Goal: Reduce cost and improve performance by 40% by 2020

- Establish and validate the viability of the current generation of MHK devices.
- Focus DOE and industry technology investment through competitive demonstrations.
- Advance the performance of the next generation to be competitive with alternative generation sources.

Priorities: Demonstrate state of the art MHK technologies

- Demonstrate survivability and performance of MHK systems and components
- Identify technology improvements that can improve the next generation
- Leverage National Laboratory expertise to improve device performance and reliability
- Drive Innovation to the Next Generation
- Improve performance early in the development cycle
- Demonstrate the payoff and mitigate the risk of using innovative technologies

FY 14 Budget: $24M

DOE Unique Role – Establish the viability of a nascent MHK industry to attract private investment. Maximize sharing of knowledge and support device agnostic technologies that can accelerate and grow the industry as a whole. Research and reduce the risk of technologies ahead of industry adoption.

MHK Budget (FY 2012 – FY 2014)

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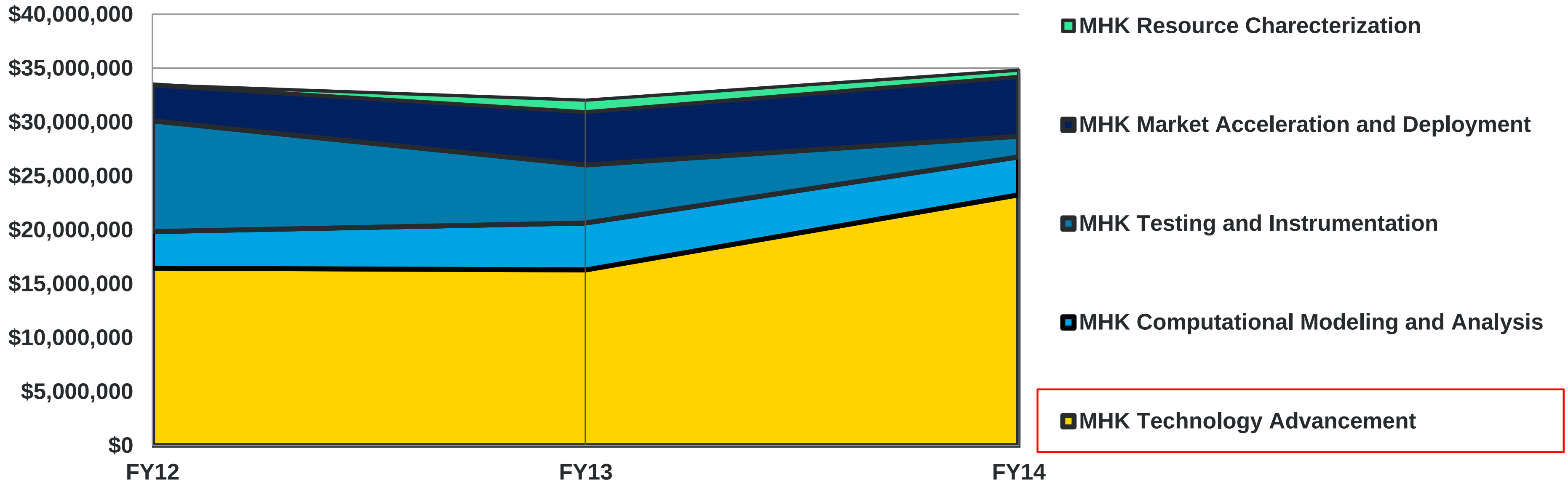
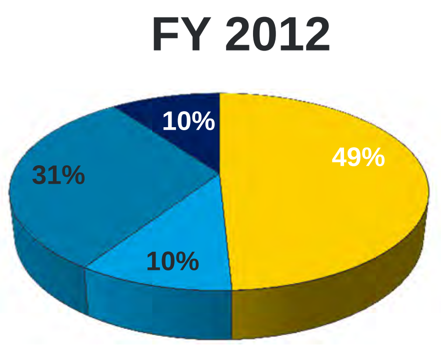
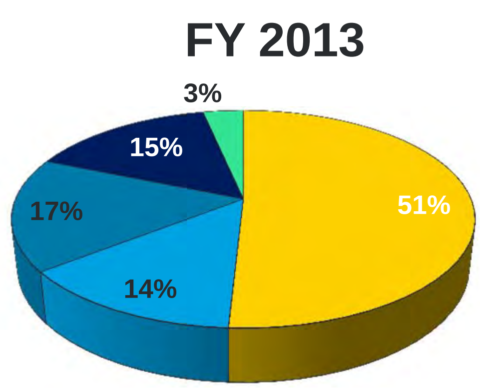
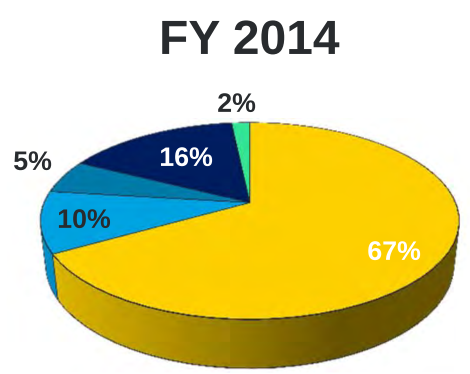
MHK Budget by Thrust Area (FY 2012- FY 2014)









Main Elements of the Tech Adv. Portfolio

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

Technical Area	Key Projects/Activities
Demonstrate State of the Art Technologies	• Technology Readiness Advancement Initiative – MHK Systems – MHK Components • National Lab Industry Support • Reliability and Survivability Risk Assessment
Drive Innovation to the Next Generation	• System Performance Advancement – Advanced Controls – Next Gen Power Takeoff – Optimized Structures • Crosscutting applications for MHK • Manufacturing Need Assessment • Advanced Materials and Coatings

Priorities in FY12 and Beyond

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

Technical Area	Priorities or Changes in Portfolio FY12 vs FY14	Key collaborators	Upcoming milestones
Demonstrate State of the Art Technologies	• Enable technology convergence • Greater focus on WECs in alignment with resource potential • Grid connected side-by-side comparative demonstrations of performance • Leverage pre-permitted infrastructure	NREL, SNL	Demonstrations at Navy WETS Complete TRL FOA demos
Drive Innovation to the Next Generation	• Reduce cost by making performance gains early in the technology development cycle • Compete early stage designs to establish potential for the next generation of device • Enable industry to move beyond building prototypes	NREL, SNL, PNNL	First prize competition in wave energy Demonstrate feed-forward controls for tidal

Water Power Program
Evolution of the TA Portfolio

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

2010	2012	2014	2020+

2010

- Advance technology readiness
- Populate the industry
- Systems and Components
- Demonstrations across all TRL's, across all resources
- Industry demonstration sites

2012

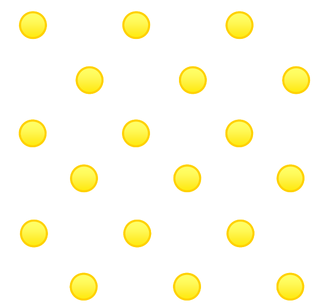
- Begin to focus investments based on resource assessments
- Facilitate success of industry projects
- Establish survivability
- Collect data from demonstrations
- Capture lessons learned from demonstrations and operational experience

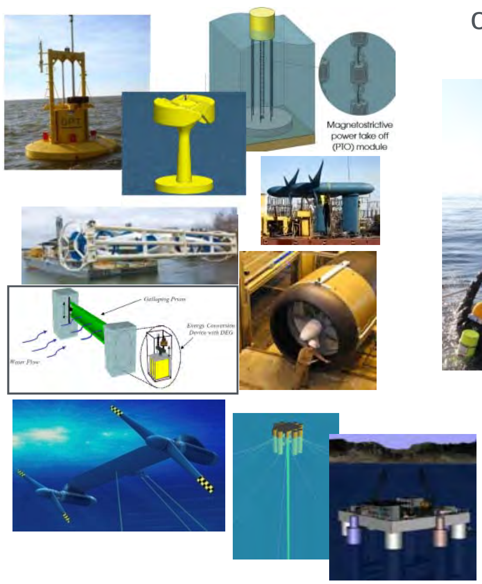
2014

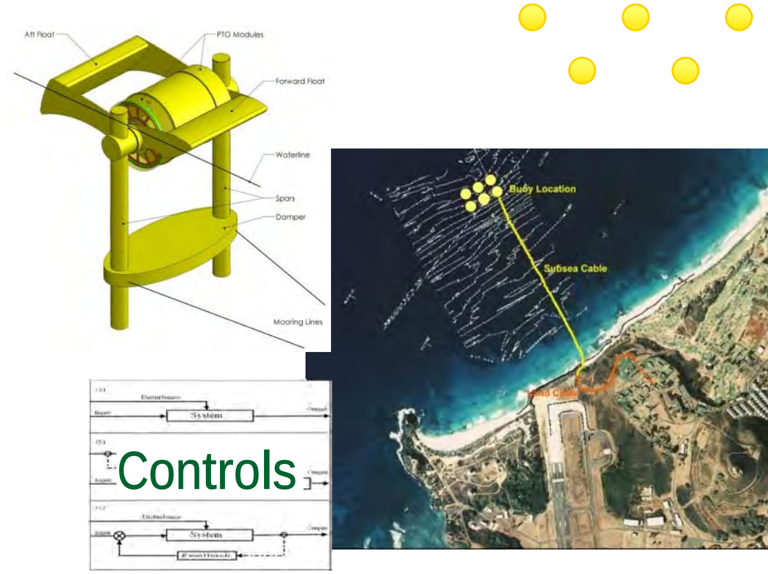
- Greater focus on Wave
- Enable technology convergence
- Improve performance and reliability
- Side by side comparative demonstrations of performance
- Leverage pre-permitted infrastructure for demonstrations
- R&D to enable the next generation to be cost competitive

2020+

- Full Scale Wave Device
- Big Array Demonstration





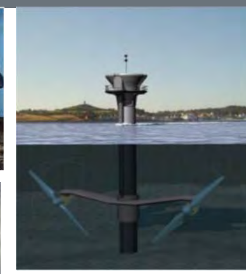


Comparison of Wave and Current Technology Strategies

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






Technology Consideration	Wave	Tidal / Current
Technical Maturity (TRL)	Entire TRL range (2 through 8)	TRL 5 through 8
Risk Profile	Higher risk, longer term effort, higher rewards	Lower risk, early term rewards
State-of-the-Art Scale	Pilot system to single full-scale system	Single full-scale system to arrays
Knowledge Transfer	Capabilities leveraged from marine industries including the Navy, oil & gas and offshore wind	Capabilities leveraged from wind industry

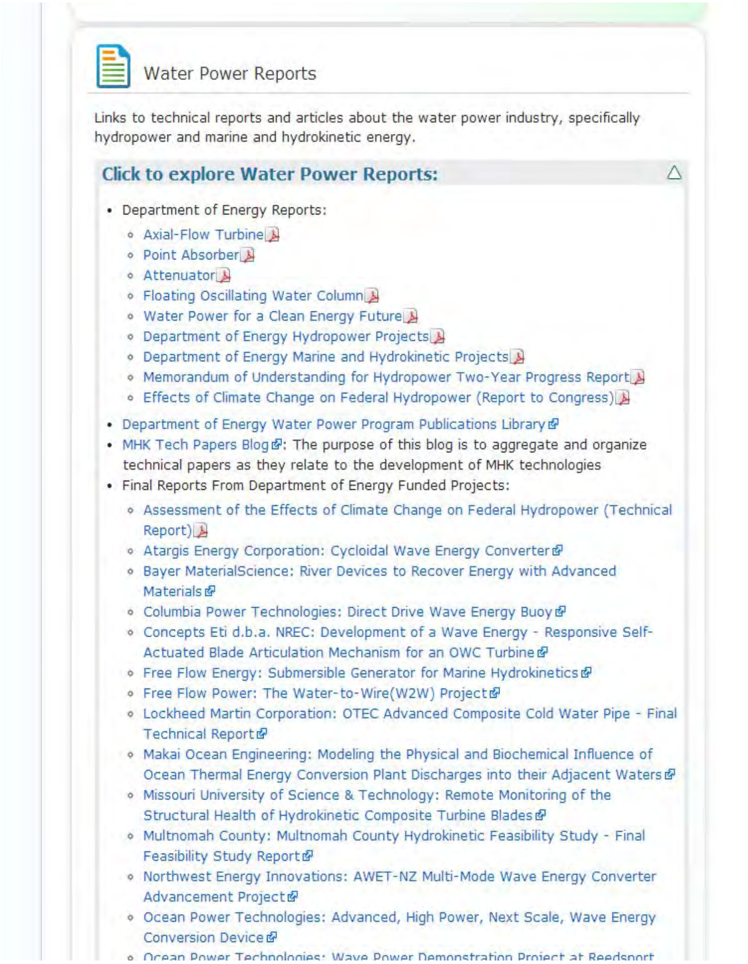
Strategic Goals	• Develop critical testing infrastructure • Move to full-scale system demonstration • Develop numerical models	• Increase in-water operational hours • Move to array-scale demonstration • Validate numerical models

Water Power Program
Technology Transfer/Industry Partnership

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

- **More than 30 completed MHK industry project reports publicly shared**
  - Enable industry to benefit from data and lessons learned

- **8 Industry - National Lab collaborative projects**
  - Supporting: OPT, ORPC, Verdant, CPT, NWEI, Ocean Energy
  - Design technical review
  - Testing and Instrumentation (Laboratory and Field)
  - Numerical modeling



Water Power Reports

Links to technical reports and articles about the water power industry, specifically hydropower and marine and hydrokinetic energy.

Click to explore Water Power Reports:

- Department of Energy Reports:
  - Axial-Flow Turbine
  - Point Absorber
  - Attenuator
  - Floating Oscillating Water Column
  - Water Power for a Clean Energy Future
  - Department of Energy Hydropower Projects
  - Department of Energy Marine and Hydrokinetic Projects
  - Memorandum of Understanding for Hydropower Two-Year Progress Report
  - Effects of Climate Change on Federal Hydropower (Report to Congress)
- Department of Energy Water Power Program Publications Library
- MHK Tech Papers Blog: The purpose of this blog is to aggregate and organize technical papers as they relate to the development of MHK technologies
- Final Reports From Department of Energy Funded Projects:
  - Assessment of the Effects of Climate Change on Federal Hydropower (Technical Report)
  - Atargis Energy Corporation: Cycloidal Wave Energy Converter
  - Bayer MaterialScience: River Devices to Recover Energy with Advanced Materials
  - Columbia Power Technologies: Direct Drive Wave Energy Buoy
  - Concepts Eti d.b.a. NREC: Development of a Wave Energy - Responsive Self-Actuated Blade Articulation Mechanism for an OWC Turbine
  - Free Flow Energy: Submersible Generator for Marine Hydrokinetics
  - Free Flow Power: The Water-to-Wire(W2W) Project
  - Lockheed Martin Corporation: OTEC Advanced Composite Cold Water Pipe - Final Technical Report
  - Makai Ocean Engineering: Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into their Adjacent Waters
  - Missouri University of Science & Technology: Remote Monitoring of the Structural Health of Hydrokinetic Composite Turbine Blades
  - Multnomah County: Multnomah County Hydrokinetic Feasibility Study - Final Feasibility Study Report
  - Northwest Energy Innovations: AWET-NZ Multi-Mode Wave Energy Converter Advancement Project
  - Ocean Power Technologies: Advanced, High Power, Next Scale, Wave Energy Conversion Device

http://en.openei.org/wiki/Gateway:Water_Power

Questions for Peer Reviewers

- In what research areas do you believe DOE's investment can make a significant impact relative to industry?
- Do you have specific comments on the shift in focus towards wave in alignment with the national resource assessment?
- Any comments on the use of power to weight ratio and availability as metrics driving cost reduction? Other appropriate metrics?
- Are there any gaps in the portfolio? What is the next big thing we should be thinking about?

Water Power Program
Tech Adv. Peer Review Presentations

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

Focus Area	Start Time	Topic	Presenter
Technology Advancement: Wave: Systems & Components	9:20 AM	WET-NZ Multi-mode Wave Energy Convertor Advancement Project	Steven Kopf, Northwest Energy Innovations
	9:50 AM	PB500, 500 kW Utility Scale PowerBuoy Project	Mike Mekhiche, Ocean Power Technologies
	10:15 AM	Reedsport PB150 Deployment and Ocean Test Project	Mike Mekhiche, Ocean Power Technologies
	10:30 AM	BREAK	
	11:00 AM	Direct Drive Wave Energy Buoy	Ken Rhinefrank, Columbia Power Technologies
	11:25 AM	Wavebob Advanced Wave Energy Converter (AWEC) & Power Take Off (PTO)	L.E. (Ted) Lesster, RCT
	11:50 AM	TidGen® Power System Commercialization Project	Christopher R. Sauer, Ocean Renewable Power Company
	12:05 PM	OCGen® Module Mooring Project	Jarlath McEntee, Ocean Renewable Power Company

Water Power Program
Tech Adv. Peer Review Presentations

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

Focus Area	Start Time	Topic	Presenter
Technology Advancement: Tidal/Current: Systems & Components	1:30 PM	Aquantis C-Plane Ocean Current Turbine Project	Alex Fleming, Dehlsen Associates, LLC
	1:55 PM	Puget Sound Pilot Tidal Energy Project	Brad Spangler, Snohomish Public Utilities District #1
	2:20 PM	Advancement of the Kinetic Hydropower System (KHPS) to Department of Energy (DOE) Technology Readiness Level (TRL) 7/8	Mary Ann Adonizio, Verdant Power Inc.
	2:45 PM	Advanced Integration of Power Take-Off in Vortex Induced Vibrations Aquatic Clean Energy	Rebecca Alter, Vortex Hydro Energy
	3:15 PM	BREAK	
	3:45 PM	MHK Industry Support	Albert LiVecchi, National Renewable Energy Laboratory
	4:00 PM	Industry Support: ORPC	Vincent Neary, Sandia National Laboratories
	4:15 PM	Performance Testing for Hydrokinetic Canal Effects NEW	Vincent Neary, Sandia National Laboratories
Technology Advancement: Operations & Maintenance	4:30 PM	Materials & Coatings + Manufacture Reliability	Bernadette A. Hernandez-Sanchez, Sandia National Laboratories (Lead)
	4:55 PM	Advanced Materials and Manufacturing Reliability	George Bonheyo, Ph.D., Pacific Northwest National Laboratory
	5:10 PM	Reliability and Survivability Risk Assessment Framework NEW	Robert Thresher, National Renewable Energy Laboratory
	5:25 PM	MHK Manufacturing Needs Assessment and Cost Database NEW	Jason Cotrell, National Renewable Energy Laboratory
Tuesday, February 25	9:00 AM	System Performance and Advancement FOA Overview	Ryan Sun Chee Fore, DOE

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

WET-NZ Multi-mode Wave Energy Convertor Advancement Project

Steven R. Kopf
Northwest Energy Innovations
skopf@nwenergyinnovations.com
484 459 8200
February 25, 2014

Purpose & Objectives

Problem Statement: Technology was TRL 4 prior to DOE funding and no correlation wave tank or open ocean testing had been completed to validate the capture length matrix.

Impact of Project: The project – which consists of wave tank testing and two iterations of ocean testing - will result in completion of TRL 5/6 and readies the technology for full scale prototype development and testing (TRL 7/8).

This project aligns with the following DOE Program objectives and priorities

To be provided at a later date. Please leave this section blank until further guidance is provided

Technical Approach

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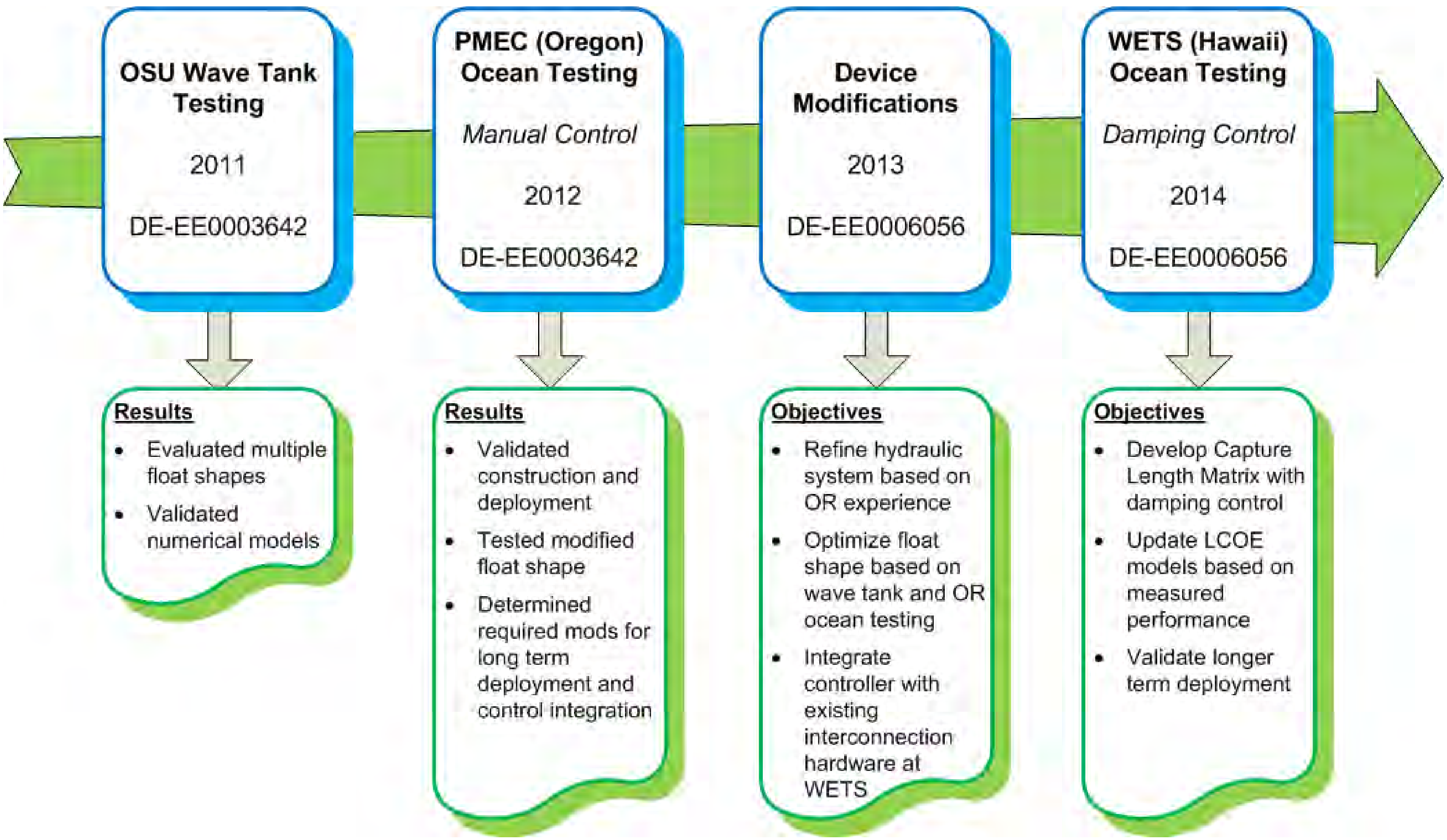


Oregon Project

Accomplishments and Progress

System Overview

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

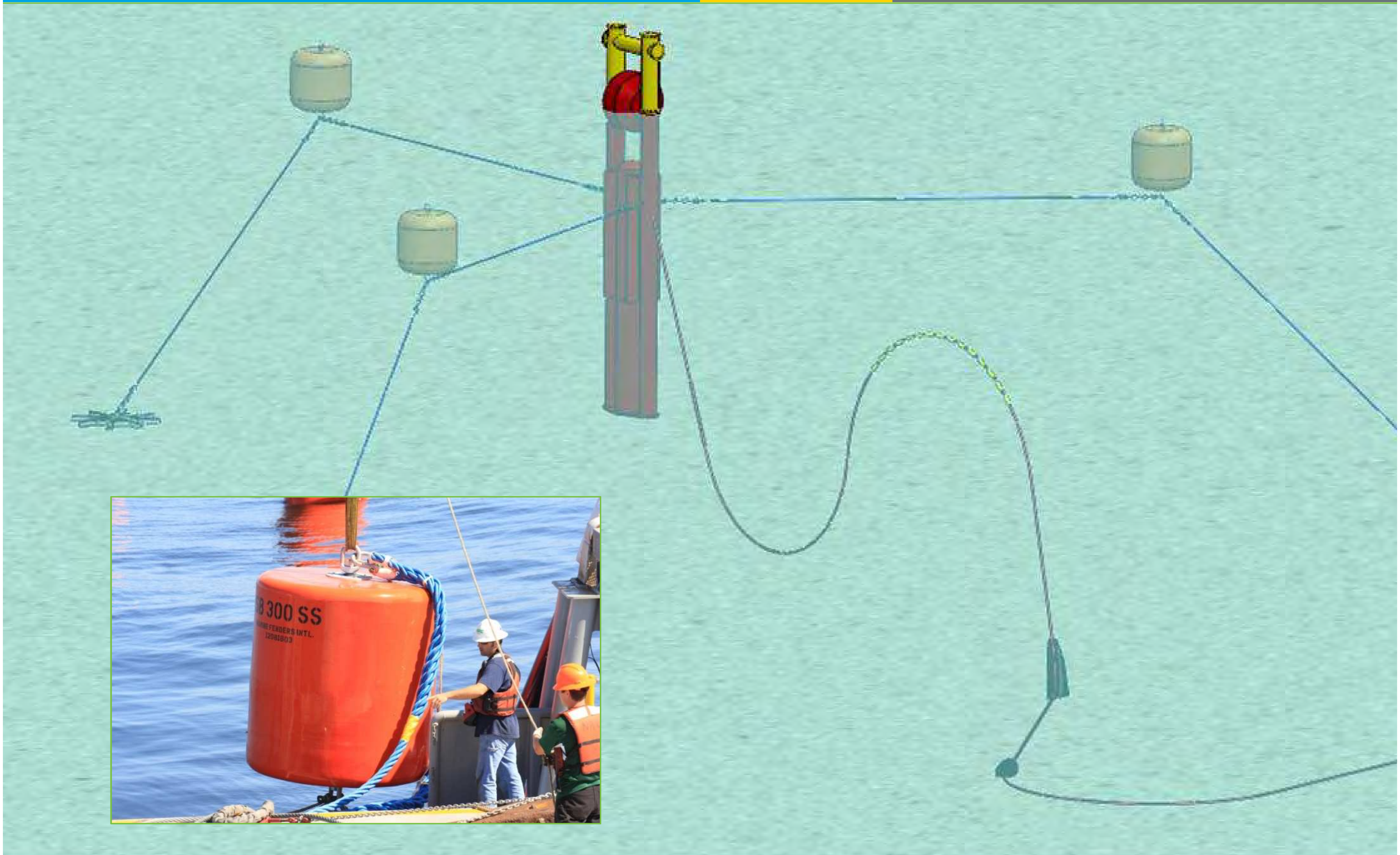
PowerPod

Float

Hull

Hull Height/Draft:	15.0 meters
Hull Width:	3.8 meters
Float Diameter:	2.4 meters
Main Tube Diameter:	1.5 meters
Side Tube Diameter:	0.7 meters
Draft (ballasted):	12.8 meters
Dry Weight:	30 metric tons
Displacement:	50 metric tons
Rated output:	20 kW

Mooring System



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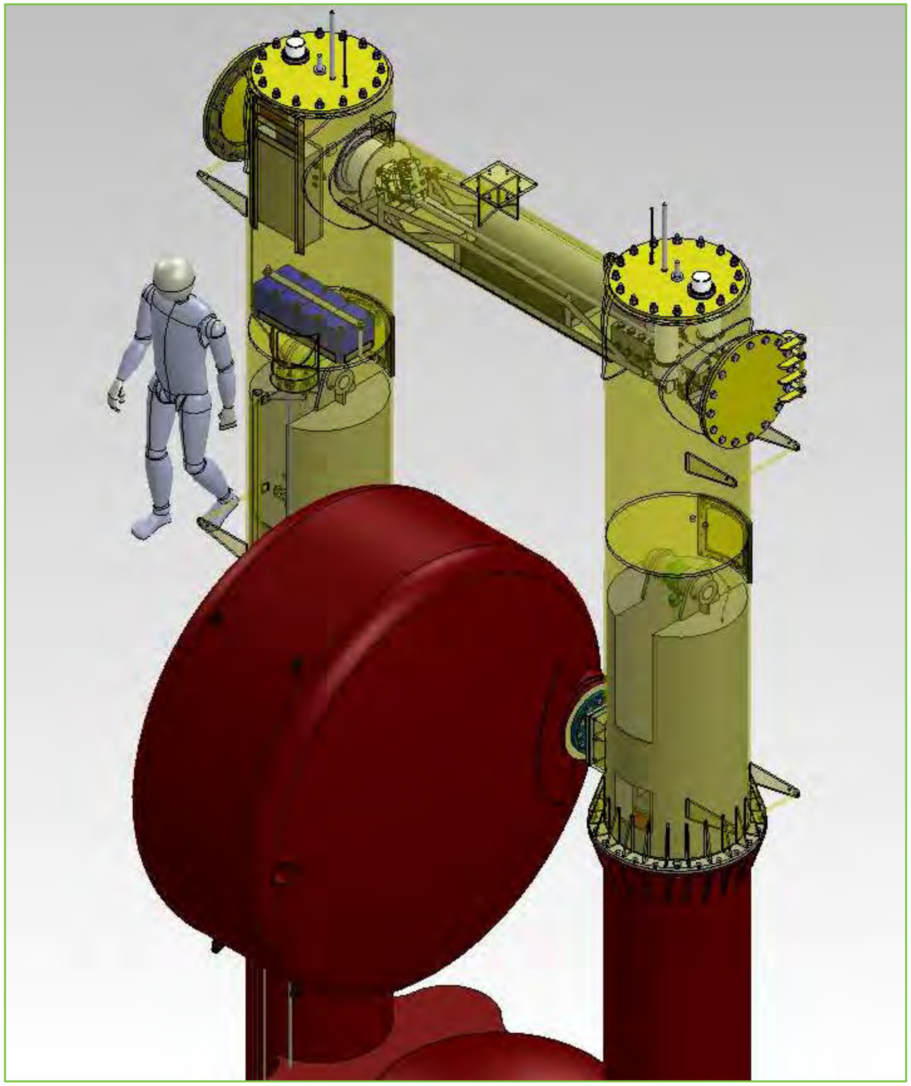
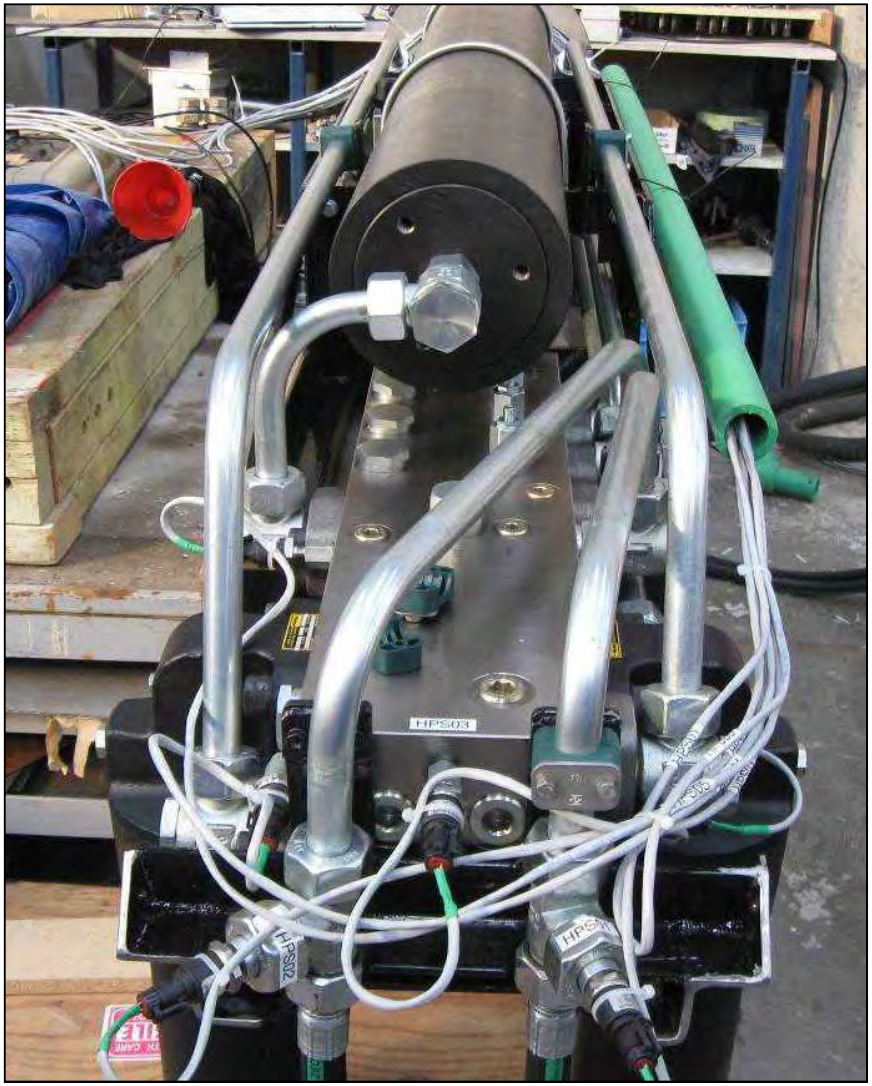
PowerPod and Float

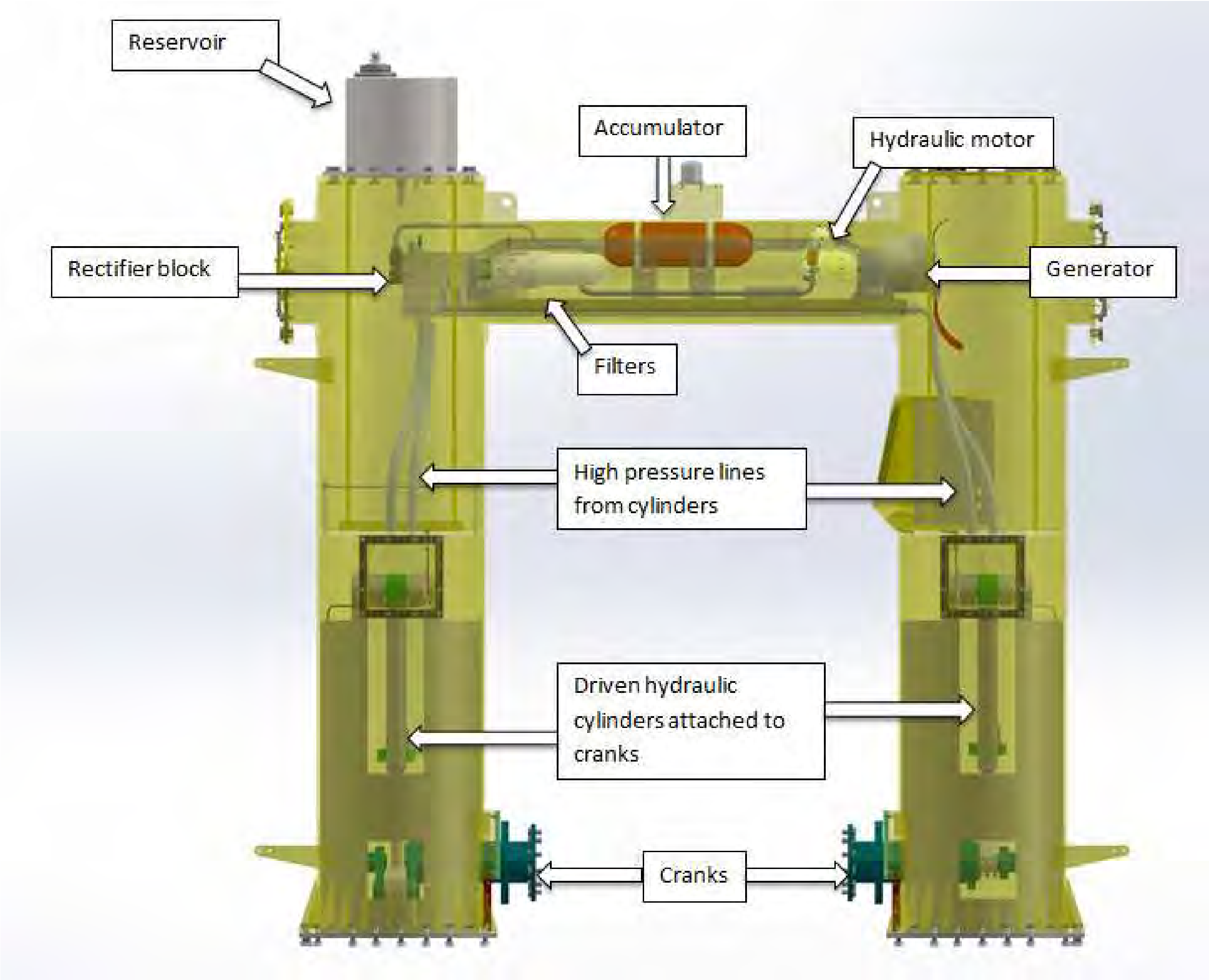
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





PowerPod Internals

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



PowerPod

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Assembly

NREL Instrumentation

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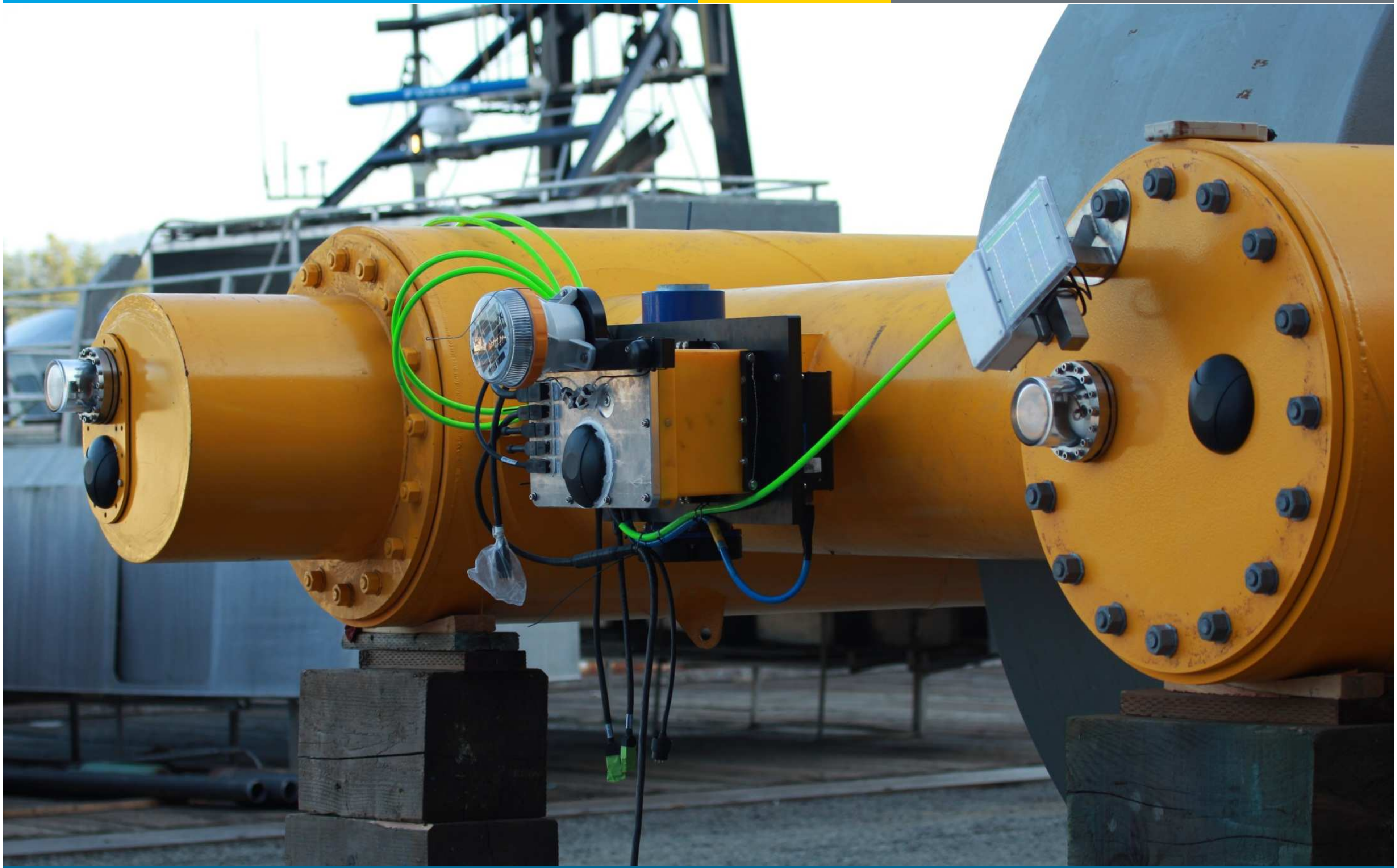

Dry Testing

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Deployment – Day 1

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Tug positioning device

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Ballasting

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Umbilical Cable

Connected to Ocean Sentinel

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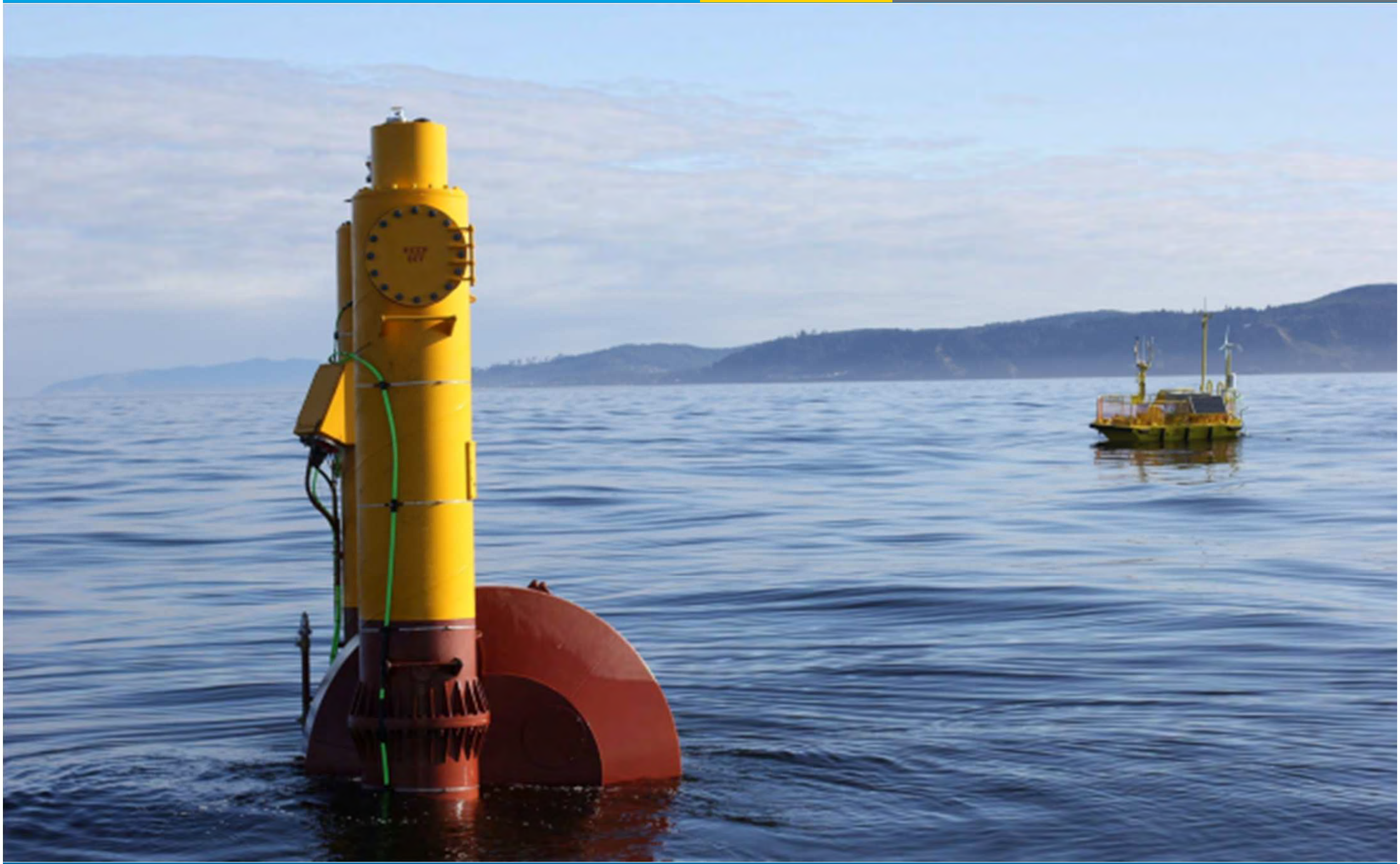
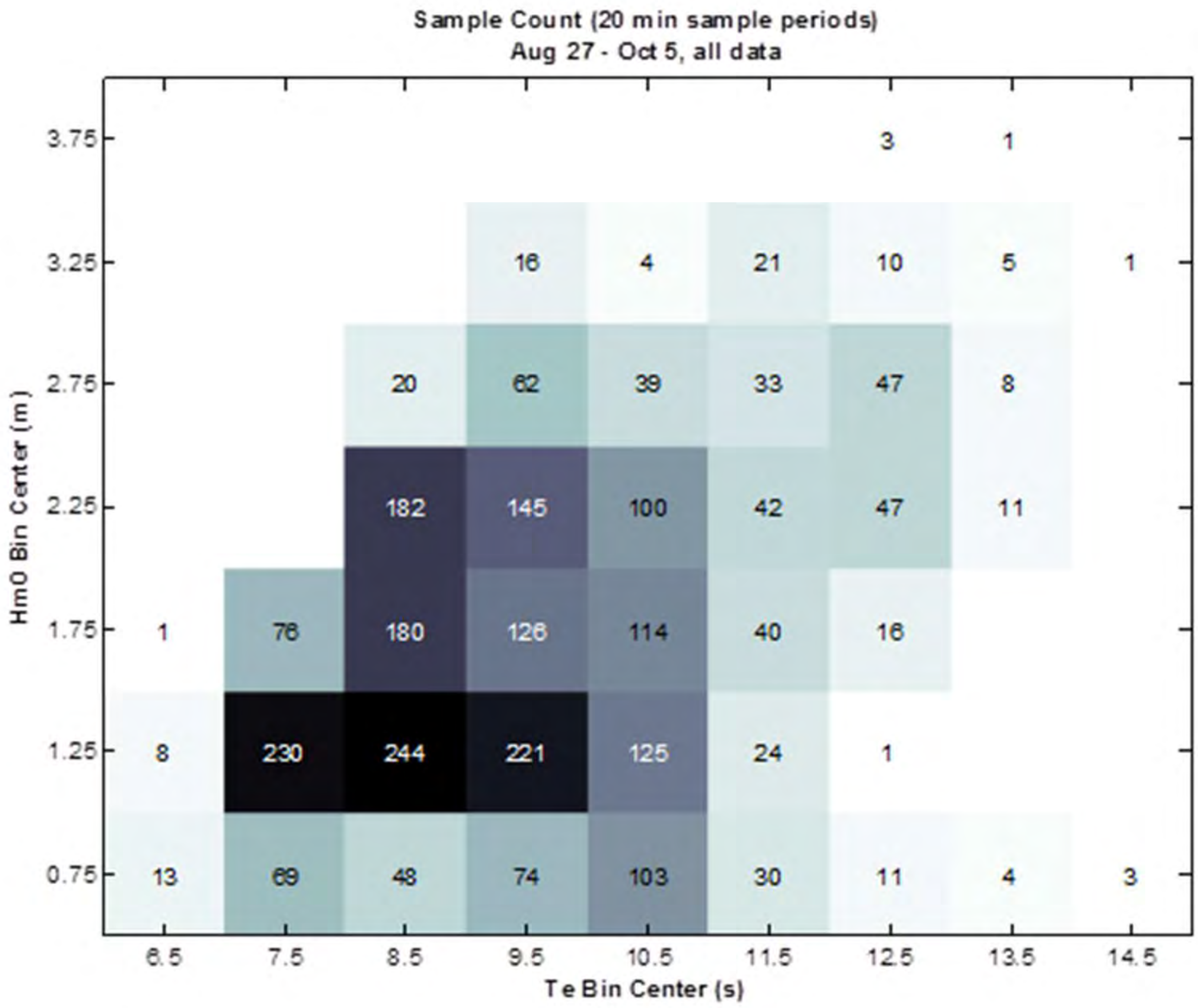


Data Bins


Sample Count (20 min sample periods)
Aug 27 - Oct 5, all data
Hm0 Bin Center (m)
Te Bin Center (s)
3.75
3.25
2.75
2.25
1.75
1.25
0.75
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
3 1
16 4 21 10 5 1
20 62 39 33 47 8
182 145 100 42 47 11
1 76 180 126 114 40 16
8 230 244 221 125 24 1
13 69 48 74 103 30 11 4 3

Oregon Project

Successes

- **Deployment** – completed on budget in 2 days.
- **Ocean Sentinel/OSU** – very successful working relationship.
- **Power Data** – collected useful power data to correlate with wave tank data

Learnings

- **NREL DAQ** – software failure
- **Reduced Power Output** – due to hydraulic system and controller software issues

Hawaii Project

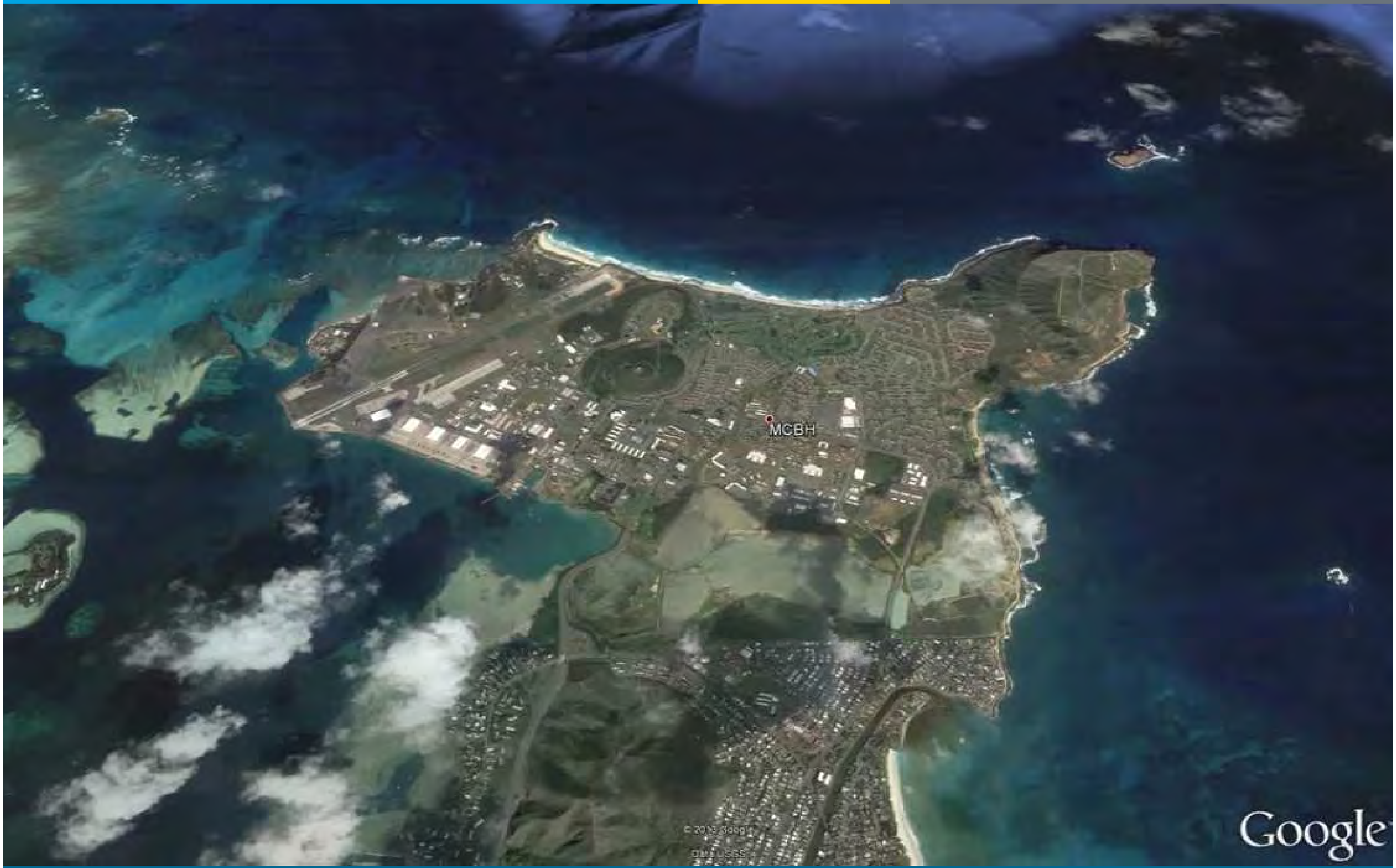
Accomplishments and Progress

Oahu, Hawai'i

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

Marine Corps Base Hawai'i (MCBH)

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



Navy's Wave Energy Test Site (WETS)

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Hydraulic Modifications

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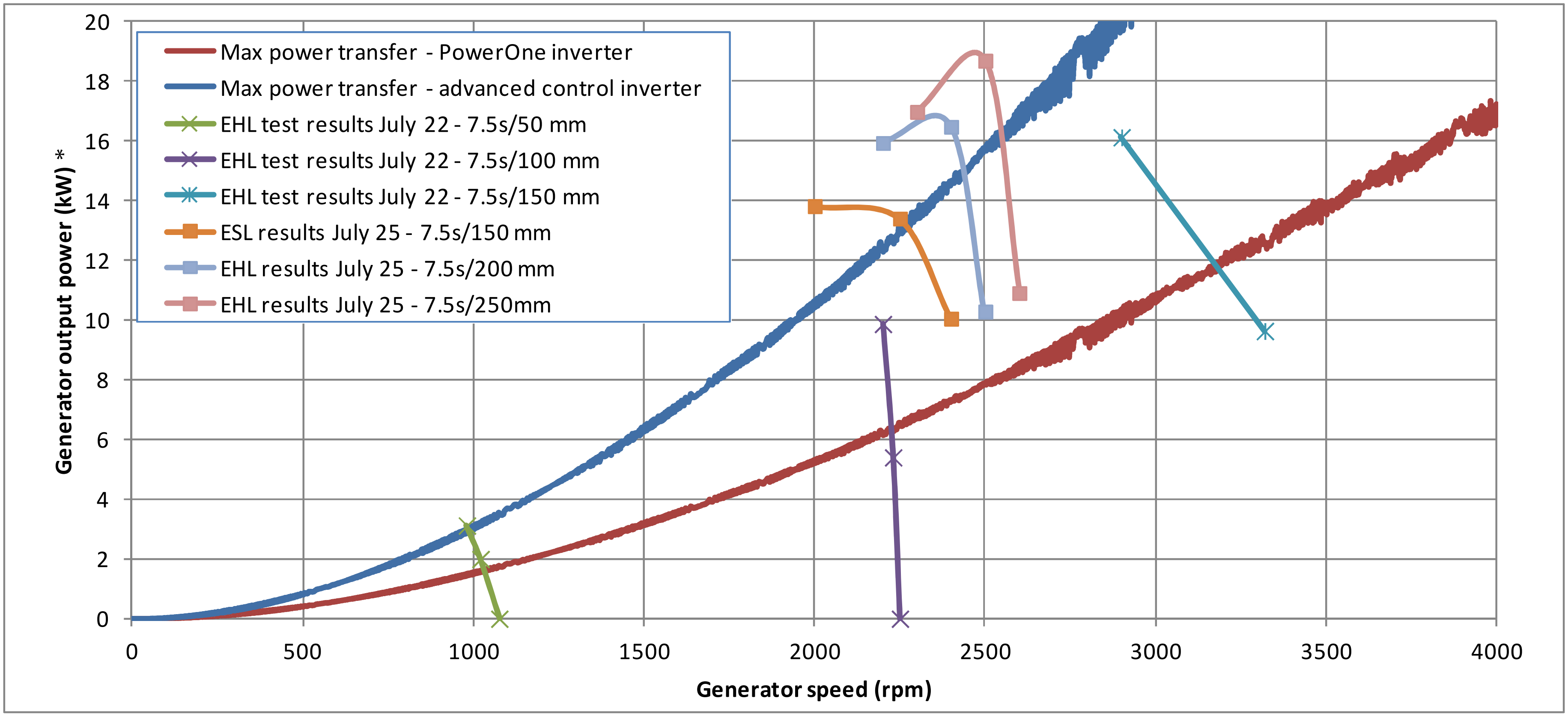
STATUS: ALL MODS AND COMPONENT TESTING COMPLETE. READY FOR REASSEMBLY WITH POWERPOD STRUCTURE.

Accomplishments:

- Disassembled and inspected all components
- Determined source of hydraulic leak
- Removed charging circuit
- Optimized control parameters
- Completed component testing

PowerPod Performance

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



Float Modifications

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

STATUS: Float completed and ready for integration with PowerPod.

Accomplishments:

- Optimized float shape for max torque
- Recycled shaft from Oregon Device
- Completed fabrication and buoyancy check
- Ready to install on PowerPod

Modified Float Designs

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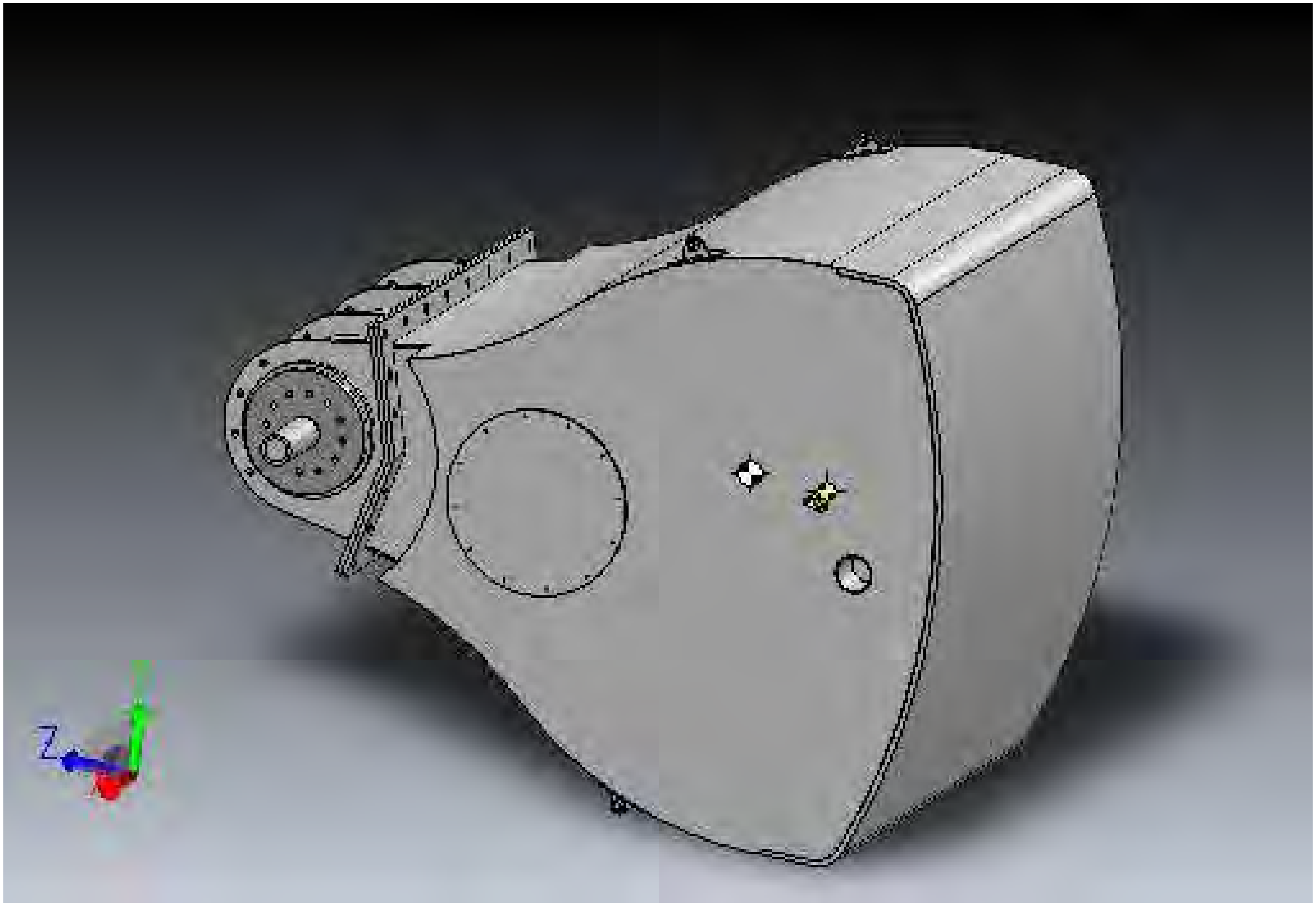

Interconnection Modifications

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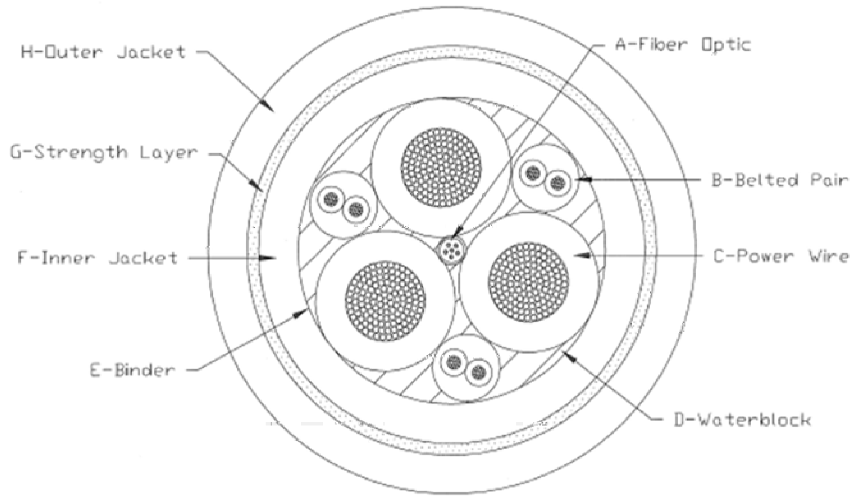
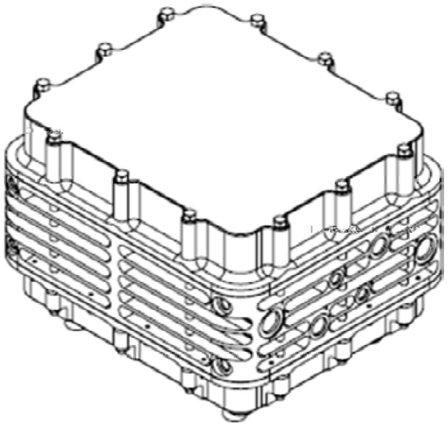
STATUS: Ready to interconnect

Accomplishments:

- Completed design and identified installation contractor (Aug-13)
- Purchased umbilical and junction box
- Received HECO approval (Dec-13)

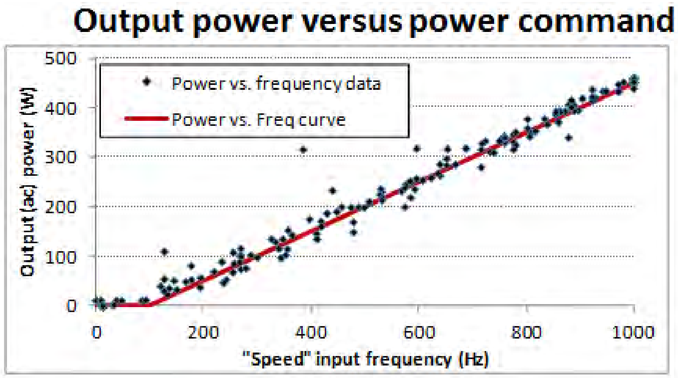




STATUS: All components are purchased, received, and ready to ship to Hawai'i.

Accomplishments:

- Extensive modelling using Simulink.
- Completed redesign of controller based on existing infrastructure
- Initiated programming



Mooring System Design

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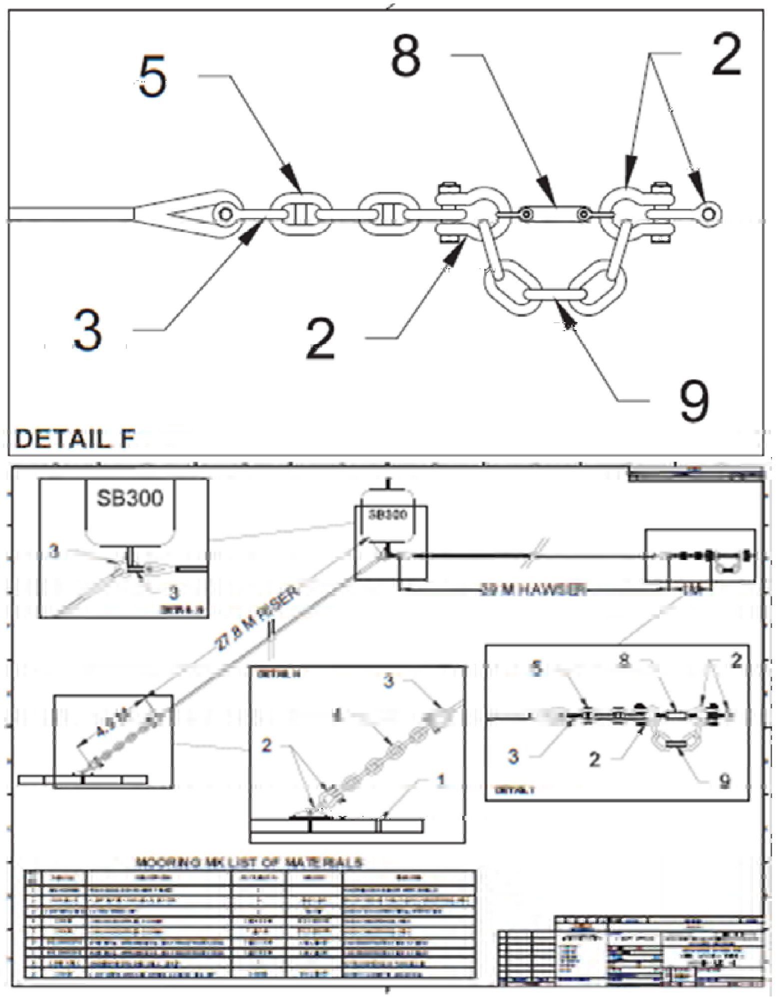
STATUS: Complete and ready to deploy.

Accomplishments:

- Custom mooring lines complete and ready to ship to Hawai'i
- Subsurface floats will be reused from OR testing and are loaded in container and ready to ship



Project Plan & Schedule

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Summary	
DE-EE0006056	

Legend	
(light blue)	Work completed
(blue)	Active Task
◇ (grey)	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Title: WET-NZ Technology Demonstration at US Navy's Wave Energy Test Site												
Mooring System Design Complete								◆				
Mooring System Procurement Complete									◆			
Grid Interconnection Components Procurment Complete									◆			
HECO Inteconnection Agreement Received									◆			
Hydraulic Mods and Lab Testing Complete									◆			
Float modifications complete									◆			
Current work and future research												
Control System Mods Complete										◆		
Assembly and Dry Testing Complete										◆		
Shipping to Hawaii											◆	
Assembly complete and Ready to deploy											◆	

Comments

- Start: February 1, 2013 Completion Date: February 1, 2015
- Project delays to date were due to NEPA hold and permitting delays
- Go/No Go decision points: None

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
		699,009	328,340		

- **Variances** – Project approximately $250K over budget due to unanticipated infrastructure modifications, shipping costs, permitting delays, and control system integration
- **Modifications** – Base award of $500K, $199K added Sept 2013
- **Expended to Date –** 68.7% at end of last reporting period
- **Other funding sources** – Callaghan Innovation, EHL, OWET, and private investors

Partners, Subcontractors, and Collaborators:

- **Callaghan Innovation (NZ)** – overall system design and analysis
- **Energy Hydraulics (NZ)** – PowerPod development and mods
- **Navy/MCBH/NAVFAC** – site access, engineering and facilities
- **NREL** – data acquisition system
- **Oregon Iron Works** – fabrication of Hull
- **OSU/NNMREC** – wave tank and open ocean testing
- **Sea Engineering** – deployment for HI
- **Sound and Sea** – mooring system design for both OR and HI
- **University of Hawaii/HINMREC** – HI project permitting and environmental monitoring, power data collection and analysis

Communications and Technology Transfer:

- **General Info -** www.azurawave.com
- **Video** – http://www.youtube.com/watch?v=Ankdy1yhQLw
- **Final Scientific Report (Oregon)** - http://www.osti.gov/scitech/biblio/1097595
- **Dr. Lettenmaier Thesis** – http://ir.library.oregonstate.edu/xmlui/handle/1957/39021
- **Marine Energy Technology Symposium Paper** - http://www.foroceanenergy.org/wp-content/uploads/2013/07/WAVE-ENERGY-TESTING-USING-THE-OCEAN-SENTINEL-INSTRUMENTATION-BUOY.pdf

Next Steps and Future Research

FY14/Current research:

- **Oregon Project** – completed
- **Hawaii Project**
  - **Deployment –** scheduled for IQ2014
  - **Testing –** 12 months following deployment

Proposed future research

- **Reactive Controller** – utilize NREL and Sandia models to predict performance of and test reactive controller on Hawaii device before decommissioning.
- **Commercial Scale Pre-Design –** utilize results from WETS testing to develop commercial scale design and LCOE estimates.

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500kW Utility-Scale PowerBuoy Project

Dr. Mike Mekhiche
Ocean Power Technologies, Inc.
mmekhiche@oceanpowertech.com
(609) 730 0400 x500
February 25, 2014

Purpose & Objectives

Problem Statement: Minimizing the levelized cost of energy (LCOE) is critical to the growth of the MHK industry.

Impact of Project: Currently, The Power Take-off (PTO) System accounts for approximately one-third of the cost of the PowerBuoy® system (structure and mooring accounting for the remaining two-thirds), so cost and efficiency savings in the PTO have a significant impact on the overall cost of the system.

This project focuses on the advancement of the OPT PB500 (500kW) PowerBuoy design, from TRL 4 to TRL 5/6.

DOE is to provide guidance for this section

Technical Approach

The technical approach:

- Stage-gated development program with clearly defined stage reviews.
- Clearly defined stage deliverables.
- Overseen by interdepartmental management and peers prior to proceeding to the next stage (go/no-go decision).

Key issues:

- New technology adoption at the subassembly and assembly levels may introduce new technical risks
- New Modular PTO and scalable approach could introduce packaging and arrangement challenges
- Scale-up additionally places more emphasis on installation costs and maintenance considerations.

Unique approach:

- Rigorous subassembly and assembly testing to mitigate subsystem and system technical risks.
- Final PTO integration testing to ensure the implementation of new technology and arrangement does not introduce interference and alter PTO operational characteristics.
- Highly developed simulations/modeling validated by test.
- Extensive wave tank and ocean testing experience.

Accomplishments and Progress

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

Design for Manufacturing (DFM)

- The MPTO was designed to have three major assemblies (significant DFM advantages): the Master Control Assembly (MCA), the Power Conversion Assembly (PCA), and the Power Delivery Assembly (PDA).
- The Modular Design takes into account the functionality and operation of each PTO system and modularizes it to be buildable, testable and field replaceable independently from other systems.
- The Modular PTO system designed to be utilized on cross-platform PowerBuoys: Increasing or decreasing the number of modules required for the specific PowerBuoy® platform

System Performance and Reliability Improvements

- In addition to the MPTO's modular design, performance and reliability of the PTO were also improved:
- Significantly reduced hotel loads by implementing design philosophies that leverage intelligent data capture and analysis and usage to reduce the required number of sensors. Further, the use of efficient and intelligent components that operate on a "system need basis" allows for power consumption to be reduced, while prolonging the life and the reliability of such components.
- Compliant linear actuators that eliminated the need for linear table and fabrication accuracy.
- A lower cost and simpler linear brake system on the MPTO.
- Improved encoder implementation – OPT developed an improved generator encoder implementation that is highly reliable and performs better.
- Improved Energy Storage System – OPT designed and implemented an advanced energy storage system that improved system life from 6 years to 25 years, leveraging state of the art battery technologies and intelligent state of charge management techniques.
- More reliable Motor-generator Drives - OPT implemented a Motor Drive solution designed for a minimum of 10 year service life, resulting in doubling their life compared to previous designs.

Multi-Physics System*

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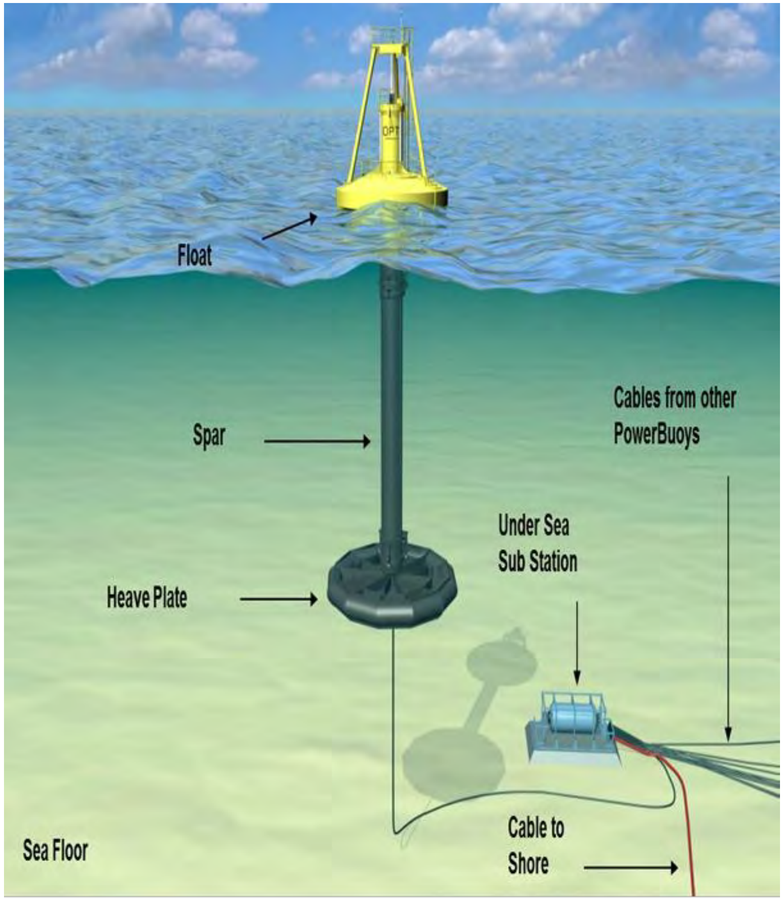

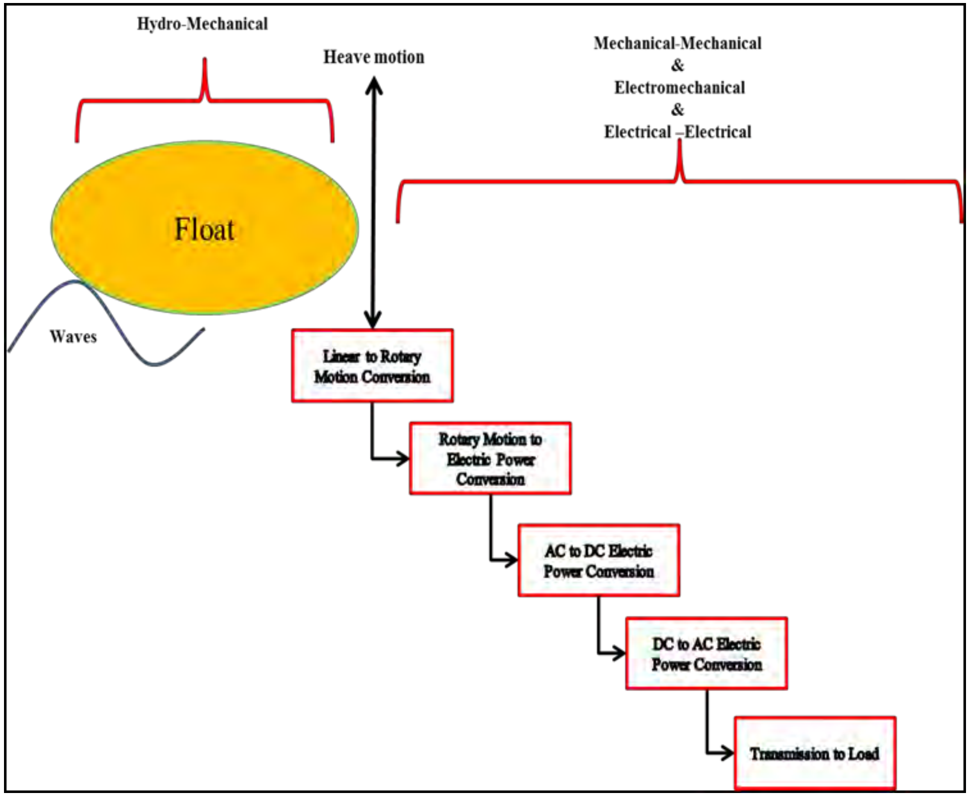

Systems approach and concurrent engineering critical to success

Validation of Simulation Results*

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Closing the gap with reduced scale Wave Tank testing is critical

- Tests include operational testing of a model with a working PTO to measure generated power across a wide range of sea states,
- A smaller model in representative 100-year wave conditions to measure survival loads,
- In both cases, the models are significantly smaller than the full-scale PowerBuoy (typical ratios are 1:20 to 1:40),
- OPT's experience is that this reduced-scale-model range allows for meaningful data to be collected and then correlated with the performance of the full scale systems

Determine a systematic way to replicate the site wave environment

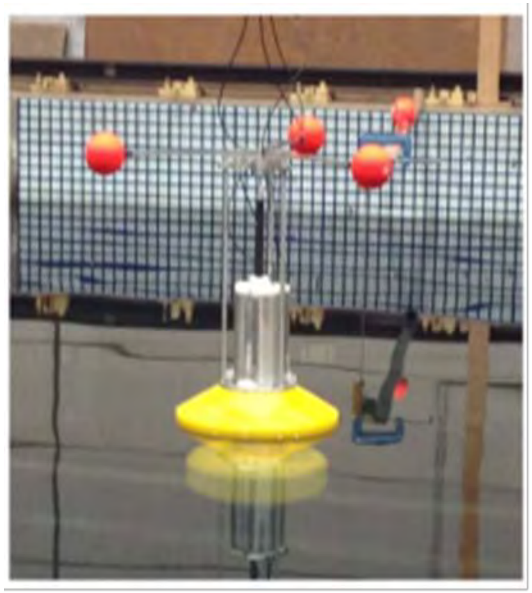
Test a succession of increasingly complex reduced-scale models to understand impact of system parameters

Carry out the appropriate parameter adjustments to capture the design metrics

Evaluate reduced scale model performance for power and loads for different sea states and parameter settings.

Use the results to validate the numerical modeling tools

Using these model tools, make predictions for cases not tested, (sea states or water depths)



Maximizing the value of the WTT and mitigating risks early on in the development process to ensure a viable approach at the onset of the project.

PTO Design*

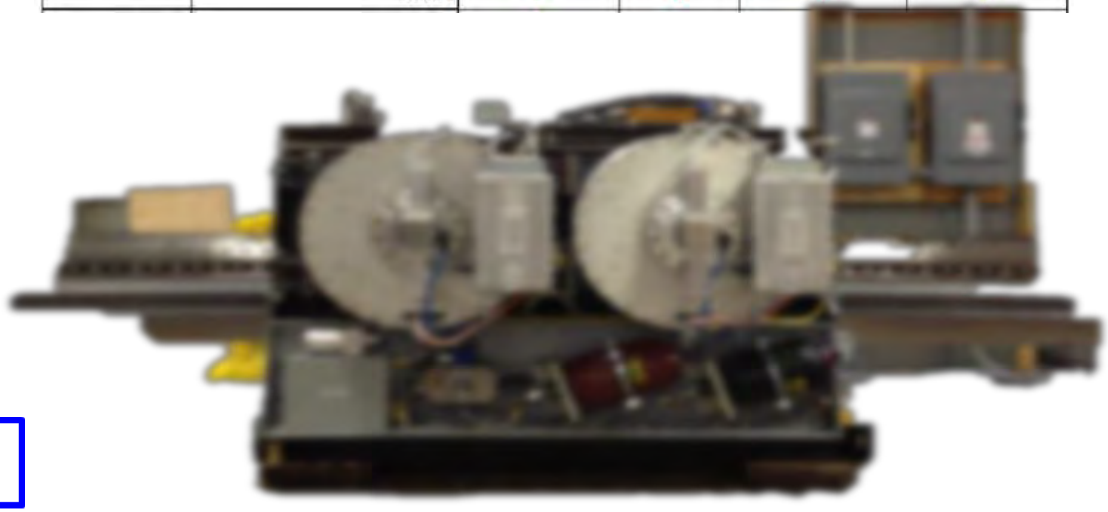
Example of generation of two PTO concepts and final down-select:

1. Rack and pinion PTO:
    1. Rack and Pinion actuator investigation
    2. Input rod and associated cabling
    3. Speed increasers… etc

2. Belt Drive system PTO: Double sided belt connected to the float and engages a fixed rack relative to the spar.
    1. Eliminated input rod and seals
    2. Increases the number of rack options
    3. Simplifies PTO assembly and alignment
    4. No need for lube
    5. Smaller PTO

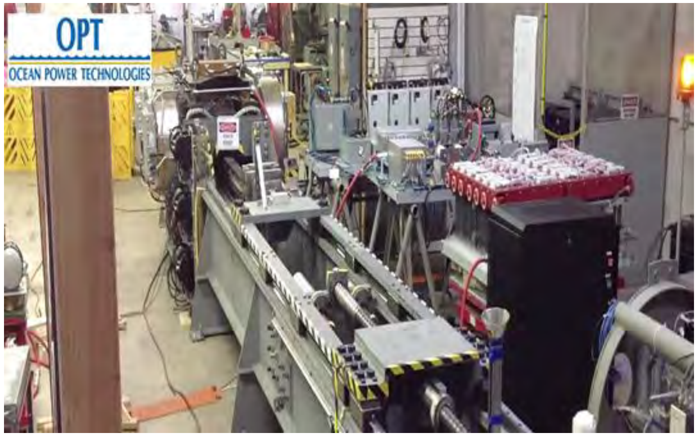
Key aspects of investigation: Belt drive, rack options, rotary bearings, gimbal system…etc

		RP#1 Adjustable input rod Option?	RP#2 Fixed input rod Option?	Belt #1 External rack on spar Option?	Belt#2 Internal rack in float Option?
Input Rod	Fixed Input Rod	✗	✓	✗	✓
	Wire Rope Adjustable Input Rod	✓	✗	✗	✓
Speed Increaser	Gearbox	✓	✓	✓	✓
	Beltbox	✓	✓	✓	✓
	Chain drive	✓	✓	✓	✓
Brakes	External linear brake	✓	✓	✓	✓
	Rotary spar to sheave	✓	✗	✗	✓
	Internal linear rod lock	✓	✓	✗	✓
	Internal rotary pinion caliper brake	✓	✓	✓	✓
Locking Mechanism	Latch	✓	✓	✓	✓
	Shear pin	✓	✓	✓	✓
Pinion	Vendor 1	✓	✓	✓	✓
	Vendor 2	✓	✓	✓	✓
Wire Rope	Vendor 1	✓	✗	✗	✓
	Vendor 2	✓	✗	✗	✓

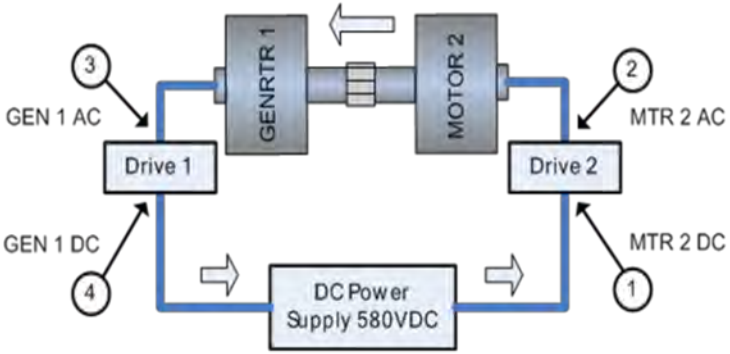


THE FINAL SELECTED PTO WAS A RACK AND PINION WITH A FIXED INPUT ROD.

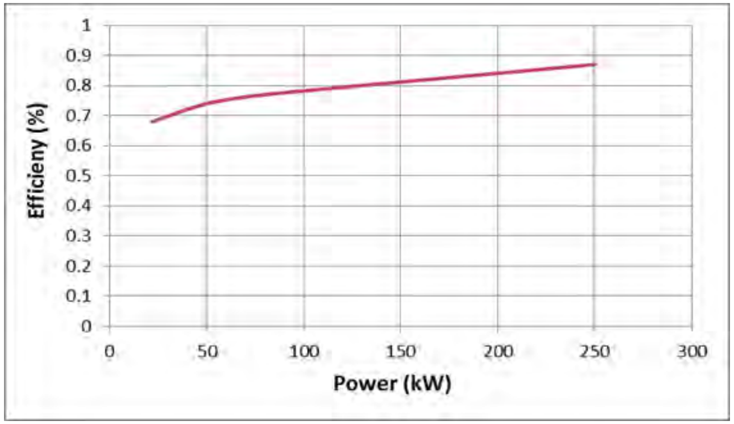
PTO Testing and Validation*



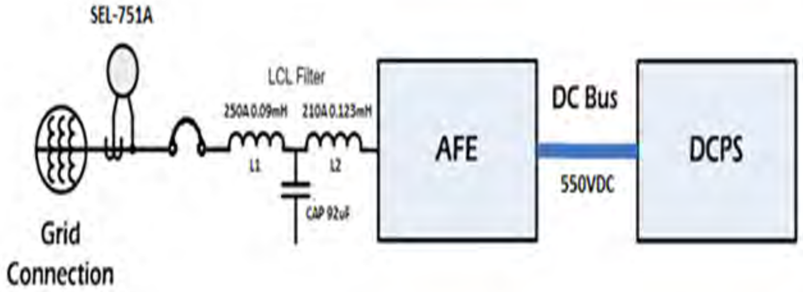
PTO endurance test setup at OPT



Setup for back-to-back testing of generator-drive



Measured mechanical to electrical PTO efficiency



AFE subsystem test setup

PTO Integrated Into the Spar*

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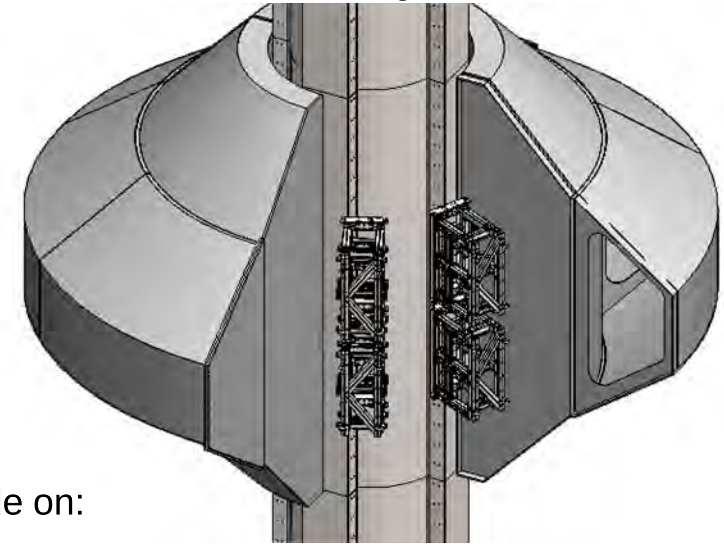
Post FAT and Endurance testing, the PTO was integrated into a PowerBuoy with plans for deployment next summer

Preliminary Design and Performance Model of PB500 PowerBuoy Structure*

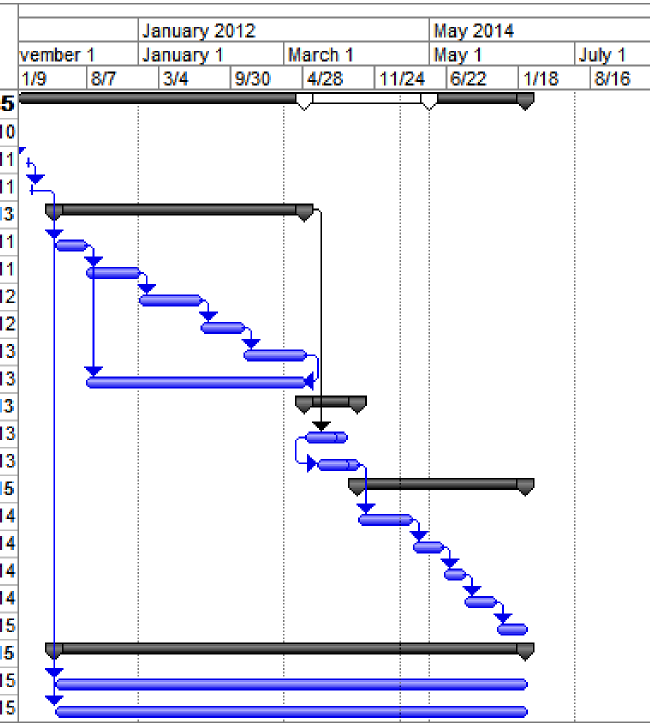
- Conducted preliminary design and a performance model of the PB500 Structure Float.
- OPT delivered a preliminary design package to Fabrication partner and conducted a Design for Manufacturing (DFM) study.
- The concept design was updated with all DFM recommendations



- Conducted detailed hydrodynamic study and tank testing to decide on:
    1. Symmetrical float
    2. Monopile mooring structure
- Tank test details, analysis and decision criteria discussed under Task 6.
- Conducted revised conceptual design and tradeoff study to determine viable deployment water depth.
- The PB500 Mooring structure exhibited significant level of mooring loads at <u>45 to 50m deployment water depth</u>; making it cost prohibitive to manufacture and deploy.
- Conducted extensive analysis and trade study of Power Generation vs. Water Depth
- Results of study showed that PowerBuoy can be deployed at a much shallower <u>water depth of 30m</u>; significantly reducing manufacturing and deployment costs without affecting power generation.

Project Plan & Schedule

ID		Task Name	Start	Finish
1		**Project - Grant DE-EE0003645**	**Wed 9/1/10**	**Fri 2/6/15**
2		Contract Effective Date	Wed 9/1/10	Wed 9/1/10
3		DOE Contract Issue Date	Fri 2/11/11	Fri 2/11/11
4		OPT Contract Approval Date	Fri 2/18/11	Fri 2/18/11
5		**Phase I - PB500 Strucutre and MPTO Development**	**Mon 5/2/11**	**Tue 4/30/13**
6		Task 1 – Revised Concept of PowerBuoy Structure	Mon 5/2/11	Fri 7/29/11
7		Task 2 – Preliminary Design and Performance Model of PowerBuoy Structure	Mon 8/1/11	Fri 12/30/11
8		Task 3 – Procure and Build Subassemblies	Mon 1/2/12	Fri 6/29/12
9		Task 4 – Procure and Build Assemblies	Mon 7/2/12	Tue 10/30/12
10		Task 5 – Integrate PTO Assemblies into PTO System	Wed 10/31/12	Tue 4/30/13
11		Task 6 – Hydrodynamics Analysis of Scale Model Testing Results	Mon 8/1/11	Tue 4/30/13
12		**Phase II - Design For Manufacturing of PB500 Structure**	**Wed 5/1/13**	**Mon 9/30/13**
13		Task 1: Design for Manufacturing	Wed 5/1/13	Fri 8/30/13
14		Task 2: Parametric Cost Model Study	Mon 6/3/13	Mon 9/30/13
15		**Phase III - Optimized PTO Development**	**Tue 10/1/13**	**Fri 2/6/15**
16		Task 1: Development of Project Charter and System Requirement Specification	Tue 10/1/13	Fri 3/7/14
17		Task 2: Determine Concepts and Technology Solutions for Optimized PTO	Mon 3/10/14	Fri 6/6/14
18		Task 3: Final solution Development for Optimized PTO	Mon 6/9/14	Fri 8/8/14
19		Task 4: Preliminary Design, Analysis, Component Testing and Design Verification	Mon 8/11/14	Fri 11/7/14
20		Task 5: Detailed Design and Fabrication Drawings for Optimized PTO	Mon 11/10/14	Fri 2/6/15
21		**All Phases**	**Mon 5/2/11**	**Fri 2/6/15**
22		Task 6: Project Management	Mon 5/2/11	Fri 2/6/15
23		Task 7: Reporting	Mon 5/2/11	Fri 2/6/15



Project Budget

Budget History					
FY2012		FY2013		FY2014 (As of Dec 31, 2013)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$539K	$414K	$984K	$853K	$212K	$311K

- The project plan for the remaining effort was modified to focus on PTO optimization
- Approximately 79% of the project budget of $4.2 million has been expended as of December 31, 2013.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: The Modular Power Take Off (MPTO) was integrated into an OPT PowerBuoy (PB40). While the fabrication of the MPTO was part of this DOE contract, the design, fabrication and build of the PB40 was carried out under a European Union (EU) award (FP7) to Ocean Power technologies. This EU contract involves a number of partners and subcontractors located in Europe.

Communications and Technology Transfer:

OPT shares pertinent findings and lessons learned with the DOE, various industry players, suppliers and other stakeholders in the MHK industry. For instance, the main results of this effort are being disseminated as follows:

- Presentation of OPT authored paper, "System-Level Approach to the Design, Development, Testing, and Validation of Wave Energy Converters at Ocean Power Technologies" to the 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE) 2014 Conference in San Francisco.

- Submission by OPT of the Final Scientific Non-Proprietary Report to the Department of Energy for the "Advanced, High Power, Next Scale, Wave Energy Conversion Device" (Contract DE-EE0002649).

Next Steps / Future Work

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- OPT under contract to further optimize the Modular PTO (MPTO)
- Using the MPTO results as the benchmark, the goal is to achieve the following:
  - Power Take-Off (PTO) Material Cost: Develop a design that will reduce recurring material cost of the PTO by 10% to 25% from the baseline system.
  - Manufacturability/Producibility: Develop a design that will reduce manufacturing time and cost by 10% to 25% from the baseline system.
  - Efficiency: Increase overall PTO efficiency by 3% to 10% from the baseline system.
  - Operations and Maintenance Cost (O&M): Develop a design that requires reduced maintenance and operations cost by 5% to 10%.
  - Reduce the PTO footprint: Improve the PTO design to reduce the PTO foot print (volume and/or weight) by 5% to 10% from the existing system. This will help reduce the PowerBuoy® structure size and weight, and hence further reduce the overall cost of energy.

Solving the problems above allows for achieving a more competitive Levelized Cost of Energy in the global marketplace.

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Reedsport PB150 Deployment and Ocean Test Project

Dr. Mike Mekhiche
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mmekhiche@oceanpowertech.com
(609) 730 0400

February 25, 2014

Purpose & Objectives

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

Problem Statement: Minimizing the levelized cost of energy (LCOE) is critical to the growth of the MHK industry.

Objectives

- Deploy a full scale 150kW PowerBuoy in “relevant ocean testing” in the Oregon Territorial Sea, and collect detailed operating characteristics.
- Establish manufacturing methodologies to maximize production and minimize cost in volume production in conjunction with Lockheed Martin

This award is a follow-on to a previous DOE project wherein OPT successfully designed, built, and land-tested a fully functional, utility-scale, wave power generating buoy and unique Power Take-off system, and then integrated these two essential components into a system at Reedsport.

Impact of Project: Achievement of these objectives would significantly advance the MHK industry toward the widespread adoption of the technology and hence commercialization

This project aligns with the following DOE Program objectives and priorities:

Technical Approach

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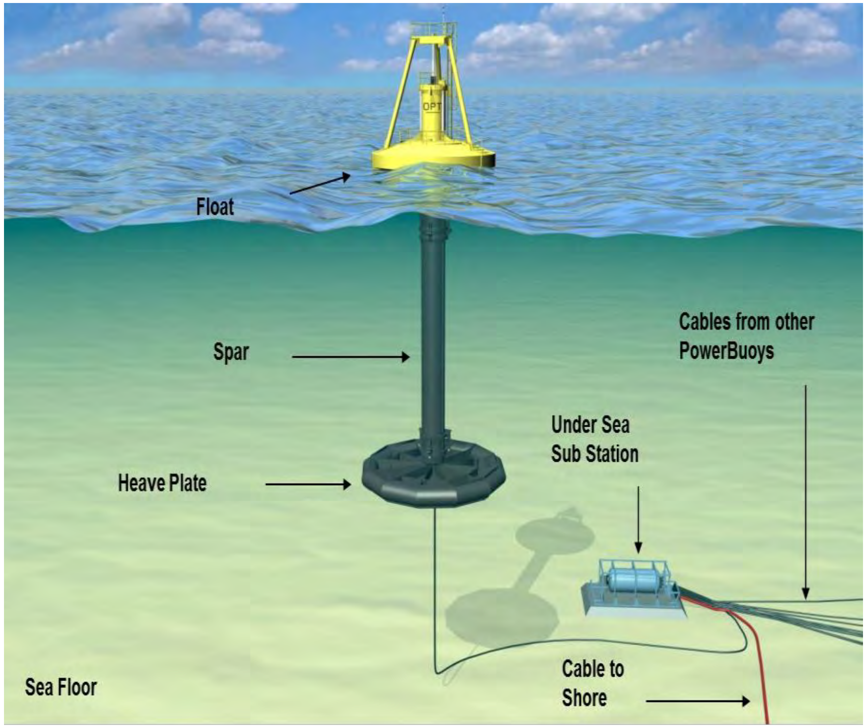
Project is based on a phased approach:

1. Complete the final assembly, deployment and commissioning of a single, autonomous PB150 at Reedsport, Oregon.
2. The original plan was for the PB150 to undergo ocean testing in the aggressive environment of the Oregon Territorial Sea.
3. During this time, the PB150 would be continuously monitored for power production, reliability, mooring system performance, and sea-state responsiveness.
4. Acoustic and EMF testing would be performed on the single unit prior to and during deployment in accordance with the Reedsport Settlement Agreement Study Plans.
5. The manufacturability of the PB150 and component and fabrication cost reduction strategies to achieve manufacturing cost targets would also be analyzed by OPT's partner, Lockheed Martin.
6. Interim reports would be delivered on deployment, commissioning, acoustic and EMF testing, interim buoy ocean testing reports and a final report.
7. Upon completion of this initial phase, additional buoys would progressively be added in the subsequent phases of the project.

Accomplishments and Progress

- During the Summer 2012, construction of the PB150 PowerBuoy main assemblies were completed, utilizing several local Oregon suppliers including Oregon Iron Works, Vigor Marine and American Bridge.
- During Summer 2012 anchor/mooring system was ready for deployment.
- During the summer of 2012 baseline acoustic testing was performed at the Reedsport site with one month of data acquisition as required by the Cetacean Plan.
- Electromagnetic Field ("EMF") baseline testing was performed by a third party vendor with the data collected over two (2) days, prior to the start of construction activities.
- On October 4, 2012, OPT conferred with the Oregon Water Resources Board regarding the next steps on the Hydroelectric License (HE-591). The hearing for the License was held on August 9, 2012.
- OPT filed a draft Navigation Lighting Plan and SPCC Plan Addendum with the Commission on November 13, 2012.
- On February 1, 2013, OPT responded to the Division of Hydropower Administration and Compliance Letter dated January 16, 2013 regarding two License Articles due in November 2012.
- OPT met with Division of Hydropower Administration and Compliance Staff on February 7, 2013 to discuss the Reedsport 1.5 MW Project. OPT indicated that the Company planned to file an Extension of Time request.
- On February 25, 2013, OPT filed a letter indicating the March 19, 2013 date of the next Coordinating Committee Meeting and plans to consult with stakeholders regarding planned project schedule revisions at that time, in Oregon.
- In December 2013, OPT's sub awardee, Lockheed Martin completed the life-cycle cost reduction which included Design For Manufacture (DFM) and design for transportation work.

OPT PowerBuoy™ System

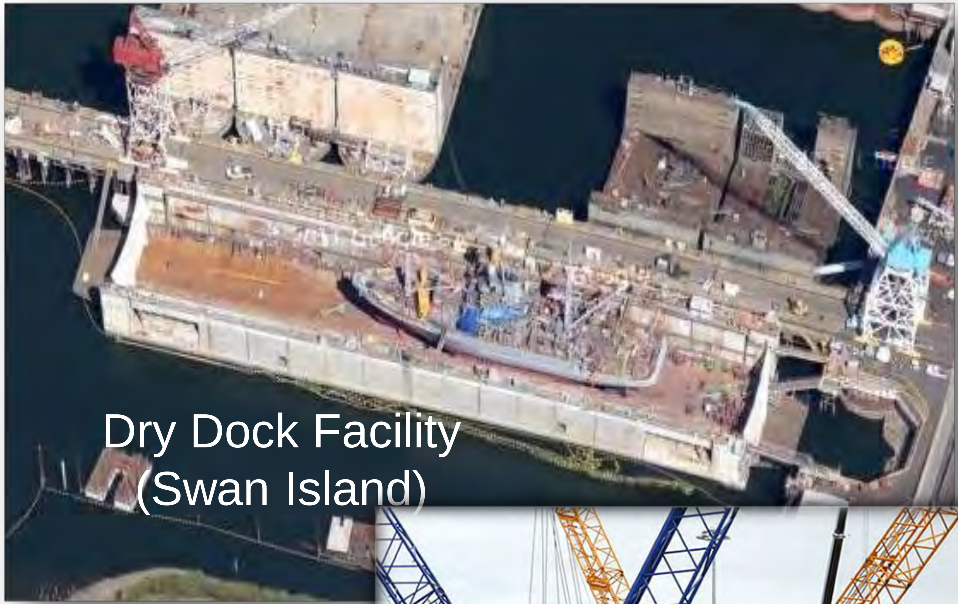


- PowerBuoy is a floating power generation system that captures energy from waves.
- A mooring keeps the PowerBuoy on station in the ocean.
- A float moves in response to ocean waves along a spar which has a reduced response to waves due to a heave plate at its base.
- Relative motion between the float and spar drives a push rod into the spar.
- A mechanical actuator converts the linear motion into a rotary action that drives a vector-controlled generator and outputs three phase AC power.
- A state of the art power management and conditioning system converts AC power into DC power.
- Energy Storage System (ESS) utilizing state of the art battery and ultra-capacitor removes the transient nature of the power.
- DC power is converted back into constant voltage and constant frequency AC power.

PowerBuoy Fabrication (Vancouver, WA)

Fabrication of Sub-Surface Buoys for Moorings (Reedsport)

Planned Deployment similar to OPT Scotland B1 deployment

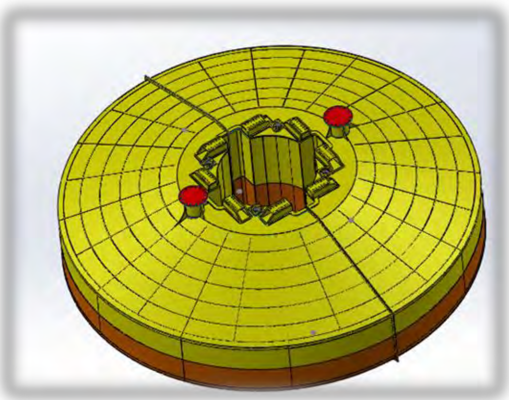


Design for Transportability

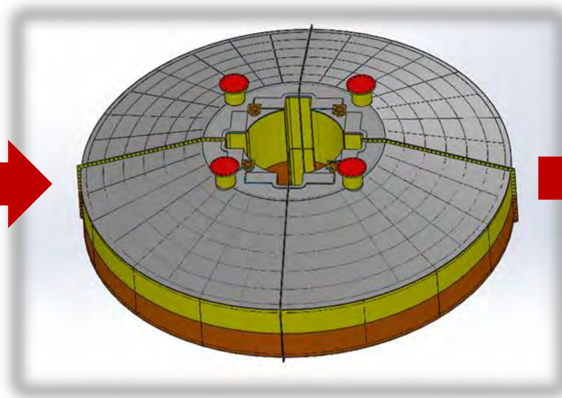
In conjunction with Lockheed Martin

- Update float design to incorporate cylindrical inner diameter
  - Weight and/or stress factor of safety neutral design
- Incorporate roller bearing assemblies
  - Roller concept is scaled from existing design. Mounting to be updated to support PB150 with rollers or bearing pad

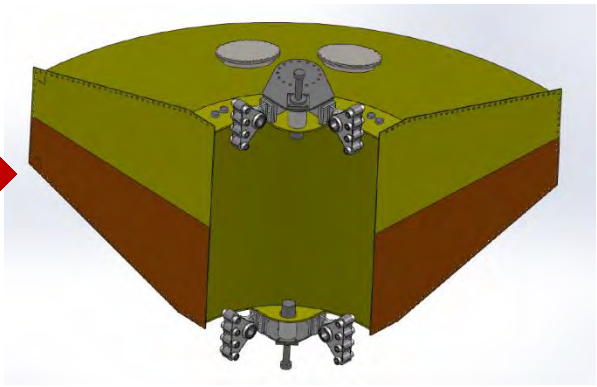
2-Piece Baseline Float Design



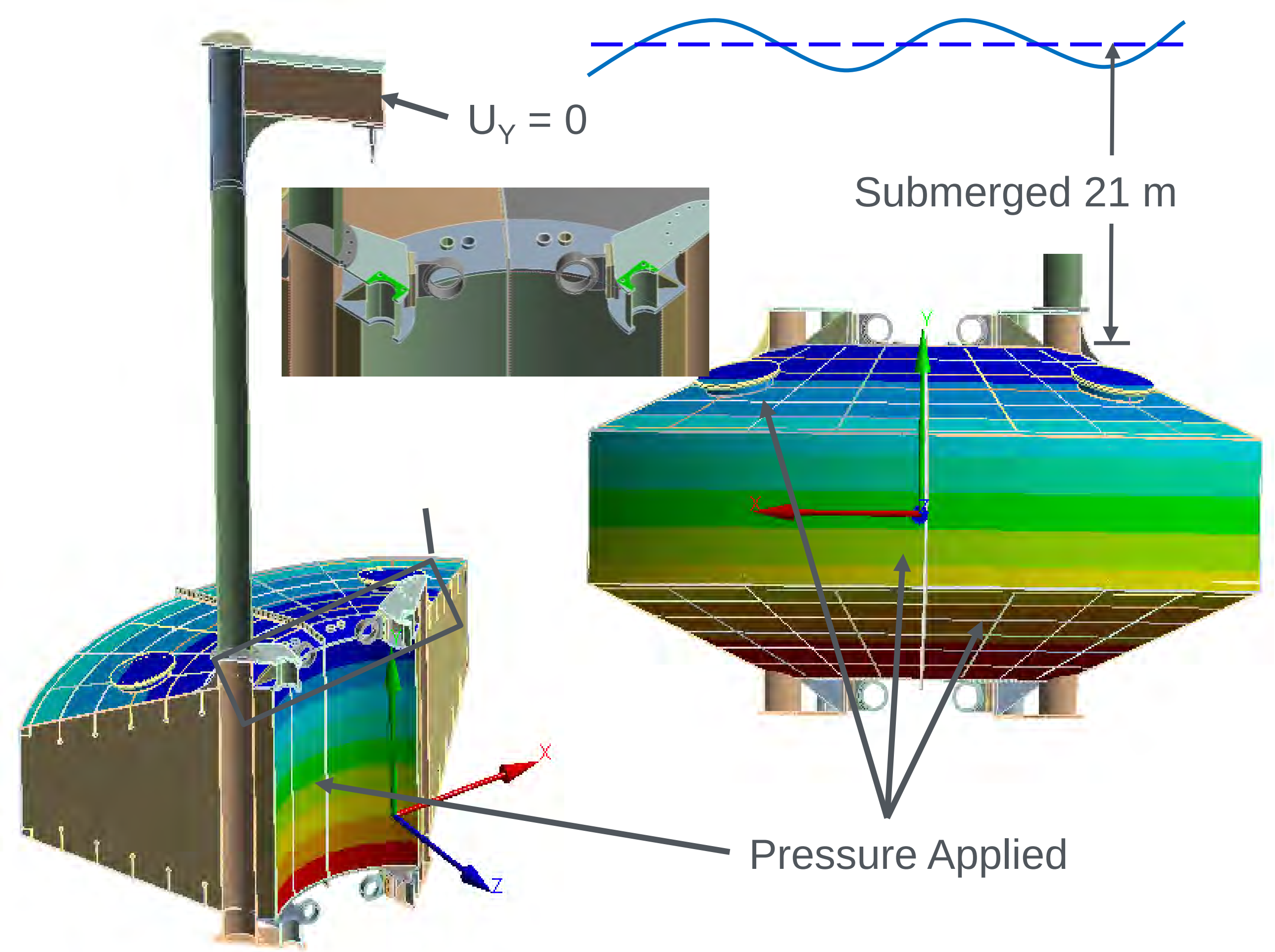
Quadrant Float Design



Quadrant Float Design w/ Cylindrical ID and Rollers



Example: Hydrostatic Pressure Analysis

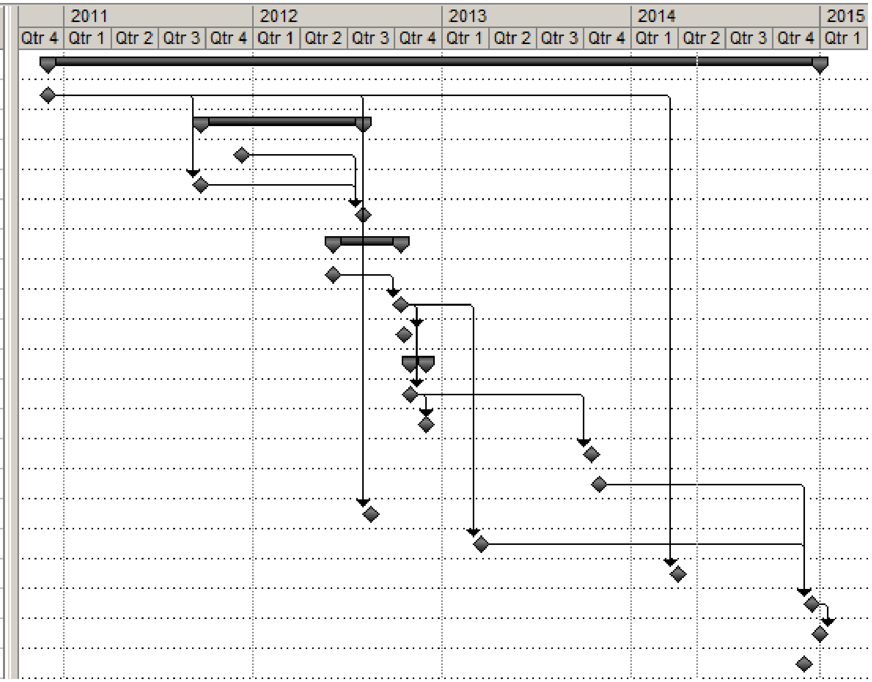


- Simulate effects of 100 year storm on float structure
- Ensure safety factors meet OPT standards
- Identify design areas where cost can be taken out

Load Case Represents 100 Year Storm Impact

Project Plan & Schedule

Notes	Task Name	Finish
	Project - Grant EE-0003646	**Tue 9/30/14**
	Contract Effective Date	Wed 9/1/10
	Task 1.1 Predeployment Activities	**Tue 5/1/12**
*1	Final Deployment Vendor Selection	Fri 9/9/11
*1	Prepare FGBAs	Thu 6/23/11
*2	Assembly of PowerBuoy (PARTIALLY COMPLETE, ON HOLD)	Tue 5/1/12
	Task 1.2 Deployment Activities	**Fri 7/13/12**
*1	Final Vendor Selection	Fri 3/2/12
*3	Deployment - Ocean Test Start (ON HOLD)	Fri 7/13/12
	DOE Go/No-Go Meeting, Proceed to Budget Period 2	Wed 7/18/12
	Task 2 PowerBuoy Commissioning	**Fri 8/31/12**
*3	Commissioning (ON HOLD)	Tue 7/31/12
*3	Commissioning Test Report (ON HOLD)	Fri 8/31/12
*3	**Task 3 PowerBuoy Ocean Test Completion (ON HOLD)**	Mon 7/15/13
*3	**Task 4 PB150B2 Removal and Demobilization (ON HOLD)**	Thu 8/1/13
*2	**Task 5.1 Environmental Studies: Pre-deployment (PARTIALLY COMPLETE, ON HOLD)**	Tue 5/15/12
*3	**Task 5.2 Environmental Studies: Post-deployment (ON HOLD)**	Fri 12/14/12
*1	**Task 6 Manufacturing Plans**	Tue 12/31/13
*3	**Task 7 PB150B2 Redeployment (ON HOLD)**	Mon 9/15/14
*2	**Task 8 Project Management**	Tue 9/30/14
	Contract End Date	Sun 8/31/14



Notes/Comments

DOE Go/No-Go meeting resulted in decision to proceed to Budget Period 2.

*1 Task complete, actual completion date shown

*2 Task partially complete - on hold pending outcome of discussions between OPT and DOE

*3 Task on hold pending outcome of discussions between OPT and DOE

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$379K	$392K	$772K	$2,932K	$83K	$1,394K

- The total project budget was $5,684K of which, $2,409K were DOE funds and $3,275 were OPT.
- As of December 31, 2013, more than $5,952K of funds have been expended, of which $1,234K are DOE funds and $4,718 are OPT.
- DOE, OPT and Lockheed Martin are the funding sources.

Partners, Subcontractors, and Collaborators: In addition to the supply base contracted by OPT to fabricate the PB150 in the Reedsport, Oregon area, Lockheed Martin was also subcontracted to carry out a design for transportability study for some of the larger structural components of the PB150.

Communications and Technology Transfer: As is the case with other similar contracts and efforts, OPT continues to make every effort possible to share pertinent findings and lessons learned with the DOE, various industry players, suppliers and other stakeholders in the MHK industry. For instance, the main results of this effort are being disseminated as follows:

- EMF study results for Oregon-based NMREC project were presented by OSU's NMREC Director to FERC at a U.S. DOE sponsored MHK Environmental Seminar on April 9, 2013 in Washington, D.C. The Reedsport baseline EMF readings obtained in 2012 by OSU incorporated these new techniques, developed as a result of the work funded by USDOE for other projects.
- Presentation of OPT authored paper, "System-Level Approach to the Design, Development, Testing, and Validation of Wave Energy Converters at Ocean Power Technologies" to the 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE) 2014 Conference in San Francisco.
- Submission by OPT of the Final Scientific Non-Proprietary Report to the Department of Energy for the "Wave Power Demonstration Project at Reedsport, Oregon" (Contract DE-FG36-08GO88017).

Next Steps and Future Research

FY14/Current research: Ocean Power Technologies has been pushing the state of the art in PowerBuoy technology in parallel with the Reedsport project. In particular, Power Take Off technology is now at least one generation ahead of the system that is part of the Reedsport PB150 PowerBuoy. OPT and DOE are now in discussions to identify the next steps.

Proposed future research:

- Additional technical achievements towards fully commercial PowerBuoy systems are being made, leveraging among others, other DOE contracts and support.
- Focus on overall system reliability and life, design for manufacturability (DFM) and design to cost (DTC) to achieve the most competitive Levelized Cost Of Energy (LCOE) remains a must. Such efforts must include the PTO as well as the hydrodynamic structure.
- Further, attention to permitting and regulations related the deployment of PowerBuoy farms and their interconnection with the grid shall also remain an important focus in the mid to long term future.

Water Power Peer Review

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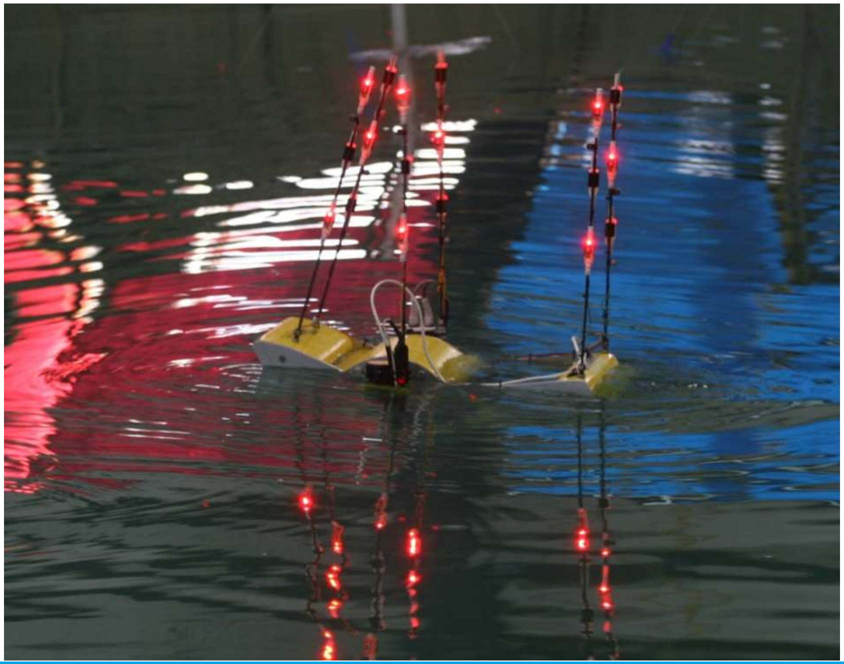
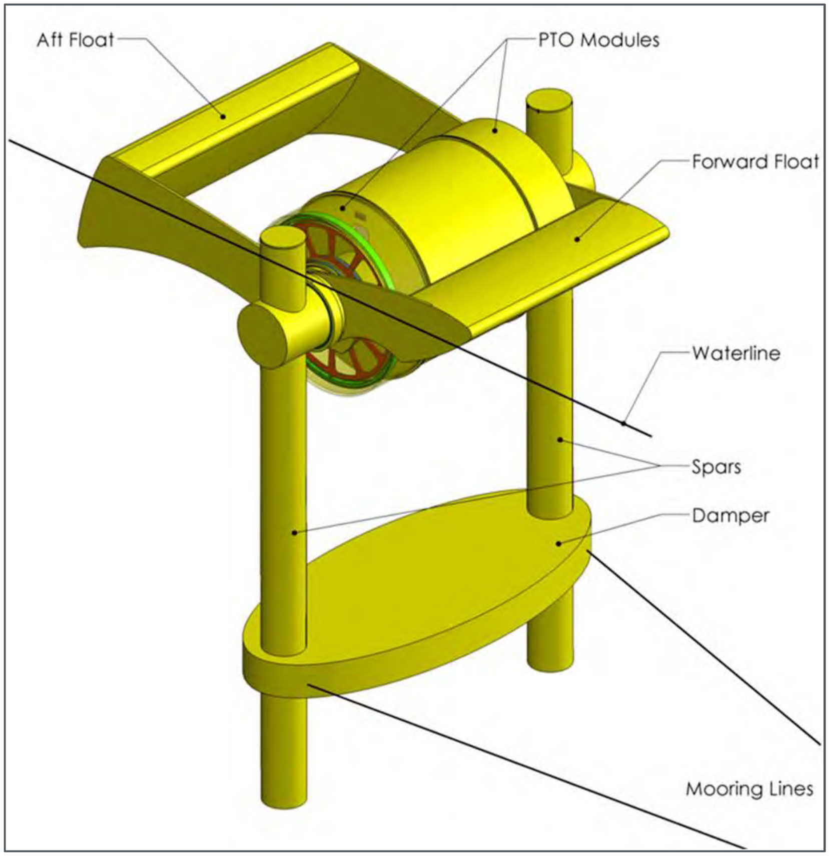
COLUMBIA POWER TECHNOLOGIES

power from the next wave





Direct Drive Wave Energy Buoy

StingRAY v3.2

Ken Rhinefrank

Columbia Power Technologies, Inc.

krhinefrank@columbiapwr.com, 541 760 1833

February 25, 2014

Purpose & Objectives

Problem Statement: To design a survivable, low-environmental-impact, cost-effective utility-scale WEC for demonstration in a vigorous wave environment.

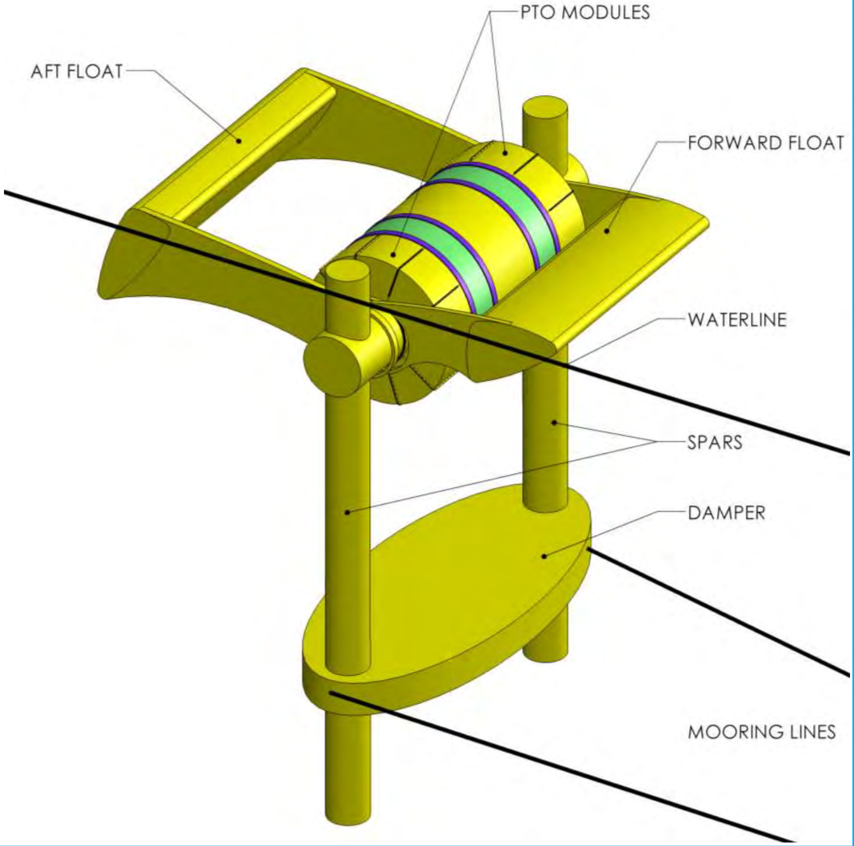
Impact of Project: Delivers a certifiable v3.2 system detailed design (SDD), addressing key industry needs for survival, station keeping, PTO performance, and LCOE.

This project aligns with the following DOE Program objectives and priorities:

- ✓ Advance the state of MHK technology
- ✓ Key MHK testing infrastructure, instrumentation, and/or standards
- ✓ Characterize and increase access to high resource sites
- ✓ Reduce deployment barriers and environmental impacts of MHK technologies

DOE Program objectives and priorities:

- Advance the state of MHK technology:
    - Energy capture design, critical sub-systems, components and siting needs for deployment of least cost MHK systems
    - Certification and risk assessment process integrated with designs
    - Advance TRL with a full scale WEC design for deployment at WETS
    - A novel direct-drive power take off design that increased energy capture



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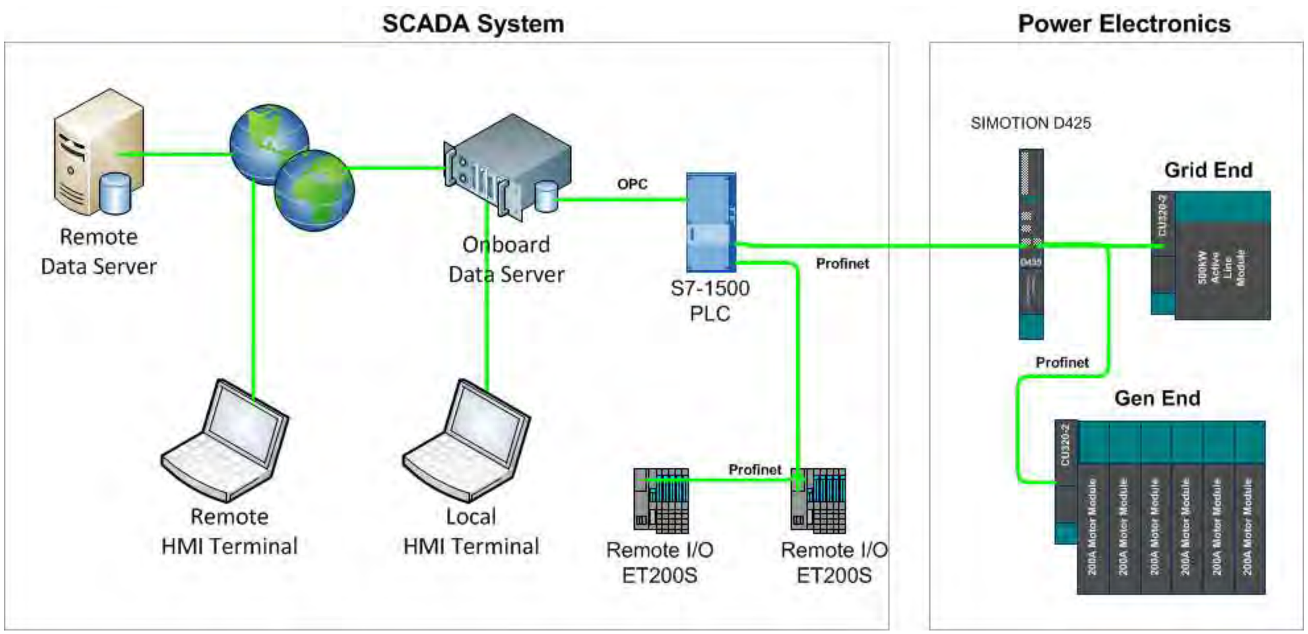
DOE Program objectives and priorities:

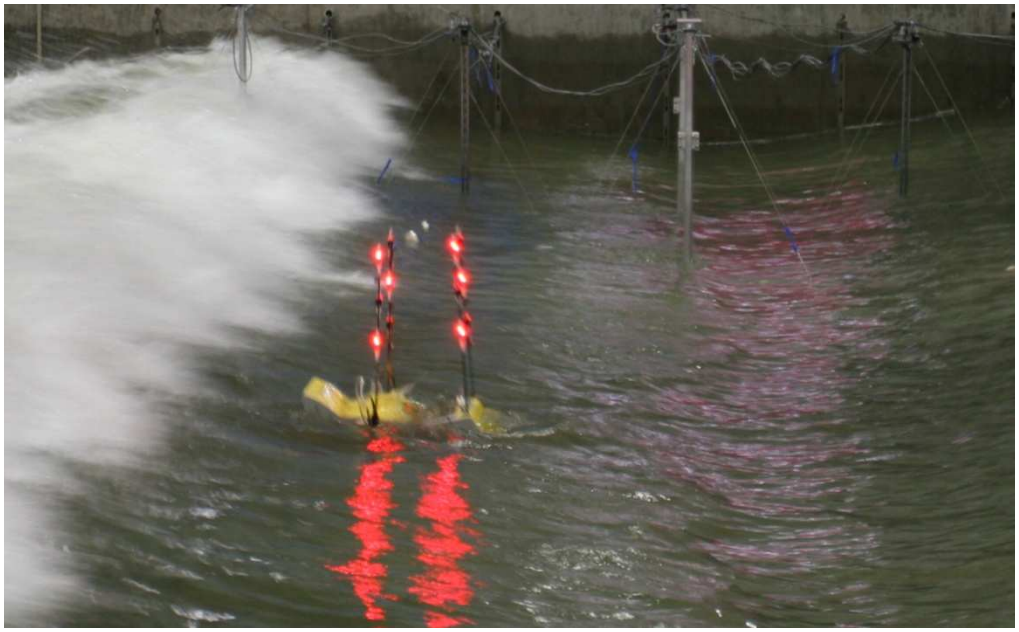
- Develop key MHK testing infrastructure, instrumentation, and/or standards
  - Introduces a highly-instrumented supervisory control and data acquisition (SCADA) system.
  - Certification standards integrated into design process



DOE Program objectives and priorities:

* Characterize and increase access to high resource sites

The design introduces a WEC structure with unlimited range of motion, that is unencumbered by a requirement for end stops, allowing operation in all seas.



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DOE Program objectives and priorities:

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The design introduces a WEC structure with unlimited range of motion that is unencumbered by a requirement for end stops, allowing operation in all seas.

Purpose & Objectives

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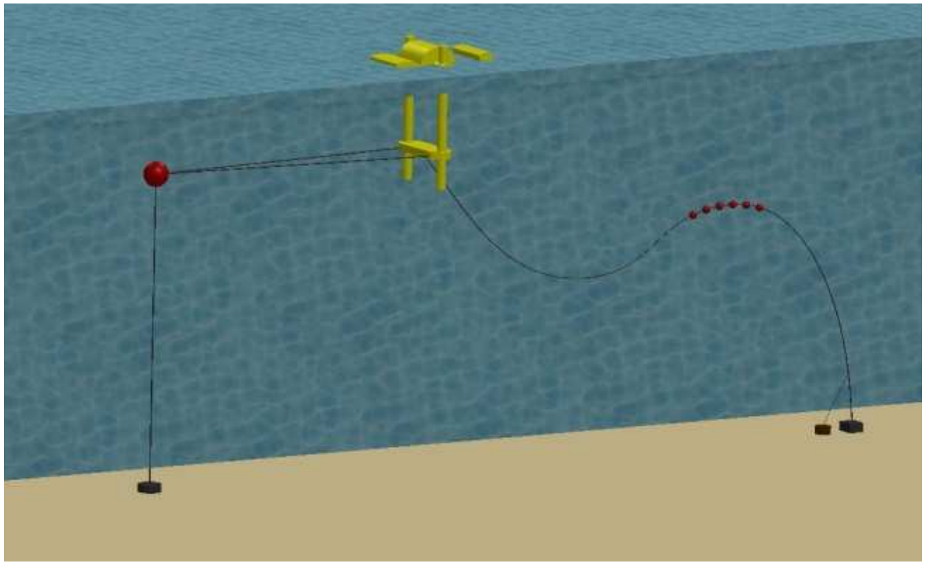
DOE Program objectives and priorities:

* Reduce deployment barriers and environmental impacts of MHK technologies

Single point mooring system

- reduces environmental impacts,
- minimizes gear in the water,
- improves stakeholder acceptance.



Technical Approach for StingRAY v3.2:

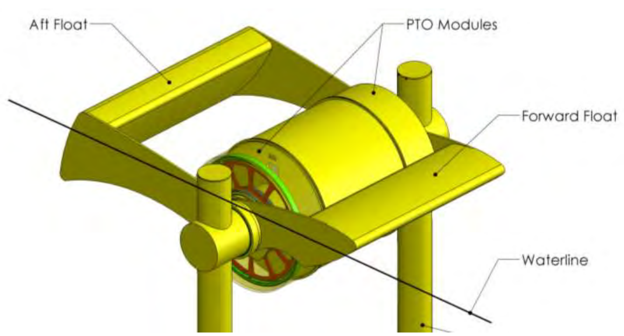
- Develop novel conceptual design improvements including:
  - increased RCW, reduced impact mooring, elimination of end stops
- Numerically optimize WEC improvements
- Experimentally validate concepts, performance, numerical models and survival at 33rd scale.
- Incorporate design and accompanying assessment (DAA).
- Assess loads, Include all DLC's recommended by certifying agency.
- Partner with experts in essential design areas to develop SDD including;
  - mooring, power take off, controls, structure and marine operations
- Assess permitting and logistical requirements
- Design and build SCADA for PTO testing

Key issues currently being addressed:

- Mooring interface at WETS is pending redesign. Mooring design substantially affects the WEC structural loads and places load assessment and structural design on hold until the mooring re-design is completed. Expect continuance of plan in March 2014.
- SCADA SDD in progress
- Passive-ballast for overtopping and all ballast plans addressed
- Investigation of preferred hull coatings
- Design Basis report submitted to GL/DNV and under review.
- Design integration with PTO project
- Comprehensive risk assessment in progress

Unique Aspects of Approach:

- Inclusion of DAA in design process which allows for:
  - comprehensive buy-in on load assessments
  - detailed risk assessment
  - offshore marine expertise in the design



Technical Approach

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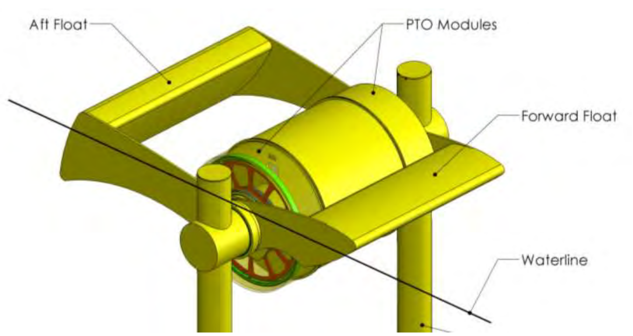
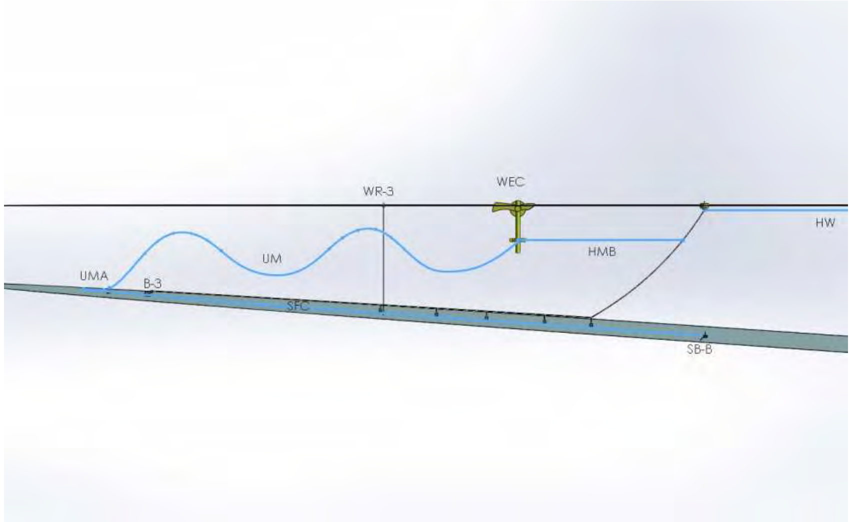
Unique Aspects of Approach:

- Inclusion of DAA in design process which allows for:
  - comprehensive buy-in on load assessments
  - detailed risk assessment
  - offshore marine expertise in the design
- Low-impact, single-point mooring





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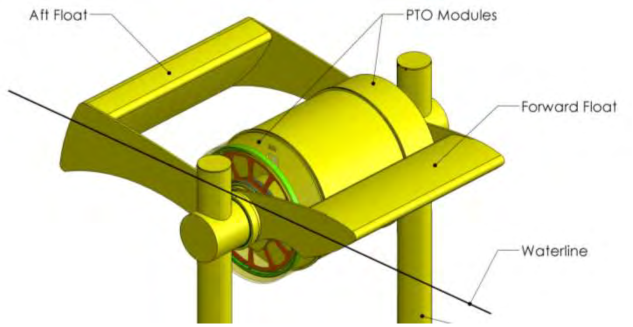
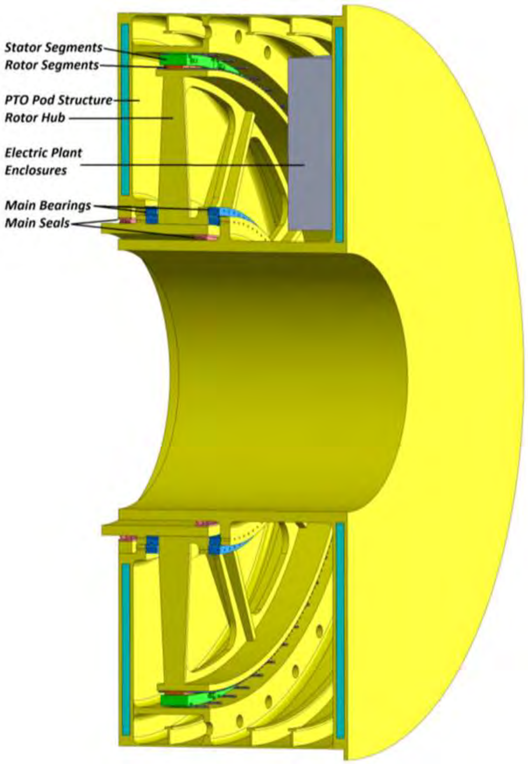
- Inclusion of DAA in design process which allows for:
  - comprehensive buy-in on load assessments
  - detailed risk assessment
  - offshore marine expertise in the design
- Low-impact, single-point mooring
- No end stops

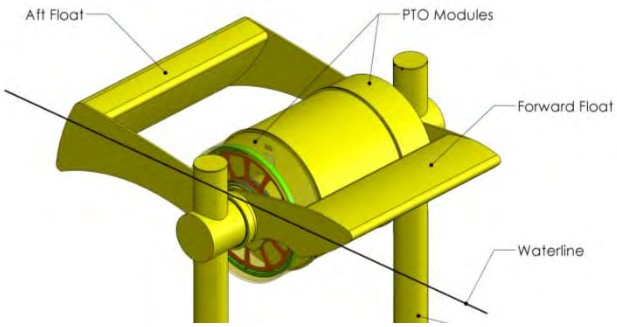


Technical Approach

Unique Aspects of Approach:

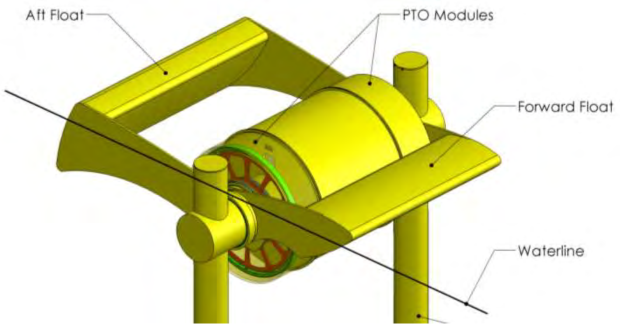
- Inclusion of DAA in design process which allows for:
  - comprehensive buy-in on load assessments
  - detailed risk assessment
  - offshore marine expertise in the design
- Low-impact, single-point mooring
- No end stops
- Direct drive PTO operates in all sea states

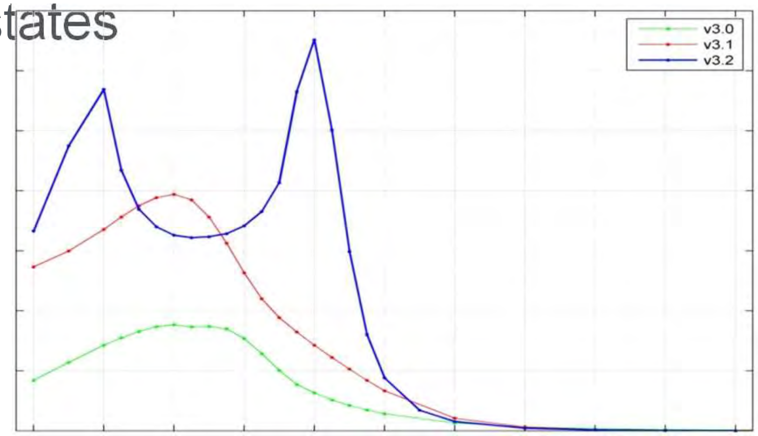




Unique Aspects of Approach:

- Inclusion of DAA in design process which allows for:
  - comprehensive buy-in on load assessments
  - detailed risk assessment
  - offshore marine expertise incorporated in the design
- Low-impact, single-point mooring
- No end stops
- Direct drive PTO operates in all sea states
- Improved RCW





Accomplishments and Progress

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Major accomplishments 2012-2013:

- 33rd scale experimental verification of models/concepts
- load analysis approach defined, DLCs proposed
- design basis completed and under review
- design of SCADA PTO

Recent awards:

- FOA 848: DE-EE-0006399, “ Build and Test of a Novel, Commercial-Scale Wave Energy Direct-Drive Rotary Power Take-Off Under Realistic Open-Ocean Conditions”

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number: FOA 293	
Agreement Number DE-EE0005930.000	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Revised)
	Milestones & Deliverables (Actual)

	FY2012			FY2013				FY2014				FY15
Task / Event	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)
Project Name: Direct Drive Wave Energy Buoy												
Task 1.0 Wave Tank Testing and Assess Results												
Task 2.0 Environmental Forces and Associated Load Analysis												
Task 3.0 Complete Full Scale Design												
Task 4.0 SCADA Hardware Build and Programming for PTO												
Task 5.0 Certification of Design and Accompanying Assessment (DAA)												
Task 6.0 Site Selection, Shipping, CONOPS and Logistics Planning												
Task 7.0 Permitting												
Task 8.0 Dissemination of results												

Comments

- Project initiation: June 2012 / Project completion: Dec 2014
- Task 1 test schedule and post analysis slipped to improve the precision of testing and analysis
- Task 2 loads analysis delayed to assure accurate loads are used in design
- No cost extension of project to Dec 2014 to accommodate load analysis delays
- No Go/no-go decision points assigned to project

Project Budget

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	Budget History					
	FY2012		FY2013		FY2014	
	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
Actual	0 $K	0 $K	662 $K	662 $K	61 $K	61 $K
Planned	0 $K	0 $K	1,500 $K	1,500 $K	0 $K	0 $K
Difference	0 $K	0 $K	+ 838 $K	+ 838 $K	-61 $K	-61 $K

- FY 2013 – Forced design delay until mooring is finalized
- 48 % of budget expended to date
- 100 $K funding match from OWET

Partners, Subcontractors, and Collaborators:

Concept Systems	Albany, OR
Ershigs, Inc.	Ridgefield, WA.
InterMoor	Houston, TX
Oregon State University	Corvallis, OR
Siemens	Norcross, GA
GL Garrad Hassan / Germanischer Lloyd / DNV	

Other Collaborators:

NFESC, NAVFAC
NREL and SANDIA
University of Hawaii
Sound and Sea Technologies
Sea Engineering
Navatek / Pacific Marine Shipyard

Communications and Technology Transfer:

- v3.2 design unveiled and demonstrated at 33rd scale to:
  - attendees of the OREC VII Conference on 9/28/2012 at the OSU, OH Hinsdale Wave Research Lab.
  - visitors from the Office of Naval Research,
  - TC114 technical advisory group members and
  - numerous K-12 students visiting the HWRL lab.
- Wave tank test data shared with SANDIA and NREL

Next Steps and Future Research

FY14/Current research: Major efforts remaining:

- finalize load analysis, post Navy WETS mooring design
- complete SCADA design and build for PTO
- complete design and design assessment
- ground work for logistics and permitting at WETS

Proposed future research:

- build and open-ocean deployment of grid-connected WEC

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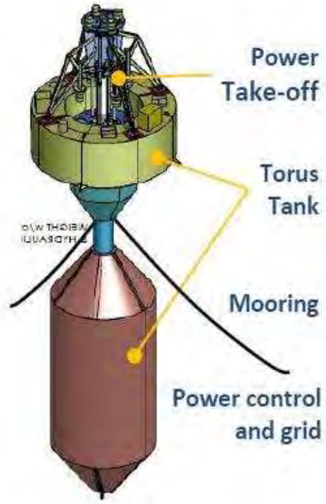
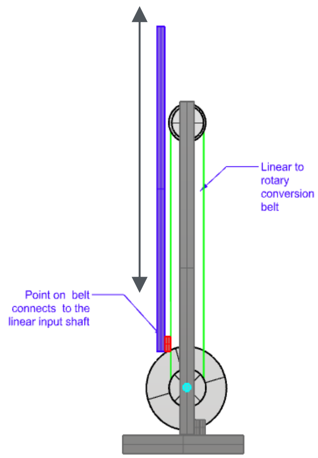
AWEC
Wavebob (Prime)

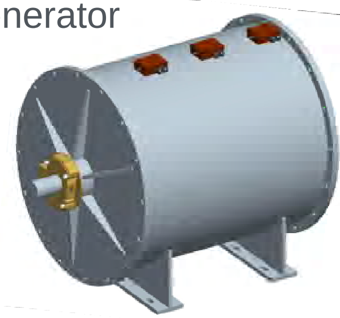


Power Take Off (PTO)
RCT Systems (Sub)



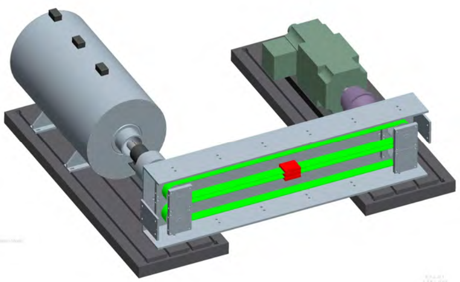
Linear / rotary converter

SRM generator



Utility Interface

SRM Drive Inverter



TRL5 test set up

Wavebob Advanced Wave Energy Converter (AWEC) & Power Take Off (PTO)

L.E. (Ted) Lesster
RCT Systems, Inc.
tlesster@rct systems.com, (410) 694 8046
February 24, 2014

Power Take Off (PTO) Subcontract

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Purpose:

- Design, construct and test to TRL5 a scalable Switched Reluctance Machine (SRM) based Power Take Off (PTO) to Wavebob requirements.
  Note: Trade off versus other technologies e.g.PM machines NOT tasked here
- Provide direct mechanical to electrical energy conversion between a linear stroking point absorber AWEC and a grid interface to which it must provide utility grade power.
- Provide four quadrant control to implement generating and motoring as well as controllable system damping

Challenge:

- Efficiency >75% from high force low speed/frequency wave input source linear motion
- High crest factor zero crossing wave energy input.
- Negative magnetic stiffness across air gaps
- Reasonable size and affordable cost in production
- Marine environment (but not submerged)

Power Take Off (PTO) Subcontract

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Impact:

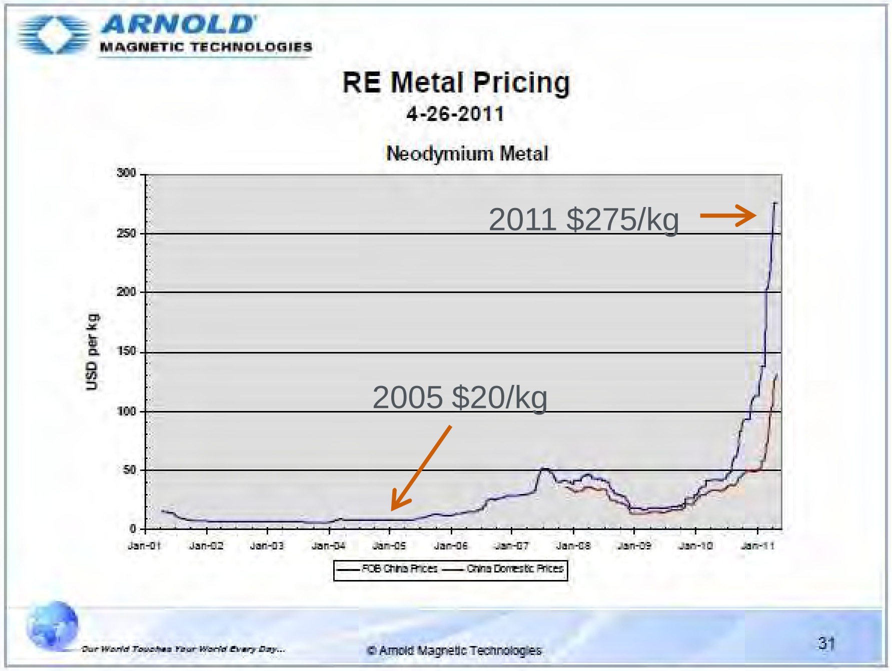
•Fully controllable four quadrant PTO for direct mechanical to electrical conversion for wave and tide energy projects.

•Safe to assemble and service. No flux when not energized.

•Not at whim of Rare Earth market. Compete with PM machines on cost. Domestically sourced material.

DOE Program Alignment:

• Advance state of MHK technology



Neodymium shown, similar price growth for Samarium and Dysprosium

PTO Program Status

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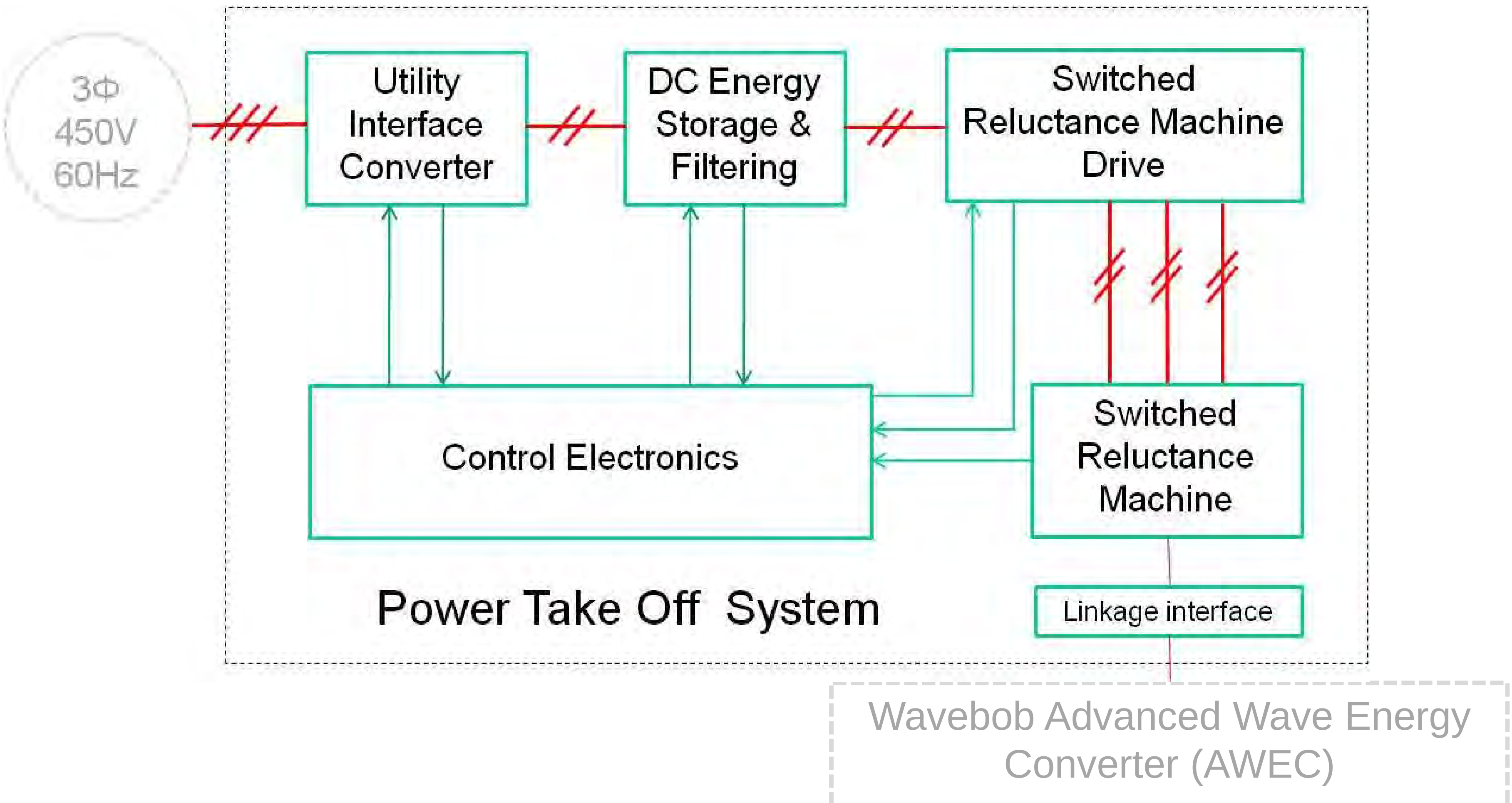
Brief history:
Subcontract kicked-off in June 2011.

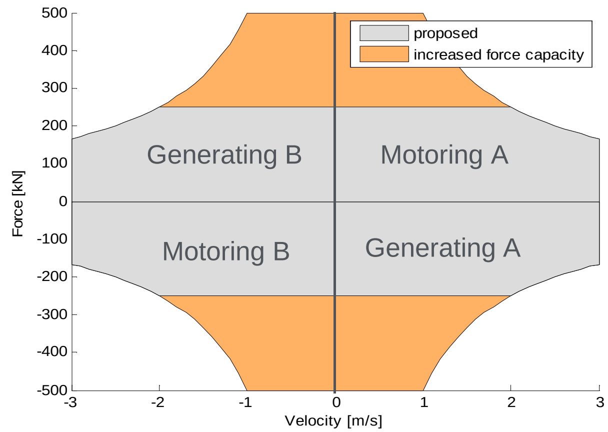
- June 2011 until June 2012
  - System level design and simulation, SDR
  - Preliminary design and analysis, PDR
  - Detail design, vendor interface, CDR
  - Cost effective revision to design, RDR
  - Component procurement and manufacture in process.
- June 2012 Program on hold due to Wavebob insolvency.
- Spending was on plan at $1.28M
- Table shows spending planned (but on hold) for manufacture and test

Month	6/1/12	7/1/12	8/1/12	9/1/12	10/1/12	11/1/12	12/1/12	1/1/13
Plan	1.28M	1.56M	1.77M	1.97M	2.03M	2.07M	2.15M	2.27M
Actuals	1.28M							
Labor		160K	87K	87K	54K	48K	72K	127K
Material		118K	118K	118K				

----Procurement (contd), manufacture and subsystem test------ ------------Test------------

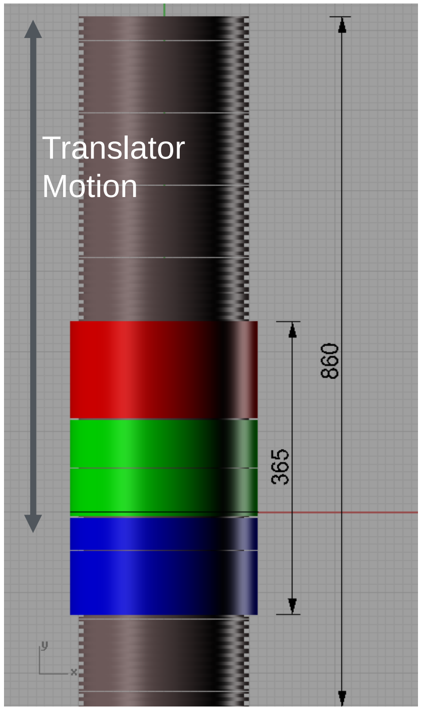
Scope of AWEC Power Take Off



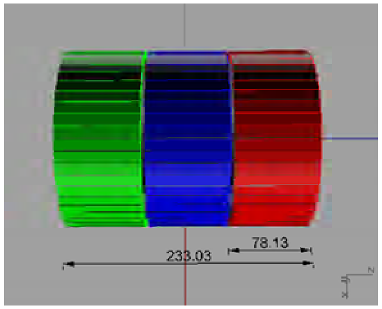


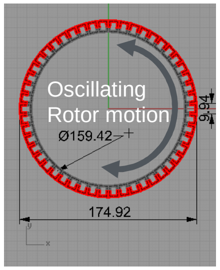
Initial AWEC buoy
Power specification

- 500kW machine – 500kN @ 1m/s, 250kN @2m/s
- Large machine – high force, very low speed
- Input from a linear actuator that is driven by displacement between two tuned buoyant masses
- Candidate 'Direct' and 'Indirect' linear machines
- Four quadrant operation
- Torque, current, motoring or generating controlled by the SRM Drive Inverter, also dynamic damping.
- Bidirectional power flow to grid via utility interface converter



"Direct"
Linear machine





"Indirect"
Machine driven via crank, for example

Full power sizing of PTO SRM generator shown to exceed project budget

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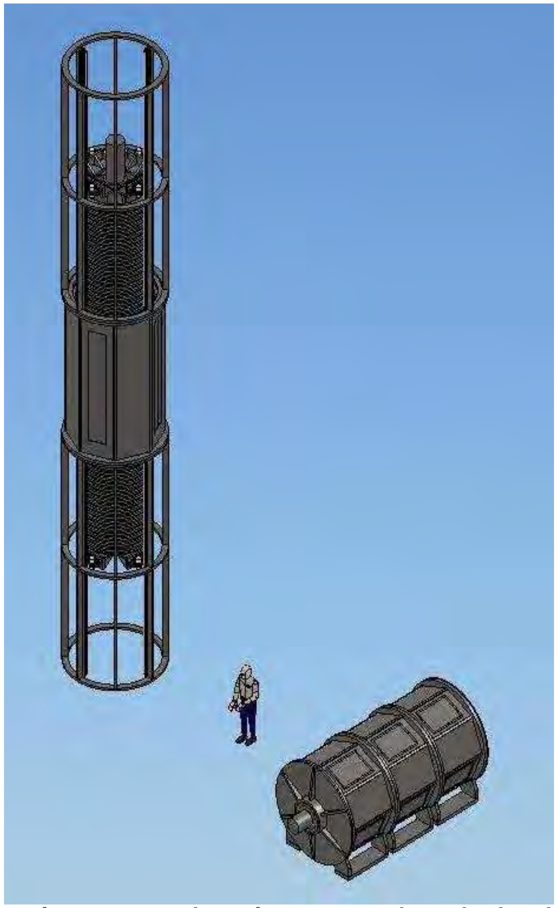

Elettro Technology Inc (ETI) designs using standard large electrical machine construction to RCT magnetic specifications

Magnetic analysis and design by RCT and a heavy machine manufacturer's construction design and costs showed both direct and indirect versions of a 500kW machine would exceed program cost allocation.

	Direct Machine	Indirect Machine
Height	550 in (14 m)	
Length		185 in (4.70 m)
Diameter	85 in (2.16 m) (dia)	85 in (2.16m)
Weight (basic machine only)	~160K lbs.	>100K lbs
Cost Estimate	~$3M	~$1M

An SRM design evolved that was affordable to the program and scalable to future AWEC

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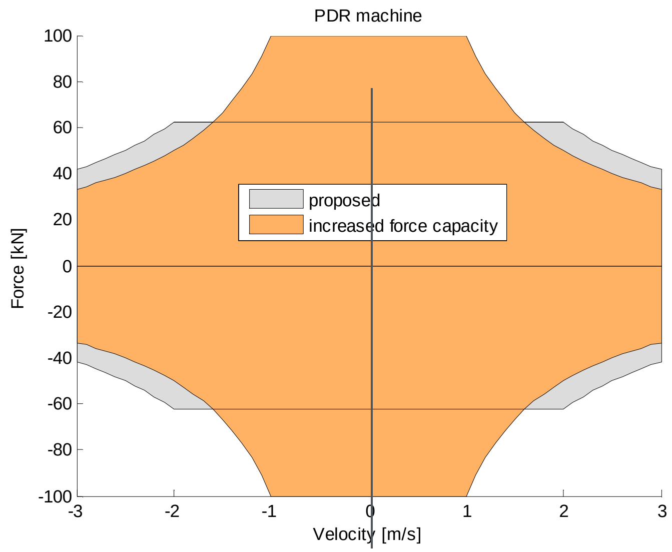
SRM	D_{airgap} (m)	D_{drum} (m)	Ratio	L_{axial} (m)	N_{coil}	Force (kN)	T_{shaft} (kNm)
Baseline SRM (SDR)	1.592	0.796	2	0.800	100	250	100
Reduced-Scaled SRM (PDR)	0.796	0.398	2	0.398	300	62.5	12.5
Reduced-Scaled SRM (CDR, Revised*)	0.796	0.250	3.2	0.398	240	100	12.5
Squarer SRM (RDR)**	0.928	0.250	3.7	0.291	280	100	12.5



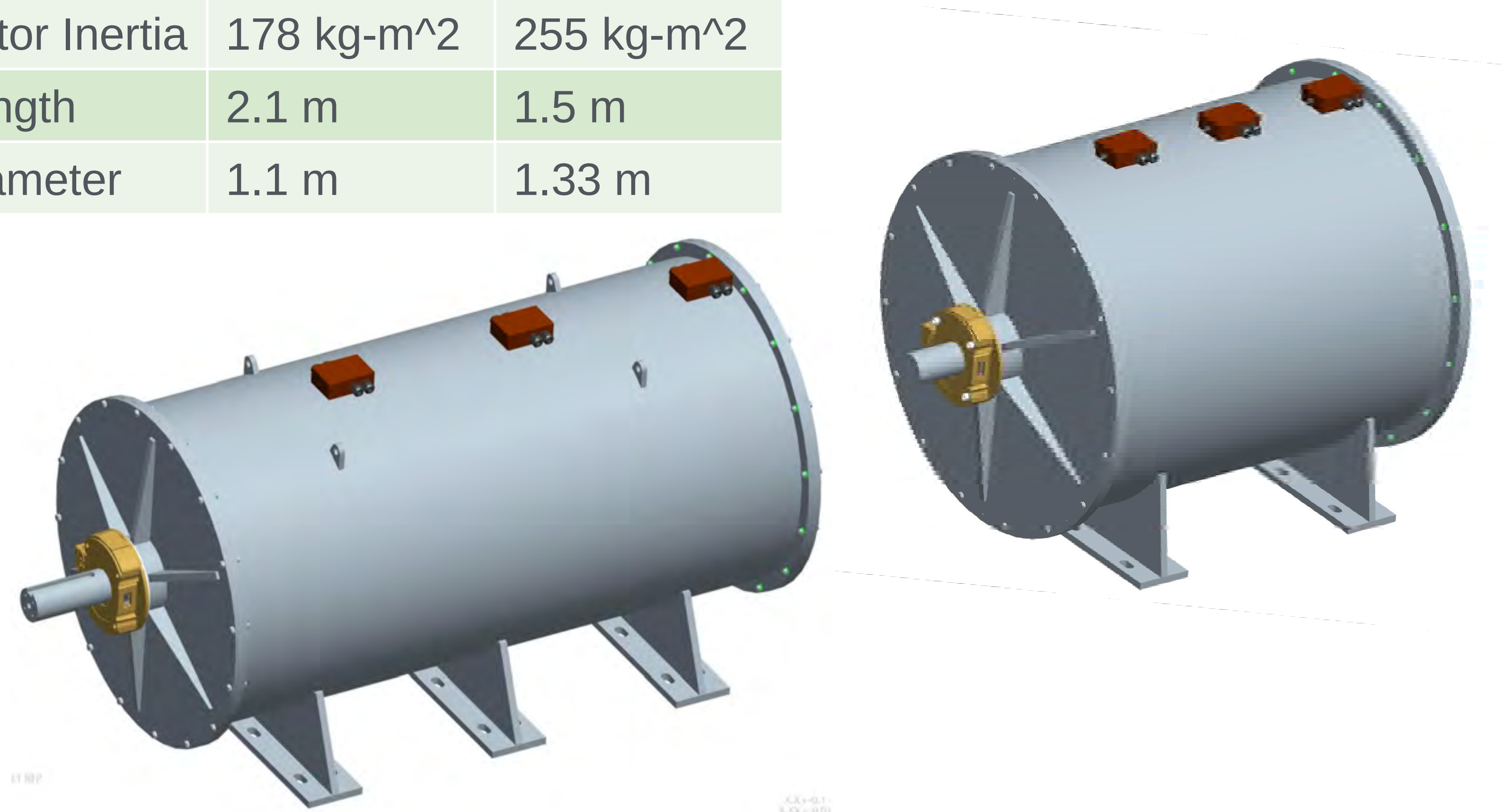
***: As revised on 12/13/2011 by Wavebob**

** RDR revisited CDR with a design improved for both weight, manufacturability and belt drive interface

- SRM pole number is increased from 24 to 28.
- Power electronics specifications stay the same.
- SRM drive controller parameters are tuned for the 28-pole SRM.

RDR design scales has twice the specific power of “indirect” machine

	CDR design	RDR design
Total Weight	7200 kg	5700 kg
Rotor Inertia	178 kg-m^2	255 kg-m^2
Length	2.1 m	1.5 m
Diameter	1.1 m	1.33 m



Power Electronics LRUs for TRL 5 Demonstration

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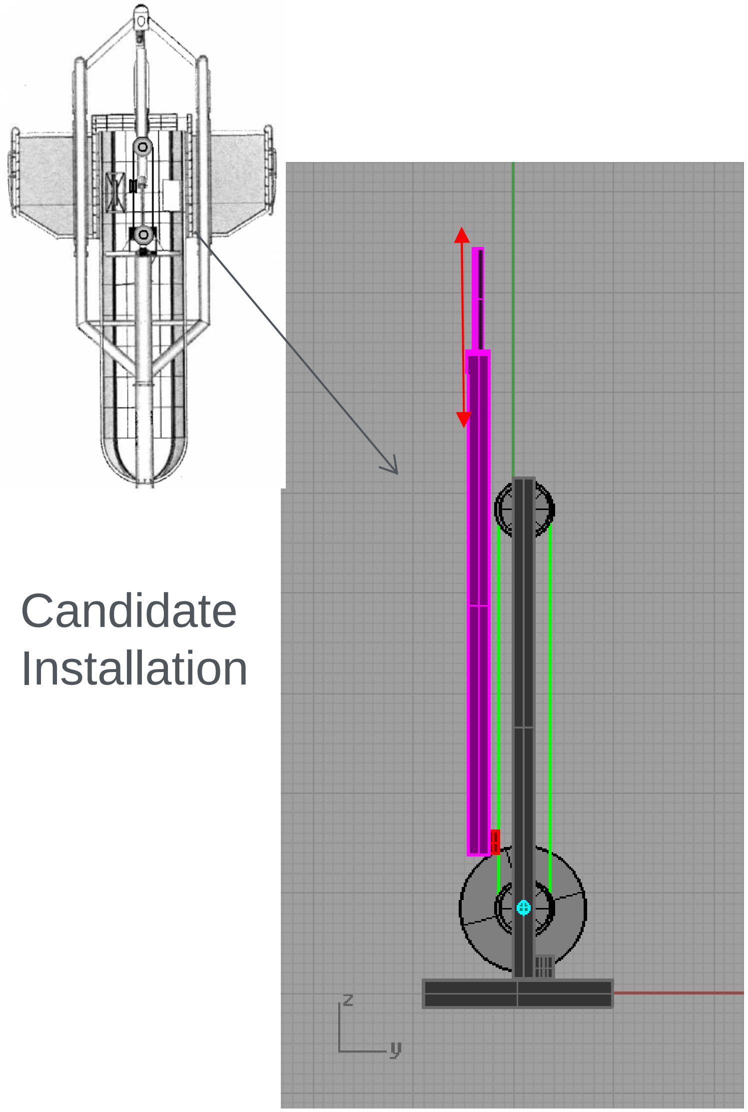
Utility Interface Converter

DC link filter Inductor components

SRM Drive Module

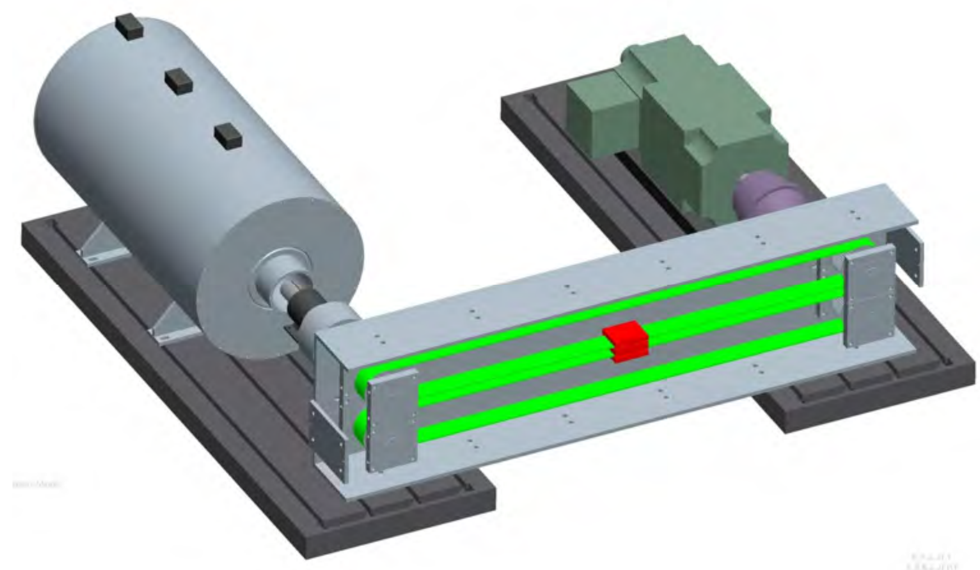
- Single String of Electronics Capable of up to 150kW
- Modules are parallelable for higher powers.
- Bulk Capacitors for DC link filter are shown in the SRM drive box

Lab Set Up designed to Test Belt Linear to Rotary Conversion for Field Use



Candidate Installation

- A Pre-tensioned Carbon Fiber Reinforced Belt is stiff enough to transmit all wave frequencies of interest
- Toothed belt spreads load for use of relatively small sprockets
- Lab test set up uses a second belt for rotary to linear conversion to give linear input to the belt driving the generator



RCT has modeled the total system including the Buoy and the Test set up

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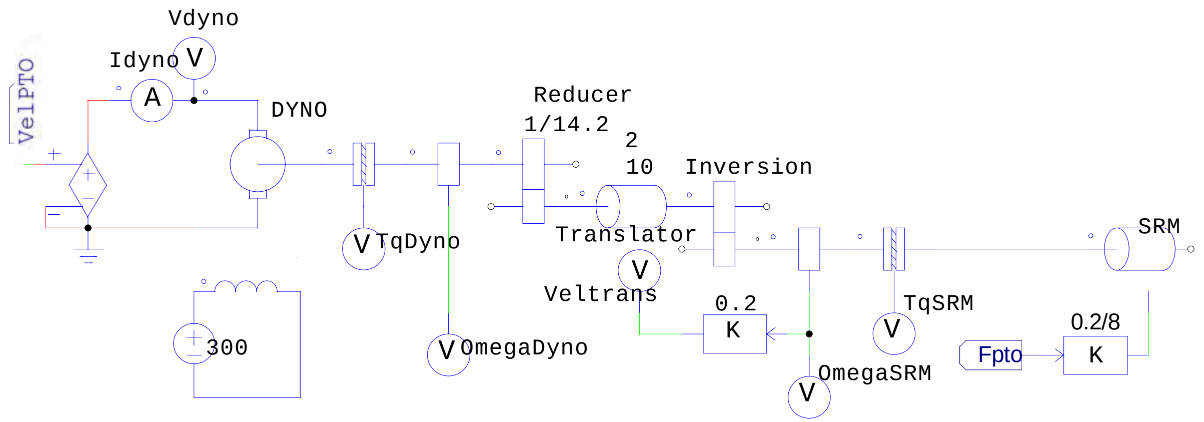
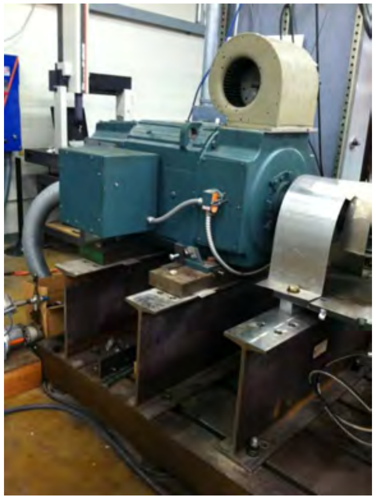
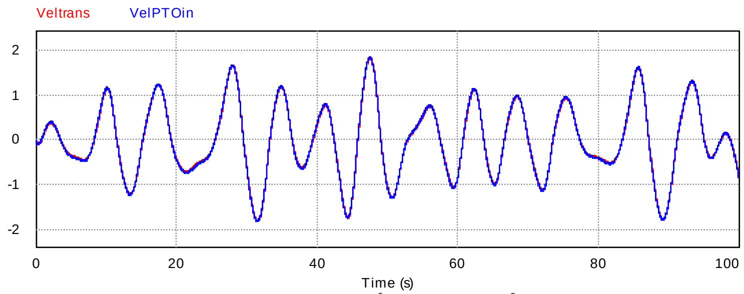
- Electro-mechanical Models of the Dynamometer, Speed reducer, Linear to rotary converter and the SRM generator, SRM Drive and Utility Converter simulate the whole system
- Model of Wavebob Buoy generates force and speed input for the PTO from wave profiles defined by fourier coefficients.





RCT 500hp four quadrant dynamometer

- Input and output velocity waveforms of loaded dyno test set up model match.



NB The two traces are superimposed

System Simulation Using Wavebob input wave data shows efficient handling of zero crossings

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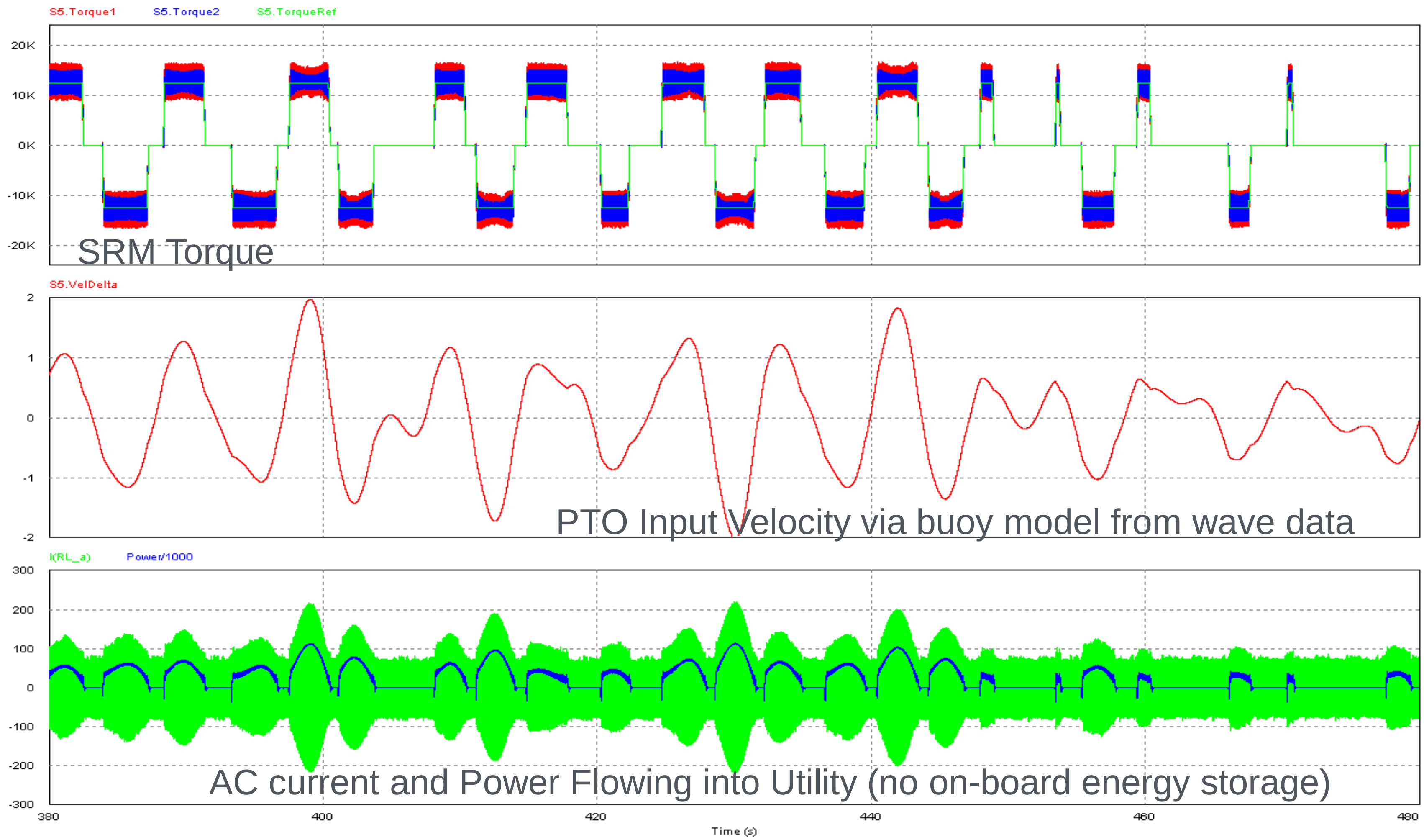

Modeled Waveforms from Wave Excitation coefficients Provided by Wavebob– 380-480 seconds

Efficiency of SRM vs Speed Constant Force / Constant Power envelope

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Speed	Mech. Power (kW)	Elec. Power (kW)	SRM Loss (kW)	Drive Loss (kW)	Total Loss (kW)	Eff. (%)
0.2m/s	20.09	8.58	9.51	2.00	11.51	42.7
0.5m/s	50.25	37.73	10.31	2.22	12.53	75.1
1.0m/s	100.00	87.44	10.18	2.37	12.55	87.4
1.5m/s	100.00	91.46	6.79	1.73	8.52	91.5
2.0m/s	100.00	93.19	5.40	1.41	6.81	93.2

Notes on Cases:

- Constant Relative Speed Operation.
- Following Required Torque-Speed Curve: 0.2m/s, 0.5m/s, 1.0m/s Constant Torque, 1.0m/s, 1.5m/s, 2.0m/s Constant Power.
- Drive loss depends on torque and current regulation schemes. The present settings result in fairly low switching frequency (typically below 2kHz).

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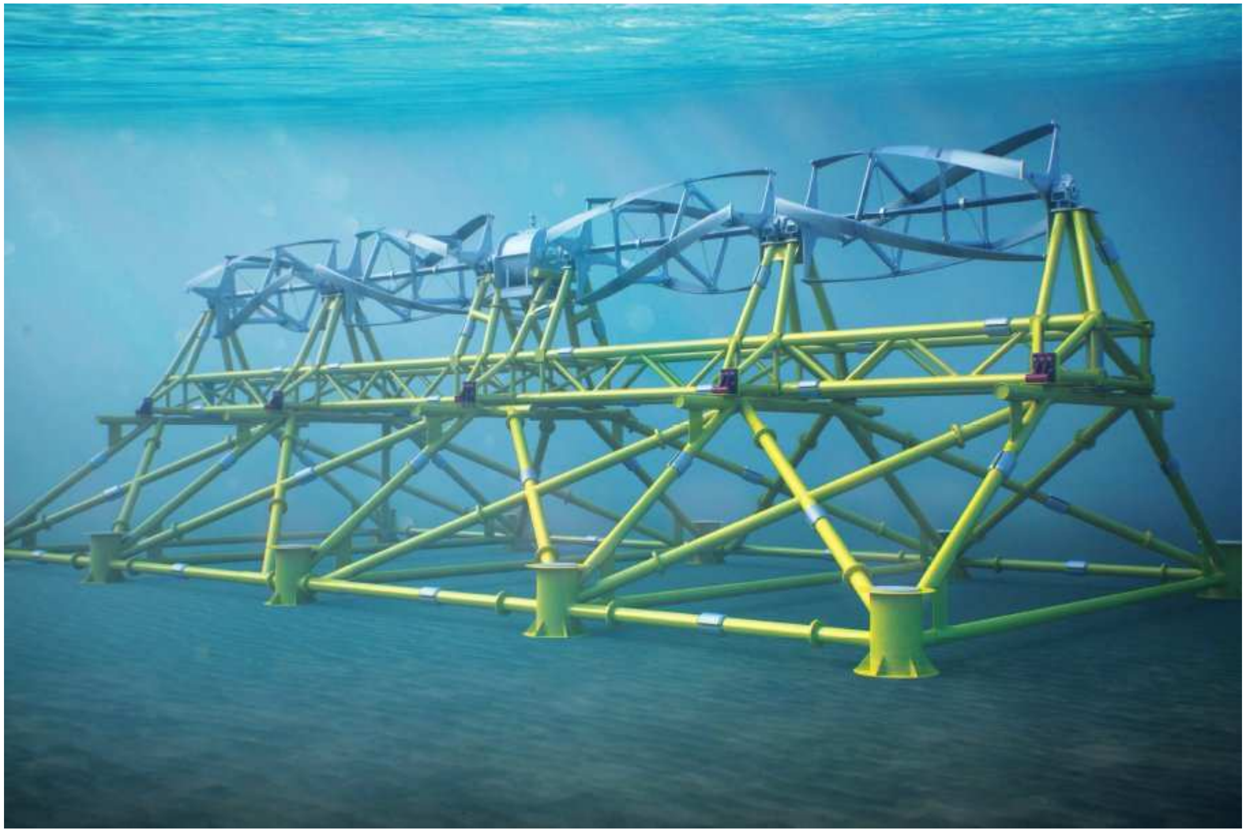

TidGen® Power System Commercialization Project

Christopher R. Sauer

Ocean Renewable Power Company

csauer@orpc.co, 207 772 7707

February 25, 2014

Problem Statement: To advance, demonstrate, and accelerate deployment of ORPC's tidal-current based hydrokinetic energy conversion technology, associated power electronics, and interconnection equipment within a replicable full-scale, interconnected array of devices capable of reliably delivering electricity to the domestic power grid.

Impact of Project: ORPC achieved goal by designing, building and operating the TidGen® Power System in 2012 and becoming the first federally licensed hydrokinetic tidal energy project to deliver electricity to a utility power grid and first tidal project with a long term power purchase agreement in North, Central or South America.

Alignment with DOE Program Objectives and Priorities:

- Advance the state of MHK technology
- Characterize and increase access to high resource sites
- Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach:

- Design system for a generic tidal resource with equal flood and ebb tides peaking at 3 meters per second
- Tailor design to unique characteristics of Cobscook Bay sites
- Follow traditional EPC approach & use marine assets available locally
- Install in increments to reduce risks (BSF, P&D Cable, TGU)

Key Issues and their Significance:

- Geotechnical requirements very onerous requiring significant redesign
- Driveline friction much greater than anticipated reducing efficiency
- Breakdowns significantly reduced reliability with bolted connections, electronics and water intrusion the most severe

Unique Aspects of Project:

- First grid-connected MHK project in the Americas
- First of its kind equipment integrated into a first of its kind system
- No precedence or existing manuals for on-water operations

PROJECT FIRSTS AND ACCOMPLISHMENTS

- ✓ ORPC designed, built, installed and operated the first hydrokinetic tidal power project (TidGen® 001) to be connected to an electric utility power grid anywhere in the Americas (North, Central and South America).
- ✓ ORPC collected a significant amount of data and has gained invaluable expertise, hands-on experience and critical insight into:
  - Most data ever collected for a U.S. hydrokinetic energy project
  - Technical aspects of siting, designing, constructing, installing and operating MHK turbines
  - Overall system and individual component performance, including identification of needed improvements
  - Costing data on fabrication, assembly, installation, operation, monitoring, retrieval and maintenance of a FERC-licensed MHK tidal energy facility
  - Development of several retrieval techniques, each significantly reducing costs associated with retrieval and deployment.
  - Environmental monitoring plans, equipment, protocols and data collection and analysis on installation and operation of an MHK facility

- ✓ ORPC has become an internationally recognized leader in the development and implementation of MHK energy technology and projects, and has moved to the forefront of the U.S. MHK industry.
- ✓ This project was the first construction of an MHK project under a FERC license in the U.S., and led to acceptance of MHK technology at multiple levels of federal and state regulatory agencies and utilities.
- ✓ ORPC negotiated and executed the first long term (20 year) power purchase agreement, utility interconnection contract, and Renewable Energy Credit sales contract for an MHK project in the U.S.
- ✓ ORPC received the first U.S. Treasury Rebate for an MHK project.
- ✓ ORPC with technical partners has developed innovative methodologies and technologies to identify and monitor environmental interactions with our tidal device. Examples include the drifting noise measurement system used to characterize pre- and post-deployment noise and the bottom mounted side looking split beam sonar to monitoring fisheries interaction with the turbine.

- ✓ ORPC submitted the first ever annual environmental report for a tidal energy project under our FERC pilot project license. The report was reviewed in detail and approved by all regulatory agencies. The report stated that there were no known adverse environmental impacts from the project.

MEDIA COVERAGE

- ✓ The TidGen® device made the cover of the June 2013 issue of Popular Science and was featured in many of media outlets, including PBS News Hour, New York Times and other newspapers and magazines around the world, greatly increasing world awareness of tidal energy.

AWARDS

- ✓ One of “World’s Top Ten Most Innovative Companies in Energy” by Fast Company, 2013.
- ✓ Awarded the 2013 Annual Tibbetts Awards from the U.S. Small Business Administration, in recognition of our unique contributions as a “Model of Excellence” for the Small Business Innovation Research (SBIR) Program

Project Budget

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

Budget History					
FY2010-11		FY2012		FY2013	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$3,399,980	$516,586	$6,100,014	$4,786,947	$500,006	$7,593,481

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

University of Maine, University of Colorado, ARL Pennsylvania State University, James A. Schneider Ph.D., Jason Moore, P.E., SGC Engineering, LLC, R.M. Beaumont Corp., Blue Hill Hydraulics, HDR/DTA, Camryn Hansen, MER Assessment, CR Environmental, Firehole Composites, Cobscook Bay Resource Center, Bangor Hydro Electric, Farr Yacht Design, Comprehensive Power, Inc., Perry Marine & Construction, James F. Jenkins, P.E., Hall Inc., New England Aquarium, Dr. Moira Brown

Communications and Technology Transfer:

4 publications
1 Ph.D. thesis
1 Master's thesis
27 conference presentations

Proposed Future Research:

ORPC is now poised to significantly advance the design of the TidGen® Power System and then to build and commercialize this tidal power generation system based on best-in-the-world technology components and to complete the development and build tidal power projects in Maine, Alaska and elsewhere around the world.

Water Power Peer Review

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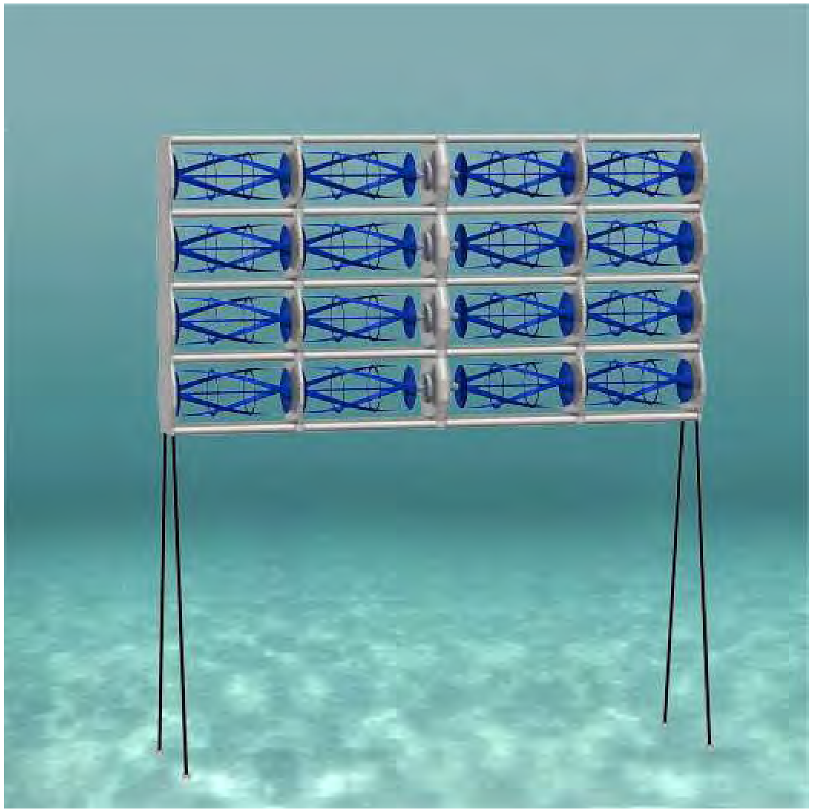

OCGen® Module Mooring Project

Jarlath McEntee

Ocean Renewable Power Company

jmcentee@orpc.co, 207 772 7707

February 25, 2014

Problem Statement: To prove the technical and economic viability of a fast-water mooring system

Impact of Project: Will help resolve a technologically significant barrier to deployment

This project aligns with the following DOE Program objectives and priorities

- Advance the state of MHK
- Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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- Identify the loads acting on the mooring system
  - Steady fluid loads
  - Dynamic fluid loads
  - Dynamic inertial loads
- Scale model testing
- Collect geophysical and geotechnical data
- Design, build and deploy field size module
  - Design of OCGen® sub-module
  - Design of mooring system
  - Deployment and monitoring of system
- Design, build and acquire mooring system for full OCGen® Power System

Accomplishments and Progress

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- Successfully utilized a commercially available CFD code to predict fluid induced loads on the OCGen™ module
  - Modular, scalable modeling technique
- Developed an analytical tool to predict the dynamic behavior of a tethered floating system in transient flows
- Identified limitations with a commercially available mooring design code and found path to address these
- Performed preliminary scale model tests
- Gathered the required geophysical information for the proposed field test site, and beginning the design process for the field test module
- Designed a two turbine version of the full scale OCGen™ floating module
- Designed mooring system for full scale system and test module
- Constructing the test module
- Test the test module in the field in Summer 2014

Project Plan & Schedule

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Summary		Legend
WBS Number or Agreement Number		Work completed
Project Number	DE-EE0002650	Active Task
Agreement Number		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: OCGen® Module Mooring Project												
Task 1: Modeling of Loads on Mooring System (Complete 1/30/13)												
Task 2: Dynamic Stability Analysis (Complete 7/31/11)												
Task 4: Scale Model Testing (Complete 5/24/12)												
Task 5: Geophysical Surveys, Initial (Complete 10/30/11)												
Current and Future Work												
Task 3: Dynamic Analysis of Mooring System and Lines												
Task 5: Geophysical Surveys, Final												
Task 6: Cable and Mooring Design												
Task 7: Experimental Mooring of a Beta Pre-Commercial Turbine Generator Unit												
Task 8: Design of OCGen® Module Mooring System												
Task 9: Project Management and Reporting												

Comments

- Project period: 03/01/2010 – 08/08/2014
- ORPC did not receive a NEPA categorical exclusion until June 2011, i.e., fourteen months after the start of the Project Period.
- ORPC proposes to moor a prototype OCGen® unit to the sea floor in Cobscook Bay, Maine at our FERC-licensed site; applied for USACE permit; awaiting NEPA approval.

Project Budget

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Budget History					
FY2010-11		FY2012-13		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$229,949	$0	$281,918	$185,271	$522,667	$849,264

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

Blue Hill Hydraulics,University of Washington, PCCI, Inc., CR Environmental, TerraSond, Ltd, Douglas Read, R.M. Beaumont Corp, University of Maine

Communications and Technology Transfer:

DuBuque, G.(2011). *A Lumped Parameter Equilibrium Model of a Submerged Body with Mooring Lines* (Unpublished master's thesis). University of Washington, Seattle, Washington.

Patent: ORPC has filed U.S. Provisional Application 61506445, Dynamic Lift System for Underwater Turbine. Filing date 07/11/2011.

Next Steps and Future Research

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FY14/Current research:

- Designed a two turbine version of the full scale OCGen™ floating module
- Designed mooring system for full scale system and test module
- Constructing the test module
- Test the test module in the field in Summer 2014

Proposed future research: Work will continue at the Cobscook Bay Tidal Energy Project site.

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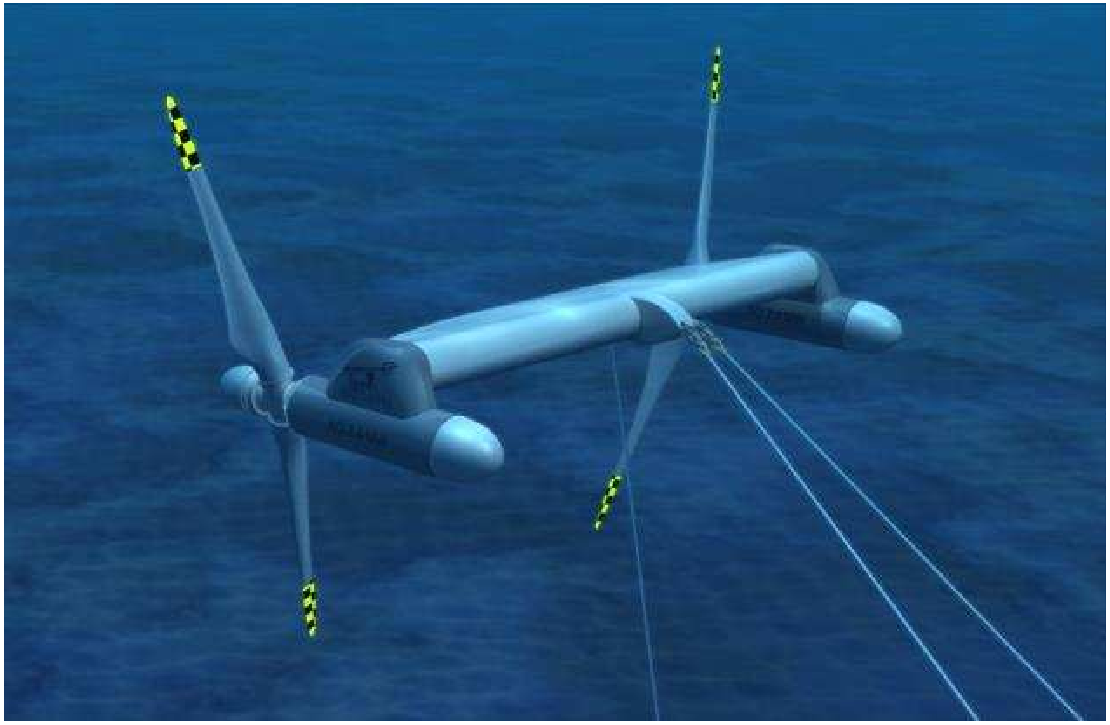

Aquantis C-Plane Ocean Current Turbine Project

Alex Fleming

Dehlsen Associates, LLC

E mail: afleming@ecomerittech.com

Phone: (650) 450 6387

25 February 2014

Purpose & Objectives

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Problem Statement: The Aquantis Current Plane (C-Plane) technology is a marine current turbine designed to extract the kinetic energy from a current flow to achieve competitively priced base-load, continuous, and reliable power generation from a source of renewable energy not before possible in this scale or form.

Impact of Project: The principal objective of the Aquantis C-Plane Project is development of technology to harness the Gulf Stream current energy resource with innovative, breakthrough power generation technology. The average power which can be extracted from the Gulf Stream is estimated by the DOE at 5 GW for the Florida region and 18 GW for the entire US East Coast.

This project aligns with the following DOE Program objectives and priorities: Marine hydrokinetics (MHK) – advance the state of MHK technology through technical innovation and by reducing capital costs and the cost of energy.

Project - Technical Approach

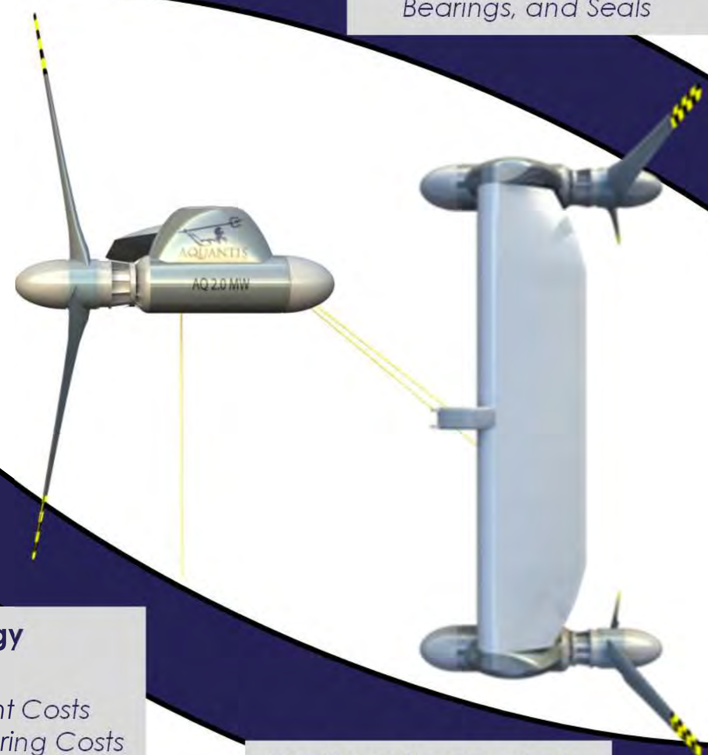
- **The Aquantis C-Plane:**
  - Operates 50-200m below the surface.
  - Generates base load power in high energy density resource.
  - Power transmitted to shore by submarine cable.
  - Surfaced for maintenance or repair.
  - Towed or barged to site.
  - Seafloor mooring based on well developed systems.
  - Slow turning rotors have minimal environmental impact.
- **Key Issues Addressed:**
  - Hydrodynamic analysis; dynamic simulation analysis; mooring analysis; tow tank testing; marine composites analysis and rotor platform; drivetrain and bearing design.

Project - Technical Approach

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

Resource Assessment
- *Mean Flow*
- *Turbulent Structures*
- *Extreme-Load Conditions*
- *Sea-Bottom Conditions*

Turbine Design
- *Hydrodynamic Blade Design*
- *Hydrodynamic Load Assessment*
- *Blade-Manufacturing Design*
- *Blade-to-Nacelle Attachments*
- *Structural Assessment Shaft, Bearings, and Seals*



Stability, Mooring, and Anchoring
- *Weight and Buoyancy*
- *Hydrodynamic Forces and Moments*
- *System Stability Modeling*
- *Mooring Lines and Attachments*
- *Anchoring*

Drivetrain
- *Turbine Input*
- *Drivetrain Components*
- *Power Electronics*
- *Power Loss Estimates*
- *Connection to the Grid*

System Optimization
- *Nacelle Designs*
- *Wing Designs*
- *Stability Surfaces*
- *Attachments*
- *Pressure Vessels*

Configuration Control
- *Component Geometry*
- *CAD Modeling*

Cost of Energy CAPEX
- *Component Costs*
- *Manufacturing Costs*
- *Maintenance Costs*
- *System Energy Output*
- *Energy Prices*

Operation and Maintenance OPEX
- *Fabrication and Assembly*
- *Installation*
- *Operation*
- *Maintenance*
- *Emergency Operation*

Project - Technical Approach

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AQUANTIS

- Jim Dehlsen: Chairman – Innovation and System Architecture
- Brent Dehlsen: Director
- Charles Vinick: CEO
- Alex Fleming: VP, Chief Engineer- CIPT
- Ken Gluck. Program Manager

Stability and Moorings

Henry Swales- IPT Lead

NAVSEA CARDEROCK

- Dr. Coakley: Stability
- Dr. Coffin: Composites
- Rich Banko: PI W&T
- Al Schwartz: Rotor Codes

Hydrodynamics and Structure

Ole Kils – Rotor IPT Lead

PENNSTATE ARL

- Dr. Zierke: PI Hydrodynamics
- Dr. Willits: Performance
- Dr. Koudela: Marine Composites
- Mike Beam: Bearings and Seals
- Dr. Dreyer: CFD Steady/Unsteady

Drive Train

Tyler Mayer– Drive Train IPT

Rexroth Bosch Group

- VP Dave Hull
- Peter Erhart
- Nathan Godiska
- Andy Fellner

PCCI Marine and Environmental Engineering

- Tom Hudon
- Gus Ruetnik

Powertrain Engineers Inc.

Ed Hahlbeck

sfsi

Tom Foley

HÄGGLUNDS

- Lars Andren
- Bo Hornsten

DNV

BEW

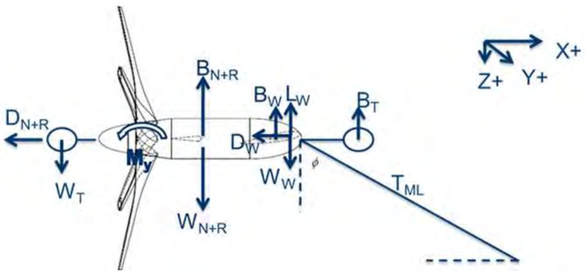
Dr. Erdman

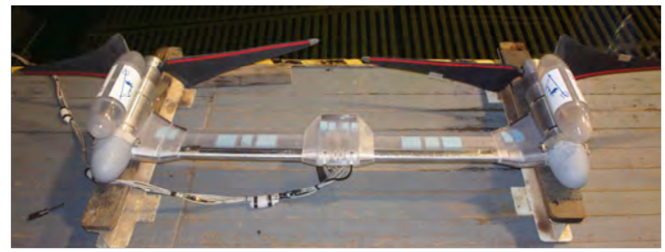
Project - Accomplishments and Progress

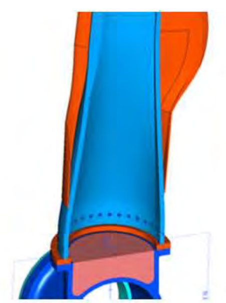
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

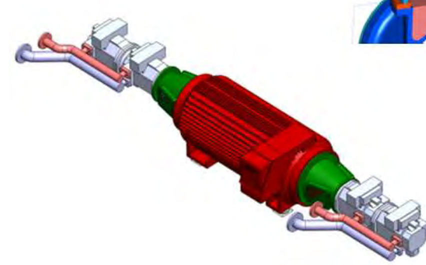
Technical accomplishments and significance:

1. Hydrodynamic analysis – key hydrodynamic properties and system stability.
2. Dynamic simulation analysis – dynamic behavior under various operating conditions.
3. Mooring analysis – mooring analysis model, dynamic loads and preliminary component sizes.
4. Tow tank testing – captured and dynamic testing to validate simulation results and stability under operating and fault conditions.
5. Marine composites and rotor design – appropriate rotor blade materials, preliminary lofting and structural analysis.
6. Platform design – transverse structure options trade off and preliminary design.
7. Drivetrain design – components selected, system design completed and scaled and full-scale test program scoped.
8. Hydrodynamic and bearing design - bearing input loads, material and commercial product solutions and preliminary sizing.



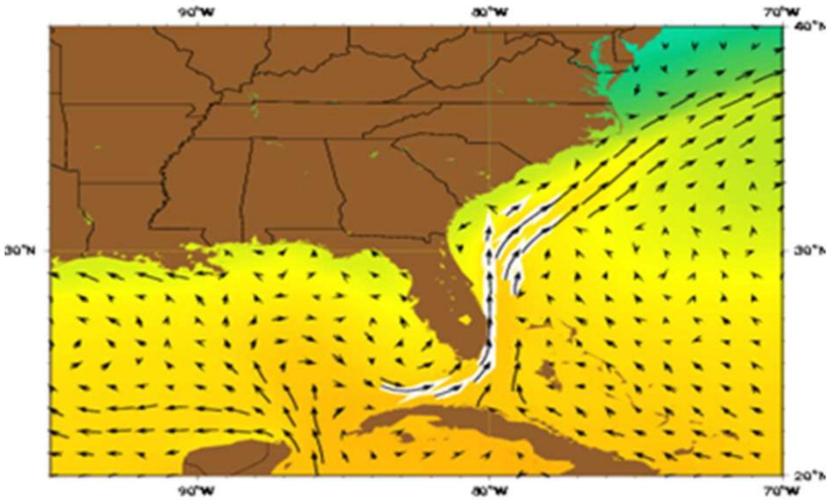






Ocean Current Resource Potential - Technical Approach

- Florida Current presents optimal conditions for siting
  - Close to shore and major load centers
  - Relatively shallow ocean floor
  - Strong vertical shear characteristics
  - Steady, constant flow will create base-load power
- Overall potential of Florida Current is estimated at 4 – 6 GW, enough to power nearly 20% of Florida
- Additional economic potential spans from manufacturing, installation and long term maintenance of C-Plane projects



- Resource (HYCOM Ocean Modeling)
- Grid Demand

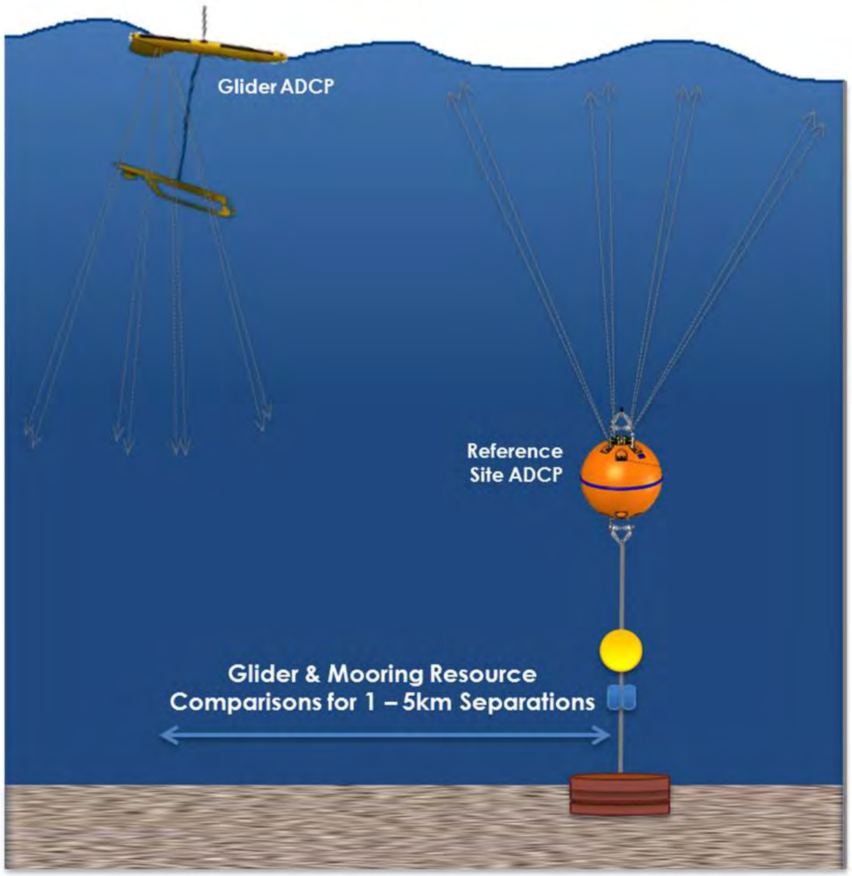
- Environmental

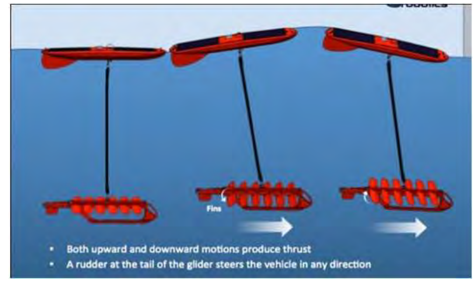
- Ship Traffic (AIS)
- Recreational
- Commercial

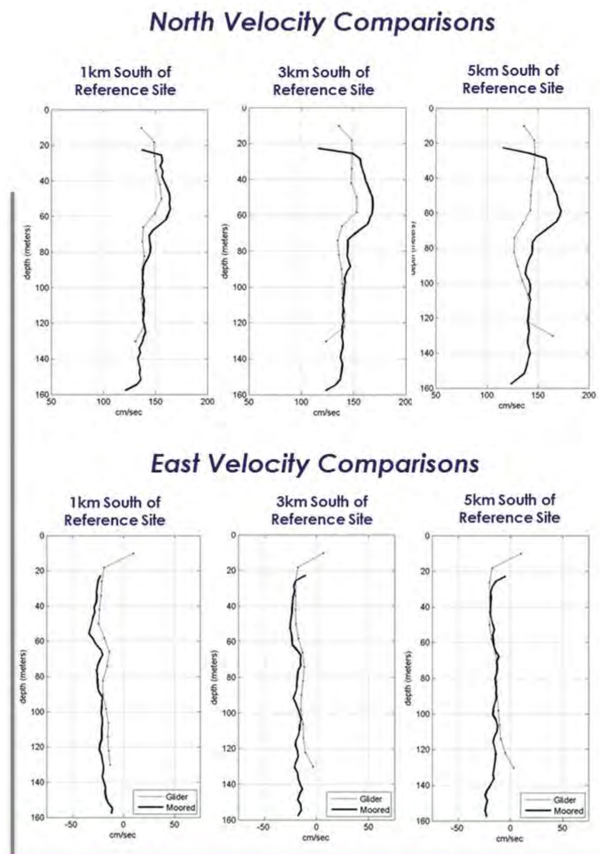
Siting: Determining an Area of Interest

→ ***Resource Measurements:***

Glider Surveys, Reference Site







Hydrodynamic Analysis - Technical Approach

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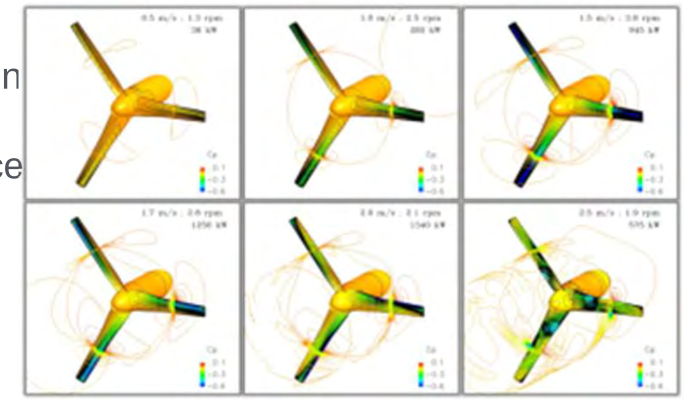
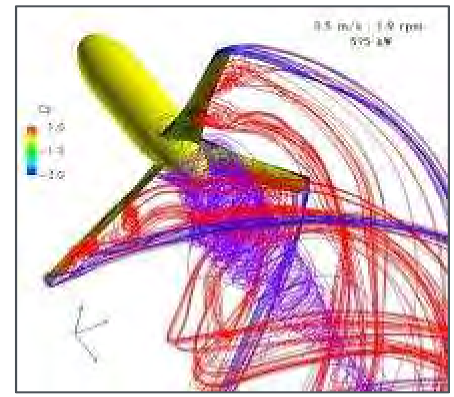
3-D <u>steady</u> CFD analysis is used to verify the time-averaged hydrodynamic performance

1. Hydrodynamic forces and moments
2. Distributed loads for structural design
3. Blade section performance
4. High frequency acoustic performance
5. Detailed flow paths





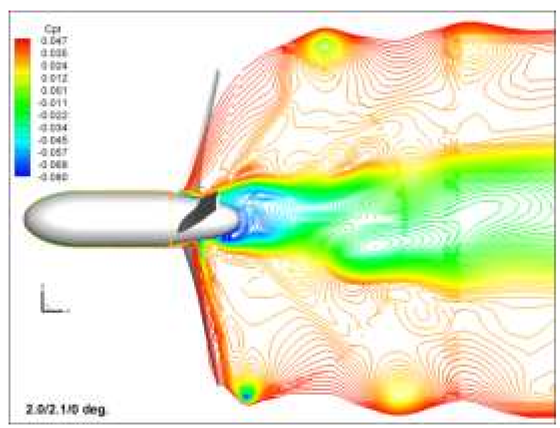
3-D <u>time-accurate</u> CFD analysis used to characterize the unsteady hydrodynamics

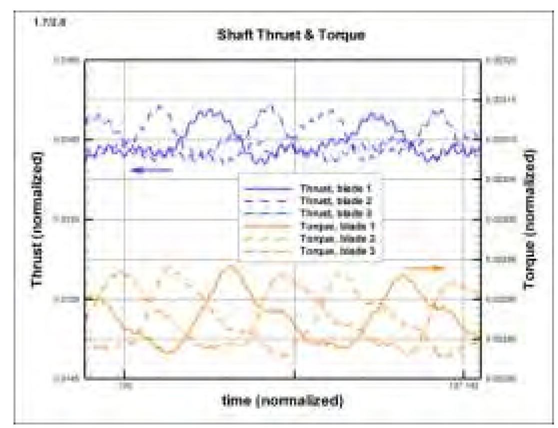
Shaft-rate correlated unsteadiness due to:

1. Paired turbines
2. Non-trimmed body attitude
3. Shear in onset flow
4. Strut wake ingestions
5. Centerbody interactions

And **random** fluctuations due to:

1. Flow separation from blades
2. Shedding from hub

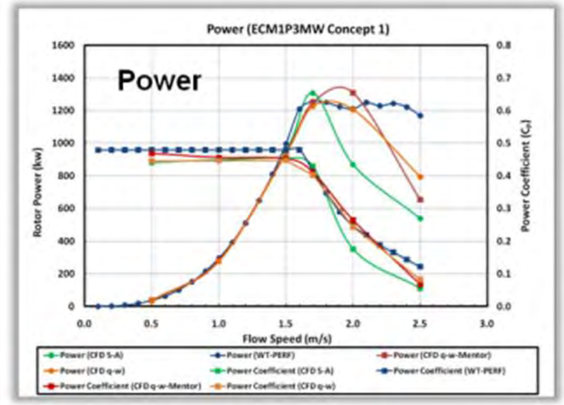




Hydrodynamic Analysis - Accomplishments and Progress

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

- Florida current concept rotor optimization using HARP_Opt
- Florida current concept rotor design using WT_Perf
- 2 vs 3 blade trade-off for moored MHK turbine
- CFD Analysis
  - post-stall rotor behavior
  - dual-rotor interactions
  - unsteady loading due to wake ingestion
  - high Reynolds number hydrofoil performance
- Validated Hydro Coefficients used in Stability Simulations

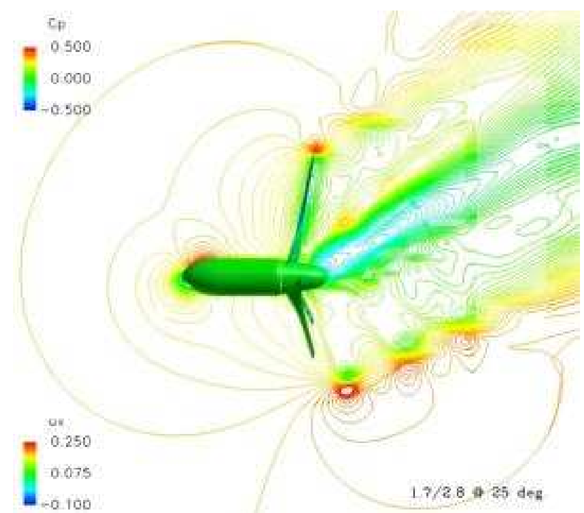


➢ Large matrix of time-accurate simulations was carried out to support stability analysis (6 conditions @ 6 pitch angles: 0°- 25°)

ECM1P3MW_Concept1			CFD Results (0-deg flow angle)							
AoA	Flow Speed	Rotor Speed	Power Coefficient	Rotor Power	Rotor Thrust	Rotor Torque	Hub Power	Hub Torque	Nacelle Drag	Blade C_{Pmin}
(deg)	(m/s)	(rpm)	(-)	(kW)	(kN)	(kN-m)	(kW)	(kN-m)	(kN)	(-)
0	0.5	1.27	0.447	34.6	127	260	-0.00002	-0.163	2.6	-0.39
0	1.0	2.53	0.458	283.2	495	1069	-0.00012	-0.455	9.5	-1.24
0	1.5	3.80	0.456	952.9	1090	2395	-0.00038	-0.951	19.9	-2.86
0	1.7	2.80	0.436	1325.4	1257	4520	-0.00028	-0.962	30.6	-1.46
0	2.0	2.05	0.339	1678.2	1336	7817	-0.00024	-1.107	49.0	-4.32
0	2.5	1.85	0.092	889.9	1306	4593	-0.00030	-1.524	74.9	-3.64

ECM1P3MW_Concept1			CFD Results (25-deg flow angle)							
AoA	Flow Speed	Rotor Speed	Power Coefficient	Rotor Power	Rotor Thrust	Rotor Torque	Hub Power	Hub Torque	Nacelle Drag	Blade C_{Pmin}
(deg)	(m/s)	(rpm)	(-)	(kW)	(kN)	(kN-m)	(kW)	(kN-m)	(kN)	(-)
25	0.5	1.27	0.365	28.2	112	212	-0.00002	-0.153	1.7	-0.43
25	1.0	2.53	0.381	235.8	437	890	-0.00010	-0.392	5.4	-1.73
25	1.5	3.80	0.385	803.7	967	2020	-0.00031	-0.777	12.6	-4.03
25	1.7	2.80	0.373	1133.2	1114	3865	-0.00020	-0.699	17.5	-2.00
25	2.0	2.05	0.254	1299.5	1115	5867	-0.00017	-0.776	31.0	-4.79
25	2.5	1.85	0.131	1266.0	1211	6535	-0.00026	-1.340	56.0	-6.20

Same operating conditions that were examined for steady powering performance; now run at pitch angles of : 0, 5, 10, 15, 20, and 25 degrees



Dynamic Simulation Analysis - Technical Approach

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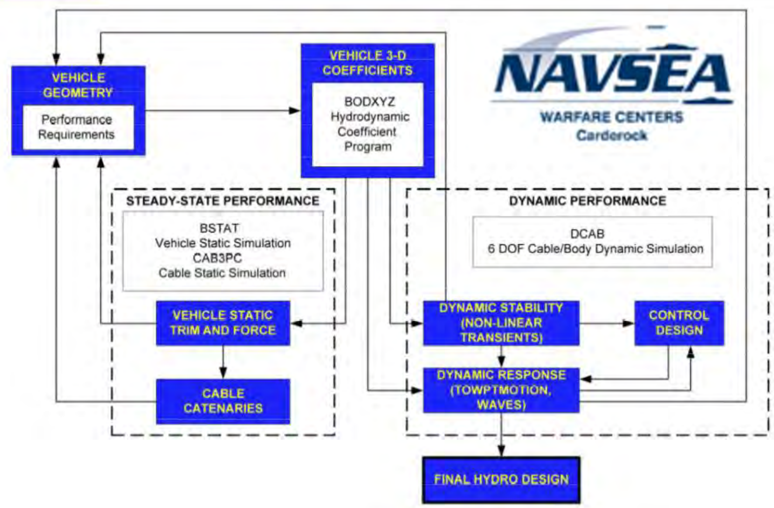
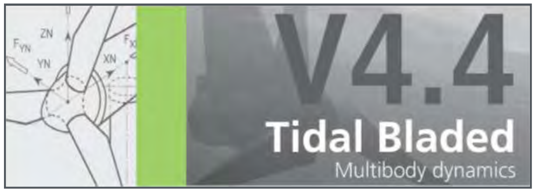
C-Plane platform dynamics analyzed using Navy's DCAB Code.

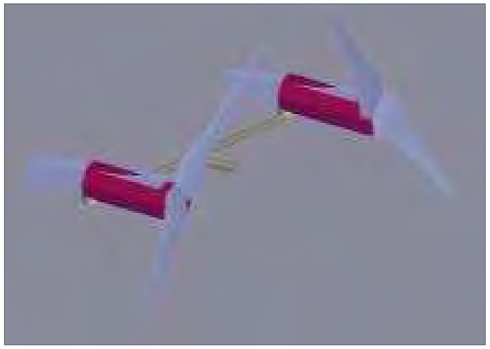
- Rotor dynamic coefficients generated by Flightlab.
- Body hydrostatic and dynamic coefficients generated by Navy BODXYZ code.
- Code has been validated for this application with CFD and BEM analysis, as well as decades of submarine analysis.

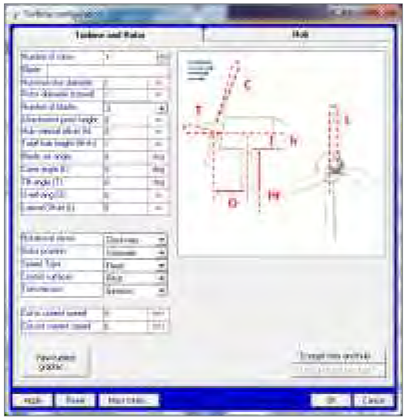
Future stability and loads simulations to be carried out in GL/DNV/Garrad Hassan's Tidal Bladed code.

- Only validated commercial tool capable of modeling all aspects of C-Plane including rotor hydrodynamics, stability, moorings, drivetrain, controls, and loads.
- Heritage of BLADED, wind turbine modeling software with almost 20 years of history.
- Comparisons made with US Navy and NREL codes.



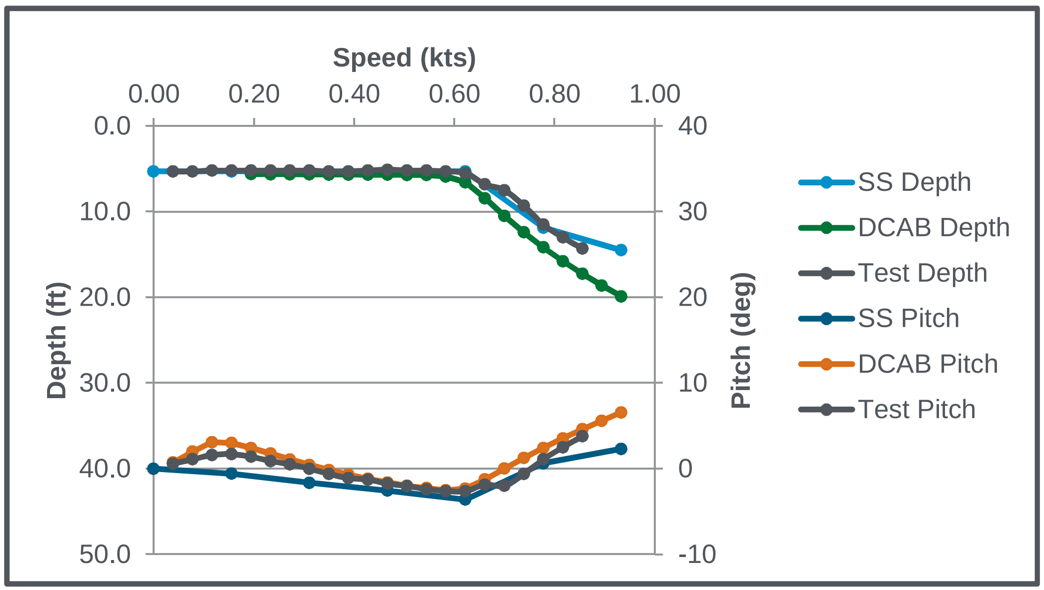


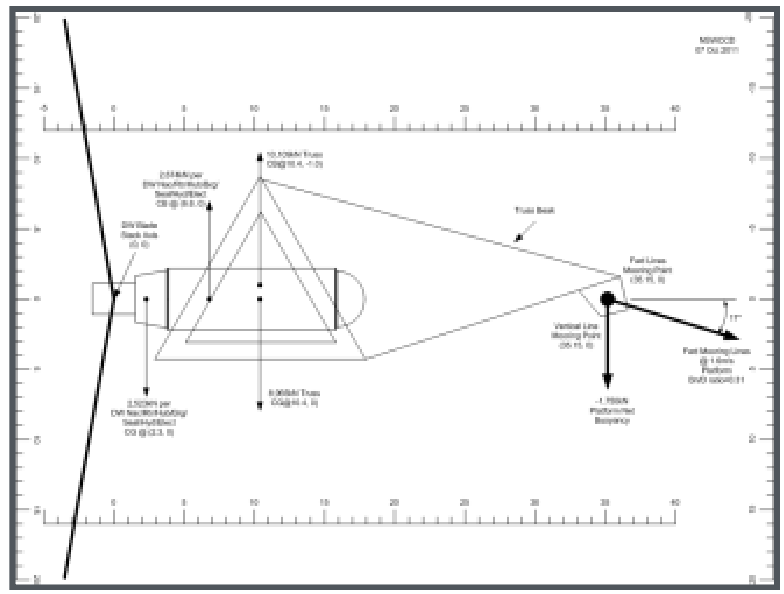




Dynamic Simulation Analysis - Accomplishments and Progress

- Accurate prediction of C-Plane steady-state and dynamic behavior.
- Optimized C-Plane design for stability and loads avoidance.
- Validation of stability simulations with tow tank test data.





Tow Tank Testing - Technical Approach

Goals:

- Validate stability simulations and loads analysis
- Demonstrate all modes of operation
- Reduce technical risk

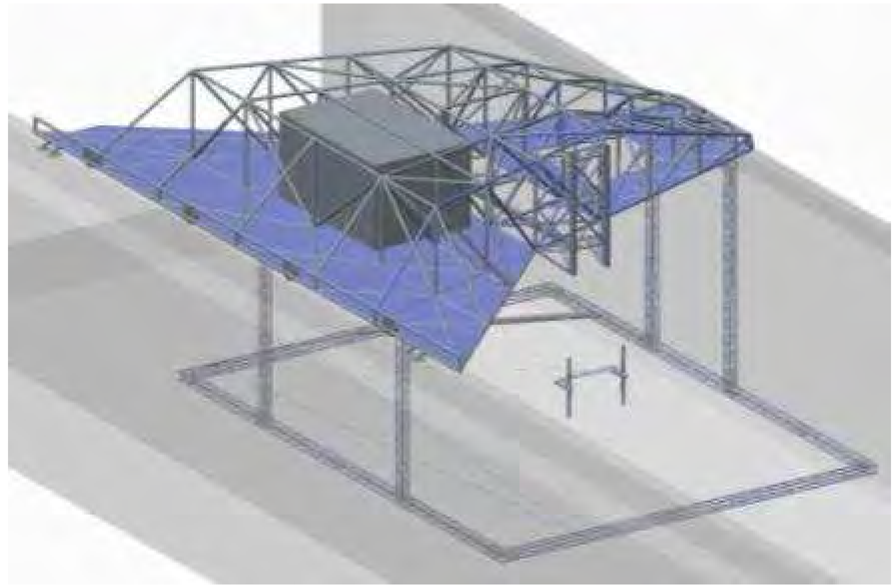
Approach:

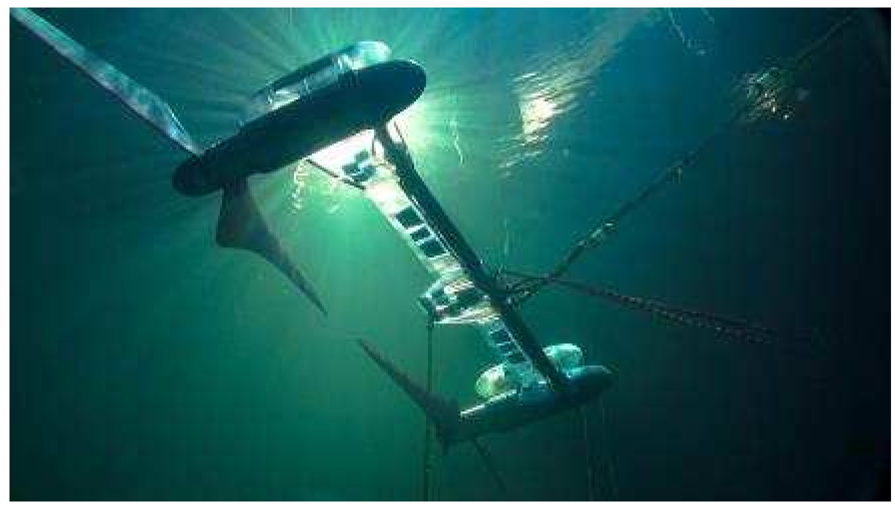
- Captured rotor and dynamic mooring tests
- Froude number scaling
- Reynolds number rotor design considerations

Instrumentation:

- Rotor position, speed and torque
- Dual 6 DOF load cells
- Dual IMUs (pitch, roll, yaw, X,Y and Z)
- Depth sensor
- Mooring tension sensors

CARDEROCK DIVISION
NAVAL SURFACE WARFARE CENTER
NSWC





Tow Tank Testing - Accomplishments and Progress

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Completed six days of captured testing:

- Independent nacelle and rotor forces
- Tip speed ratio and stall regulation
- Tow speed and Reynolds number effects
- Blade pitch angle
- Rotor cone angle
- Upstream structure wake fraction
- Upstream rotors

Completed eight days of dynamic mooring testing:

- Demonstrated C-Plane configuration is very stable under a wide range of flow conditions, operational models and failure events.
- Demonstrated stability in yawed and reverse flow conditions.
- Validated loads avoidance simulations for various configurations.

Tow Tank Testing - Accomplishments and Progress

Tow Tank Testing Video

Mooring Analysis - Technical Approach, Accomplishments and Progress

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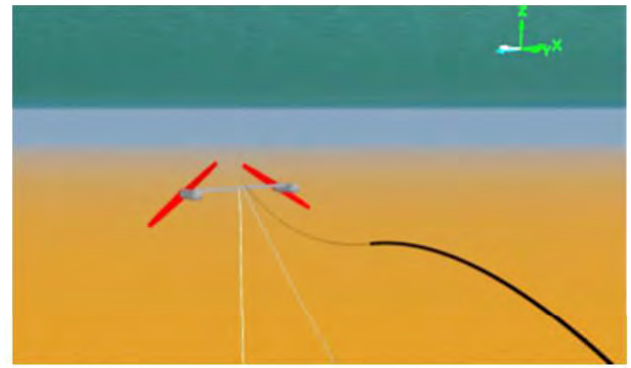
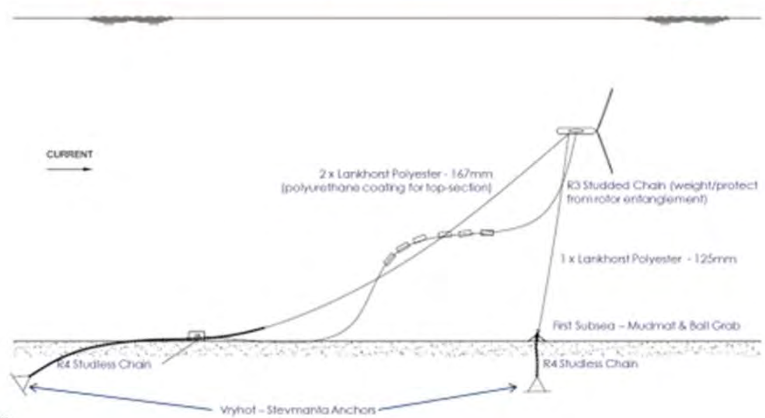
- OrcaFlex used for all mooring analyses.
- Non-linear, time domain, finite element software for dynamic modeling of offshore systems.
- **C-Plane specific requirements:**
    - Mooring loads, mooring length, clashing, anchor loads, C-Plane offsets.
- **Inputs:**
    - Environment (current, wind, wave)
    - Hydrodynamic coefficients (added mass, drag, damping)
    - Mass, buoyancy, CG, CB





- **Mooring system design:**
- **Aft (vertical) leg:**
    - Taut mooring
    - Polyester line
    - Chain at top and bottom
    - Vertically loaded anchor

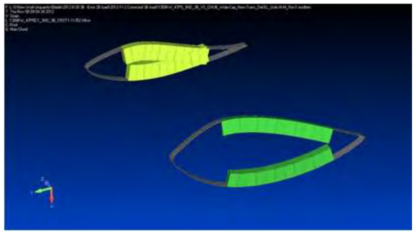
Forward legs:

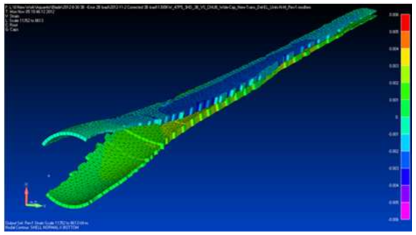
- Catenary mooring
- Polyester Line
- Chain at bottom
- Drag embedment anchors

Marine Composites and Rotor Design - Technical Approach

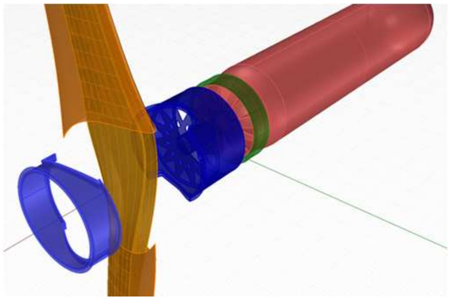
Key Issues:

- **Blade Count**
  - Tradeoff between two- and three- bladed rotors.
  - Primary implications on blade structure and wet weight.
  - Additional considerations for deployment, hub design and loading.





- **High sectional loading:**
  - Compared to wind blades, low-flow speed MHK rotors experience ~4.8 times higher sectional loading due to high bending moments and relatively thin cross section.
  - The high sectional loading requires extremely thick spars which need careful consideration of manufacturability (exotherm/waves) and quality (inspection/NDT).
- **Material performance:**
  - Effects of long term saltwater saturation on composite performance is not yet fully understood (particularly in fatigue).
  - Several research programs are ongoing to characterize performance parameters.
- **Root attachment:**
  - Design of a robust root connection for very high bending moments.
  - Ability of joint to function long-term with very limited maintenance (re-tensioning, creep).
  - Identified novel connection concepts.



Marine Composites and Rotor Design - Technical Approach

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

Hydrodynamics / System

Structures

Blade Shape
- Chord / Thickness
- Hydrofoil Selection
- Twist profile
- Performance/AEP

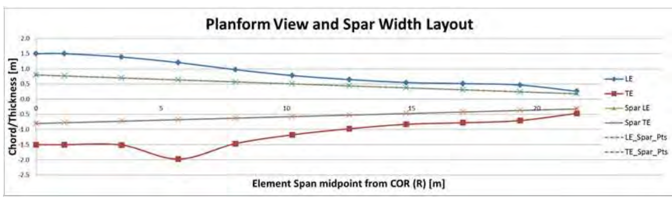
Rotor Loads
- Steady WT_perf
- GL BLADED
- CFD Wake
- Design Factors

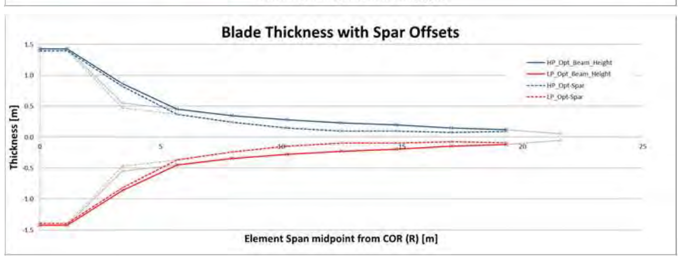
Materials
- Cost/Performance
- Saturated Performance
- Thick OoA Systems
- Material Factors

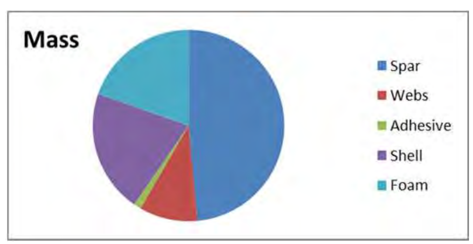
Manufacturing
- Spar Thickness Limits
- Quality considerations
- Material Factors

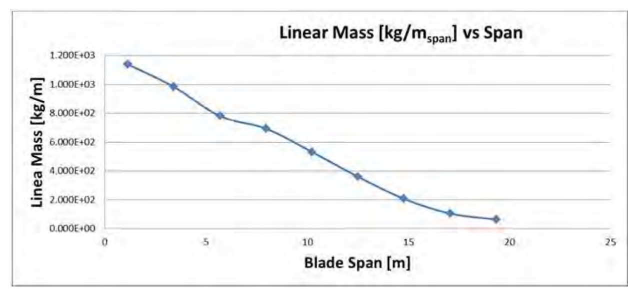
Hydro-Structural Optimization

Closed Form Blade Tool
- Spar Sizing
- Stiffness Distribution
- Mass and Volume Distribution
- Wet Weight
- Material Makeup / BOM









Marine Composites and Rotor Design - Accomplishments and Progress

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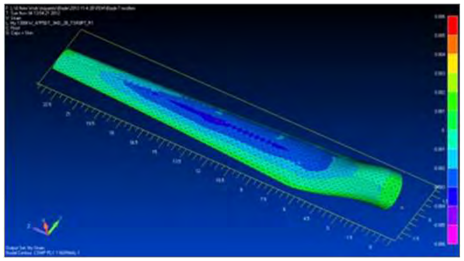
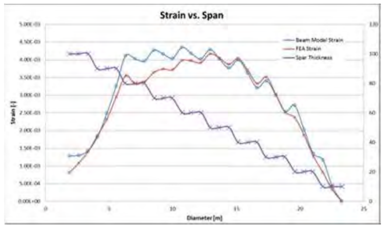
Technical Accomplishments:

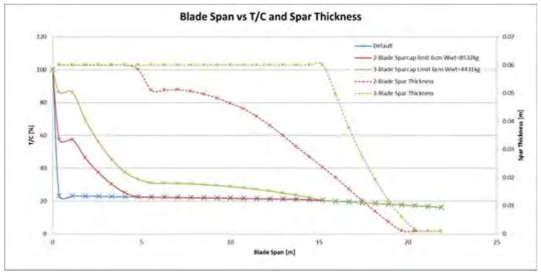


- **Design/validation of sectional blade development tool:**
  - Validated against FEA model.
  - Enabling for optimization and trade studies.

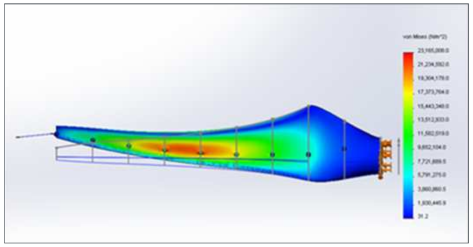


- **Selection of material allowables:**
  - Selected materials able to achieve of necessary thickness and cost targets.
  - Saturated performance degradation based on several test programs.
  - Identified strategic partner for blade design-for-manufacturing and material.

Ifremer | MONTANA STATE UNIVERSITY | Knowledge Centre | WMC | DNV | Gurit



- **Blade number study:**
  - Conducted study of 2- vs. 3-bladed rotors for Aquantis C-Plane.
  - 2-bladed rotors offer superior structural and system performance.
  - Larger physical section on two-bladed rotors outweigh increase in loading.

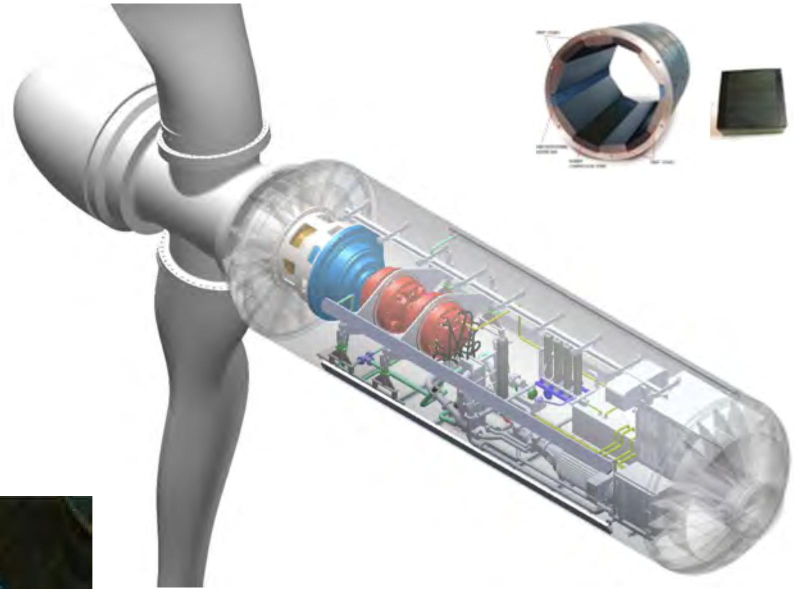


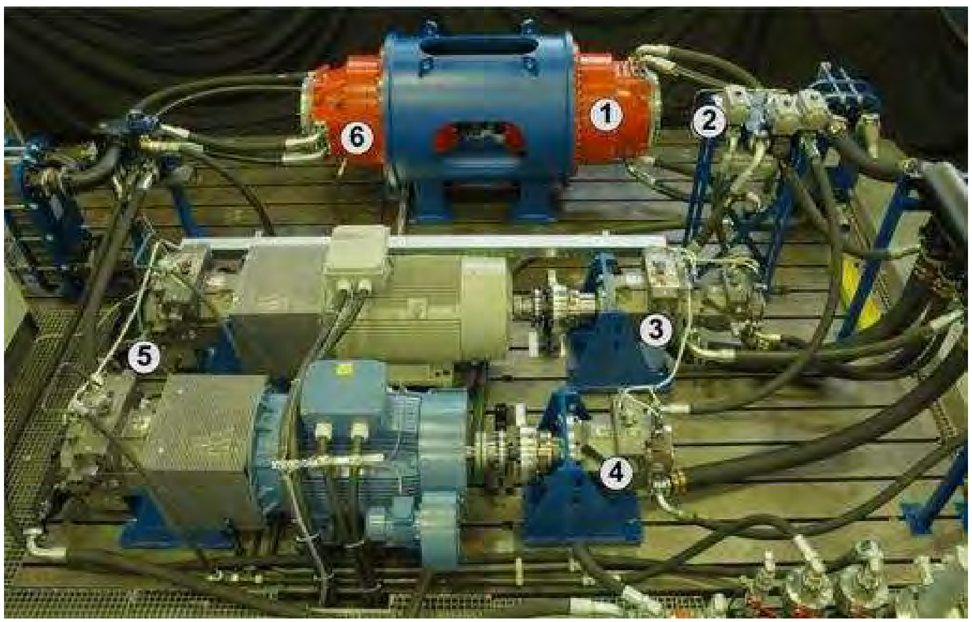
- **Tow tank rotor:**
  - Used full scale tools to design scaled rotor for tow-tank test.
  - Manufactured solid carbon fiber blades using custom tooling.

Drivetrain Design - Technical Approach

Technical Requirements

- Direct drive
- Low RPM, high torque density
- Reduced part count/weight
- High reliability; extended service intervals
- Ease of power component change-out





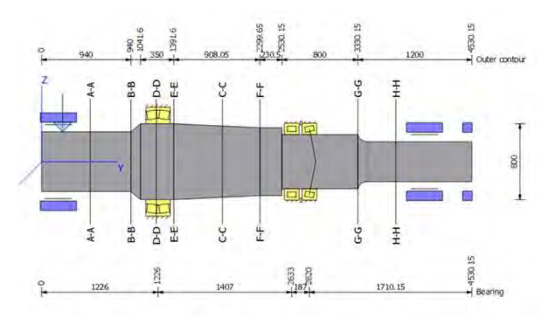
Current Status: Scaled Testing

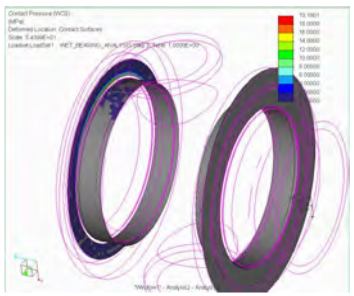
- Phase 1: System and Control Modeling
  - Toll Gate: Re baseline Risk
- Phase 2: Hardware Testing
  - Harmonize w/ Name Plate
  - System Integration Exercise

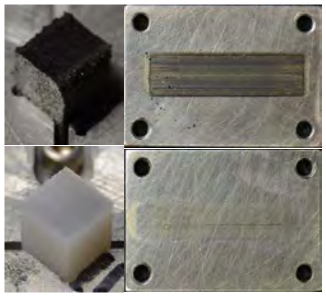
Bearing Design - Technical Approach and Accomplishments

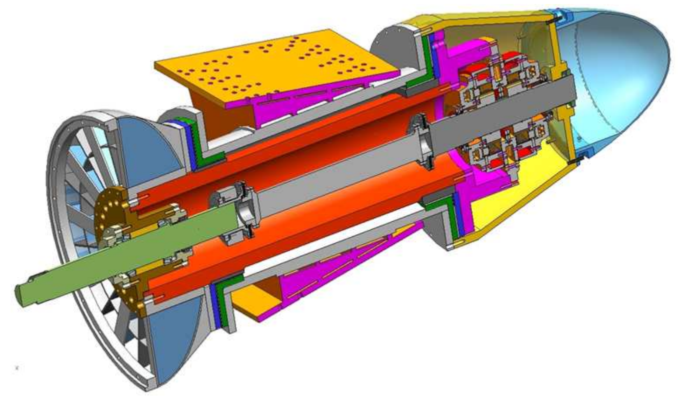
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Rotor loads calculated from hydrodynamics, vertical shear, and wake ingestion from upstream structures.
  - Wakes evaluated using CFD and Gaussian Empirical Model.
- Tapered roller bearings (TRB) bearing concept design completed.
- Elastohydrodynamic lubrication (EHL) bearing concept sizing and wear calculations.
- Sizing and materials support from manufacturers.
- Preliminary tribology tests of EHL bearing materials.
- Lifecycle cost analysis of architectures









Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	DE-EEE0003643.004
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Aquantis C-Plane Ocean Current Turbine												
TG5 Dynamic Stability/Hydrodynamic Coefficients/Tunnel Testing Complete												
Tow Tank Test Model Fabrication and Instrumentation												
DP3/TG7/D3 Experimental Validation (Scale Model Tests Complete)												
Current work and future research												
Mooring Analysis												
Electrical System Design												
Critical Design Review/TG6/DP2 - Drive Train Complete												
DP4/TG8/D4/D5 Final Report and Drawing Package												

Comments:

- Project original initiation date: 1 September 2010, Through DOE contract negotiations contract actual start date was 14 September 2011.
- Project planned completion date: 30 June 2014
- Extensive analysis, resource utilization and resources and facilities coordination was required to obtain C-Plane hydrodynamics, platform stability and complete tow tank testing.
- After an extensive trade study the drivetrain configuration was modified from the use of a direct drive generator to a hydrostatic variable speed drive system coupled with an induction generator.

Project Budget

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Budget History					
FY2012 Actual		FY2013 Actual		FY2014 Budget	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$624,584	$139,653	$1,354,427	$906,280	$420,989	$559,708

Budget/Plan Variances:

Project is tracking to budget. The project period was extended from the original end date of August 31, 2012 to June 30, 2014. The original contract initiation was delayed for one year based on negotiations between the DOE, U.S. Navy and Dehlsen Associates.

Remaining Spend:

Project-to-date through December 31, 2013 - $3,024,944 spent with a balance remaining of $980,697

Schedule:

- Initiation date: 09/01/10
- Planned completion date: 08/31/12
- Contract Award - Effective Date 09/01/10 - date signed 09/15/10 . Total Contract Cost - $4,005,641 (DOE Funded Costs - $2,400,000; Dehlsen Associates matching funded costs - $1,605,641) – period of performance 09/01/10 through 08/31/12
- Mod 001 (08/11/11) - added conditional status, added provision 21 : At Risk Clause, added provision 25: NEPA requirements, and added attachments for IP provisions, Statement of Project Objectives, Reporting Requirements, and Budget Information
- Mod 002 (09/14/11) - removed conditional status, removed "at risk for financial capability" provision 21, extended period of performance to 8/31/13, changed method of payment to ASAP Reimbursement system
- Mod 003 (11/04/11) - update recipient address and DOE/recipient contacts
- Mod 004 (09/21/12) - 1) Fully fund the award by obligating $1,200,000, 2) Approve Budget Period 2 and combine Budget Period 1 and Budget Period 2 into a single Budget Period that is coextensive with the Project Period; 3) Delete and replace Attachment 2, Statement of Project Objectives (SOPO), revising tasks 1 through 6;
- Mod 005 (09/10/13) - extended period of performance to 06/30/14, updated Special T&C's, changed DOE Award Admin to Yvette Peterson

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: Applied Research Laboratory (ARL) Penn State, Naval Surface Warfare Center (NSWC) – Carderock, PCCI, DNV - BEW Engineering and Powertrain Engineers

Communications and Technology Transfer: Indonesian Ocean Energy Conference, 2013; Global Marine Renewable Energy Conference, 2014

Next Steps and Future Research

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

FY14/Current research: Complete correlation between hydrodynamic and stability simulation results and those from tow tank testing; complete mooring analysis of current system configuration; complete rotor materials, hydrofoils and structure trade-offs, drivetrain design refinement and scaled testing and source or complete preliminary design of drivetrain main shaft seals and bearings.

Proposed future research: Detailed design and manufacturing of the rotor including novel and high performance hydrofoils ($1.2M); full scale drivetrain test ($4M); control system development and testing ($1.5M); rotor material characterization, critical element testing and tooling ($2M) and detailed design and manufacturing of the main shaft seals and bearings.

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

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Participating Organizations:

University of Washington

Northwest National Marine Renewable Energy Center

Pacific Northwest National Labs

Sandia Laboratories

Puget Sound Pilot Tidal Energy Project

Presented by:

Brad Spangler, PE
Email: brspangler@snopud.com
Phone: 425-783-8151

Purpose & Objectives

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Problem Statement:

Limited environmental and financial data re MHK arrays connected to grid-tied shore facility – inadequate to inform cost-assured development of utility-scale MHK generation resources.

Impact of Project:

Provide the platform for:

- Marine environment data collection, to inform local, State, federal and NGO queries, and
- Cost and reliability data collection for in-water and shore assets, informing life cycle analysis for full-scale implementation potential.

Project Overview

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

Alignment With Program

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

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Advance the State of MHK technology

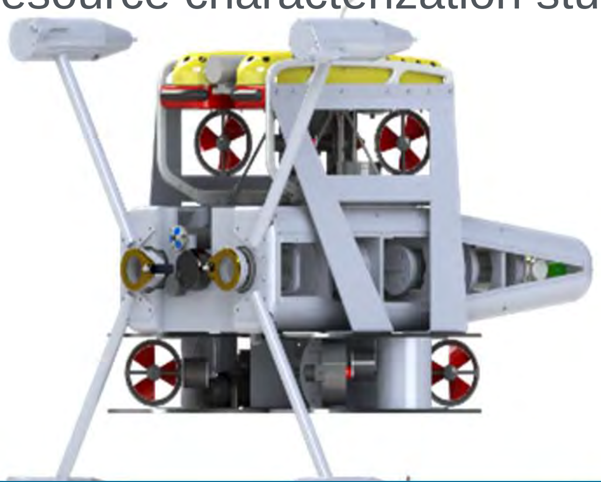
- Assist evaluating O&M costs for tidal turbine developers by producing multi-year performance data to evaluate long-term changes
- Develop processes for deep-water, live boat device installation and cable connection to reduce capital costs of construction,
- Incorporates a battery storage element into the process for which the variable energy from the tidal array is gathered and delivered to the grid.

Develop Key MHK Testing Infrastructure, Instrumentation, and/or Standards

- Each turbine equipped with Adaptable Monitoring Package developed by NNMREC.
- Platform deploys a wide range of oceanographic instrumentation and recovered independently of the turbines for environmental / resource characterization studies.

Characterize and Increase Access to High Resource Sites

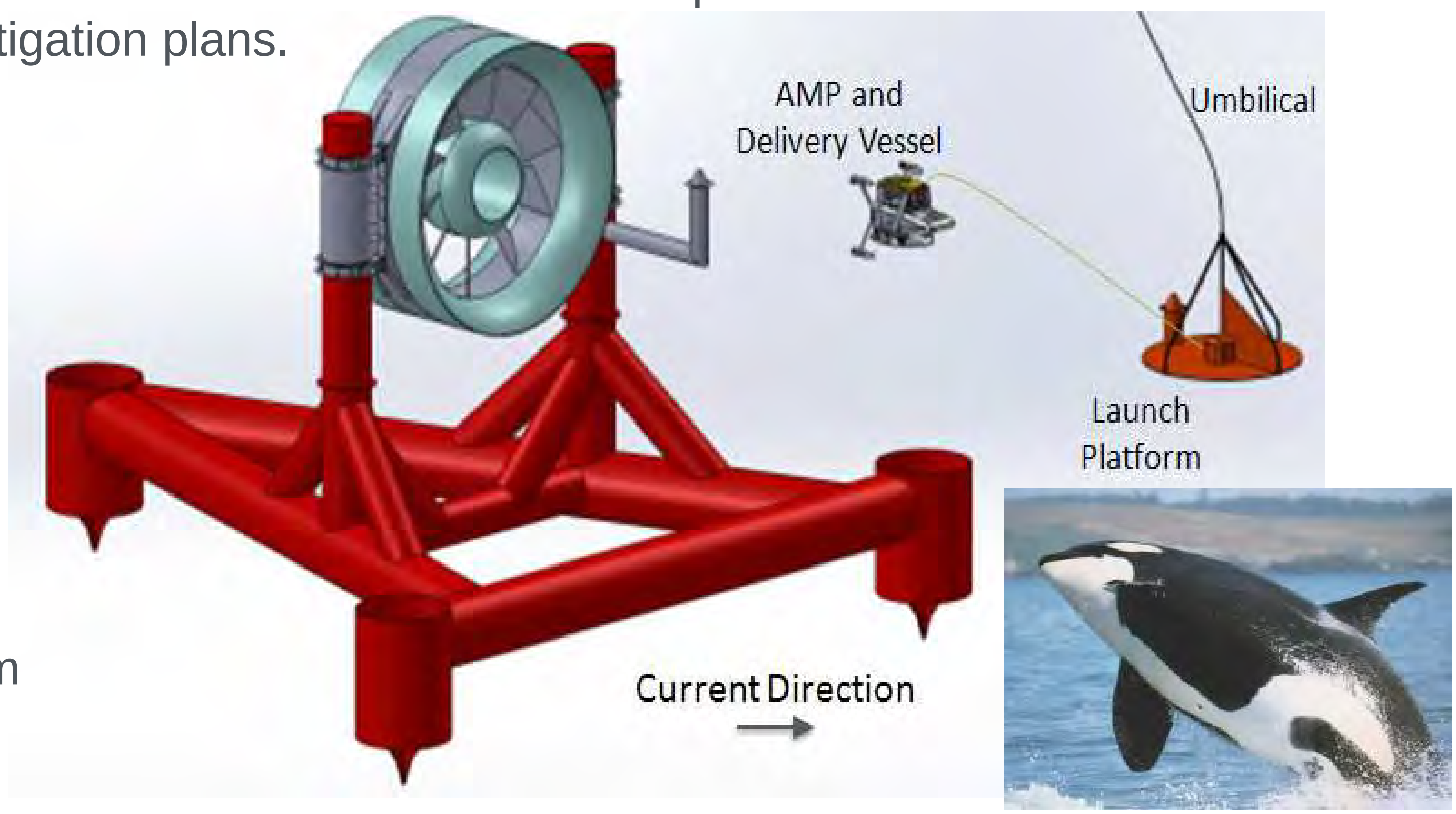
- Project siting activities led to the development of protocols for characterizing the spatial and temporal variability in tidal current resources.



SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Reduce Deployment Barriers and Environmental Impacts of MHK Technologies

- Provide data to address many unanswered questions regarding the introduction of MHK into the marine environment.
- Reduce resistance through collaboration with resource agency scientists in the development, execution and evaluation of the multiple environmental monitoring and mitigation plans.
- Facilitate the development of flexible monitoring plans for future projects, with a priority on environmental studies.
- Gather capital and O&M data to inform life cycle risk analysis.

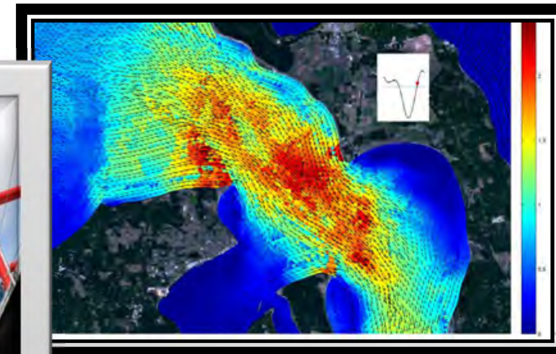


Technical Approach

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

<u>Prior to FY 2012:</u>

- High level assessment of the tidal resources in Puget Sound.
- Analyzed five potential sites, selected Admiralty Inlet for its:
    - proximity to local grid demand,
    - high velocity currents,
    - lower turbulence, and
    - greatest energy density



Technology Provider:

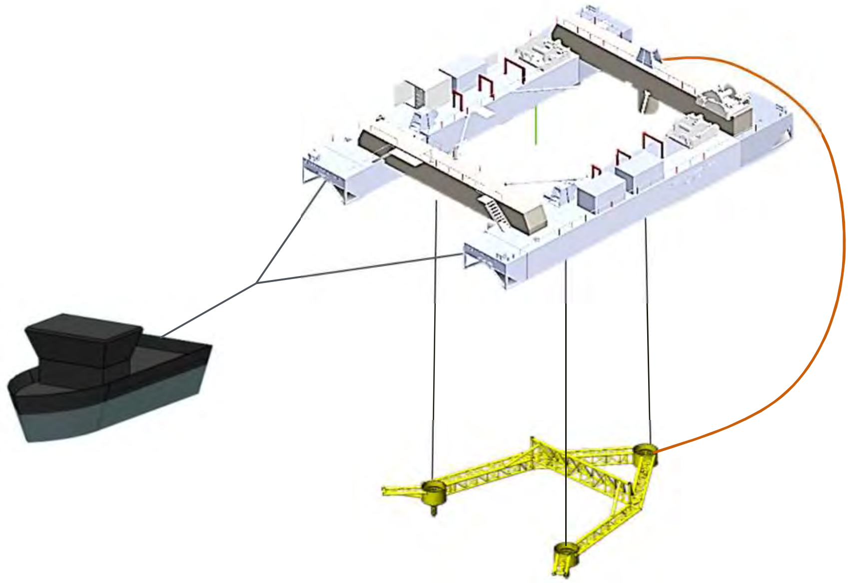
- Evaluated solicitations from 30 tidal developers worldwide.
- Selected OpenHydro Ltd., Irish technology development company, based on the following criteria:
    - a leader in the industry,
    - technology is simple in design,
    - technology determined to be the best-fit for Admiralty Inlet.

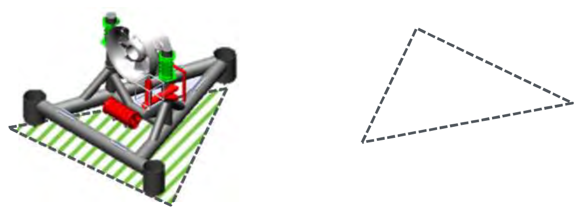
SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

FY2012 to Current:

With the technology selected, initiated the following technical processes in FY2012:

- Federal, State and local licensing and permitting, including the development of monitoring and mitigation plans
- Stakeholder Consultation
- Property acquisition (marine and terrestrial),
- Overall Project design and verification
    - Terrestrial improvements
    - Marine Operations plan
- Development of public works contract (PWC) construction documents
- Supply Agreement contracts & specifications





Accomplishments and Progress

Project (FERC) licensing (95%)

- Filed Final License Application with FERC
- All monitoring and mitigation plans have been accepted
- NOAA issued a favorable Biological Opinion
- FERC has issued a final NEPA Environmental Assessment
  - Finding of No Significant Impact (FONSI)
- District issued State SEPA Determination of Non-Significance
- Island County issued Shorelines Conditional Use Permit (currently under appeal by PC Landing and the Tulalip Tribes)
- WA Dept. of Ecology issued 401 Water Quality Certification

Awaiting issuance of Coastal Zone Management Act consistency certification from Ecology. Once issued, the FERC Commission can render a decision regarding the license application.

Licensing process has taken significantly longer to complete than originally anticipated:

- mandatory agency review periods, and
- time required to work through monitoring and mitigation plans for critical environmental uncertainties

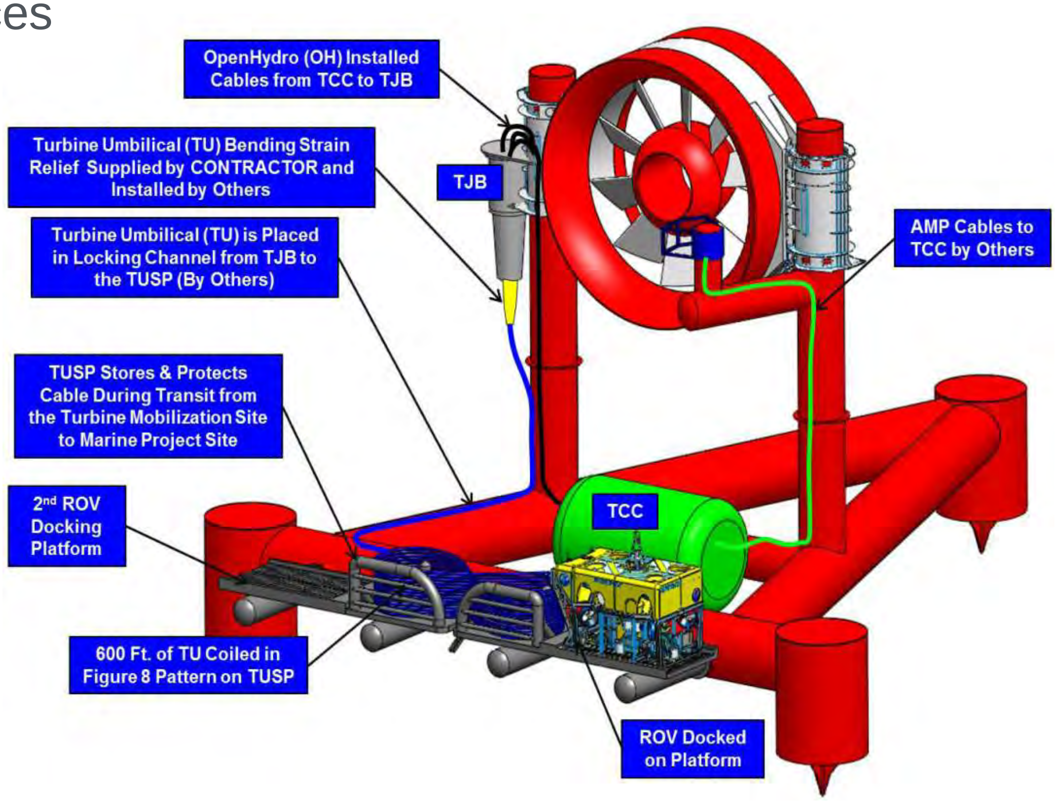
Accomplishments and Progress

Property acquisition (marine and terrestrial): 95%

- Secured all proposed terrestrial lands.
- Provided all documents to Washington State Department of Natural Resources for the proposed offshore cable route easement and turbine leases.

Overall Project design and verification: 95%

- Proof of concept test on battery storage system complete; awaiting results.
- All other design elements are at or near completion.
- Refinements to continue once the PWC is awarded



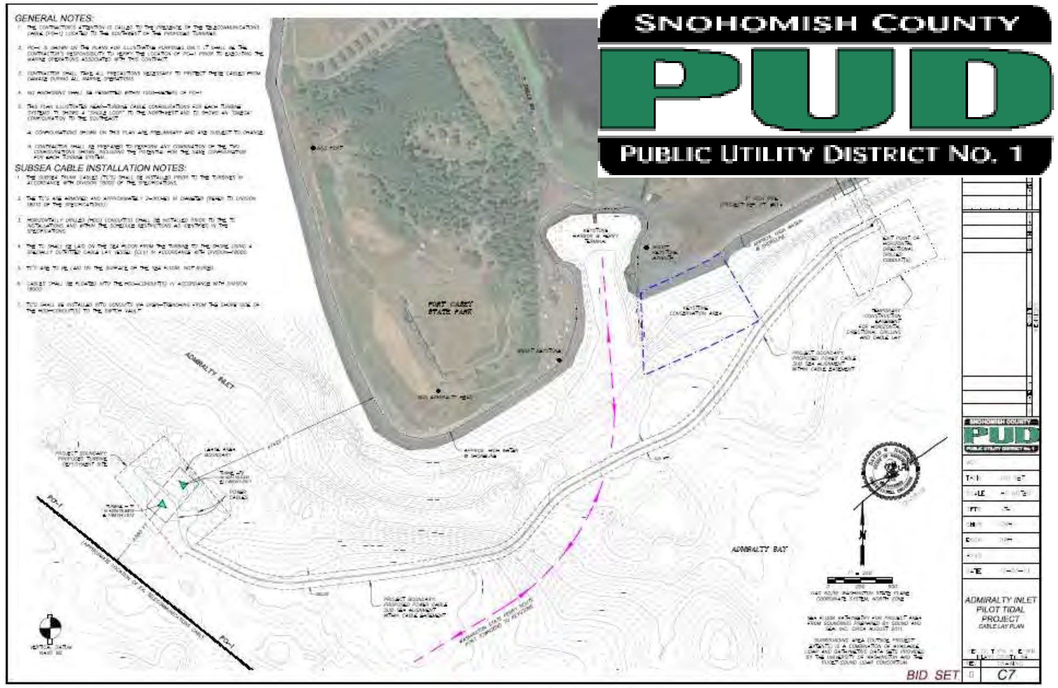
Development of PWC documents: **95%**

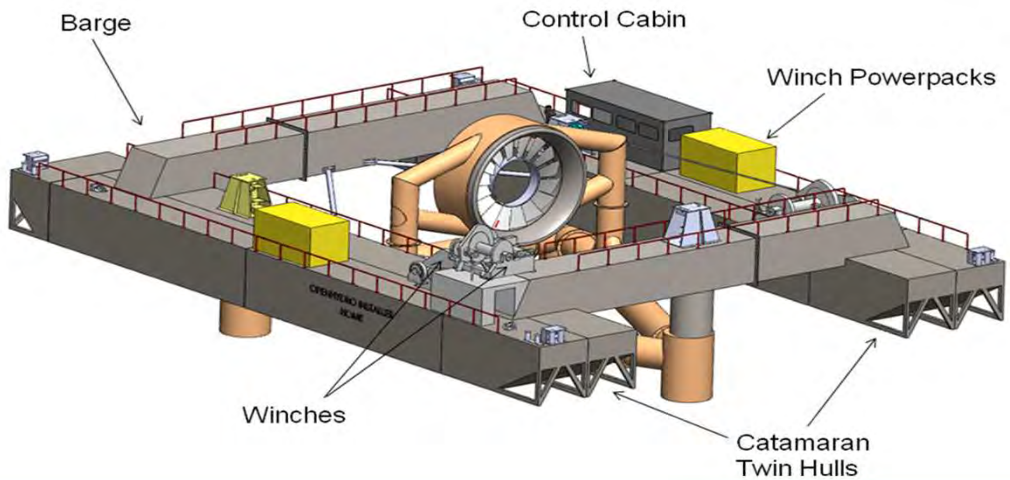
- In acquisition for the construction of all project infrastructure.
- Solicitation process and ultimate selection of final PWC contractor may result in further refinements in the design.

Supply Agreement contract specifications: **98%**

Initial notice to proceed has been issued to OpenHydro to:

- validate specific contract provisions, and
- fund proof of concept testing above.





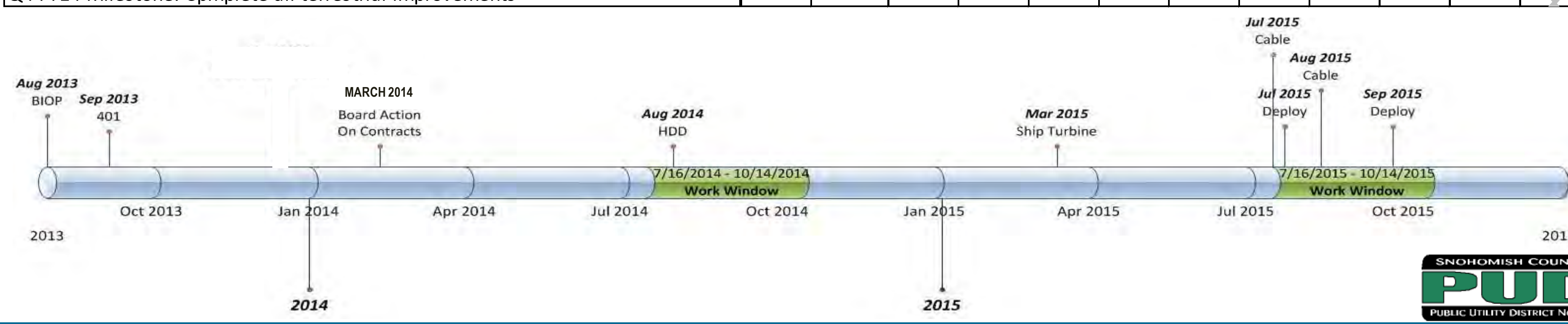
Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
◇	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Admiralty Inlet Pilot Tidal Energy Project												
Q2 FY12 Milestone Final License Application Filed		◆										
Q3 FY13 Milestone: FERC EA received							◆					
Q1 FY14 Milestone: NOAA Fisheries BiOP Received (Favorable)									◆			
Q2 FY14 Milestone: Continued FERC License Receipt										◇		
Q2 FY14 Milestone: Issue contracts for infrastructure constrction										◇		
Q2 FY14 Milestone: Issue contracts for turbine suppluy w/OpenHydro										◇		
Q4 FY14 Milestone: Perform 2014 water work window HDD effort												◇
Q4 FY14 Milestone: Cpmplete all terrestrial improvements												◇



SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Project Budget

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

FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
[$0]	[$0]	**$394,759**	**$733,124**	[$4,500,000]	[$9,000,000]

Expended to date

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$402,200	$299,500	$701,700	2.5%	
b. Fringe Benefits	$221,009	$164,575	$385,584	1.4%	
c. Travel	$0	$0	$0	0.0%	
d. Equipment	$0	$0	$0	0.0%	
e. Supplies	$0	$0	$0	0.0%	
f. Contractual				0.0%	
Sub-recipient	$611,343	$88,657		0.0%	
FFRDC	$0	$0		0.0%	
Vendor	$13,768,883	$7,483,439		0.0%	
Total Contractual	$14,380,226	$7,572,096	$21,952,322	78.9%	
g. Construction	$0	$0	$0	0.0%	
h. Other Direct Costs	$0	$0	$0	0.0%	
i. Indirect Charges	$3,120,714	$1,671,524	$4,792,238	17.2%	
Total Project Costs	$18,124,149	$9,707,695	$27,831,844	100.0%	

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

- NNMREC / UW – AMP / strategic plng
- OpenHydro, LLC – Turbine and power conversion
- DOE National Labs – Marine impact analysis
- Industry – Power conversion
- Puget Sound Energy, Inc – Utility grid connection

Communications and Technology Transfer:

- HydroVision 2013, Denver CO July 2013
- Public Outreach in NW Washington 2010 – present

Remaining Barriers:

Continued challenges with stakeholders

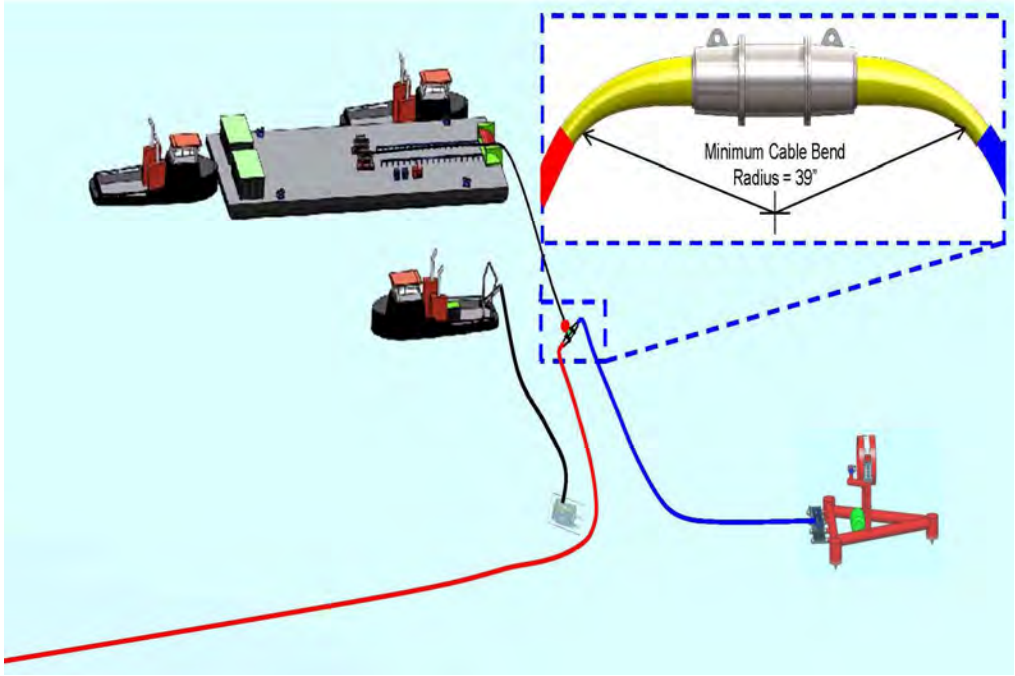
- Tribes
- PC Landing, LLC

Milestones for 2014 and Beyond:

- 1st phase of project infrastructure construction (terrestrial works)
- Award of Turbine Supply contract / begin turbine fabrication
- Continued Construction and Project Commissioning through 2015

Future Research:

- Implementation of the Environmental Monitoring and Mitigation Plans for duration of project operations
- Iterative improvement in:
  - o monitoring equipment,
  - o delivery and recovery operations, and
  - o on-site maintenance procedures.



Water Power Peer Review

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

VERDANT POWER

Advancement of the Kinetic Hydropower System (KHPS) to Department of Energy (DOE) Technology Readiness Level (TRL) 7/8
Award No. DE-EE0005929

Dec 2012 - Sept 2013

Advancement of the Kinetic Hydropower System (KHPS) to Department of Energy (DOE) Technology Readiness Level (TRL) 7/8

Mary Ann Adonizio

Verdant Power Inc.

717 730 2092 maadonizio@verdantpower.com

February 25, 2014

Purpose and Objectives

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

“Advancement of the Kinetic Hydropower System (KHPS) to Department of Energy (DOE) Technology Readiness Level (TRL) 7/8”

- Project Budget: $3.12 Million
- DOE Funding: $1.5M; VP Match: $1.6M
- Actual Cost of Project: >$5M

Project Tasks:

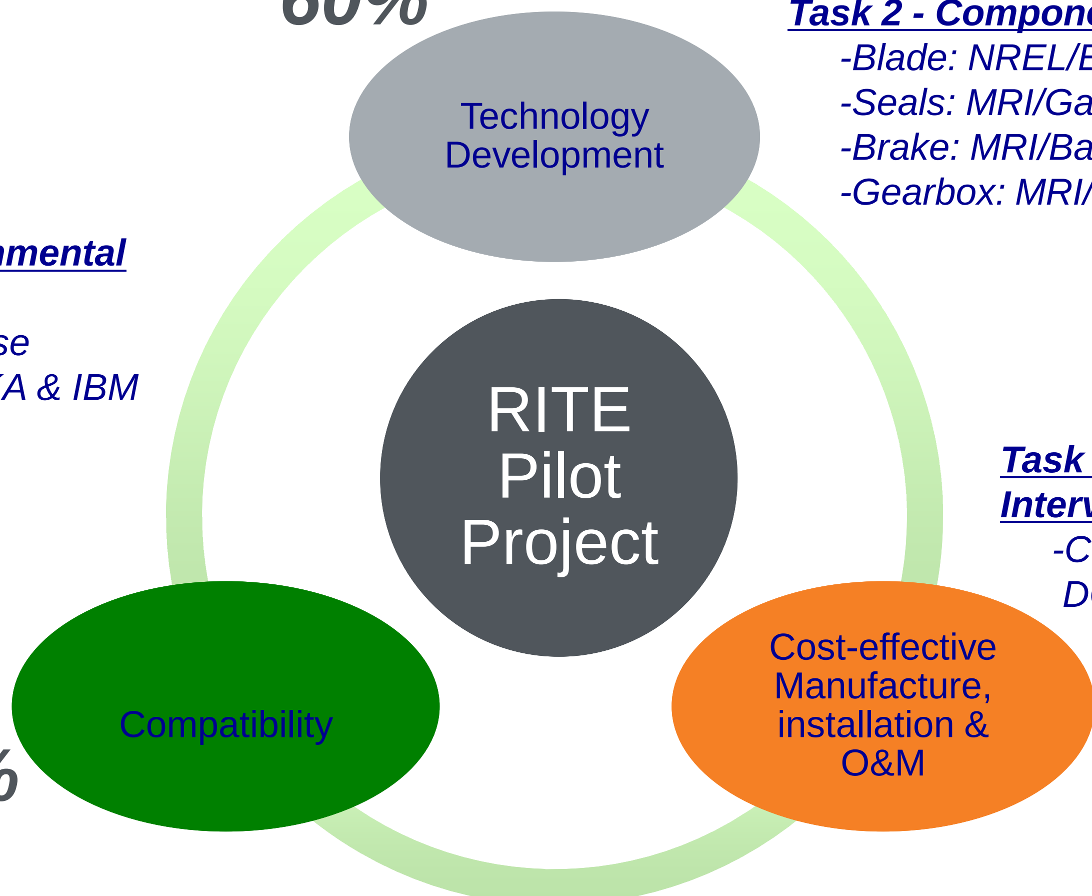
1. Continued implementation of instrumentation that supports the ***environmental compliance*** of MHK devices
2. Generation 5 (Gen5) KHPS turbine ***component tests*** (blades, main shaft seal system, brake and gearbox) for longevity and reliability
3. Evaluation of component service interval as part of cost-effective ***O&M projection***

<2012: $30M spent **Current Project: $3.12M** **>2014 RITE 2-years: $7.5M**

60%

Task 2 - Component Tests
- *Blade: NREL/Energetx*
- *Seals: MRI/Garlock*
- *Brake: MRI/Baldor*
- *Gearbox: MRI/Winsmith*

Task 1 - Environmental Compliance
- *RMEE-6 Noise*
- *Evaluation: KA & IBM*



Task 3 - O&M Service Interval
- *Components as part of DOE LCOE program*

20% **20%**

**-Percentages reflect current project*

Problem Statement – Challenges

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

- **Industry needs *cost-effective* environmental monitoring of operating MHK arrays**
  - Approved RITE Monitoring of Environmental Effects (RMEE) Plans
    - o Compliance costs
    - o Implementation – data/use proportional to costs

- **Industry needs *component testing and analysis* to progressively validate longevity and reliability parameters for operating MHK devices**
  - Knowledge gaps:
    - o TRL 7/8 test protocols specific to the MHK industry
    - o Service interval data for O&M strategies
    - o Component timing and costs to support DOE effort

Impact of Project – Deliverables

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(1) Environmental Compliance and Instrumentation

- Demonstrate progress on compliance and inform US regulatory community
- RMEE-6 noise monitoring and evaluation report
  - Costed ***alternatives*** and future for MHK industry

(2) Gen5 KHPS Turbine Component Tests & Reports at TRL7/8

- Inform the manufacturing, materials and ***service interval of four key components***
- Advance understanding of component service intervals for the MHK industry

(3) Test Results on Components Service Interval

- Inform RITE Pilot operation & maintenance strategy
- Provide DOE with data on ***projected component costs and service intervals of MHK devices***

<u>**End Result: Highly reliable TRL 7/8 System for RITE Pilot Project**</u>

Alignment with DOE Program

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

1. ***Advance the state of MHK technology***
   - TRL advancement, both device and environmental compliance

2. ***Develop key MHK testing infrastructure, instrumentation and/or standards***
   - Component tests are providing *protocols suitable for MHK industry* adaptation
   - Advances environmental monitoring instrumentation

3. ***Characterize and increase access to high-resource sites***
   - RITE site = a known highly-productive licensed site
   - Verdant has conducted 11 deployments to date
   - Prior efforts with DOE on resource characterization

4. ***Reduce deployment barriers and environmental impacts of MHK technologies***
   - Project directly addresses key challenges
   - *Largest deployment barrier is adequate funding for TRL 7/8*

Technical Approach – Task 1 Environmental

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Compliance & Implementation of Approved RITE Monitoring Of Environmental Effects (RMEE) Plans

Approach:

- Meet compliance requirements of FERC Pilot License
- Evaluate "RITE-sized" designs of noise monitoring options based on SmartBay applications as *cost-effective noise monitoring* (RMEE-6) of operating Gen5 KHPS

Key Issues and Significance:

- Cost-effectiveness of array monitoring
- Broader application for other sites and potentially O&M monitoring

Unique Aspects:

- Leverages ongoing work supported by NYSERDA and ACT
- *Leverages IBM work with SmartBay – Galway IRE*

Task 1 - Environmental Compliance

- Completed RMEE-4 Tagged Species Identification data retrieval and reporting for 2013 => Fish Interaction Model
- *Conducted preliminary design review with IBM on RMEE-6 noise monitoring*
- Completed required FERC pilot license compliance and NEPA requirements for DOE

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***RMEE-4 Report**: "Based on data collected thus far, a total of 15 tagged Atlantic sturgeon and 7 other tagged fish were identified in more than 25 months of data collection. The presence of tagged fish varies from <1 hour up to 6 hours, generally indicating a movement (at or near slack), rather than residence…"*

RMEE-6 Noise Monitoring – Accomplishments

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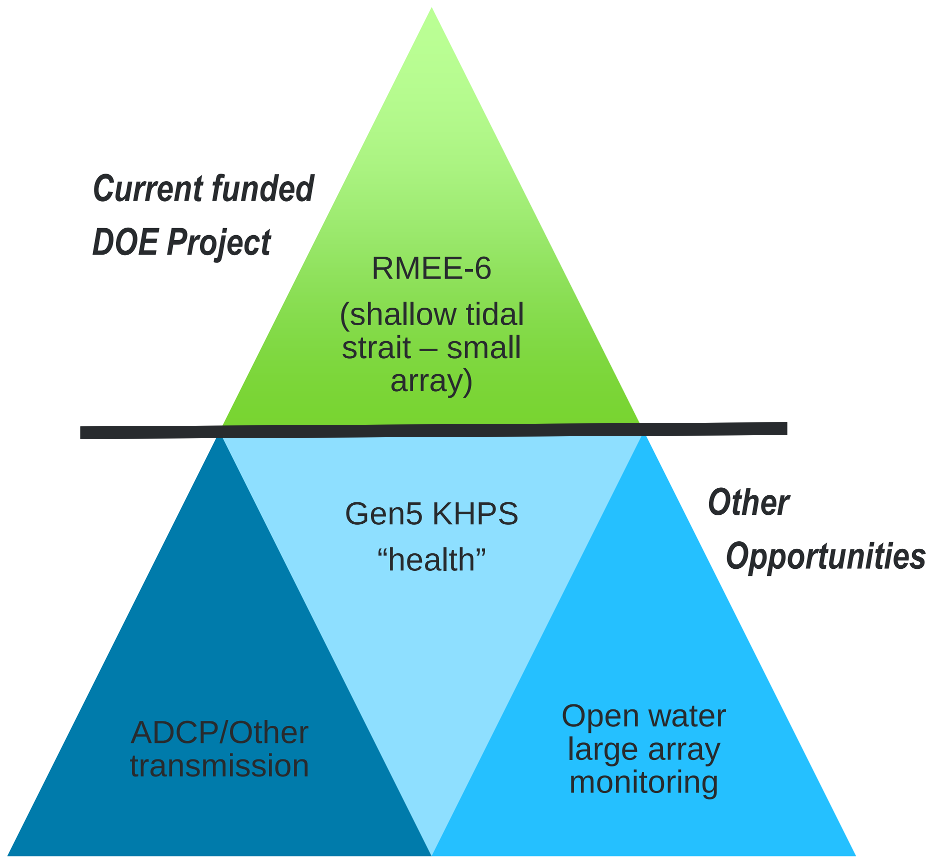
Task 1.2 Progress
($75K DOE/$200K match)

- Desktop project only
- Reviewed Galway SmartBay project parameters
- Evaluated RITE requirements
- Conducted preliminary design review of component options
- 2014: Design review for RITE applications
- *Progress and costs for task on-budget*

Opportunities for use within MHK industry



Technical Approach – Tasks 2 & 3

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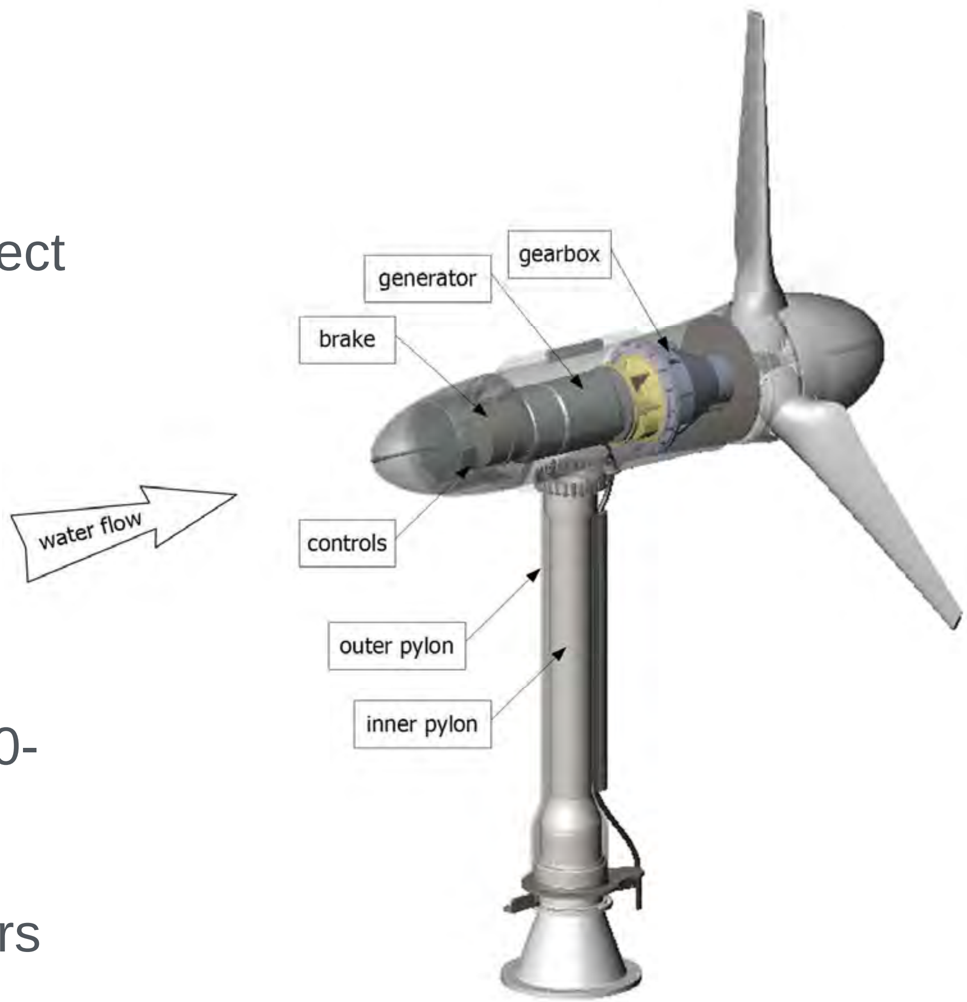
Critical Component Tests

- VP internal FMEA on Gen5 KHPS turbine revealed the following as most likely to affect *O&M Service Interval (SI)*:
    - Composite Blades
    - Main Shaft Seal
    - Brake
    - Gearbox
- RITE Pilot Project Target: 180-365 days to 3 years
- Gen5 KHPS SI Target: 5 years



Technical Approach – Tasks 2 & 3

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

1 - Evaluate design and manufacture of component for expected service life

2 - Define test protocol to reasonably approximate expected service conditions & *review with DOE*

3 - NREL/NWTC & design/adapt test stands at 3 facilities
- Release PO for manufactured parts under QMS

4 - Conduct tests, produce reports
- Incorporate results into manufacturing & Gen5/project design

5 - Summarize and disseminate results (tech transfer)
- Use results to inform service life and O&M assumptions as input to DOE effort

MRI MANUFACTURING RESOURCES, INC

Technical Approach – Component Tests

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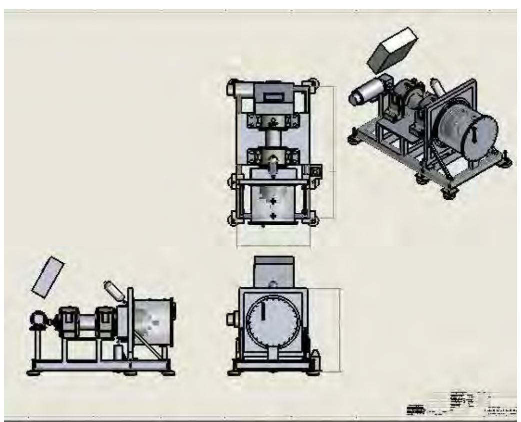
KHPS Components	Design Service Interval	Component Testing Protocol	Significance
Composite Blades, 5m Energetx (25%)	5 years/20-year life	At NREL – Perform static and fatigue testing	AWPP identified opportunities for improved manufacturing techniques
Shaft Seal Assembly (9%)	Evaluate service interval of 3-5 years in salt water	At Garlock – Simulate performance; Measure leakage rate	Could drive maintenance requirement if leak rates are too high under tidal performance
Generator Brake (12%)	Verify 5-year service interval	At Baldor – Accelerated stop/start for wear	Repeated cyclical stop/start measured for wear, longevity
Gearbox (54%)	Verify 5-year service interval	At Winsmith – Perform dynamometry and accelerated wear	Primary component driving cost – need to project wear and verify service interval

-Percentages indicate cost allocation of $2.2M DOE effort

Progress Highlights (Dec 2012 - Sept 2013)

- Task 2.1 Blade design and protocol design with NREL
- Task 2.2 Seal test design and protocol
- Task 2.3 Brake test design and protocol
- Task 2.4 Gearbox preliminary test design
- *Design review with DOE staff - January 2014*
- Task 3 discussions with DOE regarding cost input



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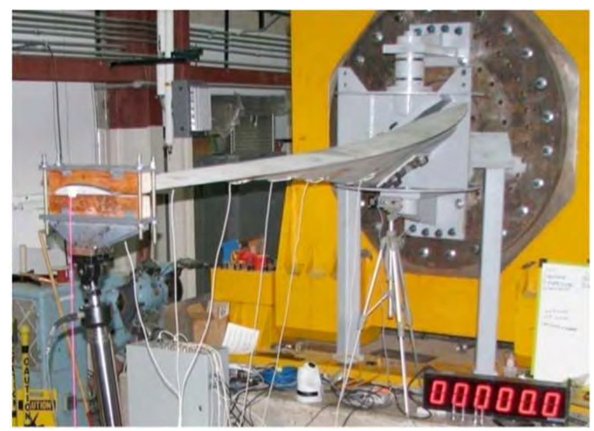


2.1 Composite Blade Test

At NREL ~ 4 months

1 Static and fatigue testing of one blade as per IEC wind blade test standard 64100-23, flap and edge
2 Environmental (salt-water) conditioning of blade
3 Seal the blade during testing
4 Fatigue test to 200% of life

Recommended test to failure:

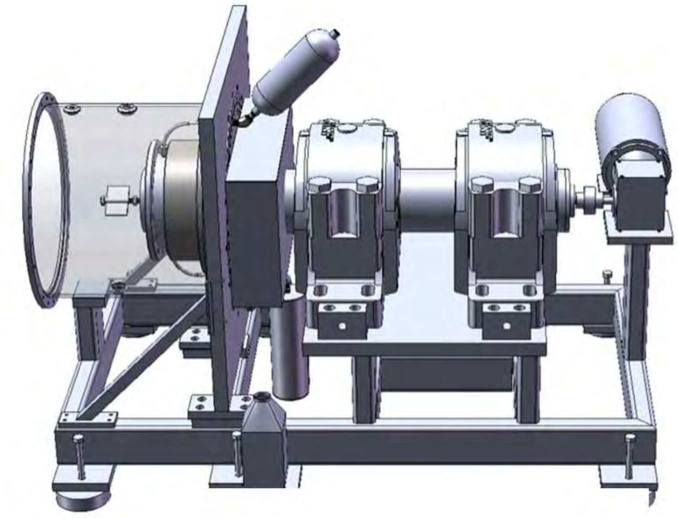
$17k more to budget (pending)

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

2.2 Main Shaft Seals (Verdant IP)

Custom test stand ~ 60 days

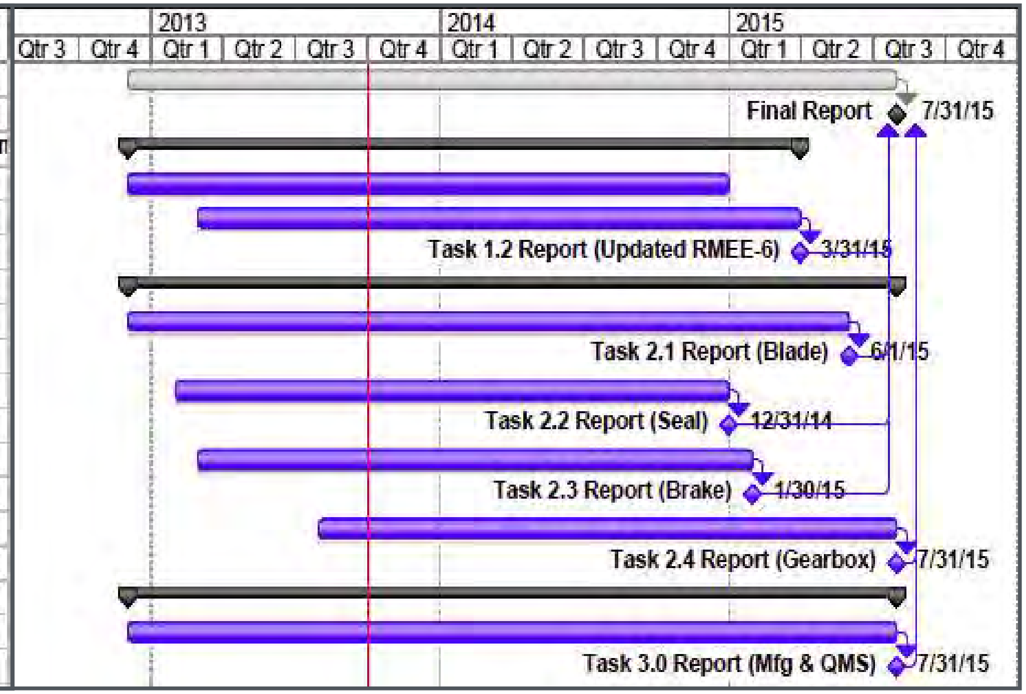
- Revolutions: 6.5M (8% of 5-yr SI)
- Start/Stop Cycles: 30k (500 per day) (125x normal 4/day) (20-yr life)



MRI MANUFACTURING RESOURCES, INC

Project Plan & Schedule – TRL 7/8

ID	WBS	Task Name
1	PM	Project Management & Technology Transfer
2	*FR DLV*	*Final Report*
3	**1.0**	**Enviro Compliance & Monitoring Instrumentation**
4	1.1	Compliance & Monitoring Instrumentation
5	1.2	RMEE-6 UW Sound Monitoring and Eval Plan
6	*1.2 DLV*	*Task 1.2 Report (Updated RMEE-6)*
7	**2.0**	**Gen5 KHPS Turbine Component Testing**
8	2.1	Testing of Production-Class Composite Blade
9	*2.1 DLV*	*Task 2.1 Report (Blade)*
10	2.2	Shaft Seal Testing
11	*2.2. DLV*	*Task 2.2 Report (Seal)*
12	2.3	Generator Brake Testing
13	*2.3 DLV*	*Task 2.3 Report (Brake)*
14	2.4	Gearbox Dynamometry Testing
15	*2.4 DLV*	*Task 2.4 Report (Gearbox)*
16	**3.0**	**Gen5 Manufacture and QMS**
17	3.1	QMS Release for Testing and Production
18	*3.1 DLV*	*Task 3.0 Report (Mfg & QMS)*



- Good progress for 9 months, project can be completed within budget
- *First-time Gen5 manufacturing setup* – QMS, tooling
- Positioning for verification and certification with Center for Evaluation of Clean Energy Technologies (CECET) and Intertek (Cortland, NY)

Project Budget

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Budget History – 4Q2013					
FY2012		**FY2013**		**FY2014**	
DOE	Cost Share	DOE	Cost Share	DOE	Cost Share
$0	$0	$499,292	$534,775	$1,000,708	$1,127,753
	Actual	$149,287	$185,748		

DOE portion is $1.5 of total $3.12 million

- *No-cost time extension request pending (to July 2015)*

As of Sept 30, 2013 (9 months) 11% of the project budget has been expended

- *Project can be completed within budget*

Cost-sharing support from Verdant Power and external partners

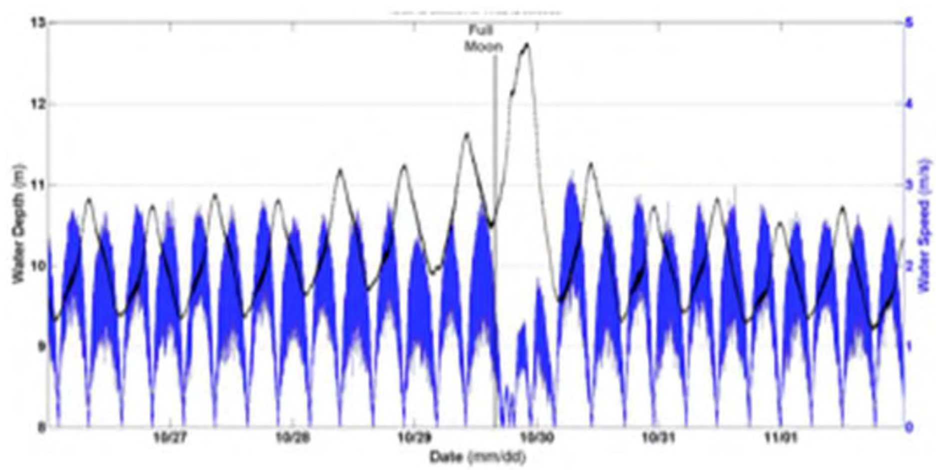
- *In-kind from ConEd, MRI, IBM*
- *Grant support from two NYSERDA contracts*

Partners, Subcontractors and Collaborators

- Kleinschmidt Associates (PA): Environmental Compliance
- IBM T.J. Watson Research Center (NY): SmartBay Project (IRE)
- Manufacturing Resources Inc (MRI): VP Manufacturing QMS
- VP supply chain: Energetx (MI), Garlock (NY), Baldor (AL), Winsmith (NY)
- National Renewable Energy Lab (CO): Composite Blade testing (Scott Hughes)

Publications and Presentations:

- *"Superstorm Sandy and the Verdant Power RITE Project"*
    - o *Presented at AGU (December 2013)*
    - o *GMREC VII (April 2014)*
    - o *All-Energy UK (May 2015)*
- www.theriteproject.com



FY 2014 Deliverables

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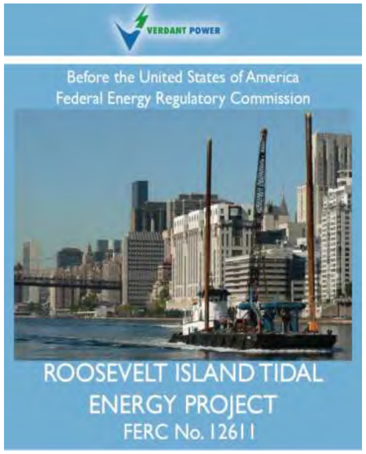
Task 1 - Environmental Compliance
- Ongoing compliance including FERC amendment
- RMEE-6 noise monitoring report

Task 2 - Component Tests & reports
- Blade manufacture 3Q14 and testing 4Q14
- Seals testing – Targeted for 3Q14
- Brake testing – Targeted for 4Q14
- Gearbox manufacture release 2Q14 and testing 1Q15

Task 3 - Cost-Effective O&M
- Input on component service life and cost estimation



Next Steps ... TRL 7/8
Not Research

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RITE Pilot Project – Gen5 in the water and operating

Work under DOE project supports this objective;
Private investment outlook for complete project

- Manufacturing, Assembly and Installation: ~$4 of 6 million
  - *Auburn, NY Supply Chain*
  - *Monopile installation*
- Operation & Performance Certification: ~$1.5 million
  - *Under FERC Pilot License*
  - *Possible partnership with CECET; verification process leading to certification using IEC TC-114 standards*
  - *Removal and inspection*

Target:

Project funding finalized by April 2014, In-water 4Q 2015; Performance after 180 days

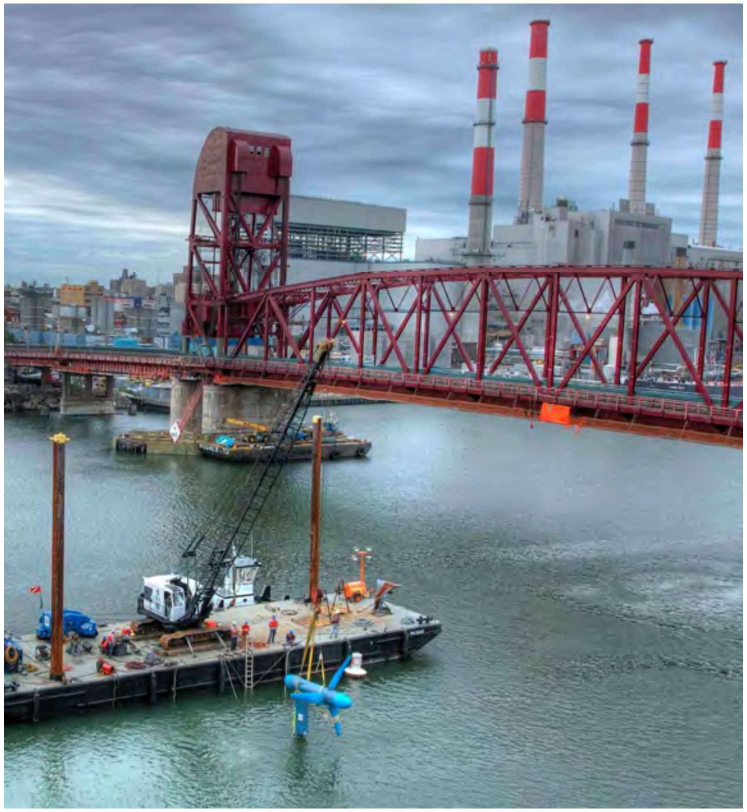
Future Research & Development

1. **RITE Pilot Project – TRL 7/8 Operation**
   - 2015-16: $7.5M required, $4M in-hand
   - Gen5 KHPS verification leading to performance certification

2. **Field Measurement Campaign (FMC)**
   - With DOE National Labs: Instrumentation of blade for hydrodynamic measurements and model calibration (~$900K)
   - Predicated on #1 going forward

3. **Cost-Effective Installation & O&M**
   - Fund final design and test of VP TriFrame foundation (~$500k)

4. **Environmental Monitoring (RMEE Plans)**
   - Completing ORNL study of fish behavior & strike model (funded)
   - Fund triangulation methods for RMEE-4 (~$300k)



Thank You!

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Advancement of the Kinetic Hydropower System (KHPS) to Department of Energy (DOE) Technology Readiness Level (TRL) 7/8

Mary Ann Adonizio
Verdant Power Inc.
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February 24, 2014

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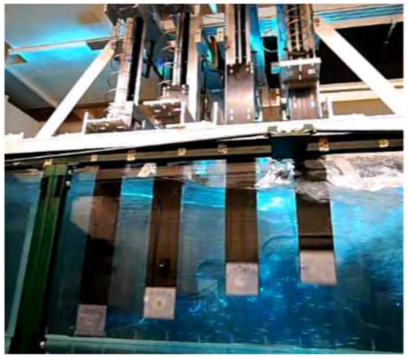
VORTEX HYDRO ENERGY



ADVANCED INTEGRATION OF POWER TAKE-OFF IN VORTEX INDUCED VIBRATIONS AQUATIC CLEAN ENERGY

Rebecca Alter

Vortex Hydro Energy

alterr@vortexhydroenergy.com

734 253 2451

February, 2014

Purpose & Objectives

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

Problem Statement: To commercialize a cost-competitive technology (VIVACE) to tap into the MHK energy source to aid in solving the energy crisis

Impact of Project: VIVACE accesses an untapped clean renewable energy source.

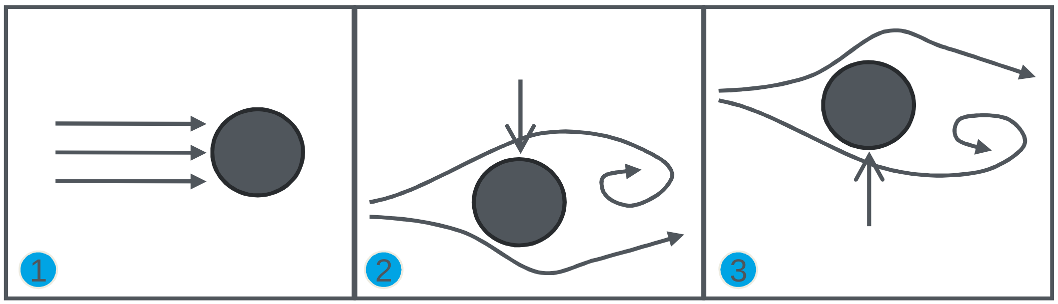
- *Larger operation range*
- *Environmental compatibility*
- *Increased power density*

This project aligns with the following DOE Program objectives and priorities: Advance the state of MHK technology

How VIVACE works:

Enhances natural flow instabilities using school-fish biomimetics

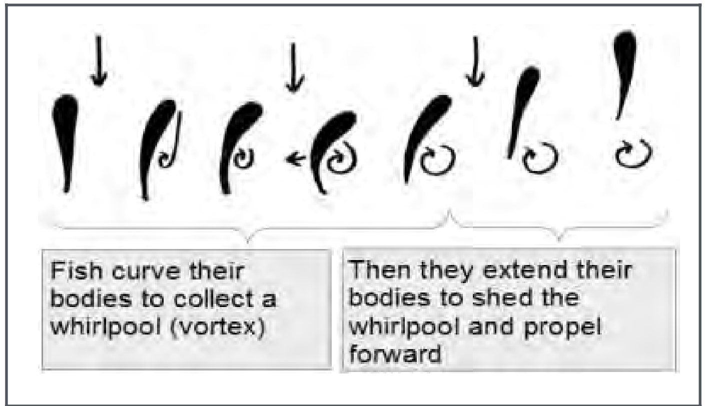
- Flow Induced Motion
- Vortex Induced Vibration
- Galloping

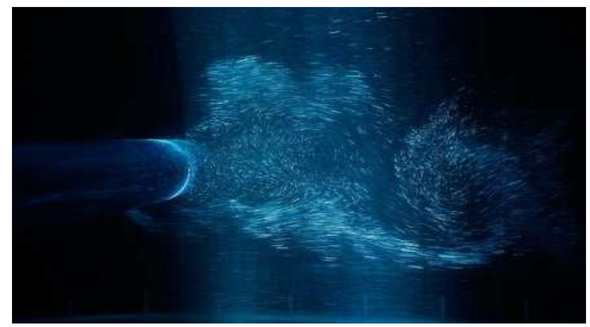


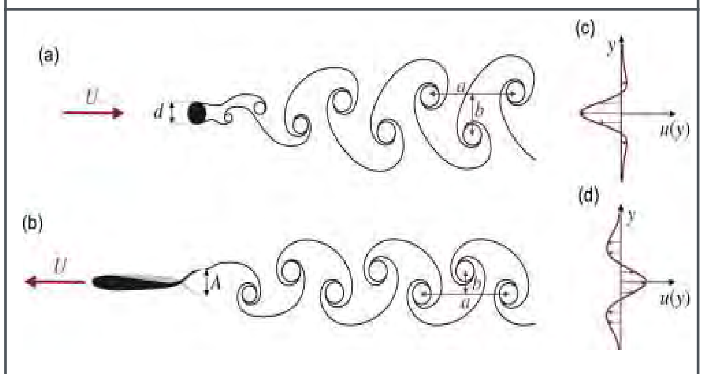
1 Water flow direction

2 VIV moves cylinder downward

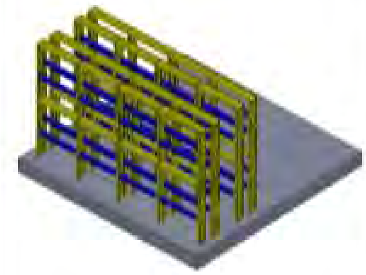
3 VIV moves cylinder upward







Where VIVACE works:

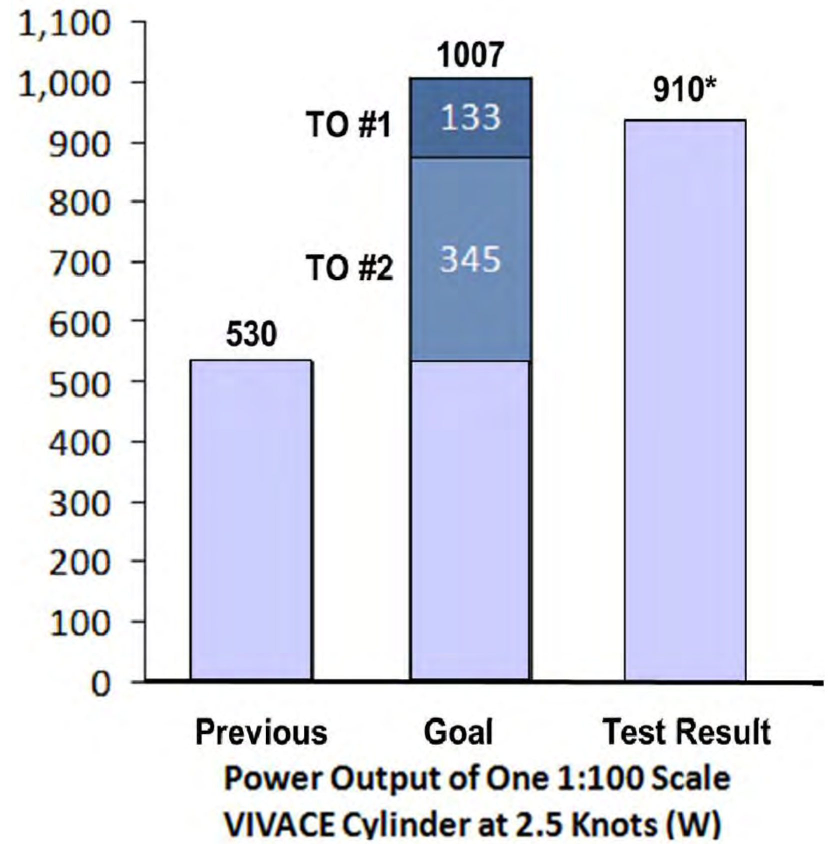
Scale	Scale 1 1,000≤Re≤20,000 Early Laminar Flow	Scale 2 20,000≤Re≤300,000 Late Laminar Flow	Scale 3 300,000≤Re≤500,000 Critical to Turbulent	Scale 4 500,000≤Re Post Super-Critical
Unit				
Applic.	UUV, Sensors, Tracking, Pollution, Weather, Fish, Defense	Portable, Naval Expeditions, Camps	Remote communities, Lighthouses, Naval Operations	Utility Scales, Coastal Communities, Islands

Technical Approach

DOE MHK Funding Objectives:

1. Increasing the conversion efficiency from hydrokinetic energy to cylinder kinetic energy.
2. Increasing the conversion efficiency from the cylinder kinetic energy to electric energy generation.
3. Performing open water testing on an improved VIVACE system that incorporates the improvements obtained from Objectives 1 and 2.

1. VHE reached 91% of its power generation goal
2. Optimization of VIVACE hydrodynamics
3. Improvements to electronics
4. Installation experience
   in the St. Clair River



The SBIR results are currently under analysis.

(fish shape biomimetics)

Accomplishments and Progress

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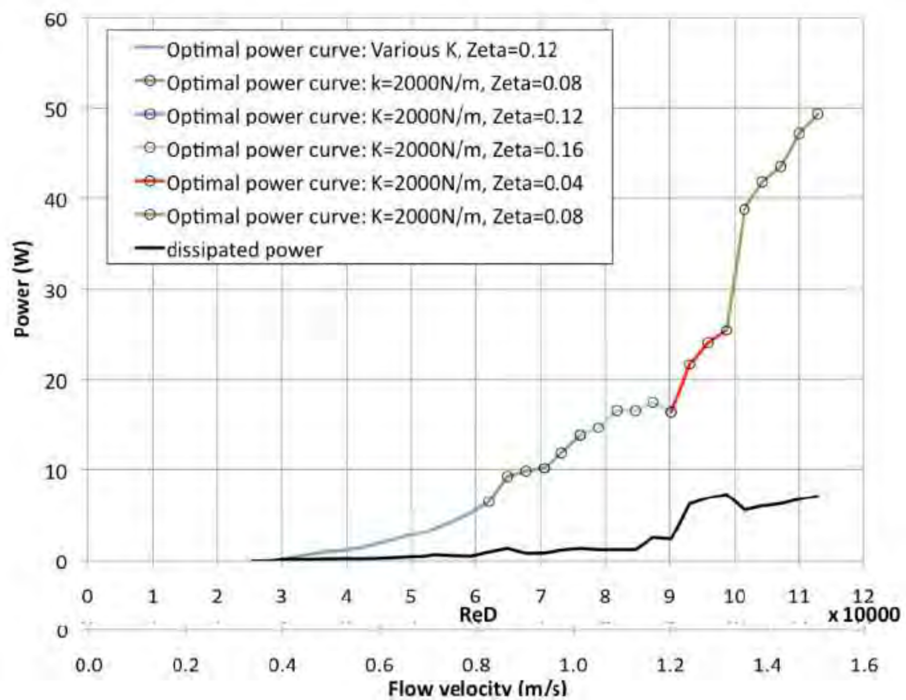
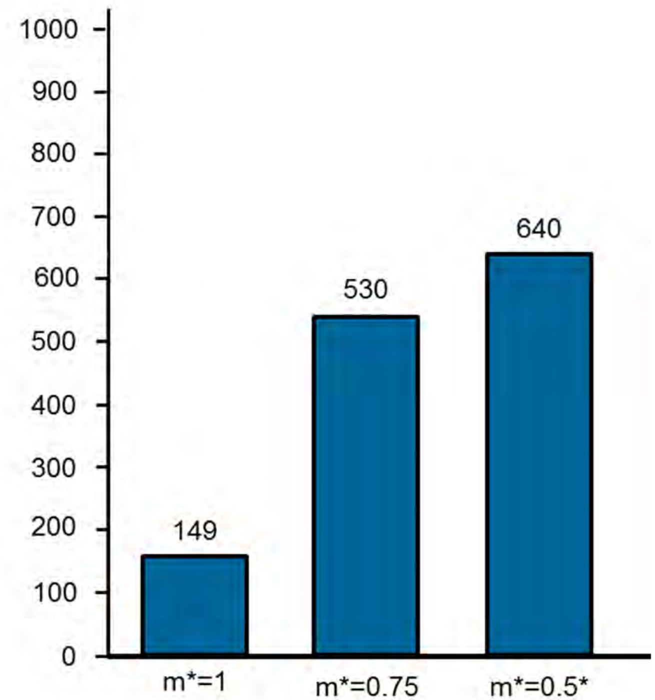
Hydrodynamic Improvements

1. Power Generation Curve



2. Mass Ratio Reduction



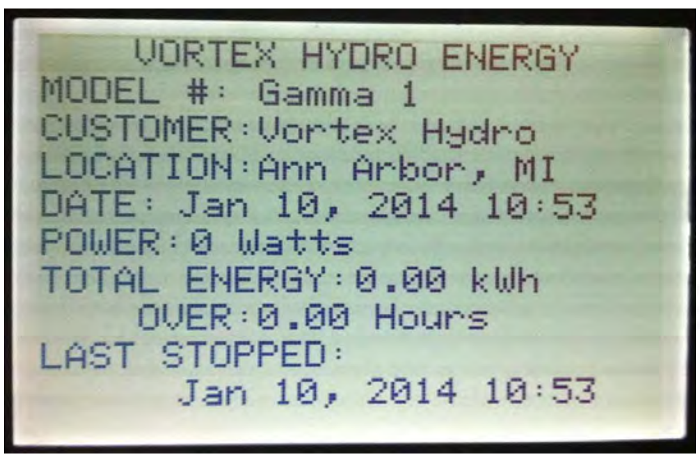
Power Output of One 1:100 Scale VIVACE Cylinder at 2.5 Knots (W)

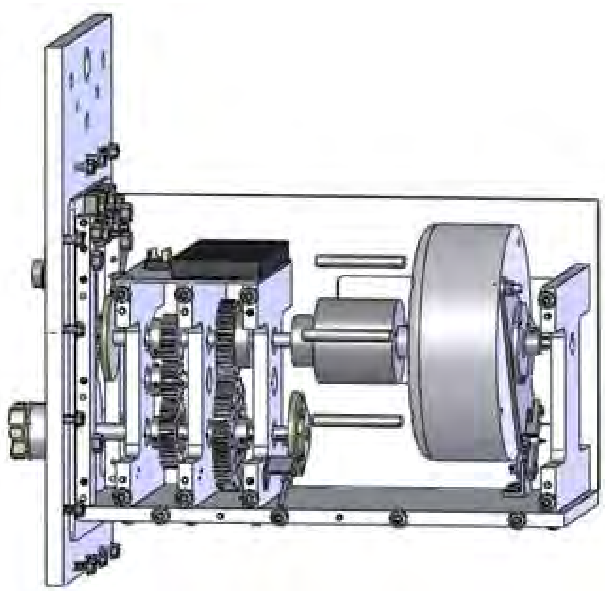
*scaled to 1:100 scale

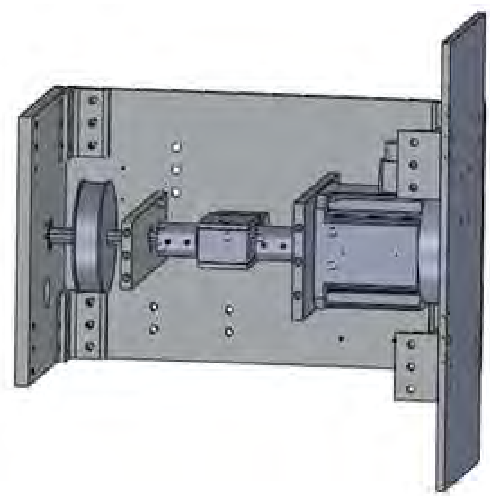
Accomplishments and Progress

Electrical Improvements

1. Reduced PTO Rotational Inertia
2. Reduced PTO Misalignment
3. Increased Generation Efficiency

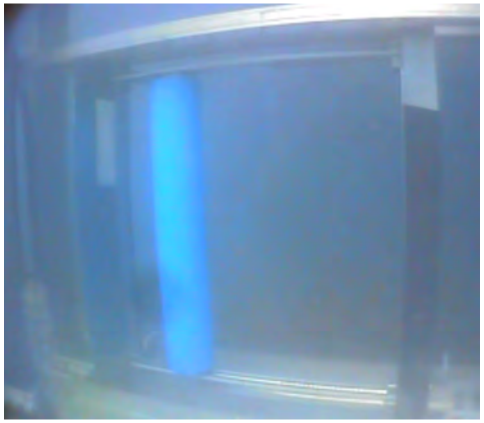




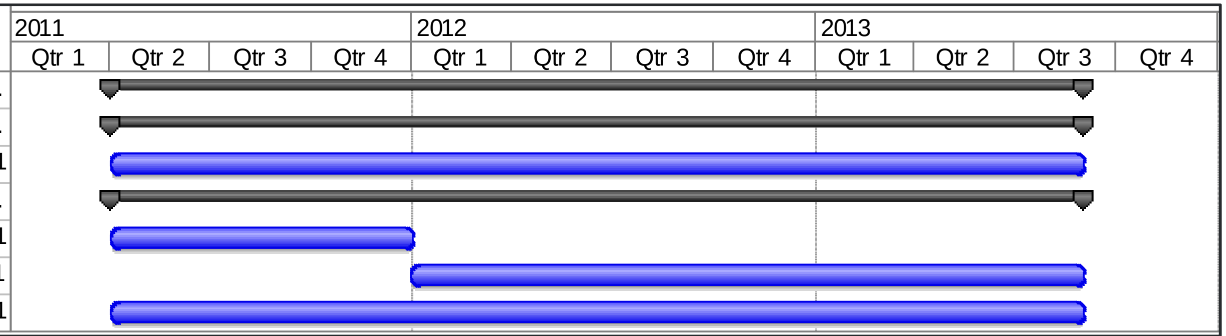


Accomplishments and Progress

VIVACE St. Clair River Installation Fall 2012 – Port Huron, MI



Task Name	Start
Total VIVACE Project	**Fri 4/1/11**
University of Michigan	**Fri 4/1/11**
1. Enhance Hydrodynamic Efficiency	Fri 4/1/11
Vortex Hydro Energy	**Fri 4/1/11**
2. Enhance PTO Subsystem Efficiency	Fri 4/1/11
3. Test System in Open Water	Fri 12/30/11
4. Task Planning and Management	Fri 4/1/11



Project Schedule and Milestones

Title / Task Description	Task Completion Date: Original Planned	Task Completion Date: Revised Planned
University of Michigan		
1. Enhance Hydrodynamic Efficiency	12/31/12	8/31/13
Vortex Hydro Energy		
2. Enhance PTO Subsystem Efficiency	12/30/11	12/30/11
3. Test System in Open Water	12/31/12	8/31/13
4. Task Planning and Program Management	12/31/12	9/1/13

Budget History

FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$412,447	$562,580	$473,791	$0	$77,253	$0

Partners, Subcontractors, and Collaborators:

University of Michigan
Virginia Tech.
Malcolm Marine
Commercial Diving and Marine Services
Energy Components Group
Dunn Paper
Economic Development Alliance of St. Clair County
Detroit/Wayne County Port Authority
Michigan Environmental Council

Communications and Technology Transfer:

- 19 journal publications during project period
- 107 journal publications referencing our technology during project period; many labs/universities studying VIVACE using analysis/tests/CFD

Next Steps and Future Research

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FY14/Current research: The MHK project is closed

Current DOE Funding:
SBIR - "Current Energy Harnessing Using Synergistic Kinematics of Schools of Fish-Shaped Bodies”

Proposed future research:

1. Large scale synergistic multiple cylinder operation
2. Optimization of cylinder shapes for multiple cylinders
3. Weight reduction design
4. Advanced controls for power take off

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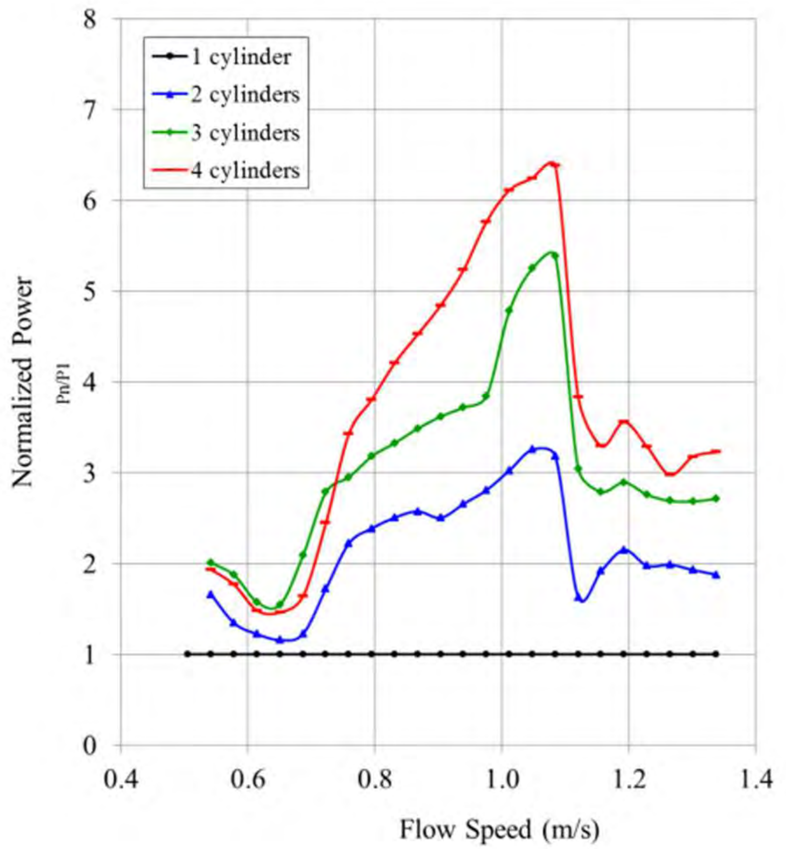
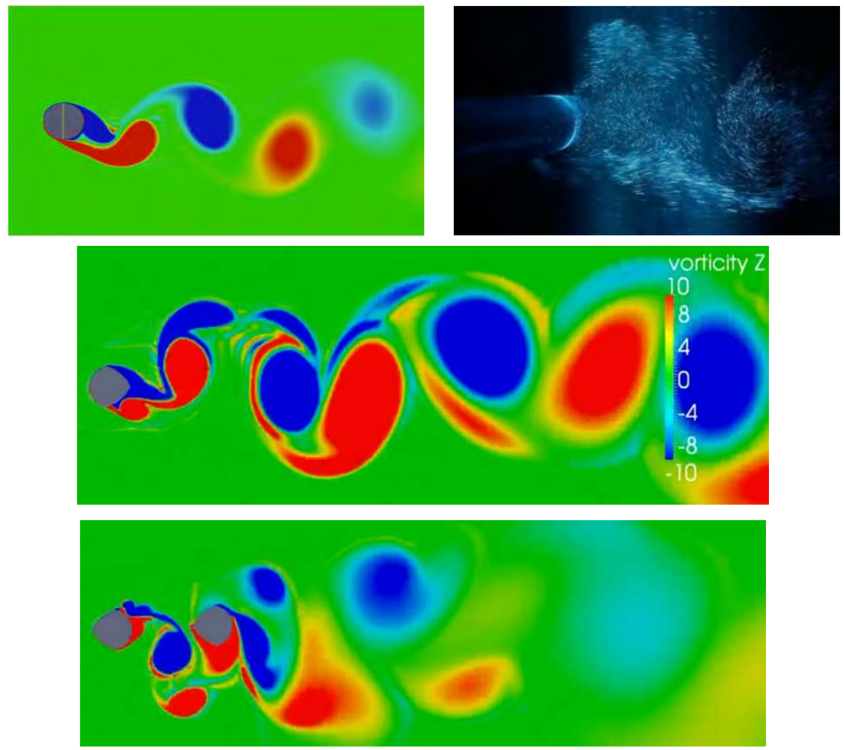
Synergistic interaction of multiple cylinders



Computational Fluid Dynamic (CFD) simulations of fish-shaped cylinders



Questions?

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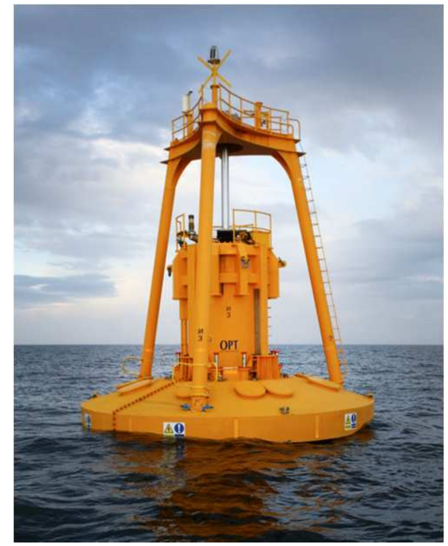


MHK Industry Support

Albert LiVecchi
NREL
Al.livecchi@nrel.gov 1 303 384 7138
February 25, 2014

Problem Statement:

The probability of success of lengthy and very expensive device development and testing cycles in the nascent MHK industry will be increased by leveraging the experience gained and lessons learned in wind energy, through the national laboratories

Impact of Project:

- Decreased risks for future device deployments
- Faster path to device commercialization
- Inform international standards

This project aligns with the following DOE Program objectives and priorities

- Advance the state of MHK technology

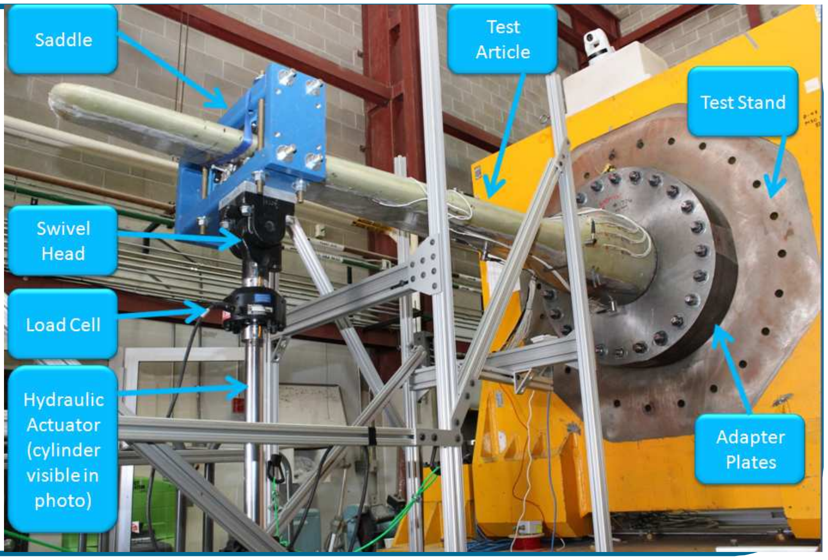
Technical Approach: General

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

- National laboratory support of DOE funded MHK projects
- Bring experience and lessons learned in wind energy development to reduce risk and increase probability of success of MHK technology development
  - Design review and guidance
  - Modeling and analysis
  - Component, sub-system, and materials testing
  - Open-water testing/Measurement/Monitoring

Verdant Power

- Develop extreme and fatigue equivalent loads from FAST model
- Develop test setup and load matrix to simulate extreme and fatigue conditions
- Adapt and apply test methods used for wind turbine blades (IEC 61400-23) to MHK blade



Ocean Renewable Power Corporation

- Design review utilized experts in structural design, wind turbine design and operation, marine instrumentation, generators, fluid mechanics, array optimization, and wind turbine SCADA and "field" testing expertise to provide guidance and feedback on system refinement

Verdant Power

- Completed flapwise fatigue and extreme static strength testing, including extreme tide events and 20-year accelerated lifetime loading of next-gen blade
- Structural testing and Modal characterization were used to validate the new blade design, and demonstrated a development pathway for larger rotors and faster flows
- Testing was used as a go/no-go strength and durability validation of the pre-production composite blades that were used for subsequent in-water testing at the Verdant RITE site

Ocean Renewable Power Corporation

- Collaborated with Sandia National Laboratories to complete design review of the TidGen™ system that identified key areas for system refinement
- Review findings, along with subsequent observations from open-water testing, are directly informing ORPC's product development efforts and national laboratory support


Ocean Renewable Power Company

Design, Deployment and Test Plan Review Report

v 2.0 Final

July 20, 2013

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number 1.1.5	
Project Number	
Agreement Number 21779	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: MHK Industry Support												
Verdant Power- Blade Testing												
Q1 FY12 Milestone: Develop static and fatigue testing plans												
Q2 FY12 Milestone: Complete fatigue testing												
Q3 FY12 Milestone: Deliver test report												
TDB FY14 Milestone: Develop blade test plan for additional testing												
TDB FY14 Milestone: Receive test article												
TDB FY14 Milestone: Complete blade testing												
Ocean Renewable Power Corporation												
Q1 FY12 Milestone: Initiate discussions with OPT to determine priority collaborative projects												
Q4 FY12 Milestone: Complete design review of TidGen™ system												
Q1 FY13 Milestone: Complete TidGen™ design review report												
Q3 FY13 Milestone: Update Cooperative Research and Development Agreement (CRADA) to contain refined list of priority collaborative activities												
Q4 FY13 Milestone: Explore feasibility of specific TidGen™ on-device measurements												
Q1 FY14 Milestone: Complete composite joint design meeting and report												
Q2 FY14 Milestone: Conduct FMEA of TidGen™ system												
Q4 FY14 Milestone: Submit summary report of ORPC SCADA and instrumentation support to DOE												
Ocean Power Technologies												
Q1 FY12 Milestone: Initiate discussions with OPT to determine priority collaborative projects												
Q3 FY13 Milestone: Establish Cooperative Research and Development Agreement (CRADA)												
Q3 FY14 Milestone: Complete draft report on power-take-off priority test objectives												
Q4 FY14 Milestone: Complete power-take-off effort- deliver summary report												
Q4 FY14 Milestone: Complete optimization support efforts and deliver summary report												
Verdant Power- Power Performance Certification Testing												
Q2 FY14 Milestone: Complete draft test plan for power performance certification testing												
Q3 FY14 Milestone: Complete design of instrumentation and data acquisition system												

Comments

- Verdant Blade Testing – FY14 schedule dependent on Verdant plans and schedule, TBD
- ORPC – Identification of priority projects took longer than originally anticipated
- OPT – Identification of priority projects and establishment of CRADA took longer than originally anticipated
- Verdant Power Performance Testing – to be performed in FY15

Project Budget

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$495k	n/a	$622k	n/a	$876k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY 2012	Funds spent by end of FY 2013	Spend Plan FY14
$123k	$96k	$657k

- FY14 project costs as of December 31st are $25k
- Verdant blade testing funded by Funds-in Cooperative Research and Development Agreement (CRADA) $102k
- Spending has been on track given DOE guidance of preserving 25% of funds for carryover

Partners, Subcontractors, and Collaborators:

Verdant Power

- Sandia National Laboratories – collaborators in development of blade FEA model to assess strain distribution and modal characteristics

Ocean Renewable Power Corporation

- Sandia National Laboratories – partners in design review

Communications and Technology Transfer:

- Proprietary and confidential projects directly support the development of specific MHK technologies
- Inform development of MHK blade testing methodologies and standards
- Inform general research planning

Next Steps and Future Research

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

FY14/Current research:

Verdant Power Blade Testing *[Note: Dependent on discussions with, and funding, from Verdant Power.]*

- Full complement of static and fatigue test load cases for a production Verdant Turbine composite blade
- Potential for utilization of environmental conditioning
- Schedule TDB: to be established based on delivery schedule of the test blade and the scope of testing

Verdant Power Performance Certification Testing

- Collaborate with Verdant to collect power performance certification data, per IEC 62600-200 TS, on an operating turbine deployed at their Roosevelt Island site
- Provide feedback to IEC TC114 through Ad Hoc Group #4
- FY14: Complete test plan and instrumentation and data acquisition system development
- FY15: Complete Power Performance Certification testing

Next Steps and Future Research

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

FY14/Current research:

Ocean Renewable Power Corporation

- Support design improvement through in-depth analysis and support of areas identified in design review and test deployments
- NREL to focus on supporting composite structure joint design improvement and a system Failure Modes and Effects Analysis (FMEA)
- Composite joint and FMEA tasks to be completed by end of FY14
- Sandia will collaborate on above efforts, along with supporting additional ORPC activities *(see Sandia presentation)*

Ocean Power Technologies

- Utilize numerical modeling, CFD and WEC-Sim Simulations to support PowerBuoy optimization
- Define priority power-take-off (PTO) laboratory testing objectives, relevant testing requirements, and assess potential testing approaches
- Optimization and PTO tasks to be completed by end of FY14

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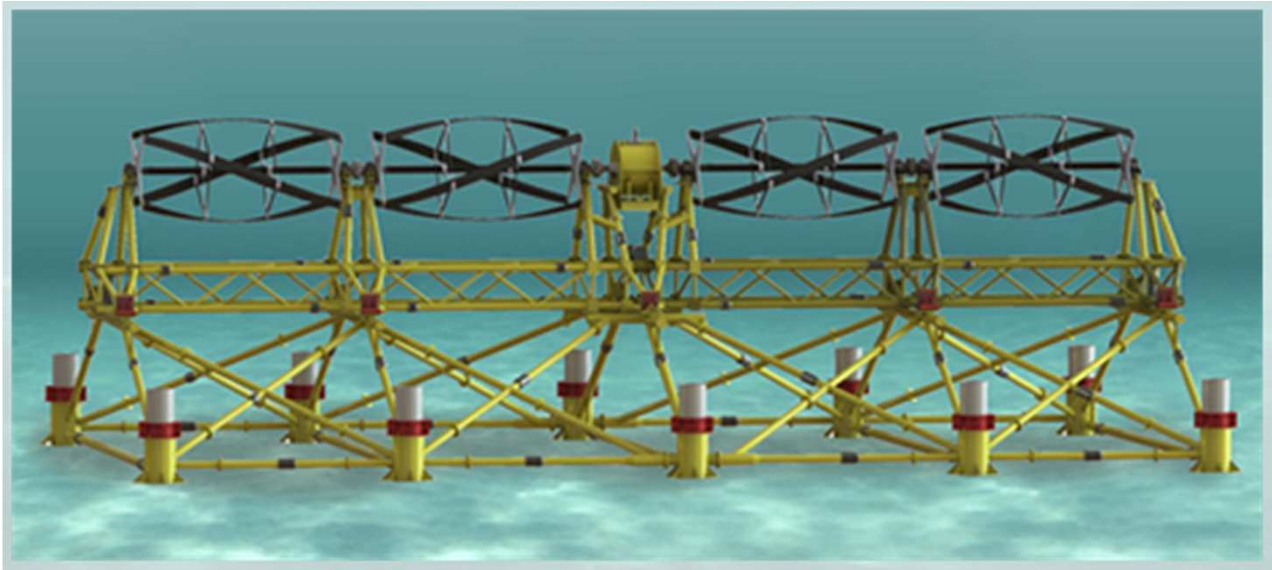
Proposed future research:

Support MHK technology development projects in relevant areas of national laboratory expertise to reduce risks and increase projects' probability of success:

- Design review and guidance
- Modeling and analysis
- Component, subsystem, and materials testing
- Open-water testing/Measurement/Monitoring

Water Power Peer Review

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



www.orpc.co

Industry Support: ORPC

Technical Support of Marine & Hydrokinetic Technology Industry Solicitation

Vincent Neary

Sandia National Laboratories

vsneary@sandia.gov | 505 284 2199

January 25, 2014

Purpose & Objectives

Problem Statement: To advance marine hydrokinetic (MHK) system development by leveraging DOE R&D investments in wind energy

Impact of Project:

Increase the probability of success for DOE FOA Awardee (ORPC) devices

Reduce LCOE through improved power performance and structural reliability of single device and entire array

This project aligns with the following DOE Program objectives and priorities: Advance the state of MHK technology: 1) Demonstrate leading US technology; 2) Drive innovation by developing next generation system that is cost effective; 3) Improve understanding through advanced instrumentation.

- **Leverage National Laboratory experience:** NREL and SNL have institutional knowledge and tools transferrable to hydrokinetic turbine technology design and analysis
- **Key contributions:**
  - **Review ORPC plan**: Review ORPC TidGen® design, deployment, and test plan. *Provides independent critique from national laboratory experts to identify needs for design refinement*
  - **CACTUS model**: Apply CACTUS (originally developed for wind applications) to predict power performance curve for TidGen™ turbine. *Provides benchmark for evaluating the hydrodynamic performance of improvements and alternative designs*
  - **Design-space search**: Apply CACTUS for design-space search to further optimize design. *Informs ORPC of possible design changes that can improve performance of their device*

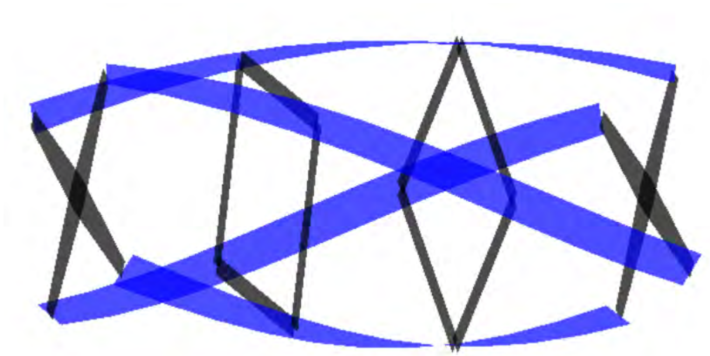
Technical Approach

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

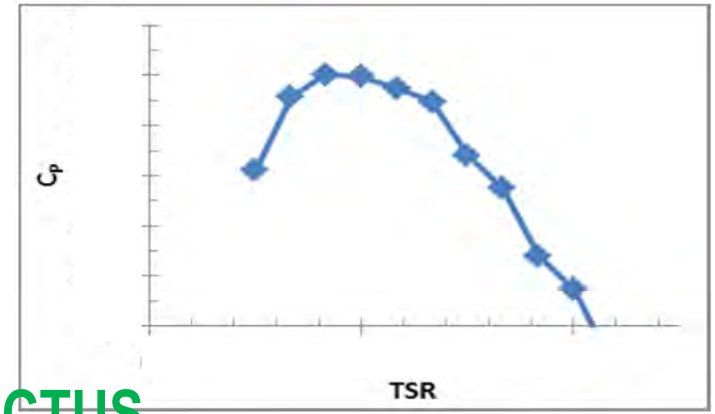
- **Key contributions:**
  - **Structural analysis**: Perform detailed structural analysis of blade interconnections (joints). *Provides insight on structural failures encountered by ORPC*
  - **Blade instrumentation**: Develop conceptual design for FBG sensor system for Cobscook Bay field measurement campaign. Perform experimental tests to investigate strategy for attaching FBG strain sensors onto hydrokinetic blade surfaces subject to sea water environment. *FBG sensors provide direct measurement of the blade structural dynamic characteristics and performance*
  - **Array Optimization**: Apply SNL-EFDC model for array optimization at site. *Provides guidance to ORPC on placement and layout of multiple unit array*

- **Review of ORPC plan:**
  - Extensive critique of ORPC's TidGen™ design
  - Helical blade design difficult to manufacture to design tolerance and expensive compared to straight blade design
  - Mid-strut drag may reduce performance
- **CACTUS model:**
  - CACTUS model applied to predict performance curves for TidGen®

TidGen® Rotor



Power Performance



Leveraged past DOE investments in CACTUS

Accomplishments and Progress

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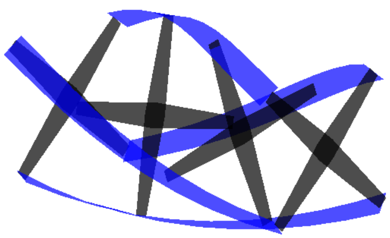
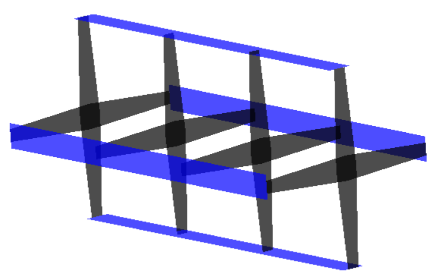
- **Design-space search:**
  - Blade design parameters
    - shape (straight vs. helical)
    - number of struts
    - solidity (number of blades and chord-to-radius)
  - Results for blade shape: Very similar power performance but verifying effects on cyclical loading

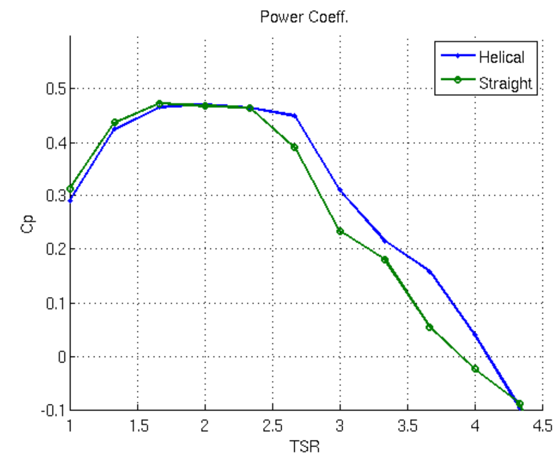
TidGen®



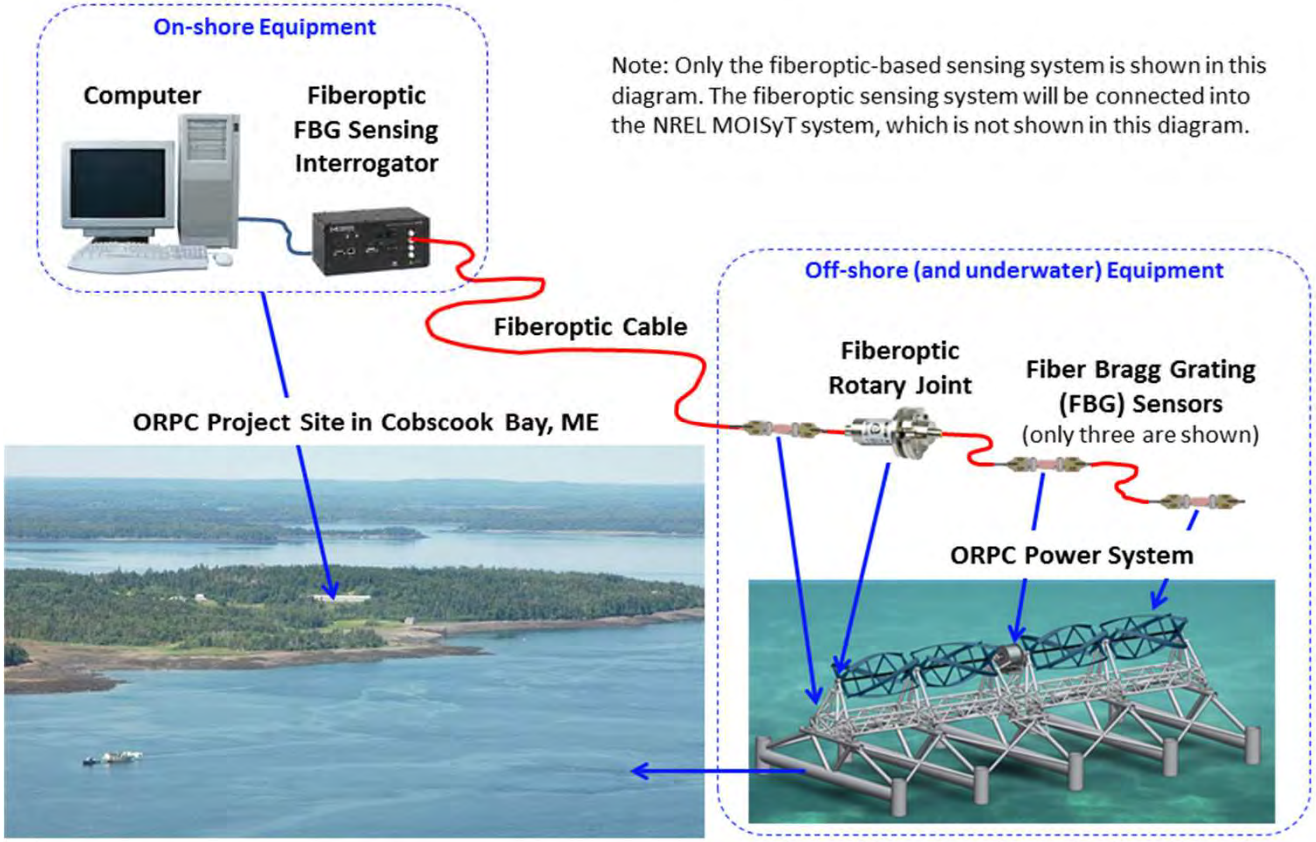
Straight-Bladed Design



Power Performance



- Blade instrumentation:
  - SNL developed conceptual design of fiber Bragg grating (FBG) system for measuring blade structural response

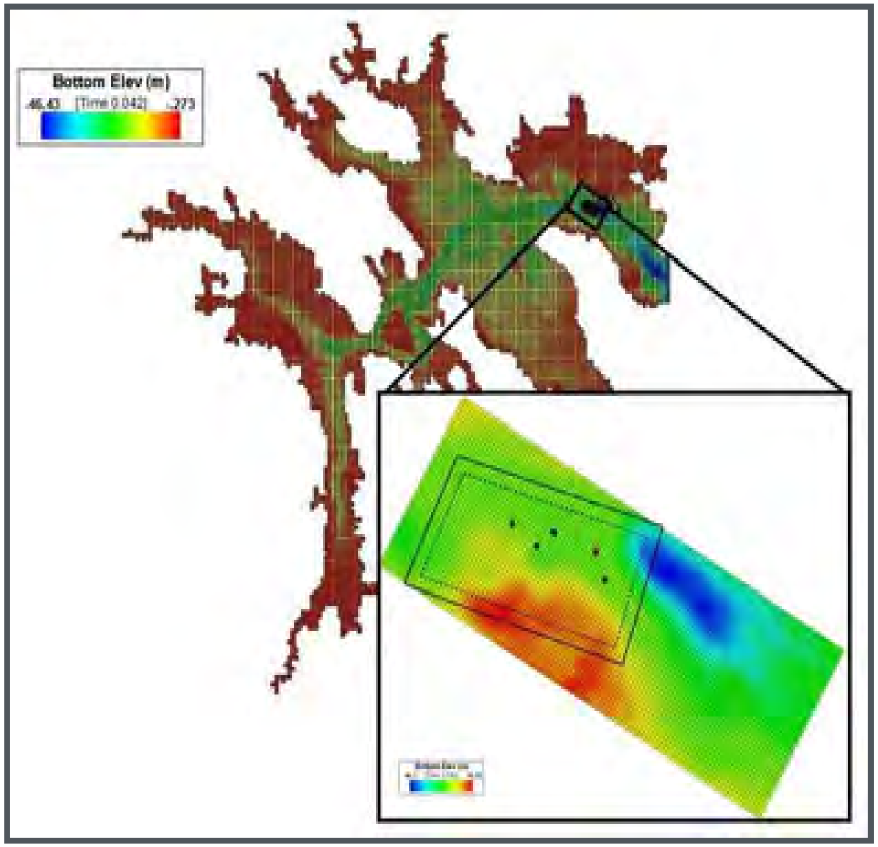


FBG System Design

FBG Sensor

DOE wind experience used to design system for blade response measurements

- Array Optimization:
  - Array optimization for 5 devices using SNL-EFDC
  - Increased energy production over the ORPC baseline by about 18%, or almost 20 MWh of additional energy production in one month
  - These results show critical importance of using hydrodynamic models, like SNL-EFDC, to maximize energy extraction



ORPC 5-unit array, Cobscook Bay

Leveraged past DOE investments in SNL-EFDC

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	1.1 (FY12) | 1.1.5 (FY13) | 1.2.3.1
Project Number	
Agreement Number	21959

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Technical Support of Marine & Hydrokinetic Technology Industry Solicitation												
FY12Q1 Scoping meeting with ORPC												
FY12Q2 Allocation of lab support funds												
FY12Q3 Technical design review of one TRL7/8 awardee project												
FY12Q4 Assesment of potential further lab support												
FY13Q1 Milestone: Report on review of the ORPC design, deployment, test plan												

Comments:

- Project FY12 - FY14
- Identification of priority projects took longer than originally anticipated

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$343,381	N/A	$510,436	N/A	$645,950	N/A

Figures include Carryover

Project Spending		
FY2012	FY2013	FY2014 (as of Q1)
$82,945	$164,487	$53,434

- Budget shows total FY funding with carry-over

CRADA completion and identification of priority projects took significantly longer than anticipated

Partners, Subcontractors, and Collaborators: ORPC, NREL, Montana State University, Micron Optics Inc., SEA Engineering

Communications and Technology Transfer:

- Open-source code available at CACTUS collaboration web site (http://energy.sandia.gov/cactus). Just launched December 2013.
- DOE Project newsletter, December 2013, "CACTUS coupled with DAKOTA for Design-Space Studies and Optimization"
- Michelen et al. (2013), CACTUS Open Source Code for Hydrokinetic Turbine Design and Analysis: Model Performance Evaluation and Public Dissemination as Open Source Design Tool, *Marine Energy Technology Symposium, 7th Annual Global Marine Renewable Energy Conference*, Seattle, Washington, April 15-18, 2014
- HPC Resources available to ORPC numerical modelers and collaborators, including ARL-Penn State, Stevens Institute of Technology and MIT

Next Steps and Future Research

FY14/Current research:

- Structural analysis of entire rotor, with focus on joints
- Detailed analysis of current design, including hydrodynamic and structural modeling, to improve joint design
- Provide alternative rotor design that enhances performance and reduces manufacturing complexity and cost
- SNL will support NREL in FMEA

Proposed future research:

- If ORPC is interested in pursuing an alternative design, an LCOE analysis is recommended to evaluate economical performance as well as hydro-structural performance

- High-fidelity CFD modeling with strongly coupled fluid-structure-interaction (FSI) can further improve performance and reduced costs

Water Power Peer Review

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

New: Performance Testing for Hydrokinetic Canal Effects

Vincent Neary

Sandia National Laboratories

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February 27, 2014

Problem Statement: Hydrokinetic (HK) electricity generation from canals shows potential to support local electricity needs with minimal regulatory or capital investment vs. conventional hydropower. However,

- Effects of HK deployment on water operations in canals not well understood
- No experience full-scale *in-situ* testing of HK devices in canals

Impact of Project:

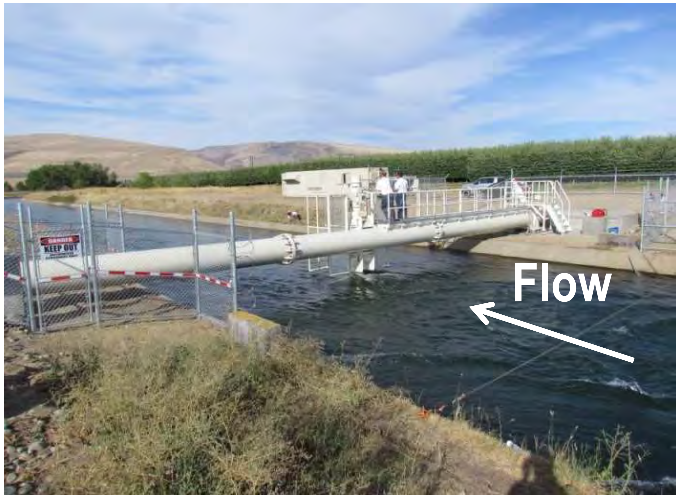
- Enable stakeholders to accurately quantify HK turbine performance and effects on water operations in canals
- Product: Best practice manuals for HK device performance characterization and quantifying effects to water operations

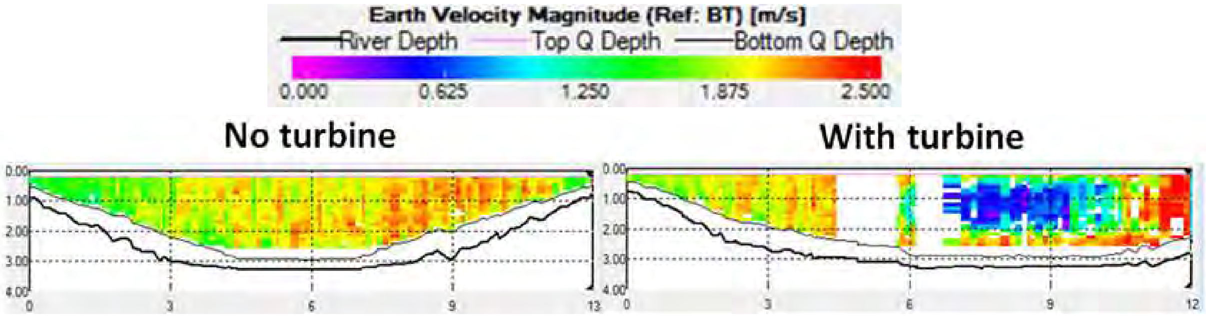
This project aligns with the following DOE Program objectives and priorities:

- Advance the state of MHK technology for canal deployment
- Develop key MHK testing infrastructure, instrumentation
- Reduce deployment barriers and environmental impacts of MHK technologies

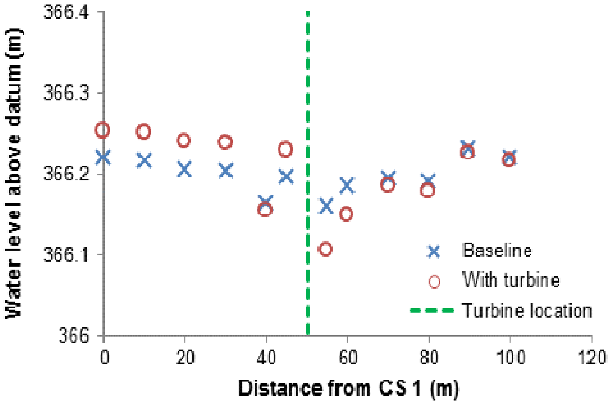
Performance testing and analysis

- Field measurements
  - Water levels
  - Inflow and wake velocities
  - Turbulence
  - Thrust and torque (if feasible)
- Analysis of all flow field measurements around device
- Develop performance curves
- Measurement of uncertainty quantification and propagation





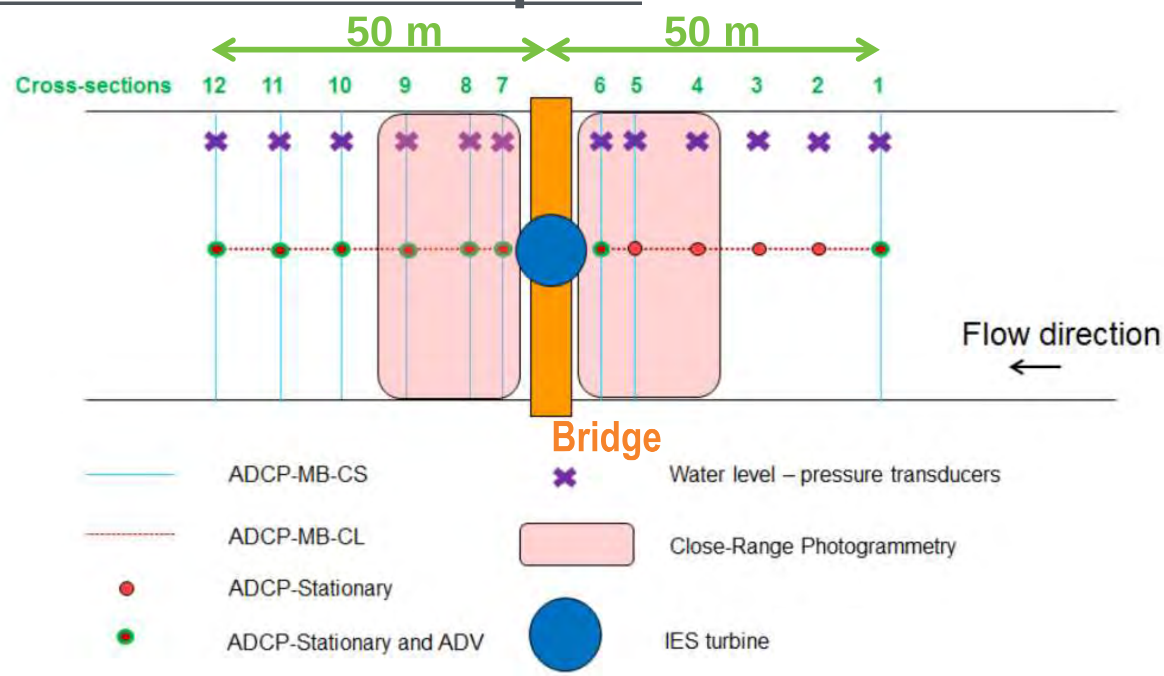
Velocity magnitude downstream turbine (ADCP)

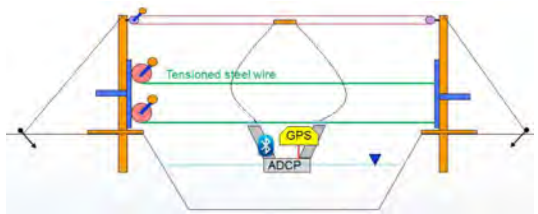


Water level differences along canal

Leveraged DOE R&D investments in scaled-device flume testing

Measurement test plan

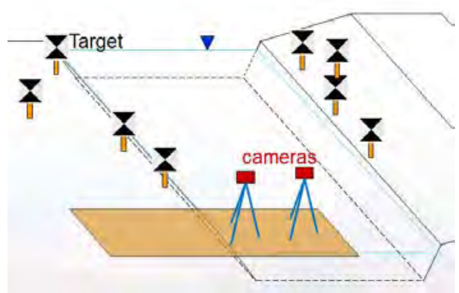




ADCP and ADV cableway system

Bridge-mounted ADV

Comprehensive and integrated suite of measurement to accurately characterize turbine performance and effects on water operations

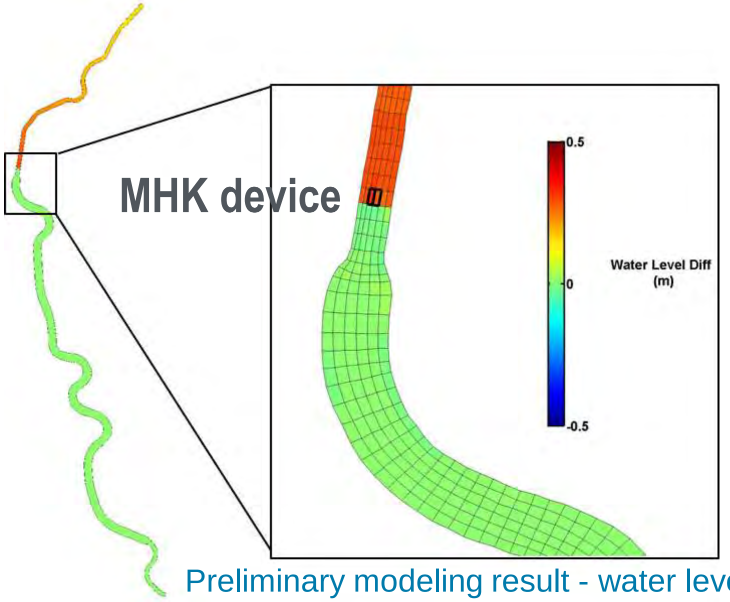


Close-range photogrammetry (CRP)

Effects of energy losses on water operations

- Model the baseline (without turbine) condition for benchmark
- Model the effect of energy extraction by a single turbine and validate with measurements
- Model the effect of energy extraction by multiple turbines, with different arrangements

Study site



Preliminary modeling result - water level (with turbine – baseline

Determine relationship between array configuration, density, and effects to water operations - opportunity to validate SNL-EFDC at high Re and Fr values

Summary	Legend
WBS Number or Agreement Number 1.7.2.1	Work completed
Project Number 21865	Active Task
Agreement Number 26507	Milestones & Deliverables (Original Plan
	Milestones & Deliverables (Actual)

	FY2013	FY2014			
Task / Event	Q4 (Jul - Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Tidal Device Field Measurement Campaign to Validate Tools					
Q4 Milestone: Test field measurement; initial SNL-EFDC model development					
Q1 Milestone: Complete draft test plan for performance characterization field work and device effect on water operations					
Q2 Milestone: Finalilze test plan for performance characterization field work and device effect on water operations					
Q3 Milestone: Field measurement campaign at Roza Canal, Yakima, WA; submit preliminary report to DOE					
Q4 Milestone: Field measurement campaign at Roza Canal, Yakima, WA (cont.); submit year-end report to DOE					

Comments

- Project initiated summer 2013
- Actual field measurements scheduled for FY2014 Q3/Q4
- Planned completion date FY2015 Q2

All work is progressing according to plan

Project Budget

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

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$900,000	-	$0	-

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent as of Dec 31, 2013	Spend Plan FY14
$136K	$672K

- Received $900k at the end of FY13 for 18 month effort
- Spending will ramp-up during field testing, March-September 2014

Project spending is on schedule

Partners, Subcontractors, and Collaborators:

Government Agency:

- US Bureau of Reclamation (Site owner, responsible for the water level measurement using pressure transducers)

Industry:

- Instream Energy System (Technology owner and operator)

Sub-contractors:

- Sea Engineering (Numerical modeling support)
- Local contractor (TBD, support sensor deployment and retrieval)

Communications and Technology Transfer:

1. Data at SNL's *MHK Technology* SharePoint site or Energy.data.gov,
2. Topical SNL project reports at SNL's Water Power Publications website, http://energy.sandia.gov/?page_id=834
3. Selected project results disseminated at national and international conferences
   a. Gunawan, B., Neary, V.S., Dallman, A., McWilliams, S., Roberts, J. and Jones, C. (2014) Numerical investigation of effects of hydrokinetic turbine deployment on water operations in an irrigation canal in Yakima, WA. Marine Energy Technology Symposium 2014 (METS2014), Seattle, WA, April 15-17.
   b. 5th International Conference on Ocean Energy, November 2014
4. Peer reviewed journal publication submitted Q3, FY15: *Journal of Hydraulic Engineering* or *Renewable Energy*

Next Steps and Future Research

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

FY14 and FY15 research plans

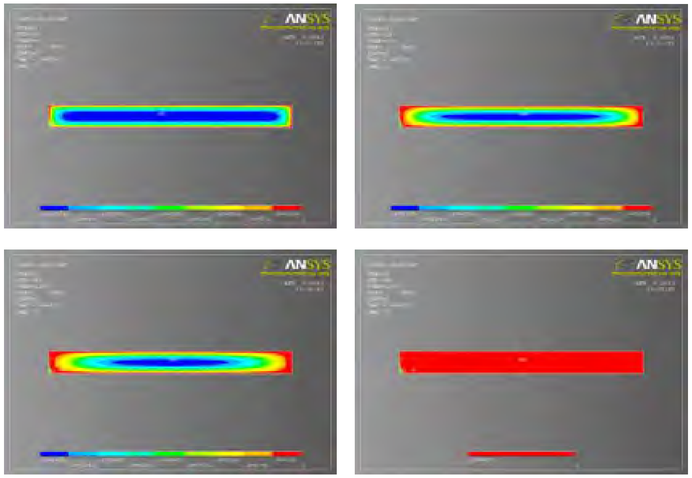
1. **FY14 Q2:** Finalize experimental test design in collaboration with USBR and IES; Build instrument deployment systems
2. **FY14 Q3/Q4:** Conduct field measurement campaigns; Post-process and analyze data; Perform SNL-EFDC modeling
3. **FY15 Q1:** Continue data analysis and SNL-EFDC modeling; Complete analysis on HK device performance characterization and HK device effects on water operations
4. **FY15 Q2:** Complete best practices guidance manual for HK device performance characterization and HK device effects on water operations (version 1)

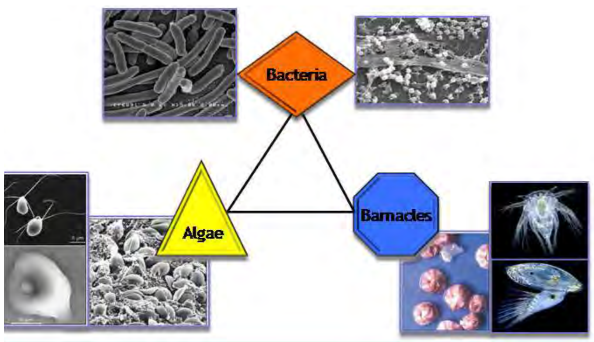
Future Research

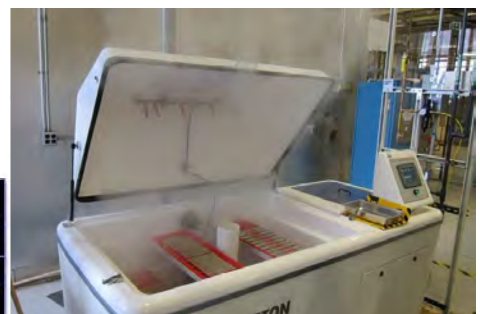
Field measurement campaign around multiple devices

Water Power Peer Review

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







Materials & Coatings + Manufacture Reliability

Bernadette A. Hernandez-Sanchez

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February , 2014

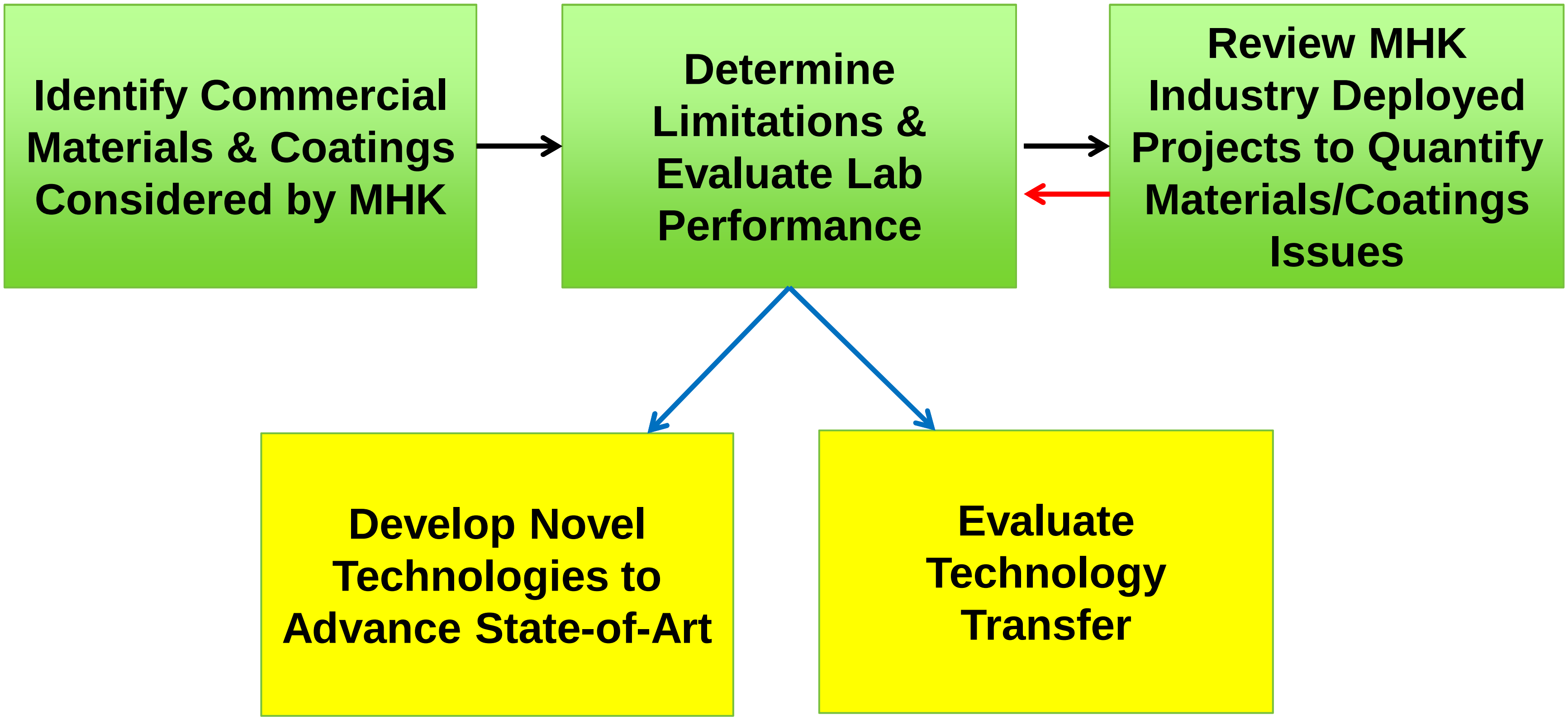
Problem Statement: Materials & Coatings are not performing to industry expectations during deployment investigations. Novel solutions are needed to overcome barriers caused by commercial materials & coatings failures resulting from: environmental degradation; component materials reliability; environmental impact (toxicity).

Impact of Project: Advanced Materials program provides solutions based on: (1) Leveraging wind structural composites for MHK, (2) quantifying commercial materials/coatings for manufacturing efficacy, (3) development of MHK specific coatings & materials.

This project aligns with the following DOE Program objectives and priorities:

- **Advance the state of MHK technology** (improve O&M, reliability, advance manufacture)
- Develop key MHK testing infrastructure, instrumentation, and/or standards (materials & coatings properties can impact on validity of structural health measurements by sensors, etc.)
- Characterize and increase access to high resource sites (materials properties impact structural response model outcomes)
- Reduce deployment barriers and environmental impacts of MHK technologies (develop environmentally benign coatings)

Technical Approach



MHK Specific Coatings & Materials Development Testing Performance

Leverage DOE Wind & Materials Capabilities

Technical Approach

Industrial Guidance | **Technology Transfer** | **Novel Materials & Coatings**

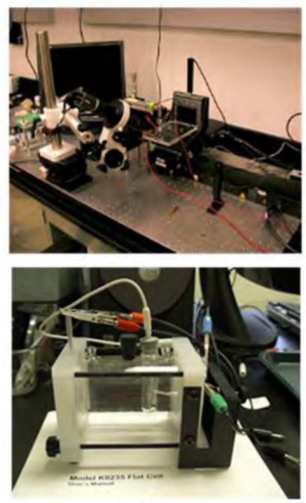
Novel Coatings Synthesis

SNL, BYU

Biofouling Testing

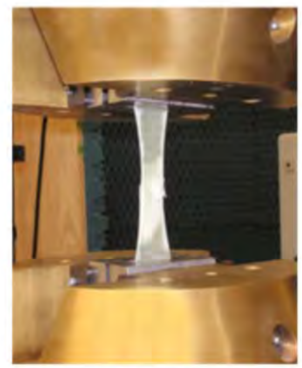
SNL, NDSU

Corrosion/Reliability Testing



SNL

Composite Fabrication & Performance Testing



SNL, MSU

Environmental Monitoring

ORNL

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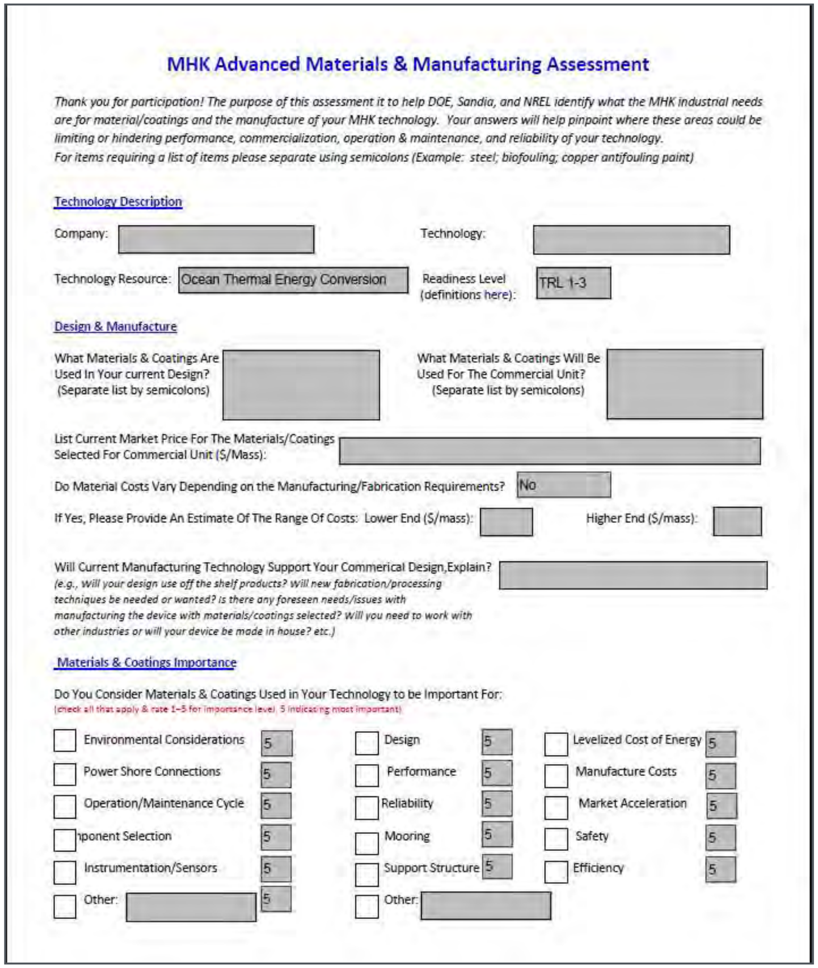
Industrial Review Materials & Coatings Issues:

- Sandia has interacted with both MHK developers & other industries that could support the manufacture of MHK technology. Depending on the developer's technology readiness level (TRL), different materials and coatings issues have been reported.



MHK Advanced Materials & Manufacturing Assessment

Thank you for participation! The purpose of this assessment it to help DOE, Sandia, and NREL identify what the MHK industrial needs are for material/coatings and the manufacture of your MHK technology. Your answers will help pinpoint where these areas could be limiting or hindering performance, commercialization, operation & maintenance, and reliability of your technology.
For items requiring a list of items please separate using semicolons (Example: steel; biofouling; copper antifouling paint)

Technology Description

Company: Technology:

Technology Resource: Ocean Thermal Energy Conversion Readiness Level (definitions here): TRL 1-3

Design & Manufacture

What Materials & Coatings Are Used In Your current Design? (Separate list by semicolons)

What Materials & Coatings Will Be Used For The Commercial Unit? (Separate list by semicolons)

List Current Market Price For The Materials/Coatings Selected For Commercial Unit ($/Mass):

Do Material Costs Vary Depending on the Manufacturing/Fabrication Requirements? No

If Yes, Please Provide An Estimate Of The Range Of Costs: Lower End ($/mass): Higher End ($/mass):

Will Current Manufacturing Technology Support Your Commerical Design,Explain?
(e.g., Will your design use off the shelf products? Will new fabrication/processing techniques be needed or wanted? Is there any foreseen needs/issues with manufacturing the device with materials/coatings selected? Will you need to work with other industries or will your device be made in house? etc.)

Materials & Coatings Importance

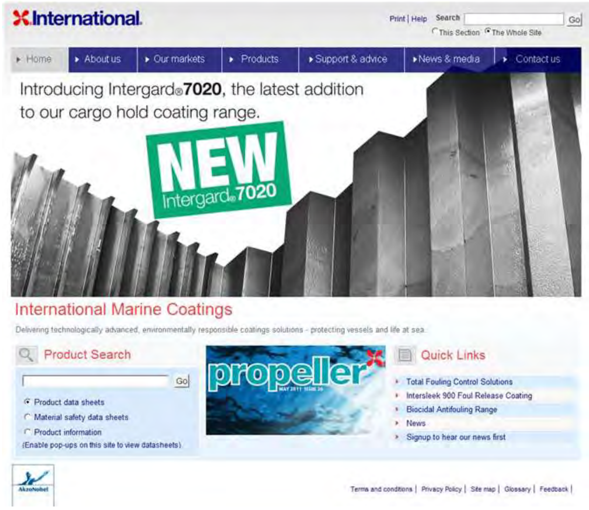
Do You Consider Materials & Coatings Used in Your Technology to be Important For:
(check all that apply & rate 1–5 for importance level, 5 indicating most important)

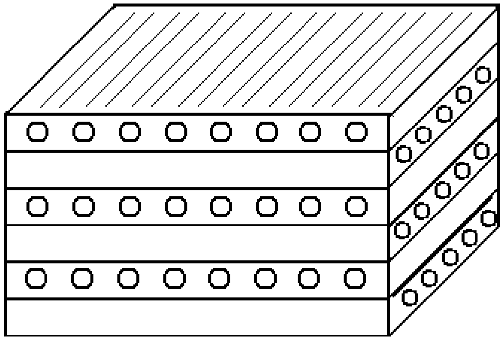
☐ Environmental Considerations	5	☐ Design	5	☐ Levelized Cost of Energy	5
☐ Power Shore Connections	5	☐ Performance	5	☐ Manufacture Costs	5
☐ Operation/Maintenance Cycle	5	☐ Reliability	5	☐ Market Acceleration	5
☐ nponent Selection	5	☐ Mooring	5	☐ Safety	5
☐ Instrumentation/Sensors	5	☐ Support Structure	5	☐ Efficiency	5
☐ Other:	5	☐ Other:			

Sandia is helping to quantify materials & coatings impact on operation, maintenance, and reliability.

Evaluation of Commercial Materials & Technology Transfer

- 2 coatings manufacture (***E-paint, International***)
- 3 composites manufactures (***Owens Corning, Hexcel,*** & ***Gurit)***
- MHK materials & coatings used by developers identified

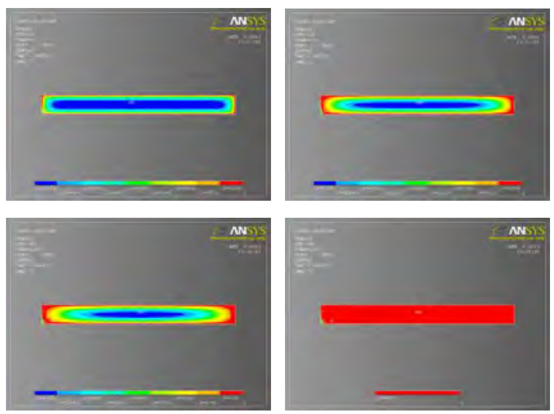


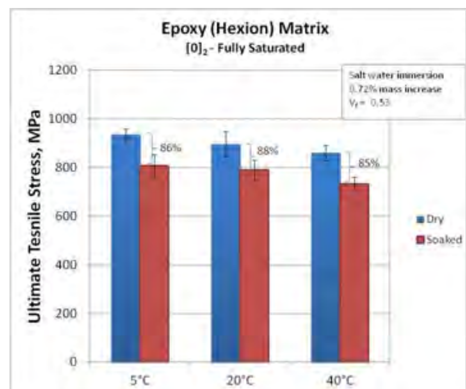


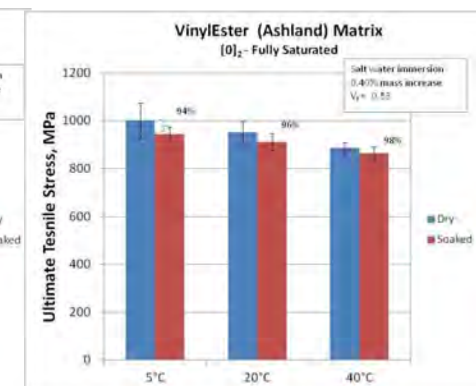
We have developed a database to help provide guidance for the MHK industry.

MHK Composites: Effects of Salt Water on Wind Based Composite

- Explored critical issues for basic blade laminates after sea water conditioning
- Modeled diffusion processes occurring for varied resin systems





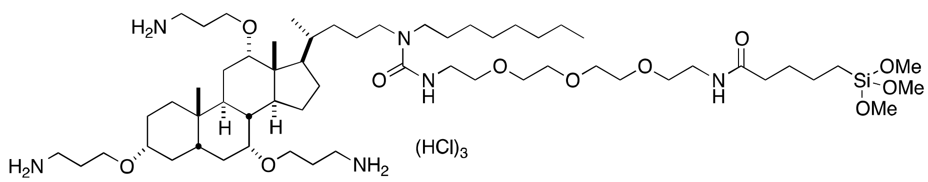


Water Diffusion makes a difference!

Reduction seen in static tensile strength at full saturation.

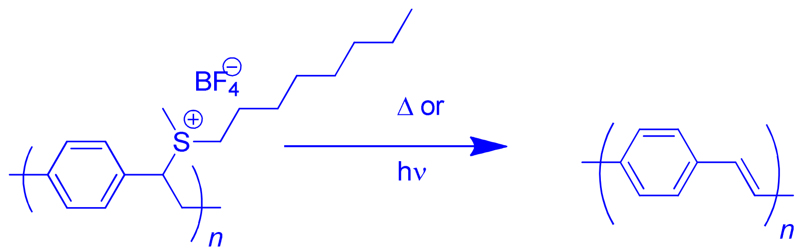
Reduction seen in static compression strength at partial saturation.

Novel Coatings Development:



CSA-121a

Ceragenins (P. Savage)



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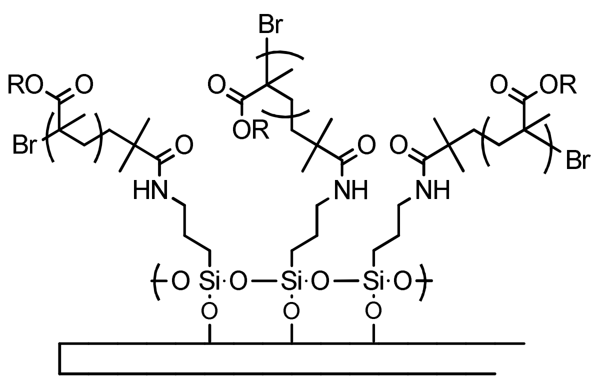
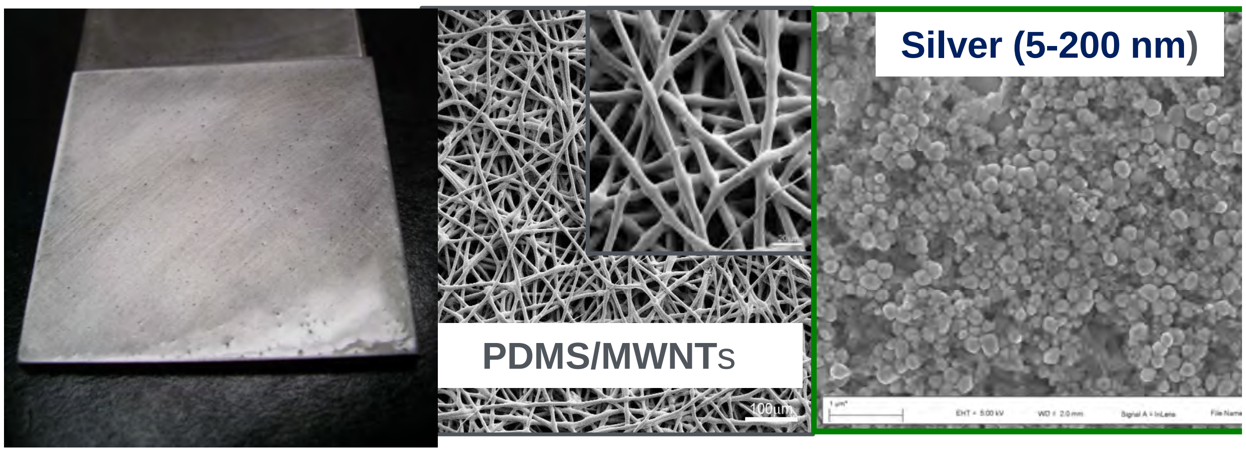
Polysulfonium (S. Dirk)

Zwitterionic (M. Hibbs)



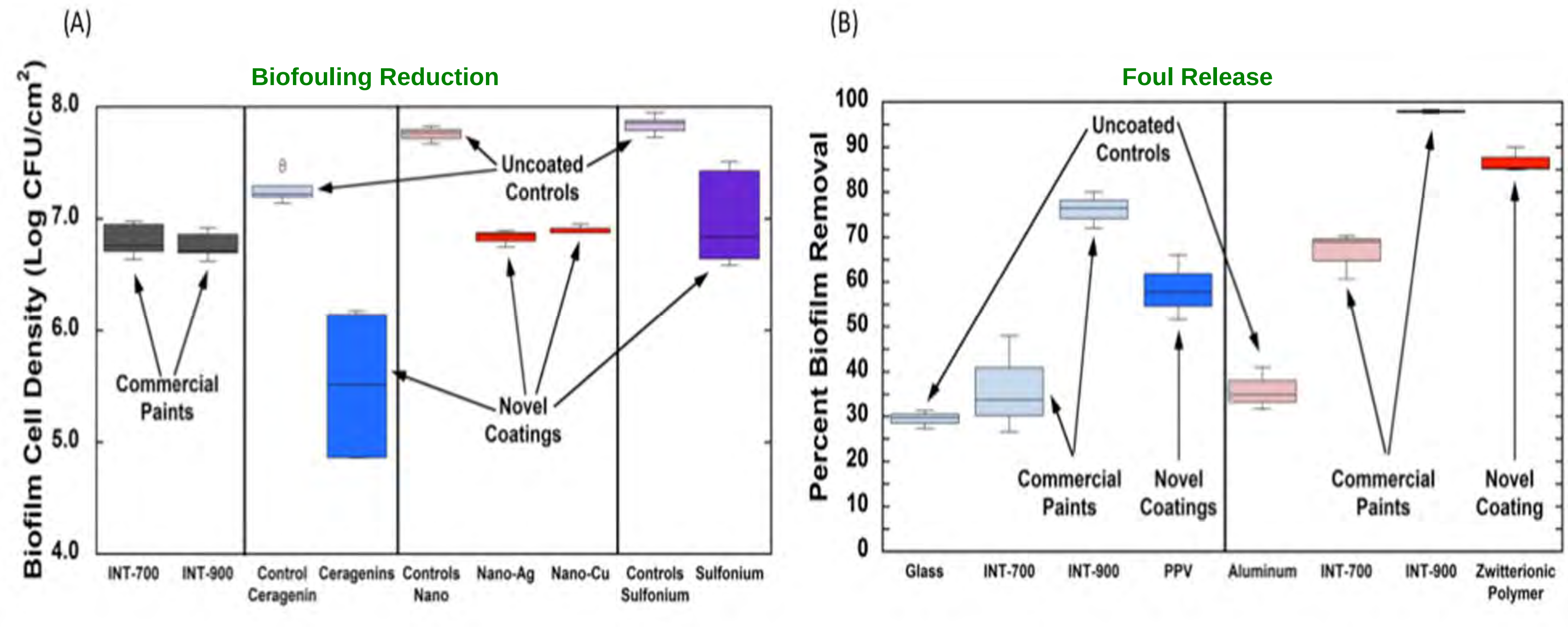
Nanobased Coatings (BAHS & Dirk)



Sandia has developed MHK specific coatings. Advantages: potential broad-spectrum (micro to macro) antifoulants, having low toxicity, and lowered resistance formation.

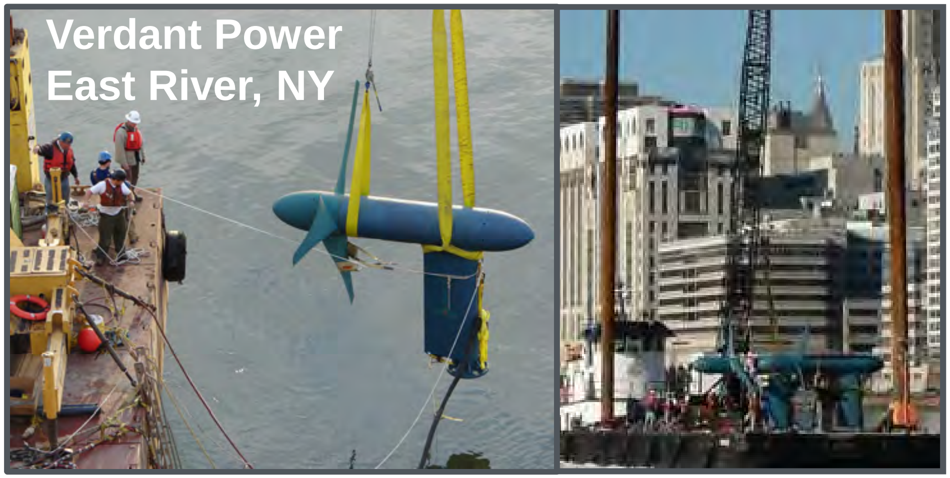
Novel Coatings Development:

Novel Coatings Development: Show Significant Statistical Reduction in Biofouling!

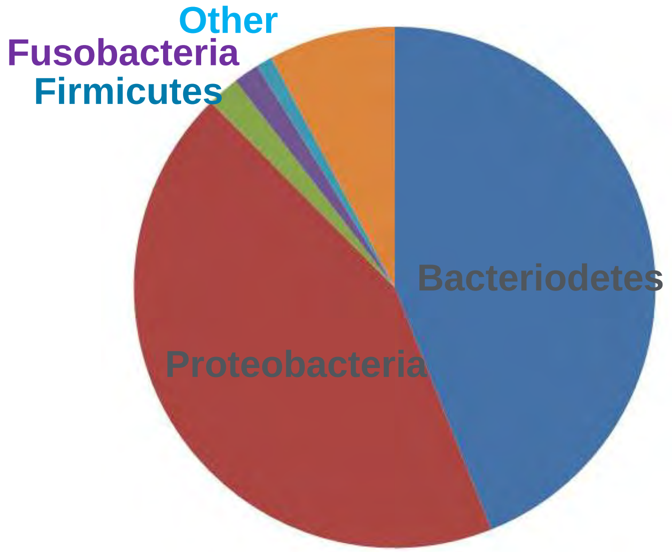


- We have successfully developed coating materials that have shown significant statistical reduction in biofouling!
- ORNL demonstrated no acute toxicity for zwitterionic molecules!

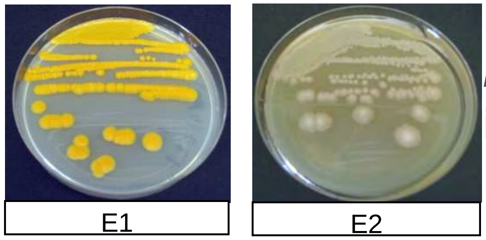
Supporting MHK Industry:



2073 Operational Taxonomic Units Found



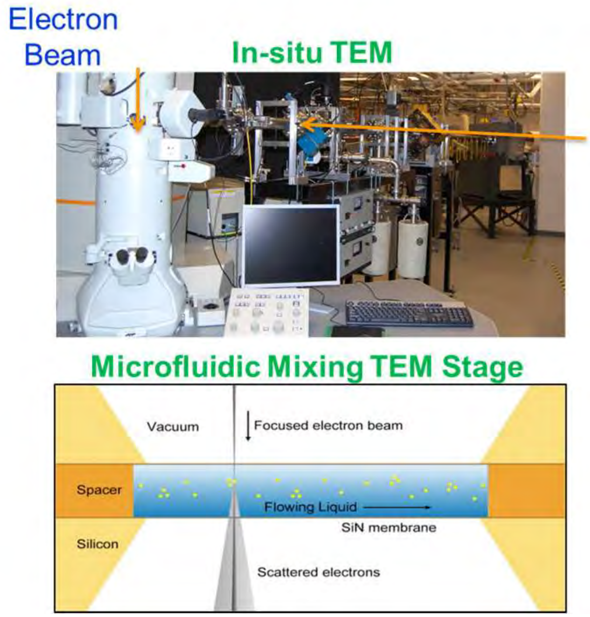
16S rDNA Profiling

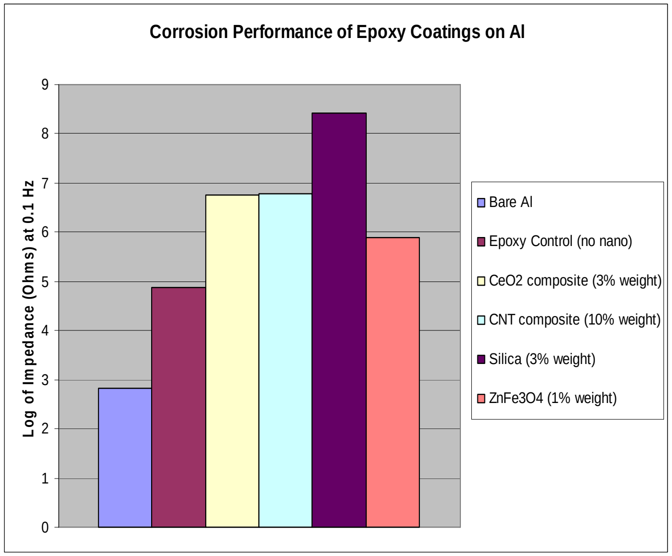


Bacillus sp. **identified**

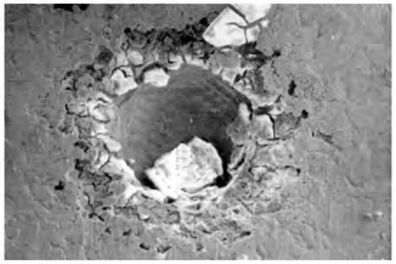
- Identified bacteria in biofilms & water chemistry. Relevant for Verdant to help prevent future fouling.

- Corrosion Evaluations: electrochemical impedance spectroscopy testing performed on novel antifouling and anticorrosion coatings-improved performance.
- Established a new corrosion and biofouling characterization capability *In-Situ Microfluidic Transmission Electron Microscopy* to facilitate novel materials development and fundamental investigations.





A pit caused by biocorrosion can increase by up to 1 cm annually



We developed new capabilities to monitor corrosion & biofouling

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	1.3.4.2
Project Number	20068
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Materials & Coatings+ Manufacturing Reliability												
Q1 Milestone: Literature Search Coatings & Materials												
Q2 Milestone: Coatings Devleopment												
Q4 Milestone: Composites Testing												
Q2 Milestone: Diffusion Studies												
Q3 Milestone: Barnacle Testing of coatings & optimization												
Q4 Milestone: Industrial Reviews began & Surveys initiated												
Current work and future research												
Testing at PNNL-Biofouling												
NDI Test matrix and coupon tests with salt water												
Test matrix for novel sensor-fiber materials												

Comments

- Initiated FY 11 with only literature review & testing in FY12
- Met all milestones and are currently on task for project schedule
- FY14 Q1 slips due to shipping delays for coupons

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$485K	N/A	$650K	N/A	$421K	N/A

- No variance from spend plan for FY12, 13
- High spending rate in FY14 to facilitate testing at PNNL
- **SNL, NSF** Leveraged $20K: External & Internal programs for students support from Sandia's Star Program (high school) & National Science Foundation's Undergraduate Research Experiences (REU) program, Sandia's National Institute of NanoEngineering (NINE) program for undergraduates
- **SNL** : Leveraged $25K Center 06120 Cross Cut Program *Offshore Wind and Water Environmental Composite Material Testing*, PI: Todd Griffith, B. Hernandez-Sanchez, J. Mandell

Partners, Subcontractors, and Collaborators:

Lead Lab: Sandia National Laboratories (Hernandez-Sanchez, Altman, Enos, Dirk, Denton, Hibbs, Hattar), Biofouling Partners: North Dakota State University (Stafslien), Brigham Young University (Savage), Toxicity Partner: Oak Ridge National Laboratories (Greeley), Composites Partners: Montana State University (Miller, Mandel)

Communications and Technology Transfer:

FY 12

- Sandia served as a Hydropower Technical Advisory Board & Topic Champion for the 2012 Materials Challenges in Alternative & Renewable Energy (MCARE).
- 20 Presentations at local and national meetings (AWA, ACS, RGSAM, MCARE).
- Dirk, S. M.; Denton, M. L. B.; Johnson, R. S. Sulfonium-Based Polymeric Biocide, U.S. Provisional Patent Application **2012**.
- Miller D A, Mandell J F, Samborsky D D, Hernandez-Sanchez B A and Griffith D T **2012** Performance of Composite Materials Subjected to Salt Water Environments *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference* Honolulu, Hawaii, April 23–26, AIAA-2012-1575.
- Mandell J F, Samborsky D D and Miller D A **2012** The SNL/MSU/DOE Fatigue of Composite Materials Database: Recent Trends *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference* Honolulu, Hawaii, April 23–26, AIAA-2012-1573.
- MSU and Sandia Water Power Websites (http://energy.sandia.gov/?page_id=834); (http://www.coe.montana.edu/composites/)
- Coatings for the Prevention of Biofouling in Marine Environments, Technical Advance filed on 8/9/11, SD#12087.

FY13

- Hibbs, M., S. J. Altman, H. D. T. Jones, and P. B. Savage (2013), Biofouling-resistant ceragenin-modified materials and structures for water treatment, Patent #8,529,681, p. 36, Sandia Corporation, United States, issued September 10, 2013.
- Hibbs, M., S. J. Altman, H. D. T. Jones, and P. B. Savage (2013), Methods for attaching polymerizable ceragenins to water treatment membranes using silane linkages, Patent #8,530,002, p. 35, Sandia Corporation, United States, issued September 10, 2013.
- 3 Presentations at local and national conferences (GMREC, ACS, MRS, ASM)
- Internal Report: Material & Coatings Industrial Review
- MSU-Master Thesis presented to Mr. Mark Thomas Stoffels “Effects of Tensile Stress on the Moisture Diffusion Characteristics of Epoxy Glass Composites”

Next Steps and Future Research

FY14/Current research

1. Evaluate MHK specific coatings at PNNL-Sequim Bay Facility (lead to tech transfer)
2. Report on non-destructive inspection and determine what specific MHK needs that differ from other industries
3. Explore graphene modified resins to enhance strength and water diffusion
4. Develop novel sensor fibers that can produce signal for NDI equipment

Future Plans

1. **Improve clean energy manufacture, O&M, and reliability through non-destructive inspection (NDI) and defect evaluation specific to MHK .** Explore how marine environment impacts NDI testing results.
2. **Lower cost of O&M, improve reliability, and reduce limitation of commercial FBGs through novel sensor development for structural health monitoring.** Can we develop manufacturing techniques to incorporate novel sensors beyond Fiber Bragg Grating?
3. **Reduce manufacturing carbon composites materials cost and prevent water uptake using alternative modified composites.** Can composite resins be modified to increase strength without using carbon based fibers? Can we manufacture composites that self heal or contain antifouling materials?

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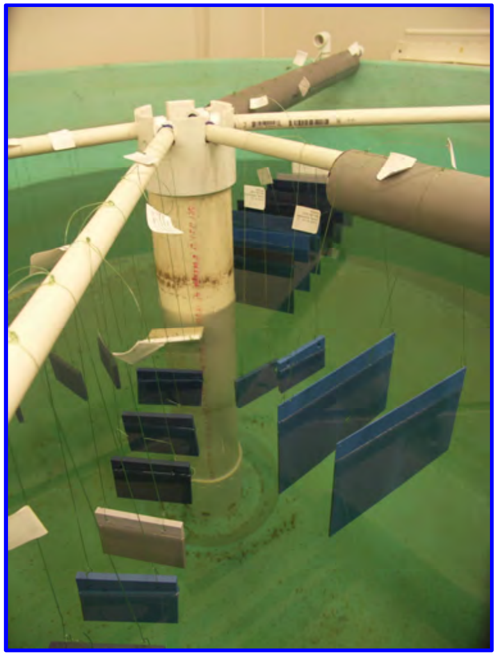
Tunicates (sea squirts) on a dock piling in Sequim, WA

PNNL Marine Sciences Laboratory in Sequim , WA



Controlled antifouling coatings tests in Sequim, WA

New Project: Advanced Materials and Manufacturing Reliability

George Bonheyo, Ph.D.

Pacific Northwest National Laboratory

George.bonheyo@pnnl.gov (360) 681 3678

Feb, 2014

Purpose & Objectives

Problem Statement: Biofouling has the potential to reduce the efficiency of MHK systems while promoting corrosion and reducing safety. To sustain performance, reliability, and reduce operating and maintenance costs, we must identify antifouling coatings that perform for extended periods under the anticipated environmental and operating conditions, are durable when cleaned, and are environmentally benign.

Impact of Project: This project will compare new, experimental antifouling materials against leading commercially available materials. A range of relevant environmental conditions will be used to provide *quantifiable* performance data to select best performers and forecast long term effects. If the coatings work well, this will lead to future durability experiments and work with manufacturers for commercialization

This project aligns with the following DOE Program objectives and priorities Advance the state of MHK Technology

Technical Approach

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Initial 24-72 hour tests in artificial seawater and with single organisms were used by the coatings development labs for an initial down-select of coatings. This study will use 30-180 day tests in natural seawater to further assess and down-select materials.

Real world conditions are likely to entail dynamic environments with variable current speed, which has a major impact on antifouling coating performance

Our tests will be performed using natural seawater in both high and low flow velocity settings. The location of the tests in the Pacific Northwest provides a direct connection to a region identified as a prime site in the resource analysis.

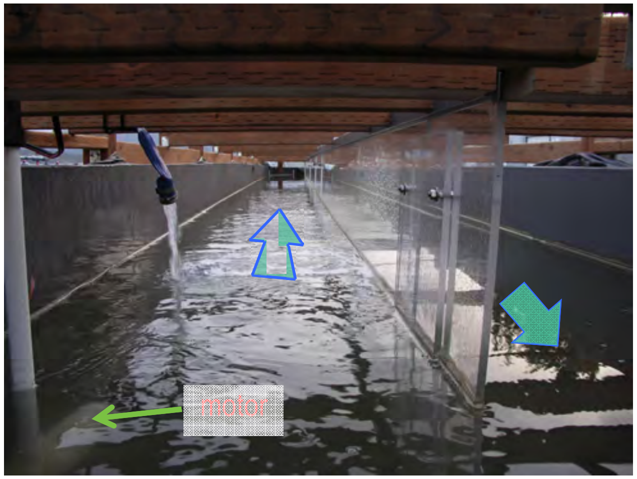
Quantifiable methods of analysis include (novel approaches developed at PNNL in red):

- Total carbon and total organic carbon accumulation
- Visual analyses (ASTM International standards, biomass staining a pixel counting)
- Molecular profiling of species
- Change in mass (partial wet and dry mass)

Note: ASTM methods were designed based upon the shipping industry and rely upon the subjective identification and quantification of organisms observed on a surface; we will supplement with quantitative methods designed to address marine power operating environments

Setup:

- The test tanks are set up and are equilibrating with pumped seawater
  - Diurnal light cycle
  - Ambient temperature and salinity
- Water is continuously replaced in all tanks to prevent toxin buildup
  - Toxicity monitored using Microtox assays
- The tests are designed to directly compare the different antifouling strategies over a range of conditions and will identify strengths, weaknesses, and overall best performers



View inside the high velocity current tank. The tank is 36' long, 5' wide, and approx 30" deep.

Test Matrix

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

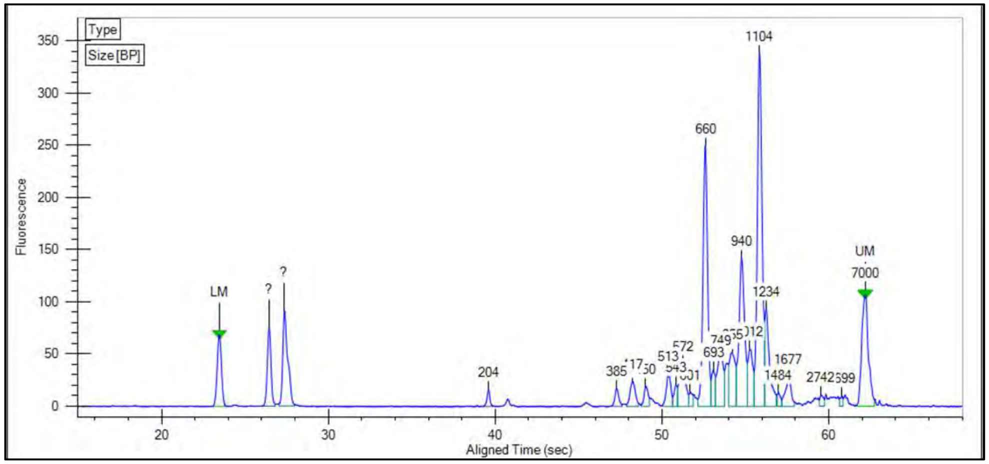
Time point	Static Flow Tank Exposures			High Flow Tank Exposures			Total	Total	Total
	Qty	Size	Test	Qty	Size	Test	1x1"	3x3"	8x8"
30 Day	3	1x1"	TC/TOC	3	1x1"	TC/TOC	6		
	1	3x3"	Weight	1	3x3"	Weight		2	
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1*
60 Day	3	1x1"	TC/TOC	3	1x1"	TC/TOC	6		
	1	3x3"	Weight	1	3x3"	Weight		2	
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1*
90 Day	3	1x1"	TC/TOC	3	1x1"	TC/TOC	6		
	1	3x3"	Weight	1	3x3"	Weight		2	
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1
	1	8x8"	Visual, Species ID	1	8x8"	Visual, Species ID			1*
							18	6	3 or 6

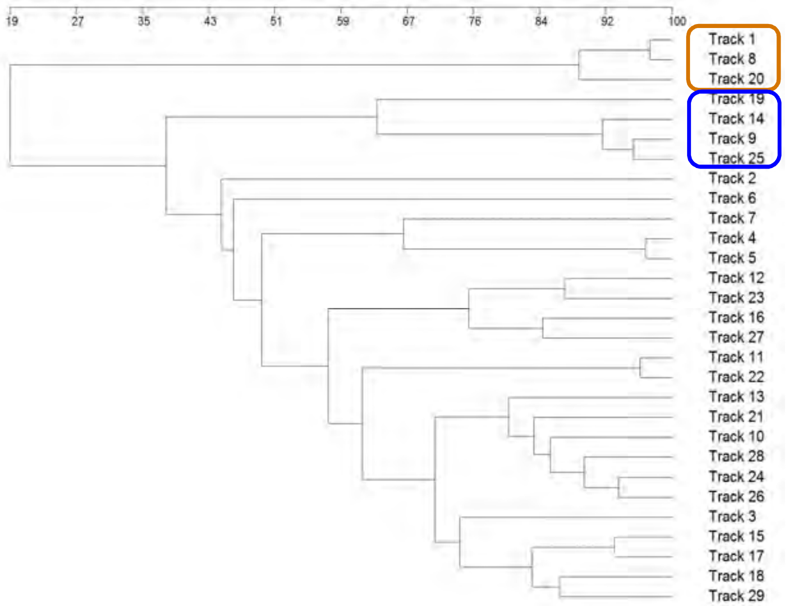
*2nd set of 8x8 coupons if possible to provide backup and greater coverage

- This is the number of coupons needed per coating for 3 time points. There are a significant number of coupons and analyses to be performed.
- This puts backward pressure on the developers to transition the developmental chemistry to production scale

Bioanalyzer Profile of Fouling Organisms

Prokaryotic fouling community on unmodified substrate





We create fouling community profiles (prokaryote and eukaryote) for the water environment and fouling on the different materials, exposure times, and exposure types for all of our projects. This allows us to compare conditions, and treatment effects/effectiveness. Allows us to identify possible benefits or unique problems between projects (e.g., exposures where light is included or excluded)

Bands may be identifiable, those that aren't may be identified.

Cluster analysis allows identification of shared and discriminatory consequences

Project Plan & Schedule

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

Summary	Legend
WBS Number or Agreement Number: 1.2.3.2	Work completed
Project Number	Active Task
CPS Agreement Number: 26497	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2014 Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)				
Project Name: Advanced Materials and Manufacturing Reliability								
Q1 Milestone: Establish test facilities and test plan								
Q2 Milestone: Complete short-term (<60 day) exposures								
Q3 Milestone: Complete second short-term exposures								
Q4 Milestone: Complete long-term (120 day) exposures								
Q4 Milestone: Submit final project report								
Current work and future research								
Current: Allowing test tanks to equilibrate								
Current: Awaiting arrival of samples for testing								
Future: Longer-term exposures, dynamic conditions, open ocean testing								
Future: Corrosion testing								

Comments

- Project original initiation date: 8/28/13; Planned completion date: 9/30/14
- Some revision to test plan anticipated to accommodate delivery of materials
  - Revised exposure plan will use visual analysis of long term set as go/no-go decision for delayed start of short exposure test sets of each material

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$100K		$92,600 (carryover)	

- Spending was a little heavier upfront to establish the high flow velocity "flume"
- Expenditures to date (1/6/2014): $34,549 (36%)
- No other direct funding sources
  - Indirect: PNNL Chemical Imaging Initiative LDRD project ($300k/yr for 3 years) that is developing methods to visualize early stages of biofouling/biofilm development and quantitative methods of analysis

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

- Materials development: Sandia National Laboratory, Brigham Young University, North Dakota State University

Communications and Technology Transfer:

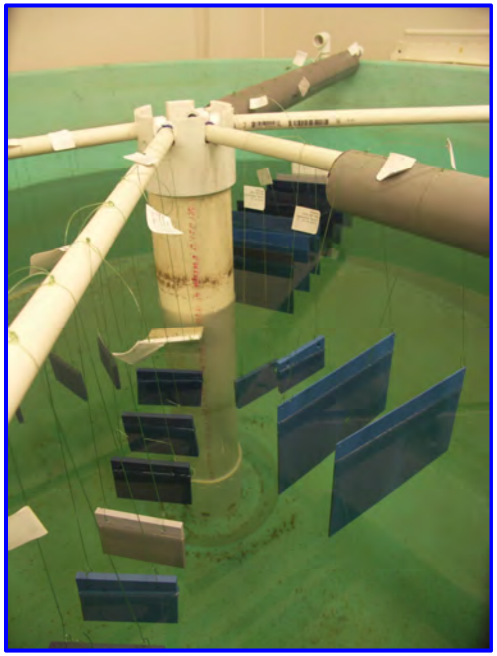
- No information releases yet
- One group meeting hosted at PNNL
- Several web-based live meetings, teleconferences, and email exchanges to discuss project scope, experimental design, and progress
- Planned publications of materials tests, analysis, and comparison in conjunction with partners
  - Target journal: *Biofouling*

Next Steps and Future Research

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

FY14/Current research:

- The start date for exposures will depend upon the arrival of the coupons; a 2 week staggered start period will be used
- Limited time and budget for the study relative to the number of coatings
  - Designed tests and selected high-data-yielding analyses to fit budget
- The test plan was designed to allow the materials providers to make decisions whether or not to modify or submit new materials up to 60 days of exposure
  - Decision points: March through April



Controlled antifouling coatings tests in low current tanks

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

New Project: Reliability and Survivability Risk Assessment Framework

Walt Musial presented by Robert Thresher
NREL
Walter.musial@nrel.gov; 303 384 6956
February 25, 2014

Purpose and Objectives

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

Problem statement: The MHK industry failure track record is not acceptable for future deployments under the DOE Water Power Program and the industry as a whole. This project will develop a risk management framework to improve system reliability and survivability for prototype systems to allow projects to attain their program and commercial objectives.

Impact of project: When utilized, the framework will increase deployment success rate and faster time to commercialization for MHK technologies. Higher success rates will improve how all MHK technologies are perceived world-wide and encourage commercial development.

This project aligns with the following DOE Program objectives and priorities:

- Develop key MHK testing infrastructure, instrumentation, and/or standards.

Technical Approach

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

- Assess U.S. and international industry failures on deployed devices and document experience with available data via telephone interviews of willing industry members, proxy surveys through email, and/or engaging industry members at relevant workshops or meetings.
- Review relevant literature on survivability, reliability, and design uncertainty and risk management with special emphasis on wind energy and MHK experience to inform the development of a framework and methodologies for identifying, prioritizing, and managing risks.
- Utilize output and experience from available Failure Modes and Effects Analyses (FMEA) (e.g., ORPC's TidGen™ device*) to inform the development of a risk management framework.
- Refine and customize the risk framework by conducting a FMEA on an appropriate Wave Energy Device and document the process.

*Will generally inform framework. Propriety and confidential information will not be disclosed

Hierarchy of Test and MHK Deployment Objectives

Minimum Requirement: Test Article Survives Long Enough to Validate Design and Advance TRL Levels

Criteria	Level	Objectives
Meets and demonstrates certification requirements	Design Compliance	**Commercial readiness**
Operates within design limits for prescribed long term operation	Life Endurance	**Demonstrates cost of energy and system reliability**
Operates and collects loads and performance data for test period	Test Endurance	**Minimum MHK Program objectives: Validate performance and safety**
Operates but without adequate data collection	Function and Operability	**Demonstrates basic system function**
Survival of primary structure	Survivability	**Demonstrates deployment methods**

Expected Outputs

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Likelihood	Consequences				
	Insignificant (*Minor problem easily handled by normal day to day processes*)	Minor (*Some disruption possible, e.g. damage equal to $500k*)	Moderate (*Significant time/resources required, e.g. damage equal to $1million*)	Major (*Operations severely damaged, e.g. damage equal to $10 million*)	Catastrophic (*Business survival is at risk damage equal to $25 Million*)
Almost certain (*e.g. >90% chance*)	High	High	Extreme	Extreme	Extreme
Likely (*e.g. between 50% and 90% chance*)	Moderate	High	High	Extreme	Extreme
Moderate (*e.g. between 10% and 50% chance*)	Low	Moderate	High	Extreme	Extreme
Unlikely (*e.g. between 3% and 10% chance*)	Low	Low	Moderate	High	Extreme
Rare (*e.g. <3% chance*)	Low	Low	Moderate	High	High

Example: Risk Severity Framework

- Fully documented literature review
- MHK specific risk management framework based on Failure Modes and Effects Strategy
- Case study of MHK Wave Device

Project Plan and Schedule

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

Summary
WBS Number or Agreement Number: 1.2.3.4
Project Number
Agreement Number 26836

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	2014 Q1 (Octt-Dec)	2014 Q2 (Jan-Mar)	2014 Q3 (Apr-Jun)	2014 Q4 (Jul-Sep)
Project Name: Reliability and Survivability Risk Assessment				
Q1 Milestone: Complete an initial literature search and document findings				
Q2 Milestone: Develop a high-level risk management framework				
Q2 Milestone: Write internal report and hold webinar				
Q3 Milestone: Develop detailed methods to manage risk for specific device				
Q4 Milestone: Submit draft technical report				
Current work and future research				

Comments

- Project initiation: October 2013
- Personnel turnover has delayed initial project start

Project Budget

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

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300k	n/a	$300k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY13	Spend Plan FY14
$0K	$225k

- Received $300k at the end of FY13; no spending until FY14
- Per DOE guidance, project is planned to preserve 25% carryover
- FY14 project costs as of December 31st: $11k.

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators: NREL leads this project. Collaborators will be industry members who share data and failure experiences.

Communications and Technology Transfer: The Risk Management Framework will be made publically available via the NREL website and OpenEI. A final report will be published and available on the NREL and DOE websites.

Next Steps and Future Research

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

Proposed Future Research:

- Validation of the strategy under actual field testing
- Definition of compliance strategies for life endurance and design compliance and certification
- Implementation and integration of process into program

Water Power Peer Review

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

MHK Manufacturing Needs Assessment and Cost Database

Jason Cotrell

NREL

Jason.Cotrell@nrel.gov, (303) 384 7056

Feb 25, 2014

Purpose

Problem Statement:

1) The emerging MHK industry is a highly competitive global industry. The U.S. must ensure it can competitively manufacture MHK devices and components.

2) Information about U.S. manufacturing and device costs is needed to make strategic decisions and investments.

This project aligns with the DOE objective and priority to

- Advance the state of MHK technology

Objectives

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

Objectives:

Manufacturing Needs Assessment

- Identify manufacturing and assembly needs and opportunities for wave energy converters (WECs)
- Create a framework, strategy, and recommendations for strengthening U.S. wave device manufacturing competitiveness

Cost Database

- Compile and organize MHK project and cost information in cost breakdown structure and cost database

Project Impact:

Provides manufacturing and cost information needed to make strategic decisions about wave device technology and manufacturing investments.

Identify MHK manufacturing and assembly needs and opportunities

1) Literature review
2) Down select the technology for consideration—point absorbers
3) Preliminary SWOT analysis of manufacturing and assembly challenges
4) Stakeholder interviews and site visits
5) Revise and vet the SWOT analysis at 2014 GMREC
6) Use the SWOT analysis to identify manufacturing needs, opportunities, and key competitiveness factors

Create a competitiveness framework, strategy, and recommendations

1) Adapt and apply available competitiveness literature and international MHK literature to the U.S. MHK industry
2) Prioritize U.S. investment opportunities by examining the largest LCOE contributors and MHK industry SWOT results

Project Plan & Schedule
Manufacturing Needs Assessment

		FY 14											
Task / Event	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Identify manufacturing and assembly need and opportunities													
Task 1a: Compile available literature and list of possible contacts													
Task 1b: Revise project plan based on literature review													
Task 2: Downselect technologies for consideration													
Task 3: Preliminary SWOT analysis of manufacturing and assembly challenges													
Task 4: Stakeholder interviews and site visits													
Task 5: Revise and vet the SWOT analysis													
Task 6: Use the SWOT analysis to identify manufacturing needs and opportunities													
Q1 Milestone: Down-select MHK technologies for further analysis (October 30)													
Create a competitiveness framework, strategy, and recommendations													
Task 7: Articulate the importance of MHK manufacturing investments to provide context, perspective, and rational for the framework and strategies.													
Task 8: Identify and summarize the high level MHK competitiveness factors													
Task 9: Analyze and prioritize U.S. strategic investment opportunities identified in Phase I													
Task 10: Document the results in a comprehensive report and presentations													
Q4 Milestone: Summary report that describes findings, references, and recommendations (September 30)													
		Milestone											
		Green boxes indicate completed work											
		Blue boxes indicate planned work											

Technical Approach
Cost Database

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1. Inventory NREL and DOE data, including previous, ongoing, and future projects -
   - Reference Model Project
   - Closing-out of recent MHK FOA projects
   - New MHK FOA projects (e.g. FOA 848)
   - WEC Prize
2. Increase level of detail of MHK Cost Breakdown Structure developed in FY 13 -
3. Develop preliminary database specifications
   - Primary audience(s) for an MHK database
   - Cost data
   - Performance data
   - Physical parameters
   - Site characteristics
   - Implementation cost
   - Implementation timeline

(FY 15) Adapt the relational database created for offshore wind projects to accommodate MHK project and industry data and populate with data from Task 1 above

Project Plan & Schedule Cost Database

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		FY 14											
Task / Event	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Task 1: Inventory NREL and DOE data													
Q2 Milestone: Document data inventory and create database overview for stakeholder review (Mar. 31)													
Task 2: Increase level of detail of MHK cost breakdown structure													
Task 3: Develop preliminary database specifications													
Q3 Milestone: Complete CBS and database specifications; summarize in a memo for DOE (June 30)													
		Milestone											
		Green boxes indicate completed work											
		Blue boxes indicate planned work											

Combined Project Budget

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Combined project funding of $400k arrived in the last month of FY13

– Manufacturing needs assessment: $300k
– Cost database: $100k

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$400k	n/a	$366k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY13	Spend Plan FY14
$34k	$366k

Partners, Subcontractors, and Collaborators:

Manufacturing Needs Assessment

- No formal partners; however, WEC manufacturer and supply chain input is essential

Cost Database

- No formal partners; however, input will be obtained from reference model partners, old and new MHK DOE projects, and WEC Prize participants

Communications and Technology Transfer:

- DOE summary presentations
- 2014 Global Marine Renewable Energy Conference (GMREC) presentations and/or breakout sessions
- NREL technical report on Manufacturing Needs Assessment
- Non-sensitive, non-proprietary information will be compiled on OpenEI

Future Research

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Manufacturing Needs Assessment

- Support the implementation of the recommendations as necessary
- Consider extending the analysis to other MHK device technologies

Cost database

- Use the specifications developed in this project to adapt a relational database created for offshore wind projects to accommodate MHK project and industry data
- Continue to collect information for the database

2014 Water Power Program Peer Review

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Introduction to the System Performance and Advancement (SPA) FOA

Wind and Water Power Technologies Office
Ryan Sun Chee Fore, DOE
February 26, 2014

Purpose & Objectives

Problem Statement: The next generation Marine and Hydrokinetic (MHK) systems need to perform better and more reliably to be competitive with alternative generation sources in the market. MHK specific component technologies are a critical enabler to better performing systems. Trend towards advancing technical readiness ahead of performance.

Impact of FOA: This FOA increases the system Power to Weight Ratio (PWR) and Availability to lower the LCOE of devices currently under development. Prototype software and hardware will be developed, built and tested under three MHK component topic areas:

1. **Advanced Controls** – potential to double power production and increase survivability with control algorithms and hardware
2. **Next-Gen Power Take-Off (PTO)** - increase energy efficiency, reduce weight, and improve reliability with high power density generators and driveline components
3. **Optimized Structures** - improve energy capture, reduce weight, and improve reliability with alternative material hulls balancing performance and manufacturing cost

This FOA aligns with the following DOE Program objectives and priorities:

- Advance the state of MHK technology

FOA Definition & Selection Process

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- FY08 - FY10 investments produced demonstrations across multiple MHK resources, archetypes and device configurations yielding over *3 yrs of operational experience* and *lessons learned*.
- White Papers based on input from US and International companies defined cost reduction pathways for major archetypes (e.g. axial flow tidal turbine, wave point absorber)
- 3 topic areas were chosen that broadly addressed cost reduction pathways across device types to advance the performance of existing systems:

Topic Areas | Advanced Controls | Next Gen PTO | Optimized Structures

- This FOA would emphasize improving performance early in the development cycle, prior to system demonstration.
- Letters of intent were required and a full merit review was performed
- The FOA sought projects with well defined performance metrics, high impact and likelihood of system integration. Commonality in component technology application, with the potential to broadly support the industry.

FOA Timeline

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- FOA Issue Date: 4/22/2013
- Letter of Intent (LOI) Due Date: 5/13/2013
- Application Due Date: 6/3/2013
- GFO Compliance Review of Applications: 6/5/2013
- Independent and Federal Consensus Merit Review Panels: 7/9/2013 – 7/12/2013
- Award announcement: August 29
- Project duration: 18 to 24 months

Awardee Summary

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Topic Area	Recipient Name	Project Title	Award Amount (DOE allocations only)
Advanced Controls	Ocean Renewable Power Company, LLC	*Advanced energy harvesting control schemes for marine renewable energy devices*	$1,893,580
Advanced Controls	Dehlsen Associates, LLC	*Advanced Controls for the Multi-pod Centipod WEC device*	$500,000
Advanced Controls	Resolute Marine Energy, Inc.	*Optimal Control of a Surge-Mode WEC in Random Waves*	$1,074,654
Next Gen PTO	ABB Inc.	*Advanced Direct-Drive Generator for Improved Availability of Oscillating Wave Surge Converter (OWSC) Power Generation Systems*	$1,995,255
Next Gen PTO	Columbia Power Technologies, Inc.	*Build and Test of a Novel, Commercial-Scale Wave Energy Direct-Drive Rotary Power Take-Off Under Realistic Open-Ocean Conditions*	$3,000,000
Next Gen PTO	Ocean Renewable Power Company, LLC	*Power Take-Off System for Marine Renewable Devices*	$3,000,000
Optimized Structures	Ocean Energy USA LLC	*Optimization of Hull Shape and Structural Design for OE Buoy*	$991,663
Optimized Structures	Ocean Power Technologies, Inc.	*Optimal PowerBuoy Structure Design for Maximized Power to Weight ratio and Reduced Installed Capital Cost*	$1,000,000
		Total	$13,455 ,152

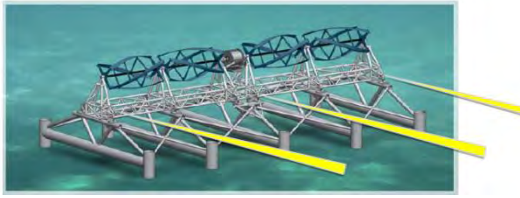
Project Outcome and Impact Potential:
A validated feed forward control system for current energy converters optimized for upstream turbulence conditions. Anticipate an increase of 38% in PWR and 20% reduction in LCOE.

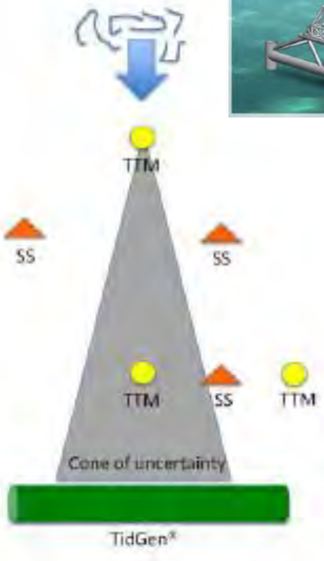
Project Summary: A feed-forward capability for ORPC's TidGen® device. The controller adjusts generator torque based on the tip speed ratio of the rotor. Upstream looking single beam current profilers will provide incoming turbulence to adjust the controller gain in real time. Directionality, flow distribution across the turbine, and ultimately, accuracy of the turbulence measurements will be the critical capabilities for validation.

Field demonstration of tidal feed forward control

DOE Funding	Cost Share	Total Project Cost
$1,894K	$473K	$2,367K

Proposed Partners:
NREL (CO), University of Washington (WA), NNMREC (WA)





Dehlsen Associates, LLC - Advanced Controls for the Multi-pod Centipod WEC device (1593)

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Project Outcome and Impact Potential: An advanced feed forward WEC control algorithm unbounded by hardware limitations. Potential doubling of power production.

Project Summary: Development of Model Predictive Control (MPC) for rapid tuning and phase control to increase power produced by a WEC featuring multiple point absorbers (pods). The MPC algorithms will be developed for real-time optimization by the WEC controller. Loading in extreme conditions and ultimately design structural weight will be reduced through development of a pod feathering control mechanism. Both improvements combine to increase PWR.

Explore full controls potential unbounded by hardware

DOE Funding	Cost Share	Total Project Cost
$500K	$125K	$625K

Proposed Partners:

GL-Garrad Hassan (CA), Oregon State University (OR), Helios Engineering Inc. (CA

Resolute Marine Energy, Inc. - Optimal Control of a Surge-Mode WEC in Random Waves

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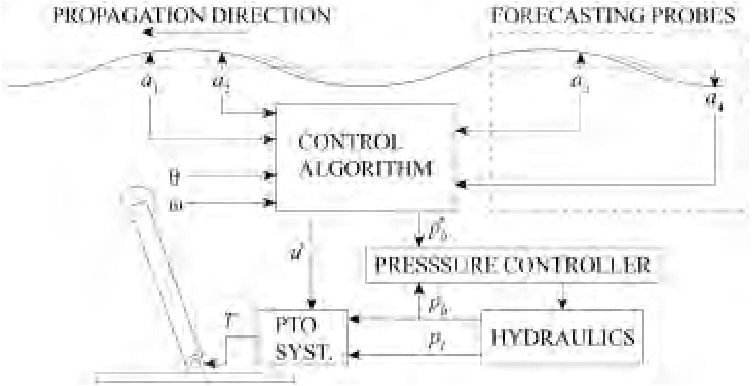
Project Outcome and Impact Potential:
A validated WEC control system (software and hardware) for an OWSC. Anticipate an increase of 67% in PWR and 41% reduction in LCOE.

Project Summary: A causal (feedback) and acausal (forecasting) control algorithms will be developed. Causal control based on wave information at the device assumes a known stochastic process. Acausal control takes advantage of wave sensing ahead of the device and wave prediction to deterministically control torque. Hardware that continuously varies hydraulic pressure increases the SurgeWEC's responsiveness in torque.

WEC Hardware in the Loop Testing

DOE Funding	Cost Share	Total Project Cost
$1,075K	$284K	$1,359K

Proposed Partners:
University of Michigan (MI), Re Vision (CA)



ABB, Inc. - Advanced Direct-Drive Generator for Improved Availability of Oscillating Wave Surge Converter (OWSC) Power Generation Systems

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Project Outcome and Impact Potential:
A validated 10kW novel direct drive generator ready for integration with oscillating wave surge converter (OWSC) systems. The result of switching from hydraulic pressure to shore to electricity transmission, could reduce downtime of the Resolute SurgeWEC by at least 50% and LCOE by at least 10%.

Project Summary: Complete an optimized design of a novel and compact pole-modulated (CPM) direct-drive permanent magnet (PM) generator. The intended application for the component innovation is Resolute Marine Energy's SurgeWEC system.

Novel direct drive generator with integrated magnetic gearing

DOE Funding	Cost Share	Total Project Cost
$1,995K	$500K	$2,495K

Proposed Partners:

Resolute Marine Energy (MA) ; Texas A&M Univ. (TX)

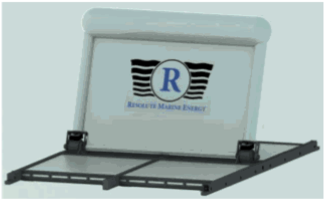


Figure 2 Photograph of RME SurgeWEC™

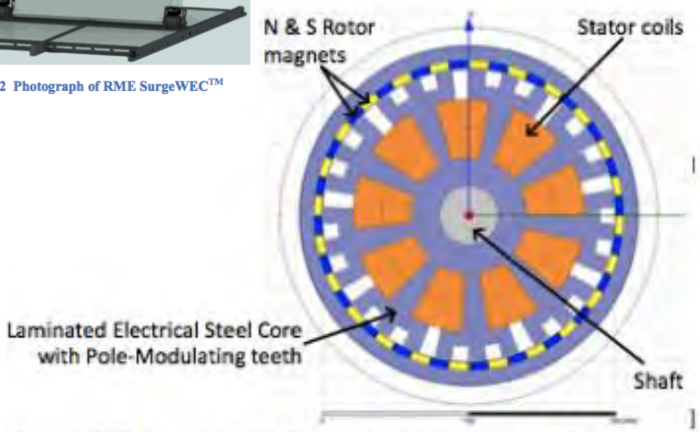
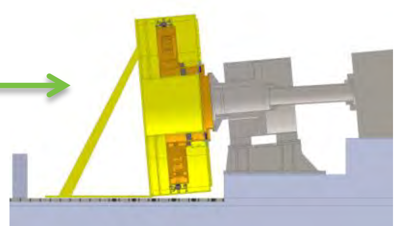


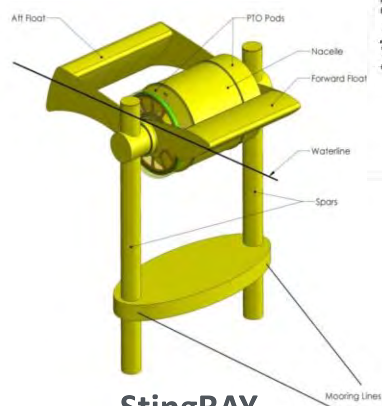
Figure 5 Example CPM generator geometry (ABB model)

Project Outcome and Impact Potential:
A demonstrated 630 kW direct drive rotary permanent magnet generator (DDR PMG) ready for integration into CPT StingRAY. The projected impact of this innovation to the system is a 28% reduction in LCOE.

Project Summary: Validate a novel generator mechanism that enables small air gaps on large diameter generators allowing for lower costs and performance gains when used in wave converters with oscillating DDR PMGs. Stator and rotor segments to be supplied by Siemens.

Testing of WEC PTO on NREL's new 5MW dynamometer



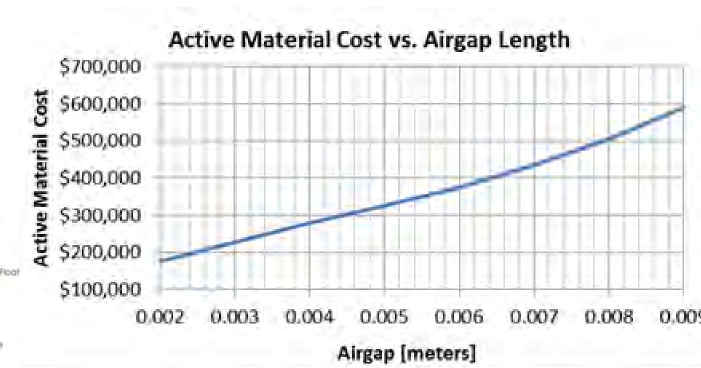


StingRAY

DOE Funding	Cost Share	Total Project Cost
$3,000K	$750K	$3,750K

Proposed Partners:

Siemens (GA and Germany); Northern Power Systems (VT); Ershigs Inc. (WA); NREL (CO)



Ocean Renewable Power Company - Power Take-Off System for Marine Renewable Devices (1518)

Project Outcome and Impact Potential:
A developed and tested 172.5 kW wet-gap low speed, high torque Switched Reluctance Machine ready for integration with the ORPC TidGen®. Once integrated, along with bearing advancements, a 25% reduction in LCOE is projected.

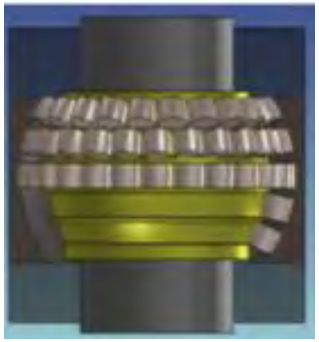
Project Summary: Develop and test high performance PTO and driveline for a cross flow tidal turbine. Design and test 2 bearing types for high load capacities, low friction, and long lifetimes. Down-select among 3 generator designs (one PM, 2 SRM: cylindrical and axial), fabricate, and test.

Full-scale land demonstration of wet-gap generator and driveline

DOE Funding	Cost Share	Total Project Cost
$3,000K	$929K	$3,929K

Proposed Partners:

RCT Systems, Inc (MD); Fontana Engineering (ME); AeroCraft (ME); NREL (CO)



Ocean Energy USA, LLC - Optimization of Hull Shape and Structural Design for OE Buoy

Project Outcome and Impact Potential:
Two (1 concrete, 1 steel) Oscillating Water Column (OWC) hull designs optimized for power, weight, and manufacturing cost. An 82% increase in PWR and 35% reduction in LCOE are anticipated.

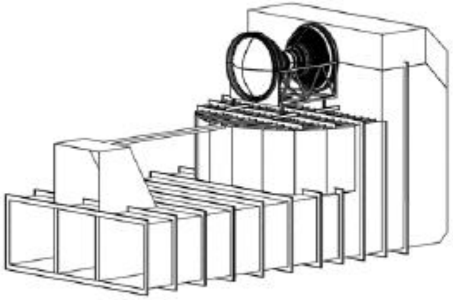
Project Summary: Cost and performance optimization of an OWC hull. A parametric geometric optimization to improve power capture efficiency, exploring chamber shapes and dimensions. Structural design optimization will consider use of light weight concrete vs. steel construction, for both weight reduction and lowering the manufacturing cost.

Engagement of US marine manufacturing infrastructure: major US shipbuilder (NASSCO), marine construction (Ben Gerwick)

DOE Funding	Cost Share	Total Project Cost
$992K	$248K	$1,240K

Proposed Partners:

NREL (CO), Re Vision (CA), NASSCO (CA), Ben Gerwick Inc. (CA)



Ocean Power Technologies, Inc. - Optimal PowerBuoy® Structure Design for Maximized Power to Weight Ratio and Reduced Installed Capital Cost

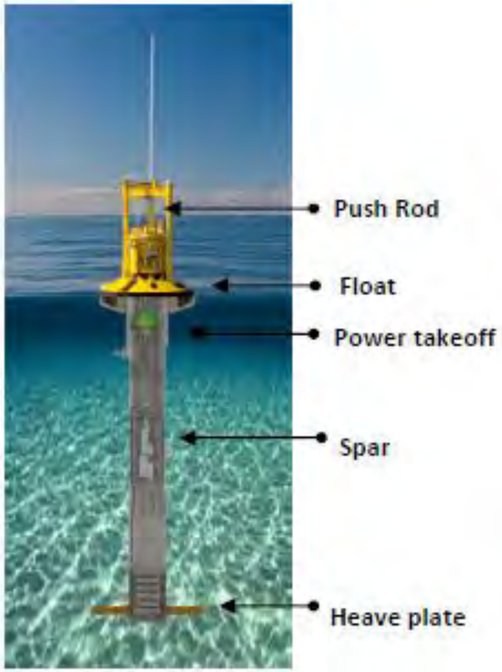
Project Outcome and Impact Potential: Composite point absorber float and spar design optimized to increase energy to weight ratio, enhance manufacturability, simplify ocean deployment and increases overall system life, reliability and availability, all while reducing life cycle costs. Anticipate a 35% increase in PWR, 10% increase in availability, and 5% reduction in LCOE.

Project Summary: The focus will be on the float and spar structures which account for approximately 50% of the overall PowerBuoy® mass. This project will evaluate alternative concepts in a wide trade space including materials and geometry related parameters These components interface directly with the ocean waves to dictate energy extraction and survival loading.

Partnered with Lockheed Martin jointly address design for manufacturing with composites

DOE Funding	Cost Share	Total Project Cost
$1,000K	$250K	$1,250K

Proposed Partners:
Lockheed Martin (NJ)



Communications and Technology Transfer (Transition) Plans

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Direct transition to targeted existing systems

- Component technologies specifically developed for integration into systems currently under development.
- Designs, software, and hardware employed in follow-on system demonstrations.

Facilitating MHK industry suppliers

- Potential MHK specific product lines available to all of industry
- Major suppliers attracted to the sector

Public Dissemination

- Information from these projects will be broadly distributed by the program through Annex V activities, including webinars, workshops, and conferences.
- All projects are highly encouraged to submit research articles to peer reviewed journals for publication.

2014 Water Power Program Peer Review

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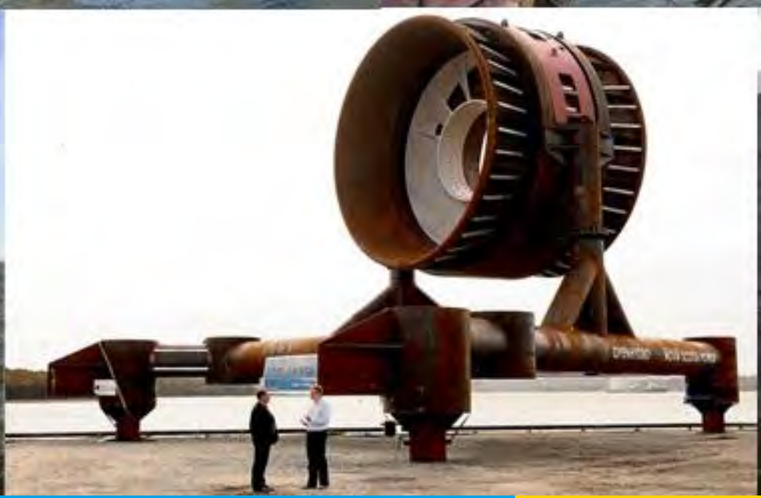


MHK Market Acceleration and Deployment (MA&D)

Wind and Water Power Technologies Office
Hoyt Battey
2/26/2014

Overview - Market Acceleration & Deployment

Goals: The Market Acceleration and Deployment (MA&D) thrust aims to minimize key risks to deployment to reduce the cost and time associated with permitting MHK projects. This includes undertaking research and developing tools to identify, mitigate and prioritize environmental risks; providing data to accelerate permitting timeframes and drive down costs; increasing opportunities for MHK researchers and regulators to be educated on these issues; and engaging in ocean planning to ensure that MHK is considered in the nation's marine spatial plans.

Priorities:

- Ensure that **rigorous data on environmental effects** are gathered to reduce uncertainty and risk to current and future projects.
- Ensure that **affordable and effective tools and proven techniques** exist for environmental monitoring, and where necessary mitigation
- **Magnify the impact of environmental research** by actively disseminating information, ensuring that there is broad access to environmental effects data from around the world, and that meta-analyses of the collective implications of these data have been conducted

FY 14 Budget: ≈$5 million

DOE Unique Role: As a science-based agency, DOE is uniquely situated to help develop tools to gather data, support novel environmental research, and synthesize and distribute credible environmental information.

MHK Organizational Structure: Market Acceleration and Deployment

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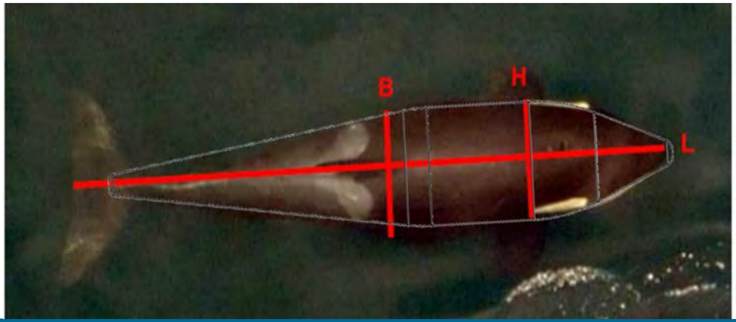
Market Acceleration and Deployment

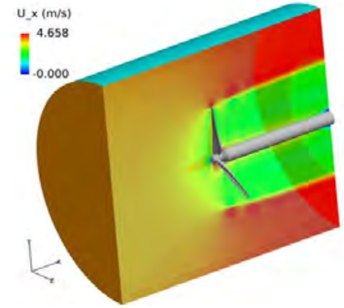
- Data Collection and Experimentation
- Monitoring & Mitigation Technologies and Techniques
- Information Sharing and Education

Key Counterparts and Collaborators

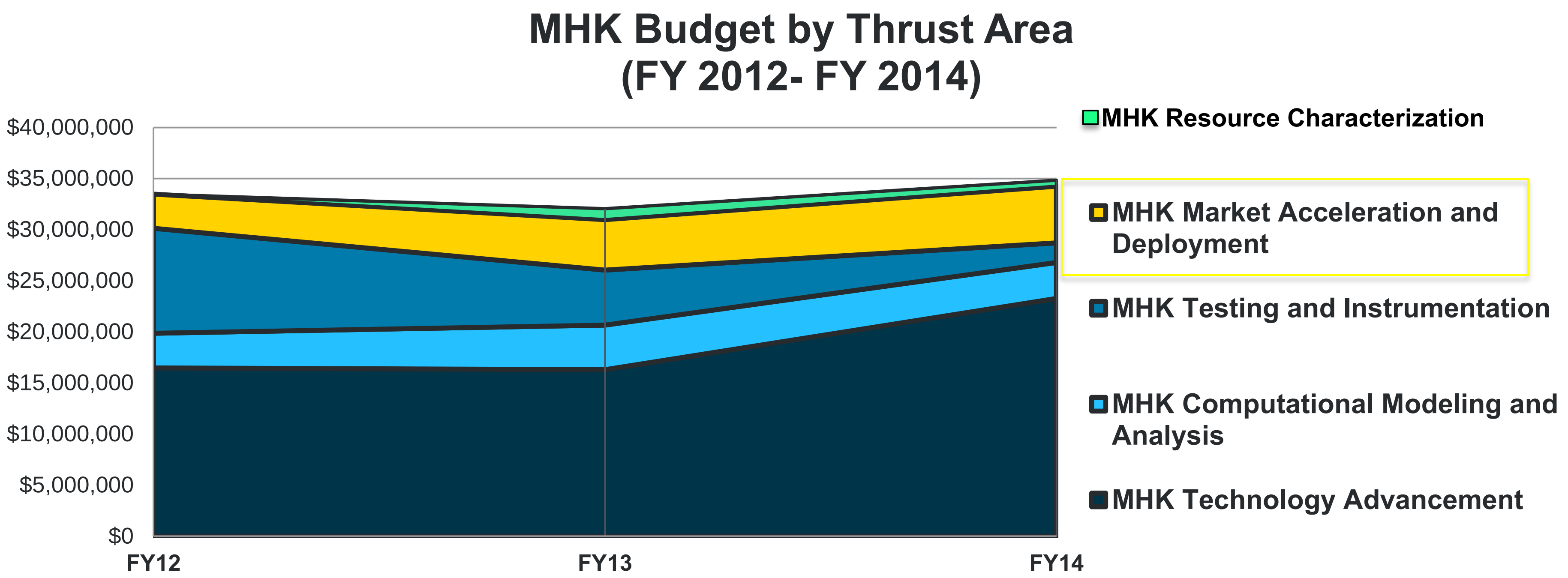
- National Renewable Energy Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Argonne National Laboratory
- Oak Ridge National Laboratory

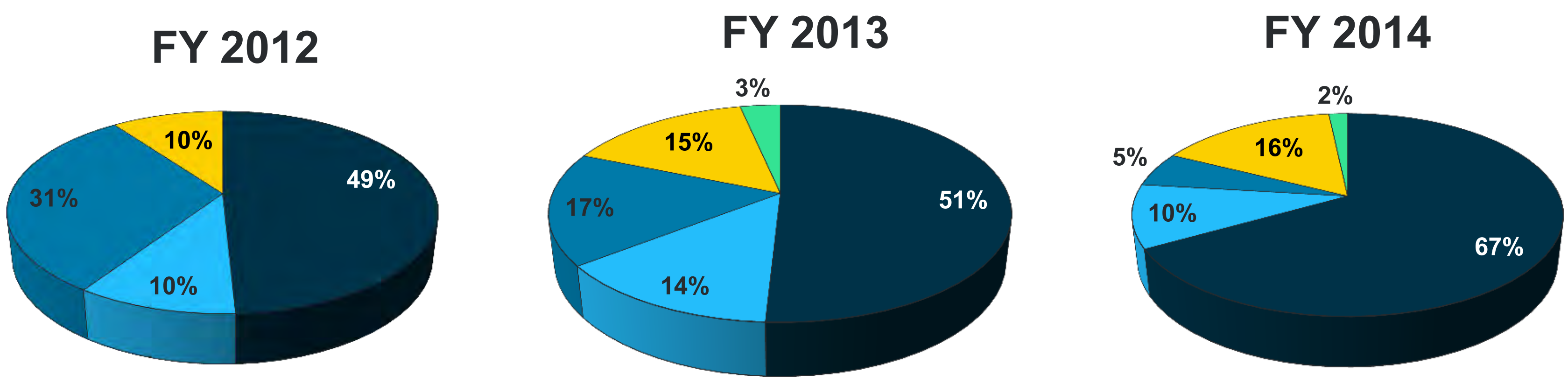
The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.	
Advance the state of MHK technology	• Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26





MHK Budget (FY 2012 – FY 2014)





Main Elements of the MA&D Portfolio

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Technical Area	Key Projects/Activities
5.1 Data Collection & Experimentation	***Research of effects on aquatic organisms*** • **Blade Strike** - Flume experimentation on fish, fish and marine mammal impact modeling • **Collision and entanglement** – Desktop analysis to inform risk • **Noise** – Lab experimentation on physiological and behavioral impacts, field monitoring of device noise and associated response, MHK noise generation and propagation modeling • **Electromagnetic fields** – Completed laboratory experimentation, field monitoring of EMFs from existing cables and organismal response • **Movement and Migration** – Field studies to examine behavior around devices, fish behavior models based on field data ***Research on effects on physical systems*** • Hydrodynamic and sediment transport dynamic modeling for both wave and current systems
5.2 Monitoring & Mitigation Technologies & Techniques	• Workshop held by PNNL + U. Washington in Summer 2013 • NOI published in November 2013 (FY14)
5.3 Information Sharing & Education	• Tethys database • Annex IV international environmental information sharing initiative • Training for the regulatory community

Priorities in FY12 and Beyond

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Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Include key collaborators	Upcoming milestones
5.1 Data Collection & Experimentation	• Increased emphasis on collecting field data around deployed devices and using this data to inform risk models and meta-analyses	PNNL, SNL, ORNL, ANL, UW, OSU, U Maine, EPRI, FAU	• Publication of peer reviewed literature on effects of noise, blade strike risk, EMF, and energy removal modeling • Initiation of a suite of field monitoring studies
5.2 Monitoring & Mitigation Technologies & Techniques	• Workshop held in summer 2013 to establish needs and priorities • Future emphasis on ensuring that cost-effective tools and techniques exist for monitoring	PNNL, UW, additional TBD	• NOI published in November 2013 (FY14)
5.3 Information Sharing & Education	• Increased support for and scope of Annex IV efforts. Information dissemination seen as being as important as data collection efforts. • Increased active outreach to a variety of stakeholder groups.	PNNL, NREL	• Monitoring workshop at upcoming EIMR conference • Updates and improvements to Tethys • Series of trainings for the regulatory community

Evolution of the MA&D Portfolio

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2010 | **2012** | **2014** | **2020+**

2010

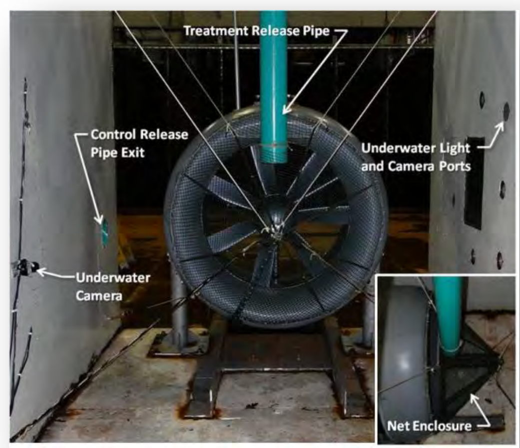
- Efforts made to identify potential environmental effects
- Initial research, especially laboratory research, to help inform the potential magnitude of effects
- Initial efforts to develop a database, Tethys, for information sharing
- Early stages of Annex IV environmental research collaboration

2012

- MA&D team conducted a rigorous analysis to identify the greatest industry environmental needs, identify gaps remaining from previous efforts, rank those gaps, and develop a plan to strategically reduce environmental barriers to deployment
- Increased emphasis on collecting field monitoring data
- Reduced emphasis on risk modeling for large scale projects until a greater pool of real-world data available to inform those models

2014

- Emphasis on improved instrumentation and tools, both hardware and software, for environmental monitoring
- Initiation of monitoring projects at deployed devices or surrogates
- Increased emphasis on Annex IV efforts and active information dissemination

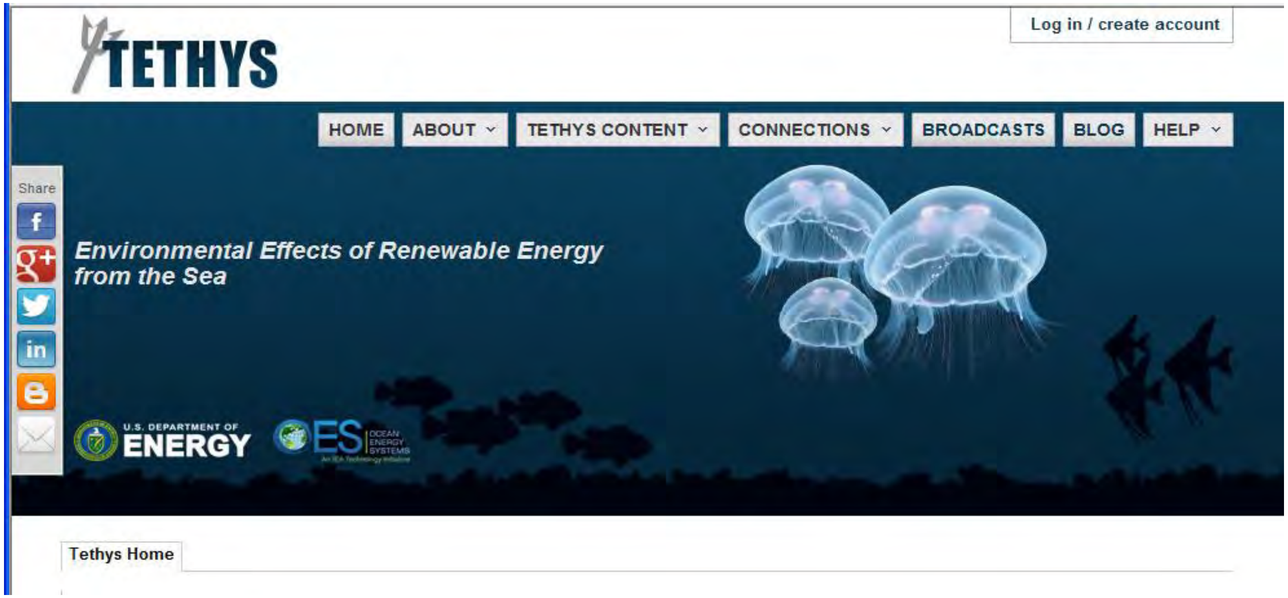


2020+

- Commercial scale environmental research
- Suite of flexible tools and models developed for predicting project impacts
- Cost-effective monitoring instrumentation developed, tested and commercially utilized
- Development of mitigation tools and techniques as needed

Water Power Program Technology Transfer

- **Annex IV Project**
  – International program in marine energy that provides new and reliable information and insights into research and monitoring of environmental effects and facilitates collaboration among the marine energy community to increase understanding of environmental effects and the role they play in marine energy project development.



- **Workshops and Trainings for Regulators**

- **Federal Renewable Ocean Energy Working Group**

Market Acceleration & Deployment – Agenda Overview

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

Subject Area	Time	Topic	Presenter
Market Acceleration: Data Collection and Experimentation	10:35 AM	Alden/ORNL Strike Flume Studies	Mark Bevelhimer, Oak Ridge National Laboratory
	10:50 AM	Impacts of Individual and Multiple MHK Stressors (Hydroacoustic /ELAM)	Mark Grippo, Argonne National Laboratory
	11:05 AM	Strike Analysis	Simon Geerlofs, Pacific Northwest National Laboratory
	11:20 AM		Rich Jepsen, Sandia National Laboratories
	11:40 AM	Acoustics Experimentation and Characterization	Mark Bevelhimer, Oak Ridge National Laboratory
	11:55 AM	Tidal Modeling, User Manual, Validation, and Acoustics Package	Daniel Laird, Sandia National Laboratories
	12:10 PM	LUNCH	
	1:10 PM	WEC Array Modeling Improvements to Assess Far-Field Environmental Effects	Daniel Laird, Sandia National Laboratories
	1:25 PM	Introduction to the MHK Environmental FOA NEW	Hoyt Battey and Jocelyn Brown-Saracino, DOE (Multiple Projects)

Market Acceleration & Deployment – Agenda Overview

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

Subject Area	Time	Topic	Presenter
Market Acceleration: Information Sharing and Education	2:40 PM	IEA OES Annex IV Support and Tethys Database Development	Luke Hanna, Pacific Northwest National Laboratory
	3:05 PM	West Coast Coastal Marine Spatial Planning Support	Simon Geerlofs, Pacific Northwest National Laboratory
	3:20 PM	EERE Post-doctoral Research Awards	Hoyt Battey , DOE (for ORISE)
	3:35 PM	MHK Regulator Training NEW	E. Ian Baring-Gould, National Renewable Energy Laboratory
	4:15	Poster Session in Lincoln Hall	Multiple

Water Power Program Questions for Peer Reviewers

- For environmental impacts research, we recently shifted towards emphasis to research at deployed devices. Given the relatively limited number of field deployments, do you agree with this emphasis? If not, what other areas should be increased?

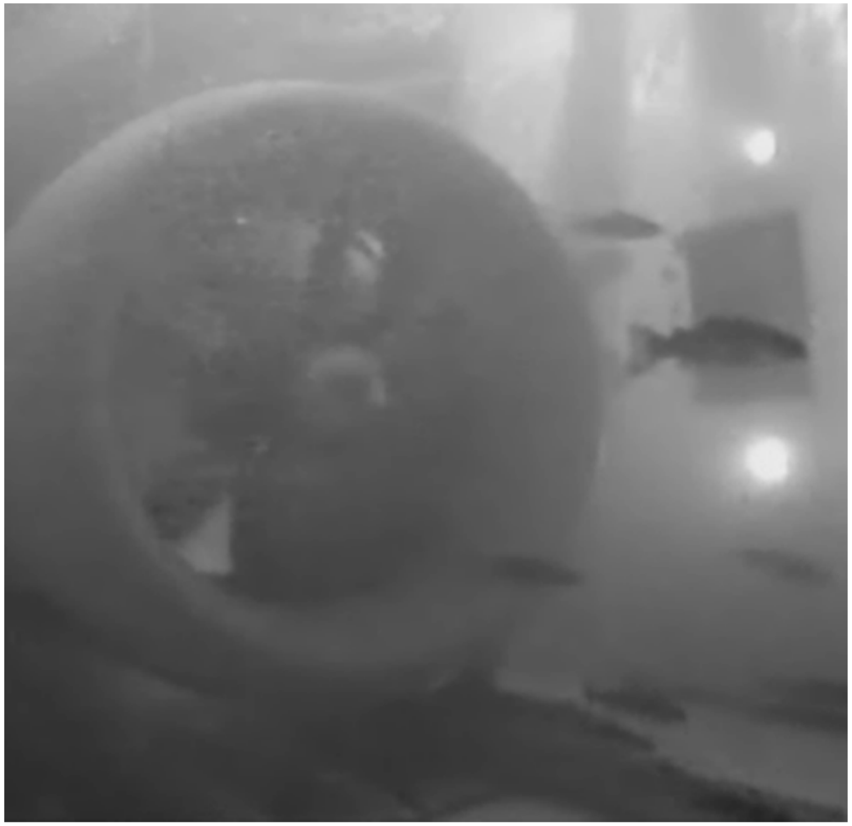
- We currently are focusing on environmental impacts of pilot and small commercial scale projects to ensure that tools and data are available to meet near-term industry priorities and to gather data that will help inform concrete assessment of larger-scale deployments. Is this the right emphasis?

- Are there additional activities or areas of emphasis that should be added to the MA&D portfolio?

Water Power Peer Review

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

Survival and Behavior of Fish Exposed to an Axial-Flow Hydrokinetic Turbine



Alden/ORNL Strike Flume Studies

Mark Bevelhimer

Oak Ridge National Laboratory

bevelhimerms@ornl.gov, 865 576 0266

February 2014

OAK RIDGE National Laboratory

Purpose & Objectives

Problem Statement: Identifying the extent and likelihood of potential environmental impacts of MHK device installation and operation is a critical part of getting test permits and licenses to operate. One of the greatest unknowns is whether resident or migratory fish would come in contact with an MHK device (especially the blades) and if so would they be injured or killed.

Impact of Project: This project will produce data and analysis that will be published in an EPRI report and a peer-reviewed journal article. Study results will be used by turbine builders, project developers, and environmental regulators to improve turbine design, inform site selection, and define and mitigate environmental risks.

Project Objectives:

- Quantify the rate of injury and mortality of fish passing through a ducted axial-flow hydrokinetic turbine
- Quantify the behavior (i.e., ability to avoid) of fish approaching an axial flow turbine
- Address the effects of turbine visibility (daytime and nighttime light conditions) on fish avoidance or injury

This project aligns with the following DOE Program objectives and priorities:
Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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

Common Study Design Features	
Design Type:	Ducted axial-flow
Number of blades:	7
Diameter (ft):	5
Velocities:	4.9 and 6.3 ft/s
Rotational speeds:	64 and 84 rpm
Species:	Rainbow trout (RBT) Hybrid striped bass (HSB) White sturgeon (WST)
Target Lengths (mm):	125 mm 250 mm (rainbow trout only)

Half-scale ducted turbine from Free Flow Power

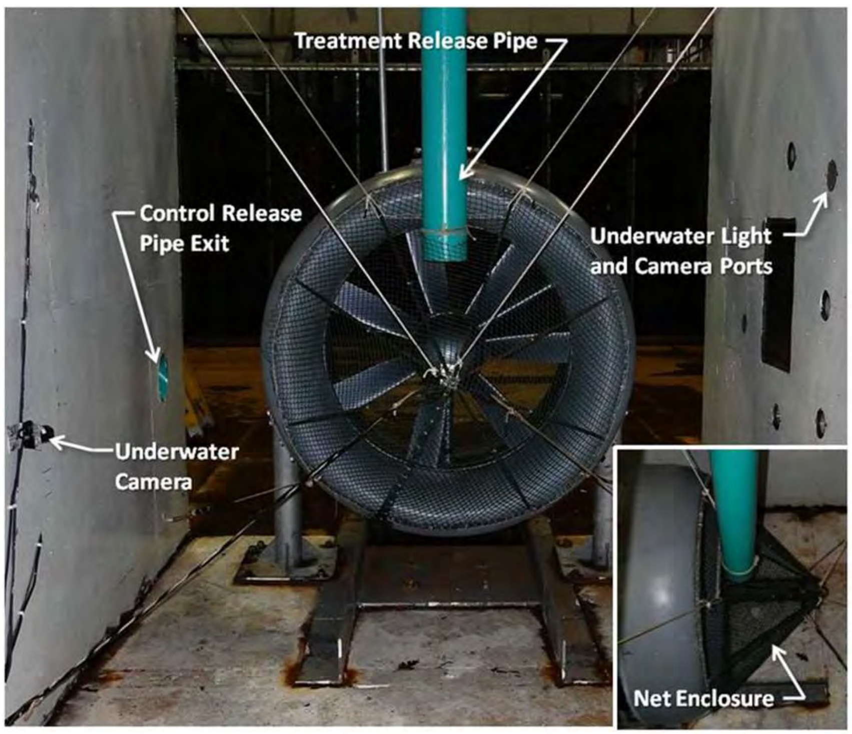
Installed in recirculating flume (24.4m long X 6.1m wide X 2.4m deep) at Alden Laboratory

Two Types of Tests Performed

- Injury/Mortality Assessment for fish passed through turbine
- Behavioral Avoidance Assessment for fish given chance to avoid turbine

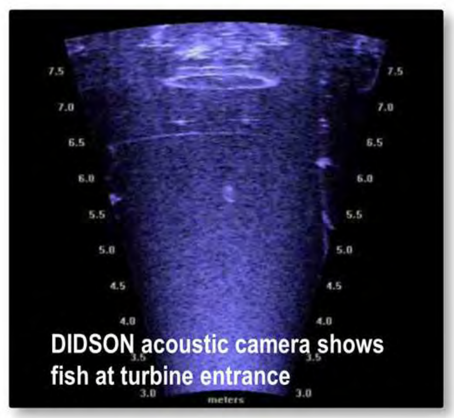
INJURY/MORTALITY TESTS

- Treatment fish released into turbine
- Control fish released beside turbine
- Fish recovered within few minutes
- Live fish held for 48 hrs to assess latent mortality
- Immediate (1 hr) and total (48 hr) turbine survival rates calculated
- External injuries were characterized at 48 hrs



BEHAVIORAL AVOIDANCE TESTS

- Fish released 2.5 m upstream of turbine
- Conducted under daytime (lighted) and nighttime (darkened) conditions.
- Underwater video and DIDSON acoustic camera used to observe fish during lighted trials.
- DIDSON acoustic camera only used for dark trials.
- Downstream camera, which recorded fish exiting turbine, used to estimate the number of fish entrained during each trial.
- Avoidance rates calculated (i.e., proportion of fish passing downstream without being entrained).



INJURY/MORTALITY TESTS

- Studies completed in early 2013
- High survival rates (97-100%) were observed
- Turbine passage injury rates ranged from 0 to 27% and increased with approach velocity and fish size for rainbow trout
- De-scaling rates associated with turbine passage ranged from 0 to 22% depending on species and approach velocity

Turbine passage survival, injury, and descaling

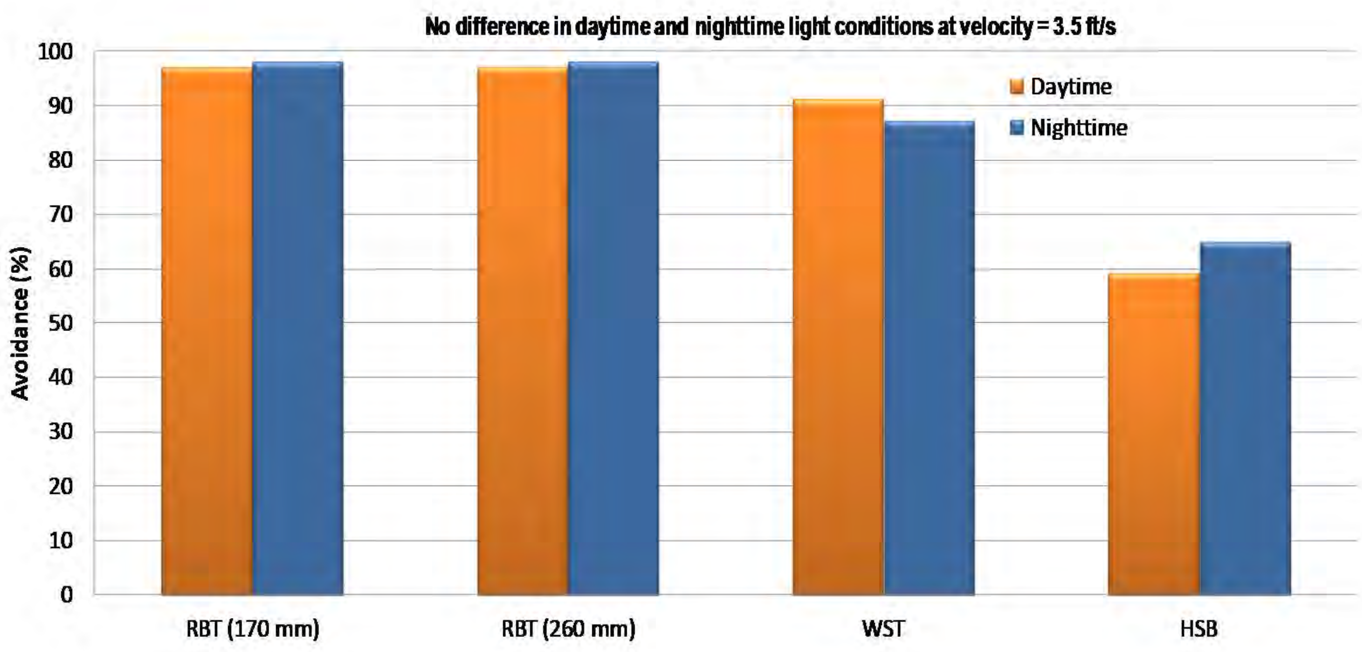
Species	Mean Fork Length (mm)	Approach Velocity (ft/s)	Total Survival ±95% CI (%)	Adjusted Injury[1] (%)	Adjusted Descaled[2] (%)
RBT	172	5.0	100.0 ± 0.0	9.9	0.0
	168	6.5	98.7 ± 1.1	12.0	0.1
	271	5.0	100.0 ± 0.0	15.6	9.5
	246	6.5	97.5 ± 1.4	27.1	22.3
HSB	131	5.0	91.1 ± 5.2	14.6	9.5
	118	6.5	100.5 ± 4.9	0.0	0.0
WST	123	5.0	101.3 ± 4.8	4.7	-
	126	6.5	100.0 ± 0.0	0.0	-

[1]External injuries were recorded as bruising/hemorrhaging, lacerations, severed body, fin damage, and eye damage.

[2] If greater than 20% scale loss at two or more locations on fish classified as 'descaled'.

BEHAVIORAL AVOIDANCE TESTS

- Studies completed in 2013
- Active avoidance by trout and hybrid bass, and passive avoidance by white sturgeon.
- Turbine avoidance rates were high for trout and sturgeon (>85%) and moderate for hybrid bass (about 33-65%).
- No apparent difference in avoidance rates for light and dark test conditions.



SUMMARY

- Survival rate of turbine passed fish was nearly 100%
- Injury and descaling was low and not lethal but high enough to be a concern and worthy of further study
- Avoidance by two species was high; a third species only avoided the turbine about 60% of time
- No difference in avoidance between dark and light conditions
- With the exception of hybrid bass tested at 5 ft/s, total passage survival rates (survival X avoidance) were essentially 100% for all test conditions
- Cautionary note: These tests did not include full range of blade speeds or fish sizes

Project Plan & Schedule

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

Summary		Legend
1.5 MHK Market Acceleration		Work completed
Alden / ORNL Strike Flume Studies		Active Task
		Milestones & Deliverables (Original Plan)
Agreement 20077		Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Milestone / Deliverable	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
ORNL direct completion of Alden lab experiments												
Complete data analysis												
Article describing blade strike experiements												
Current work and future research												
Article describing blade strike experiements												

Comments

- Completion of final report by Alden was delayed which put ORNL behind schedule in getting out the journal article for review.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$165K	0	$100K	0	--	--

- $34K additional provided by EPRI to Alden
- 95% of funds have been expended. Remaining funds are directed towards completion of peer review journal article.

Partners, Subcontractors, and Collaborators:

ALDEN (subcontractor)

Electric Power Research Institute (provided partial funding)

Free Flow Power (provided turbine)

Communications and Technology Transfer:

Journal article (submitted to N. Am. J. Fish Mgt.)

EPRI Report (available online at EPRI.com)

2013 Presentations:

- Global Marine Renewable Energy Conference – Washington, DC
- Hydrovision International – Denver, CO
- Southern Division American Fisheries Society – Nashville, TN
- Energy Ocean International 2013 – Warwick, RI
- Fish Passage 2013 – Corvallis, OR
- Am. Fish. Soc. Southern New England Chapter – Groton, CT
- University of Tennessee Departmental Seminar – Knoxville, TN

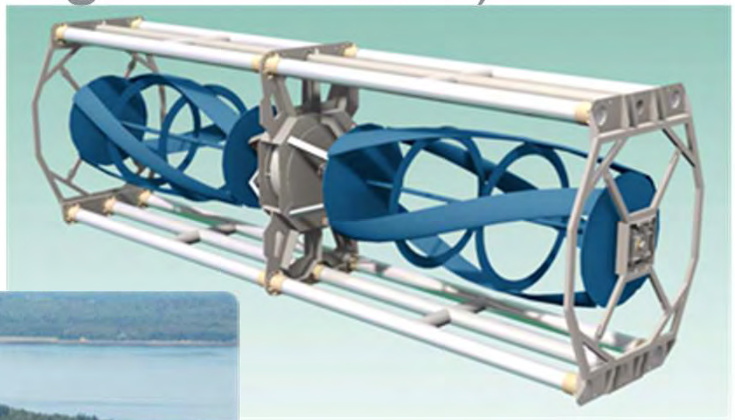
Next Steps and Future Research

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

FY14/Current research:
Completion of journal article with results of Alden study and a comparative analysis of two similar studies with different turbine types.

Proposed future research: None at this time.

Impacts of Individual and Multiple MHK Stressors (Hydroacoustic Monitoring and ELAM)



Images credit: ORPC

Impacts of Individual and Multiple MHK Stressors (hydroacoustic /ELAM)

Mark Grippo

Argonne National Laboratory

mgrippo@anl.gov+ (630) 252 3091

February 26, 2014

Purpose & Objectives

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

Problem Statement:

- Empirical data collected around MHK devices is needed to address management concerns about behavioral risks to fish resulting from MHK deployments.
- What is the magnitude and ecological significance of behavioral changes associated with the presence and operation of a turbine?
- How does fish behavioral response to the turbine inform the risk analysis of blade strike?
- What are the hydrodynamic variables driving fish behavioral responses to the turbine that can be used to mitigate any potential impacts?

Purpose & Objectives

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

Impact of Project:

The final fish behavior model can address multiple ecological MHK permitting concerns including disruption of migratory behavior, behavioral attraction to the device, and avoidance of preferred habitat occupied by the device

- These risks can be assumed to be minimal if analysis of fish movement patterns suggests the turbine has only small and temporary effects on normal swimming patterns or fish distribution within the channel.

Impact of Project:

Inform risk analysis of blade strike.

- Expands the spatial scale of earlier fish monitoring studies to determine at what distance fish begin to exhibit behavioral changes in response to the turbine and the hydrodynamic cues to which they are responding at different distances from the turbine.

Ecological impacts of MHK arrays

- To the extent possible, the response of fish to the single turbine will be used to make inferences about the potential response of fish to a turbine array

Purpose & Objectives

This project aligns with the following DOE Program objectives and priorities:

- Reduce deployment barriers and environmental impacts of MHK technologies

Technical approach

The project has three overall tasks:

1) Collection of mobile and stationary hydroacoustic fish data (Gayle Zydlewski, University of Maine)

- Hydroacoustic surveys were planned for spring 2013. However, the ORPC turbine has not been functional since April, 2013 and has been removed from Cobscook Bay.
- ORPC plans to deploy a OcGen module in midwater column for six weeks from June to August 2014 at which time hydroacoustic surveys will resume
- A new field study plan is currently being developed.
- Preliminary plans include conducting day and night, mobile surveys throughout the flooding tide with single- and split-beam hydroacoustic equipment operating concurrently. Each transect will cover a distance upstream and downstream of the center line of the device
- Processing of stationary and mobile hydroacoustic data into fish densities and/or tracks

Technical approach

2) Development of high-resolution (2-5 m) hydrodynamic modeling for Cobscook Bay

- During 2013, two separate high-resolution hydrodynamic models for Cobscook Bay were developed by the University of Maine and Sandia National Laboratory.
- The goal is to provide simulations of hydrodynamic fields, which will have sufficient detail to meet the needs of the ELAM
- ELAM performance will be evaluated using both hydrodynamic model data sets
- The SNL-EFDC is used by ORPC and has wide familiarity within the MHK industry. Therefore, if ELAM simulations are successful using SNL-EFDC it would further speed the application of the ELAM to other MHK projects.

Technical approach

2) development of high-resolution hydrodynamic modeling for Cobscook Bay

- The ocean modeling group at the University of Maine developed a second high-resolution coastal circulation model for Cobscook Bay, which will be nested in the existing Cobscook-Passamoquoddy model.

- The desired spatial resolution for the nested model is 1 to 2 m resolution several 100 m on either side of the turbine, which will cover the area of the mobile hydroacoustic fish surveys.

Technical approach

3) Integration of hydrodynamic model output and fish hydroacoustic data into the ELAM

- The ELAM analysis will evaluate the role of advective/passive forces on fate, movement, and/or densities of fish approaching the turbine. Then adding increasing levels of behavioral complexity until there is correspondence between real-world and ELAM model patterns.
- The performance of the ELAM will be evaluated against the present best available decision-support tool, which would be treating the fish as passive particles.
- The ELAM can simulate fish movement trajectories that characterize fish behavior before, during, and after they encounter a turbine and the associated area of hydrodynamic effects.
- The ELAM has been used to evaluate fish response to alternative dam operation plans and fish bypass designs.
- This would be the first application of the ELAM to MHK impacts and the first project to model fish behavioral responses to MHK turbines in a field setting.

- Developed field plan in FY 2012 and Q1 FY2013

2013 Subtask Milestones	Status
Q1 Subtask Milestone Description: Hire post-doctoral student to carry out hydroacoustic monitoring and data processing (Gayle Zydlewski, University of Maine). • Hired postdoctoral associate Dr. Haixue Shen	Complete
Q2 Subtask Milestone Description: Initiate preliminary mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine). . • Conducted initial mobile hydroacoustic surveys (25 March)	Complete

Accomplishments and Progress

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

2013 Subtask Milestones	Status
Q3 Subtask Milestone Description: Completion of high resolution hydrodynamic model for Cobscook Bay (Jesse Roberts, Sandia National Laboratory). • Sandia National Laboratory has developed an ~ 5-m resolution hydrodynamic model for Cobscook Bay.	Completed

2013 Subtask Milestones	Status
Q3 Subtask Milestone Description: Completion of high resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine). • Original plan was to reduce the model mesh size to 2 m, but the simulations were unstable and computationally intensive. A 5 m resolution model is currently being validated using ADCP data. • Plan to develop a 2 m resolution model using the Argonne supercomputer in 2014	In progress

Accomplishments and Progress

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

2013 Subtask Milestones	Status
Q4 Subtask Milestone Description: Complete mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine). • The ORPC turbine has been non-functional since April 2013; therefore no mobile hydroacoustic surveys have been conducted • ORPC plans to deploy a midwater OcGen module for study in spring 2014	Delayed

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number 20076	
Project Number	
Agreement Number 20076	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q1 Milestone: Hire post-doctoral student for hydroacoustic studies												
Q2 Milestone: Initiate preliminary mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine).												
Q3 Milestone: Developmetn of two high resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine and Jesse Roberts, Sandia National Lab).												
Q4 Milestone: Complete mobile and stationary hydroacoustic fish data collection												
Q4 Milestone: Obtain hydrodynamic model output for hydroacoustic survey period												
Current work and future research												
Develop 2-m resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine)												
Complete mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine)												
Complete hindcast hydrodynamic model output for hydroacoustic survey period (Huijie Xue, University of Maine)												
Complete Hydroacoustic data processing (Gayle Zydlewski, University of Maine)												
Initiate ELAM development (R. Andrew Goodwin, US Army Engineer R&D Center)												

- Original initiation date January 2013 & Planned completion date was October 2014
- Two high resolution (5m) hydroacoustic models were completed.
- The desired goal of two meter resolution was tool computationally intensive.
- In 2014 we will use the Argonne supercomputer to develop a higher resolution model

Project Plan & Schedule

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

Summary		Legend
WBS Number or Agreement Number 20076		Work completed
Project Number		Active Task
Agreement Number 20076		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1	FY2012 Q2	FY2012 Q3	FY2012 Q4	FY2013 Q1	FY2013 Q2	FY2013 Q3	FY2013 Q4	FY2014 Q1	FY2014 Q2	FY2014 Q3	FY2014 Q4
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q1 Milestone: Hire post-doctoral student for hydroacoustic studies												
Q2 Milestone: Initiate preliminary mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine).												
Q3 Milestone: Developmetn of two high resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine and Jesse Roberts, Sandia National Lab).												
Q4 Milestone: Complete mobile and stationary hydroacoustic fish data collection												
Q4 Milestone: Obtain hydrodynamic model output for hydroacoustic survey period												
Current work and future research												
Develop 2-m resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine)												
Complete mobile and stationary hydroacoustic fish data collection (Gayle Zydlewski, University of Maine)												
Complete hindcast hydrodynamic model output for hydroacoustic survey period (Huijie Xue, University of Maine)												
Complete Hydroacoustic data processing (Gayle Zydlewski, University of Maine)												
Initiate ELAM development (R. Andrew Goodwin, US Army Engineer R&D Center)												

- The ORPC turbine has been non-functional since April 2013; therefore no mobile hydroacoustic surveys have been conducted;
- Redeployment and hydroacoustic fish monitoring expected from mid-June to August 2014
- ELAM development

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$380K (carryover)	$0	$472K	$0	$264.6 K	$0

- $380K carryover available in 2012. Project plan completed in Q4 of 2012.
- $92K in additional funds received in 2013
- In 2013 funds were used for high resolution hydrodynamic model and preliminary hydroacoustic surveys
- The ORPC turbine has been non-functional since April 2013; therefore mobile hydroacoustic surveys, hydroacoustic data processing, hindcast modelling, and ELAM development did not occur in 2013 as planned
- 56% of the budget has been expended

Partners, Subcontractors, and Collaborators:

John Gasper and Mark Grippo, Argonne National Laboratory
Prof. Gayle Zydlewski, University of Maine University of Maine
Prof. Huijie Xue, University of Maine University of Maine
Dr. Jesse Roberts-Sandia National Laboratory
Dr. Andrew Goodwin, U.S. Army Engineer R&D Center

FY14/Current research:

Completion of high resolution hydrodynamic model for Cobscook Bay (Huijie Xue, University of Maine).

ORPC is planning a 6 week mid-water deployment of an OCGen® module in Cobscook Bay. We plan to complete mobile and stationary hydroacoustic fish data collection during this deployment. Field plan is being developed

Processing hydroacoustic data into fish tracks or densities

Begin ELAM development

Next Steps and Future Research

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

Proposed future research:

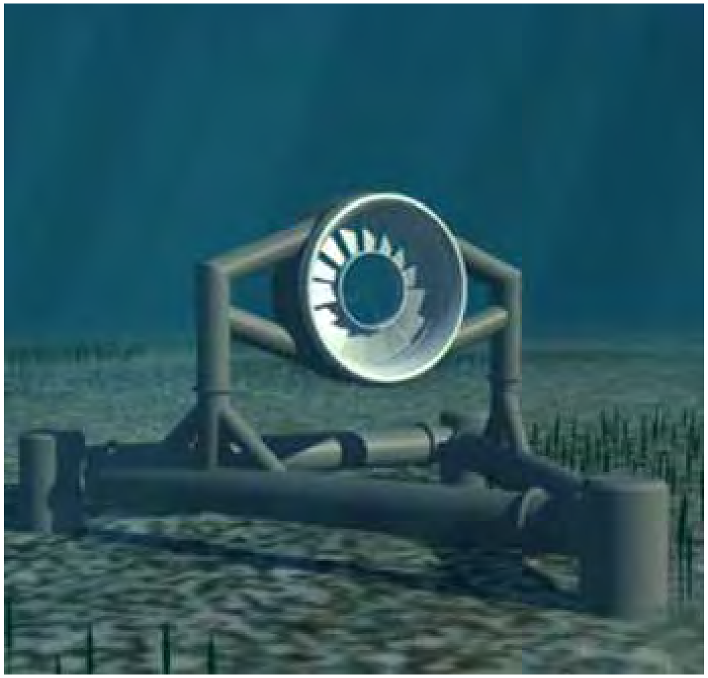
Potential future applications of the ELAM includes addressing behavioral risks at MHK sites with large seasonal fish migrations and\or more constrained channels.

With further validation using MHK array data, the ELAM could be used to “forecast” fish behavior under alternative array configurations at commercial scales.

With a mechanistic understanding of behavior patterns, simulations can be used to evaluate alternatives that may minimize impacts to fish movement behavior

Water Power Peer Review

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



Expansion of Blade Strike Analysis

MHK Market Acceleration & Deployment

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February 27 2014

Problem Statement:

- The Snohomish PUD tidal energy project's viability is threatened by the presence of a highly endangered marine mammal population (Southern Resident Killer Whales (SRKW)), which are protected against any injury, death or harassment under ESA and MMPA.
- PNNL and SNL research must determine the consequence of an OpenHydro turbine blade striking a SRKW.

Impact of Project:

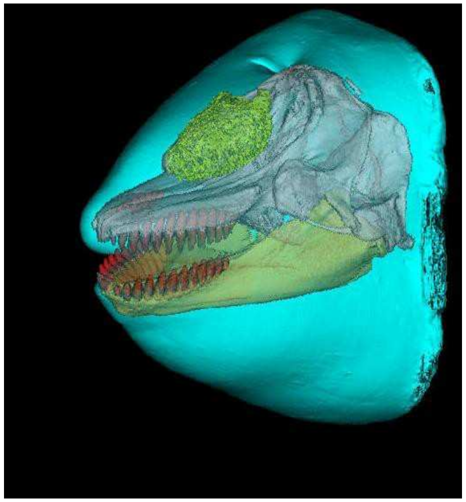
- Provided proponent (SnoPUD) confidence to proceed to final licensing
- Supported NOAA in determination of no significant effect.
- Methodology for understanding risk of tidal blades to marine mammals.

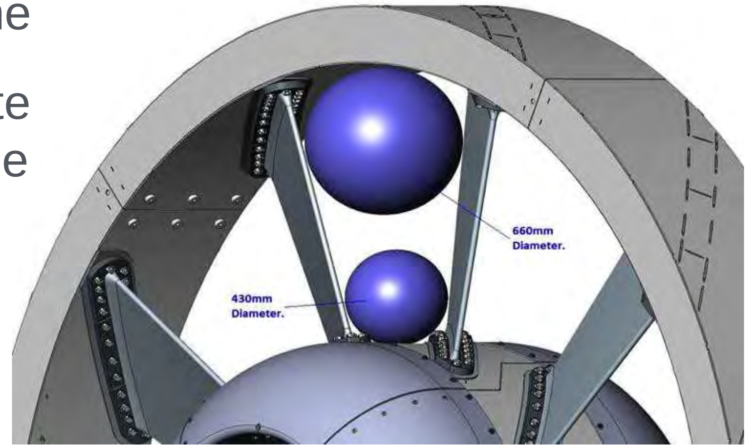
This project aligns with the following DOE Program objectives and priorities

Reduce deployment barriers and environmental impacts of MHK technologies

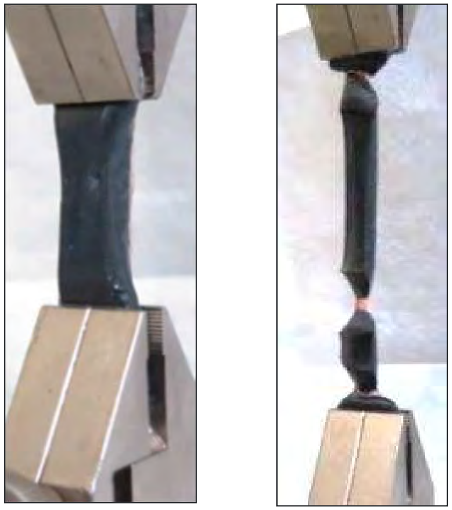
Technical Approach

- Negligible likelihood of SRKW randomly encountering turbine
- NOAA: want to know consequences of SRKW approaching turbine out of curiosity
- PNNL and SNL developed worst case scenario: largest male SRKW (greatest momentum transfer) nosing into turbine
- Determine anatomy (thickness of skin, blubber, bone) and biomechanical properties (force to deform or tear tissue) of SRKW tissue and bone
- Applied biomechanical analysis with SNL's finite element modelling of the forces from the turbine blade
- Provided estimate of potential results of blade strike





Technical Approach



- In FY12, PNNL used literature data for biomechanical tissue data, surrogate materials.
- In FY13, PNNL conducted tissue testing on dead SRKW tissue to refine results.
- Created biomechanical data for whale tissue, a previously unknown value.
- Assessed risk of injury to SRKWs using SNL's engineering models.
- Combined expertise in modeling by using both engineering and biological analyses to create a unique framework.
- Benchmarked level of potential damage against literature on blunt force head for multiple species, and against experience of marine veterinarians.
- Two additional turbine designs and two additional marine mammals being examined in same way

Accomplishments and Progress

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

- Outcome of analyses of highly unlikely event: subcutaneous damage (bruising) with small probability of skin laceration at high turbine speeds
- Established tissue testing protocol for marine mammal tissues (subadult and calf); first documented results of testing SRKW tissues
- Refined engineering model inputs based on tissue testing statistics
- Provided answer to risk of blade strike for SnoPUD/OpenHydro project that satisfied regulators (NOAA and FERC).
- Extending methodology to other turbine designs, other marine mammals

Project Plan & Schedule

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

Summary	
WBS # 2.1.3.5.1	
Project #64209	
Agreement #20072	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Expansion of Blade Strike												
Q3: Strike analysis for Southern Resident Killer Whales and a Tidal Turbine												
Q4: Report summarizing analyses in the context of the strike severity analysis.												
Q1: Assess biomechanical properties of SRKW skin; select additional species												
Q2: Identification and documentation of the marine mammal tissue												
Q3: Biological assessment of modeled marine mammals to forces provided by SNL												
Q4: Assessment presented in report format and as a journal paper.												
Current work and future research												
Assess biological consequence of SNL models of other devices												
Create journal article on marine mammal testing												
Compile additional tissue data for additional marine mammals												

Variances:

- An additional iteration of the engineering and biomechanical analysis became necessary when it was clear that the interpretation of the tissue analysis results was more complex than previously thought.
- No tissue data available for study of additional marine mammals, requiring additional analysis. NDA with turbine manufacturer for second turbine design was unavoidably delayed.

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$45K		$172K		$50K	

- No spending variances.
- 87% of FY12 + FY13 funds expended
- No other funding sources.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

- Initial partners in the project conception included: DOE WWPTO, NOAA Fisheries, SNL, NREL, Univ WA-NNMREC, OpenHydro
- SNL performed the engineering analysis
- Friday Harbor Labs, Univ WA (Adam Summer) performed the tissue testing.
- OpenHydro and Marine Current Turbines (MCT) provided technical specs for engineering analysis.

Communications and Technology Transfer:

- Page on *Tethys* on strike project
- Presented at Hydrovision 2012 (presentation), GMREC 2012 (presentation) and 2013 (poster)
- Presentation at National Hydropower Association 2012
- Paper presented at 10th EWTEC in Aalborg, Denmark

Next Steps and Future Research

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

FY14/Current research:

- Complete engineering and biomechanical analysis for two additional turbines (MCT and one Reference Model device)
- Perform analysis with two additional marine mammals: harbor porpoise and harbor seal.
- Barriers to the project are primarily the lack of species-specific tissue data, as well as the degraded quality of the SRKW tissue.

Proposed future research:

- Future research could undertake additional tissue testing to provide better inputs to analysis.
- Testing harbor seal or harbor porpoise would further inform patterns seen in SRKW biomechanical tissue testing.
- Further research could inform and simplify siting and permitting MHK devices in presence of marine mammals.

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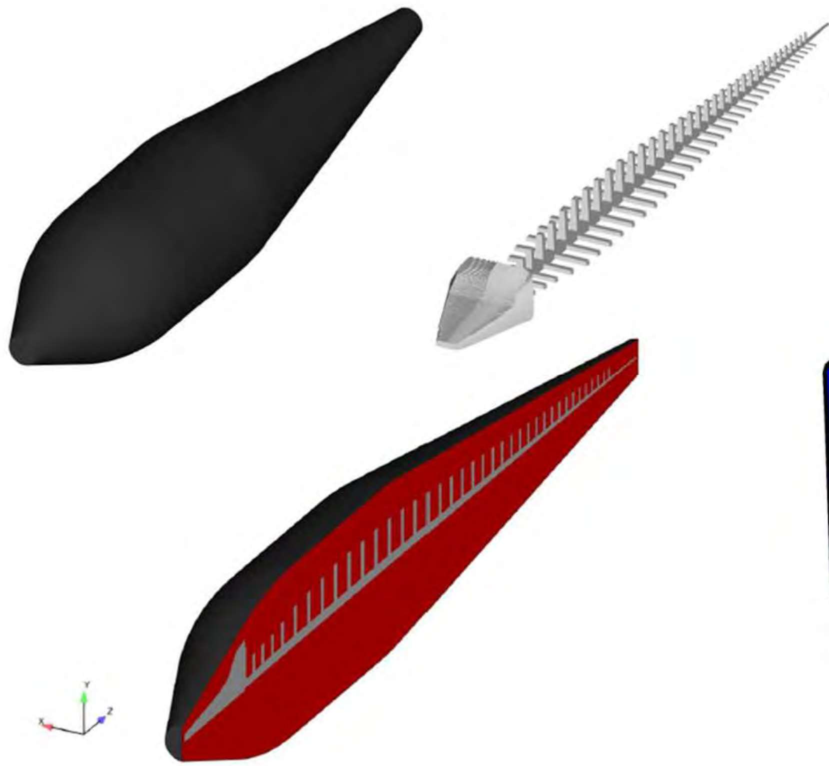

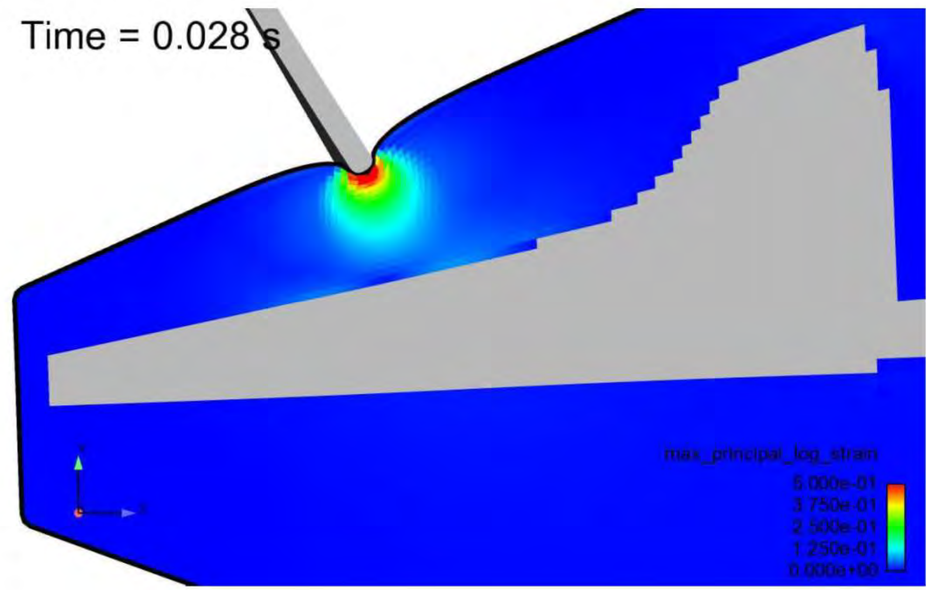

Strike Analysis

Rich Jepsen

Sandia National Laboratories

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February 26, 2014

Problem Statement:

- Recent interactions with MHK developers and regulators has demonstrated that the potential for blade strike on marine mammals is an important consideration for obtaining deployment permitting approval.

Impact of Project:

- The results of the Strike Analysis will allow DOE and developers to determine the potential impact of blade strike from various turbine/rotor designs on marine mammals of interest to regulators.
- These results have already been used to support the permitting process for the SNOPud/OpenHydro project in Washington state.

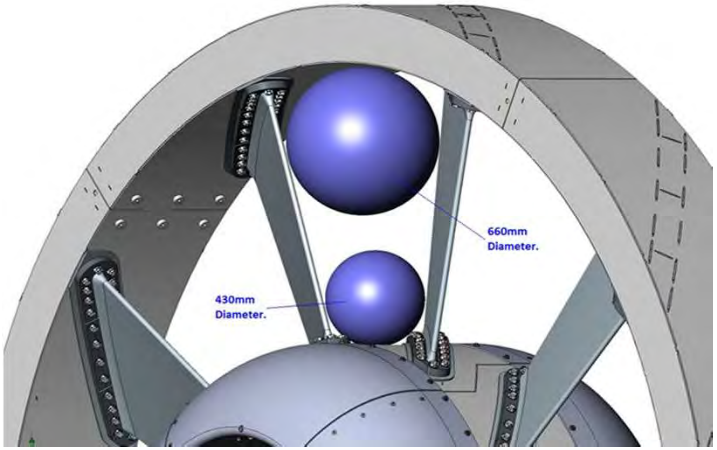
This project aligns with the following DOE Program objectives and priorities:

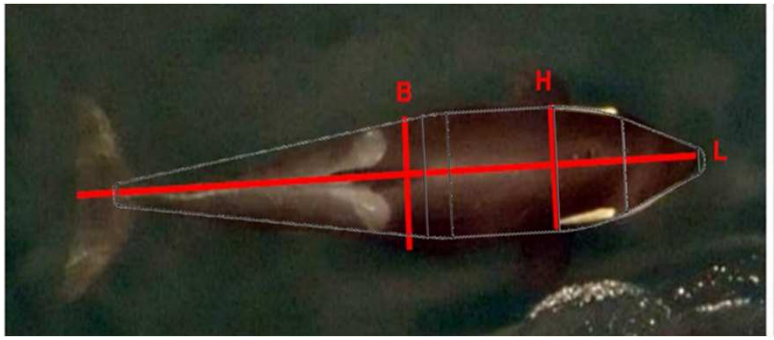
- Reduce deployment barriers and environmental impacts of MHK technologies

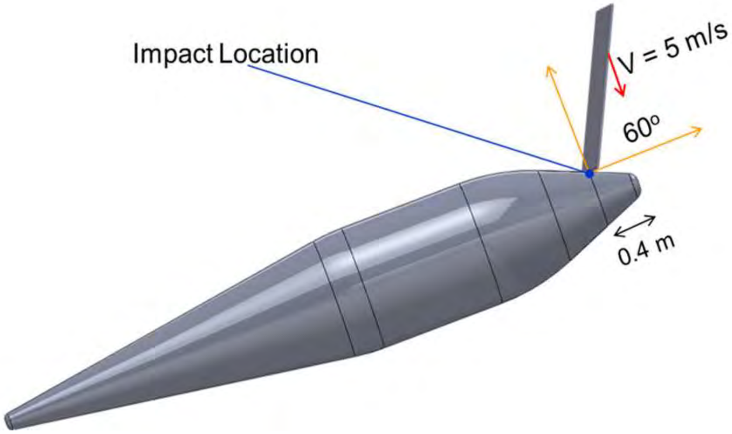
Technical Approach

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

- Develop a collaborative effort between SNL and PNNL, whereas SNL primarily provides engineering analysis and PNNL primarily provides biological assessment expertise.
  - PNNL and SNL work together to develop impact scenarios along with solid models and material properties for marine mammal tissues
  - SNL utilizes computational codes for model simulations of impact scenarios
  - PNNL assesses biological impact from results of computational analysis
- Initiate the project with analysis of a shrouded turbine strike on an adult Southern Resident Killer Whale (SRKW). Extend the analyses to other turbine types and marine mammals.







Technical Approach

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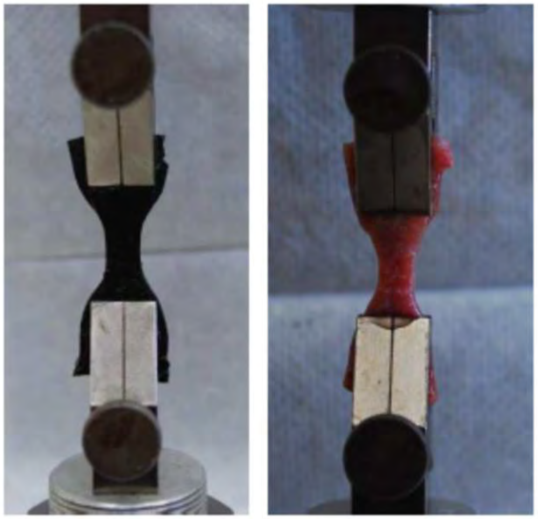
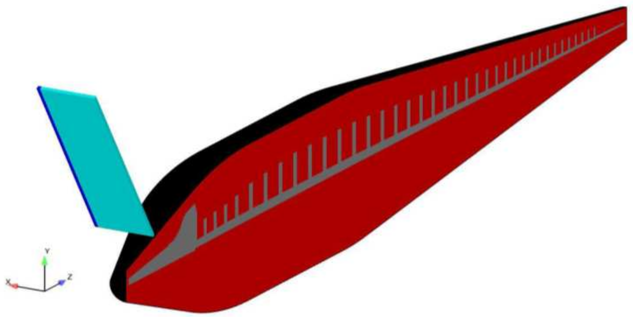
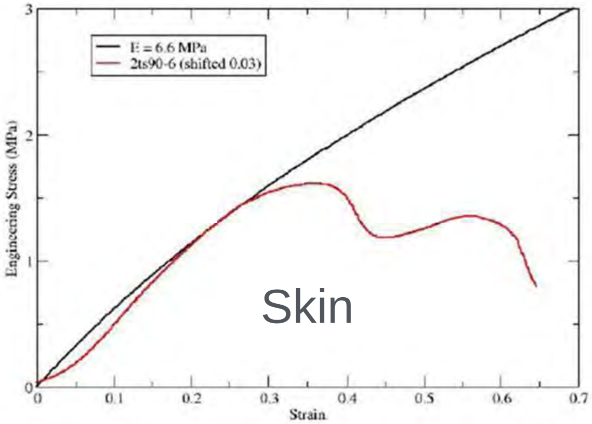
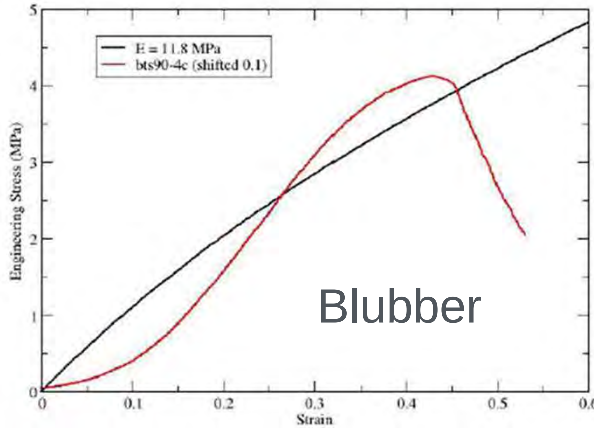
- This is a problem that has not been performed in the past and there is little information in the literature on the material properties or effects of any structural or vessel impact on marine mammals.
- The project utilizes a unique structural dynamics code (PRESTO) developed at Sandia for weapons research integrated with materials testing and evaluation from SNL engineers and PNNL biologists.



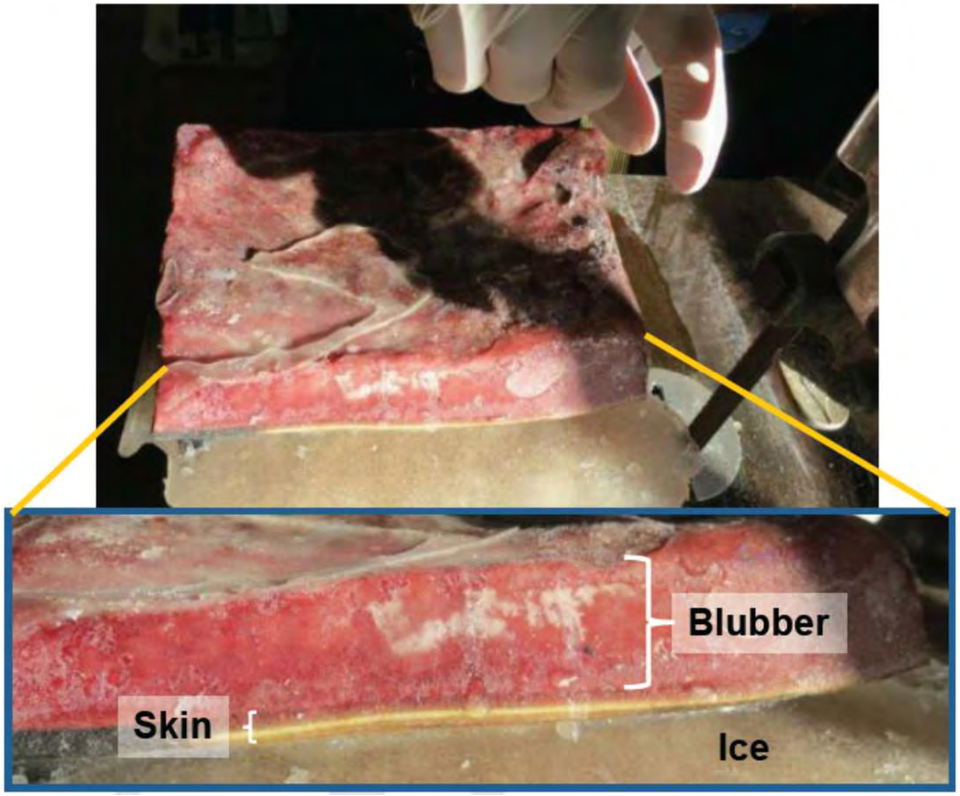
Skin Blubber







Note that materials properties are derived from testing carcass material that was partially decomposed, frozen and thawed. Thus computer simulation results are for those materials. While this is the best data that can be obtained, it may not perfectly represent the material properties and results for that of living tissue.



Technical Approach

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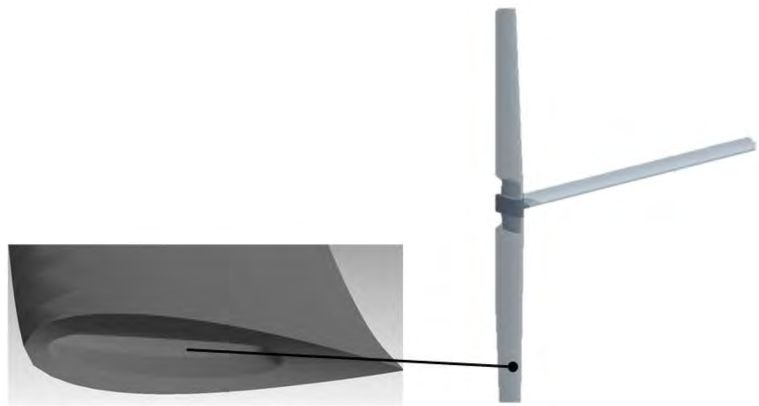
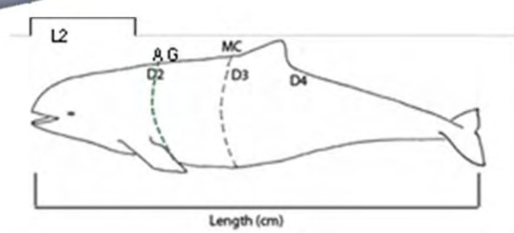
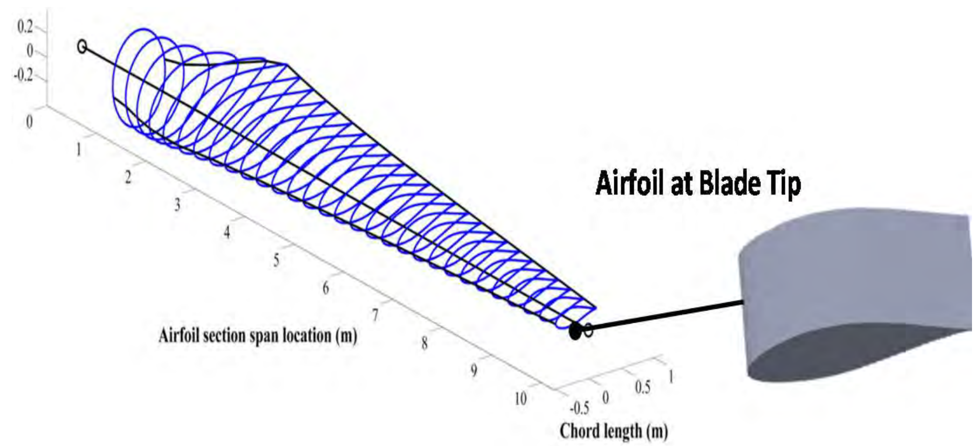
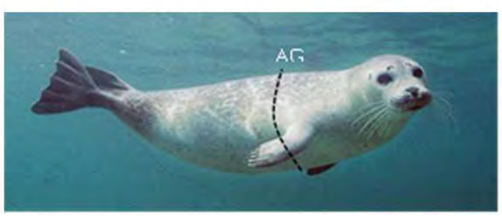
- Future SNL tasks already defined by SNL and PNNL as part of the technical approach include definition and simulation of two additional turbine types (unshrouded cross flow and axial flow) whereas PNNL has defined two additional marine mammals. The turbines will be similar to the Reference Model 1 and MCT designs. There will be 3 rotor/blade velocities simulated for each case in order to determine material deformation and damage trends.

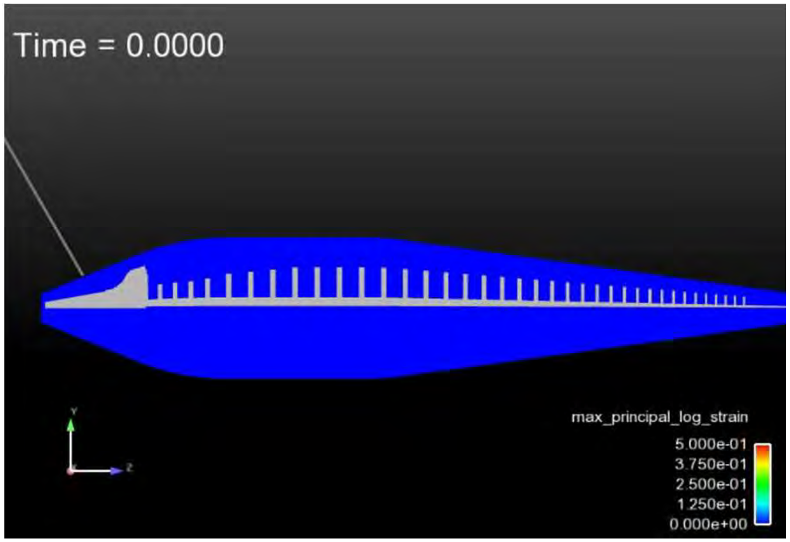








- SNL and PNNL
  - Materials testing on SRKW tissue from recently obtained carcasses
  - PRESTO simulation analysis with shrouded turbine blade strike on SRKW model
    - Evaluated at worst case impact scenario with full range of blade impact speeds for shrouded turbine
    - Shows some localized skin and blubber damage for impact speeds of 3 m/s or greater using the material properties tested
  - Biological assessment of results for SRKW
    - Includes evaluation and representation related to living tissue
    - Harmful damage is considered unlikely

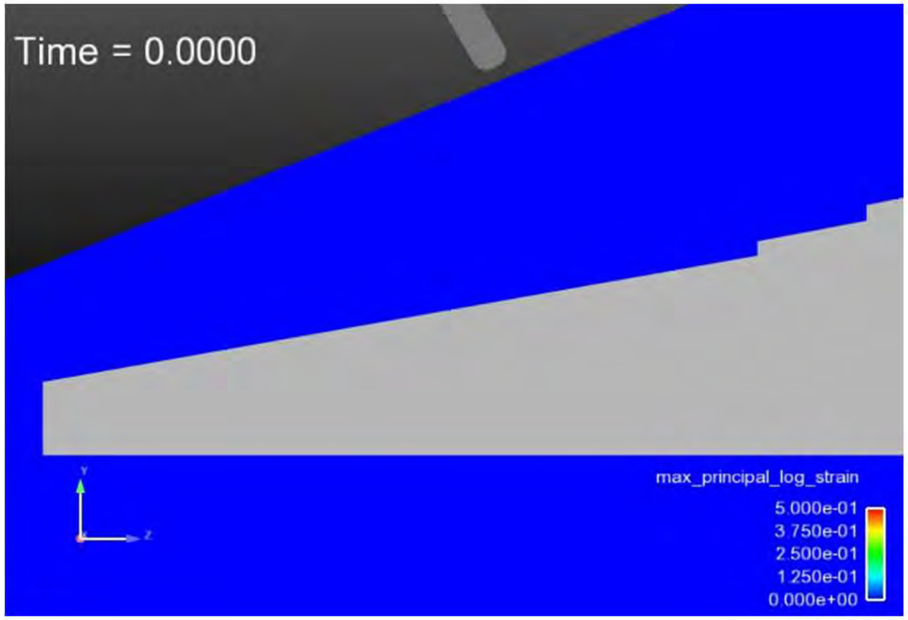


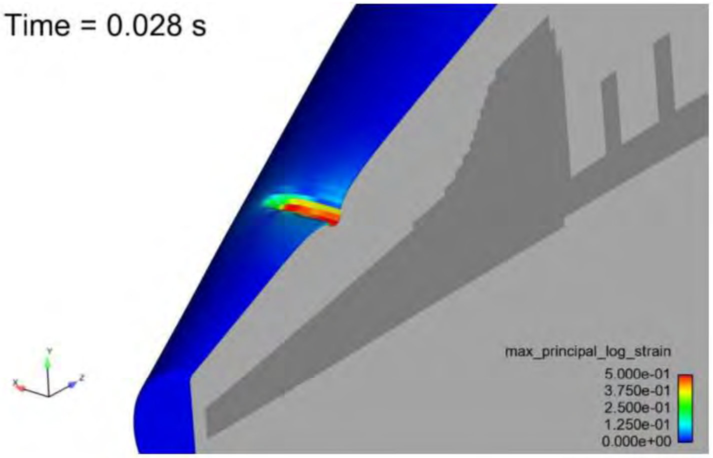
Blade Speed (m/s)	Tissue	Max Engineering Strain	Estimated Depth of Blubber Damage (cm)	Estimated Skin Damage Length (cm)
1	Skin	0.27		0
	Blubber	0.39	0	
2	Skin	0.48		0
	Blubber	0.63	1.0	
3	Skin	0.67		14
	Blubber	0.85	2.5	
4	Skin	0.92		24
	Blubber	1.00	4.0	
5	Skin	1.25		26
	Blubber	1.23	4.7	

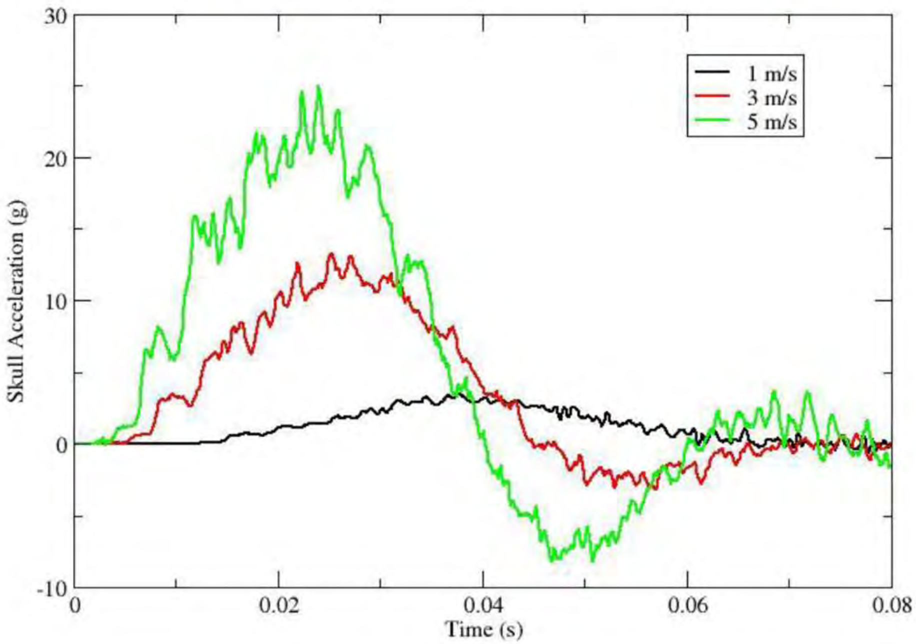
Accomplishments and Progress

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

- Additional Computational Results







Project Plan & Schedule

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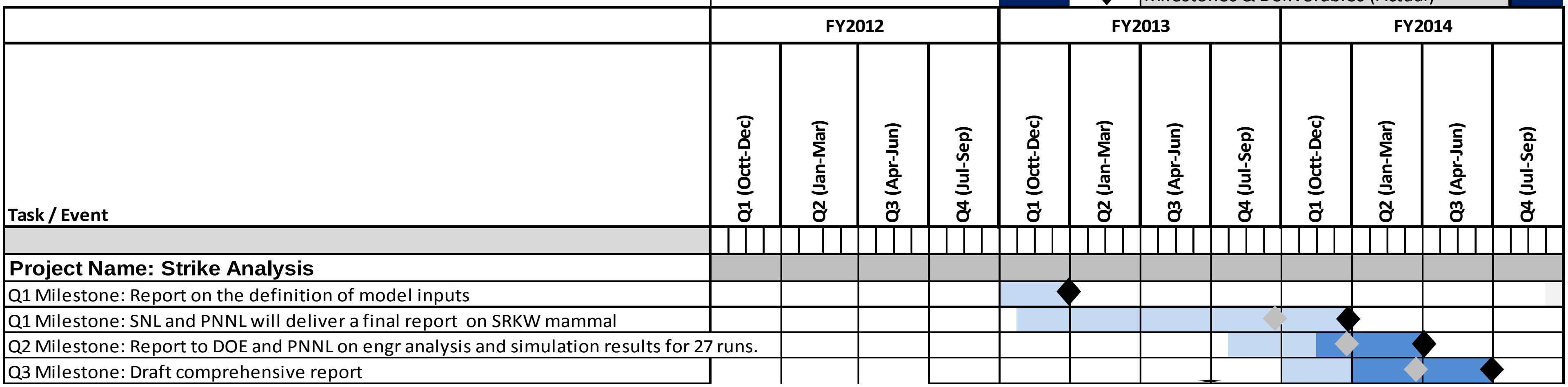
Summary		Legend
WBS Number or Agreement Number		Work completed
Project Number		Active Task
Agreement Number		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)



Subtask Milestones	Percent Complete	Date to be Completed
Q1FY13: Report on the definition of model inputs such as dimensions and material properties of both rotor and marine mammals. Report by Dec 31, 2012.	100%	12/20/12
Q4 FY13-Q1FY14: SNL and PNNL will deliver a final report including material properties, SNL engineering analysis, and damage assessment to DOE on SRKW mammal.	100%	12/31/13
Q2FY14: Draft report by SNL to DOE and PNNL on engineering analysis and simulation results for 27 runs. Report by March 31, 2014.	20%	3/31/14
Q3FY14: Draft comprehensive report including material properties, SNL engineering analysis, and damage assessment for all marine mammals will be submitted to DOE by PNNL. Report by June 31, 2014.	20%	6/30/14

Project Budget

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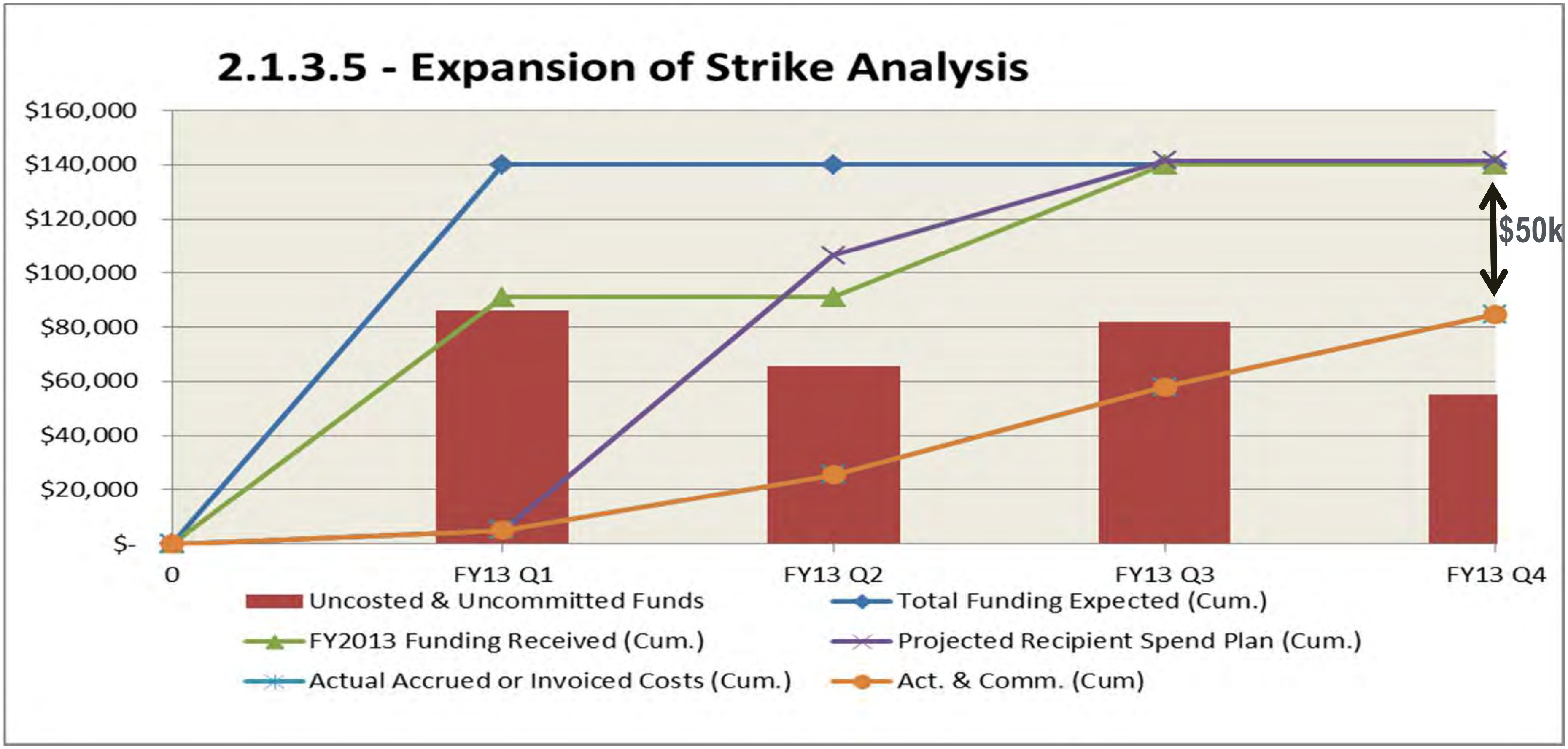

Carryover from FY13 (~$50k) plus $50k in FY14 will cover remaining computational analysis tasks

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- **Lab Partners**: PNNL
  - Defines material properties and assesses computational results for biological impact
- **Universities:** University of Washington, Friday Harbor Lab
  - Testing of tissue samples as directed by PNNL with input from SNL

Communications and Technology Transfer:

- **NDAs with OpenHydro and MCT for turbine design parameters**
- **Reporting directly to DOE**
- **Results will allow developers to design turbine and blade types that reduce or eliminate the risk of harmful impact and be accepted by regulators.**

Next Steps and Future Research

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

FY14/Current research for SNL:

- Continue analysis with PRESTO for additional marine mammals and blade/turbine types
  - In collaboration with PNNL, pursue additional materials data
  - Run 24 additional simulations (2 mammals, 3 blades, 3 velocities + 1 mammal, 2 blades, 3 velocities)

Next Steps and Future Research

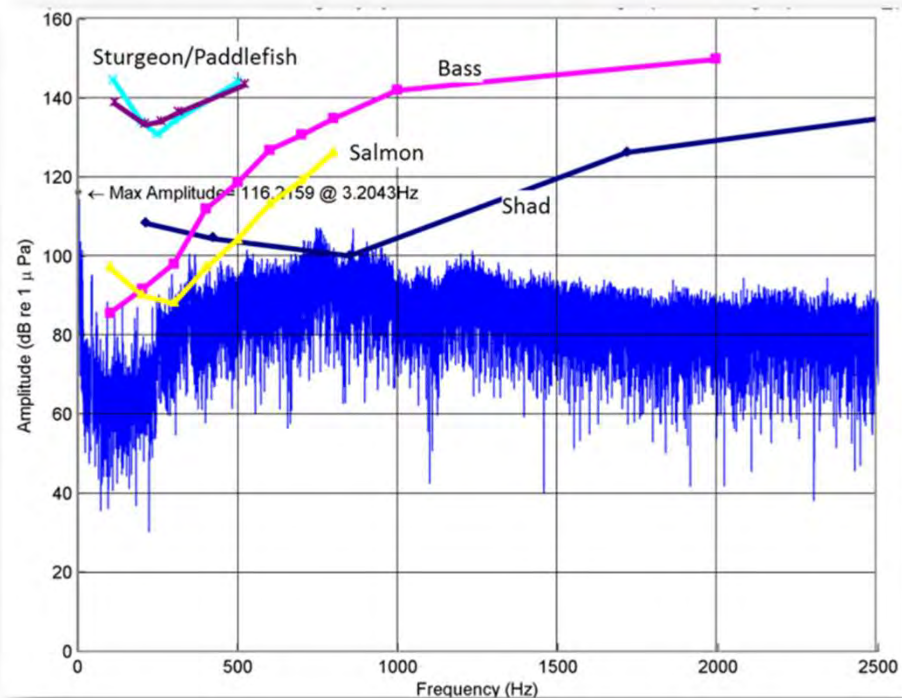
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Proposed future research:

- Obtain improved tissue and materials data
  - ➢ This information could be collected through a coordinated action to recover more biomechanical information on marine mammal tissue and bone as a routine part of the existing necropsies on animals found dead.

- Obtain data on specific properties and operational modes of turbines that could cause harm to marine animals
  - ➢ Aid in turbine design and operational modes
  - ➢ Investigate material properties that can be used on the leading edges of turbine blades to decrease potential harm.

Effects of Noise from Hydrokinetic Devices on Fish Behavior: Field Measurements and Exposure Studies



Acoustics Experimentation and Characterization

Mark Bevelhimer
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February 2014

Purpose & Objectives

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

Problem Statement: Identifying the extent and likelihood of potential environmental impacts of MHK device installation and operation is a critical part of getting test permits and licenses to operate. The amount of noise produced by a single device or an array of devices is largely unknown as are the effects that such noise might have on the behavior of resident and transient aquatic organisms.

Impact of Project: This project will produce data and analysis that will be published in an ORNL technical report and a peer-reviewed journal article that can be used by turbine builders, project developers, and environmental regulators to improve turbine design, inform site selection, and define and mitigate environmental risks.

This project aligns with the following DOE Program objectives and priorities

Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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

BACKGROUND

- Anthropogenic noise can interfere with
  1) daily movements and seasonal migration patterns,
  2) detection of prey and predators, and
  3) communication among con-specifics.
- Fish hearing thresholds can be used to indicate sound perception but not necessarily a negative impact or reaction.
- Ideally, reactions and effects should be determined directly in controlled laboratory, mesocosm, or field settings.

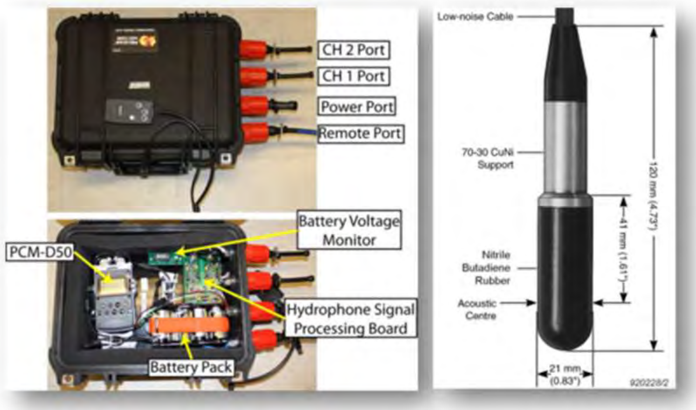
STUDY OBJECTIVES

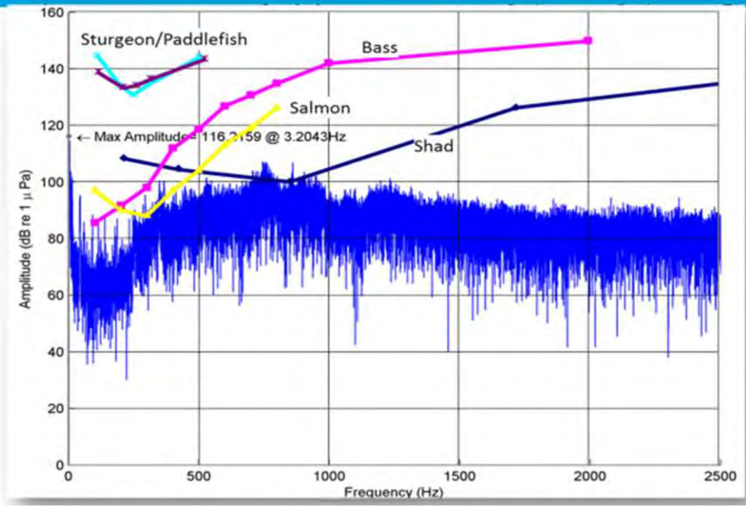
1. Characterize sound produced by hydrokinetic turbine
2. Characterize ambient sound field (natural and unnatural) for comparison
3. Conduct exposure studies to assess behavioral response of fish to turbine sound

Technical Approach

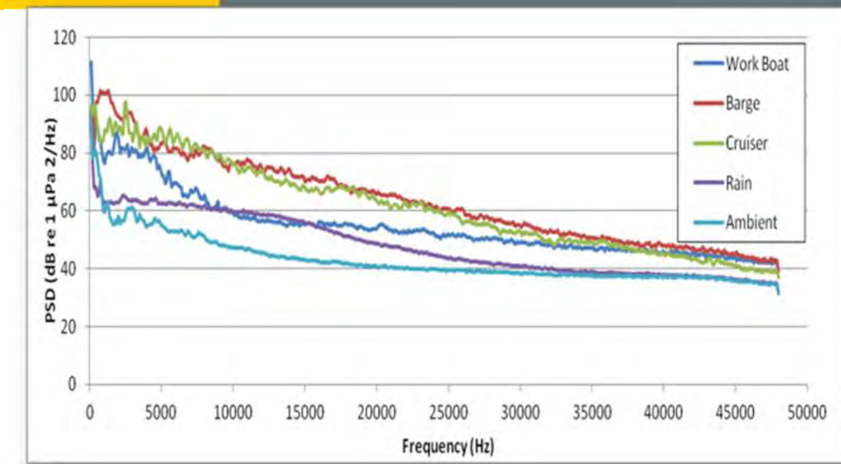
FIELD MEASUREMENT AND CHARACTERIZATION

- ORNL measured underwater sound emitted from a variety of natural (wind and rain) and anthropogenic sources (passing vessels of various sizes).
  - Controlled vessels at different distances in a lake (i.e., without ambient flow noise)
  - ‘Uncontrolled’ passing vessels on the Mississippi River
- Frequencies and sound pressure levels were compared to reported hearing sensitivities of several fish species.
- Sound pressure levels were compared to recorded hydrokinetic device sound (Ocean Renewable Power Company’s TidGen turbine).

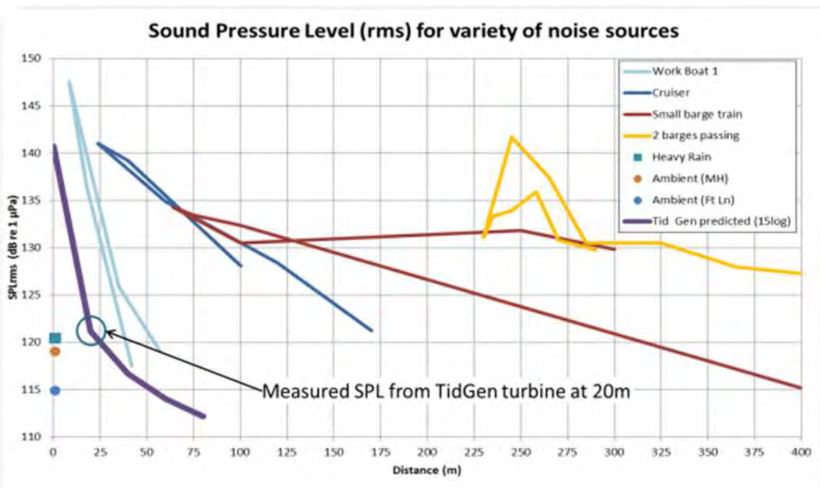




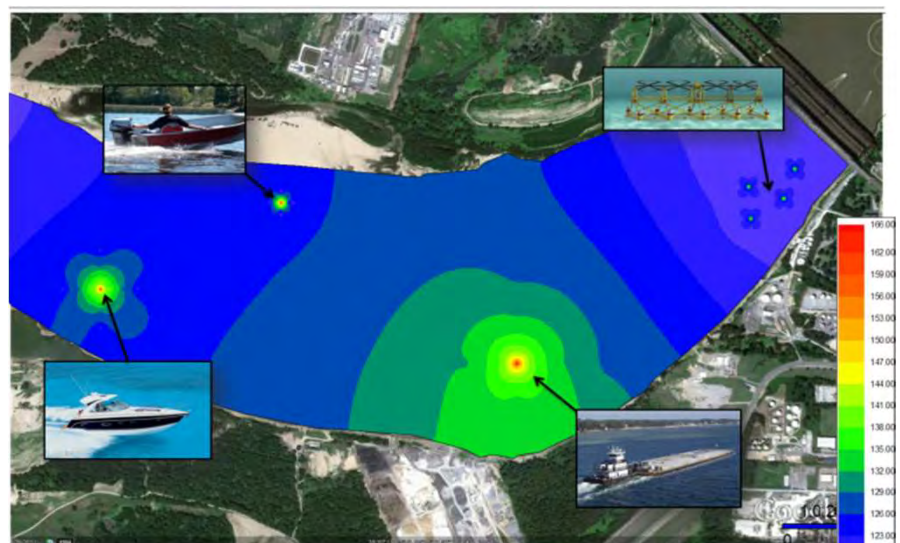
Fish hearing thresholds compared to the sound spectrum of recorded vessels.



Power spectral densities for noise sources compared.



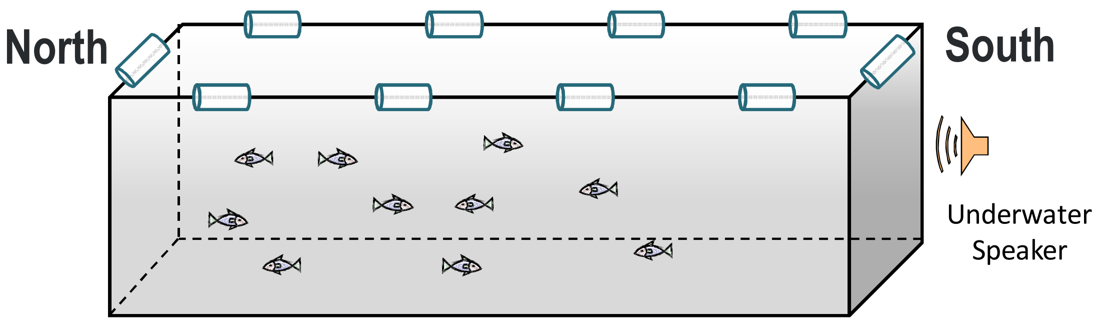
Noise levels of passing vessels at different distances compared to predicted levels of the ORPC turbine in Cobscook Bay, Maine.



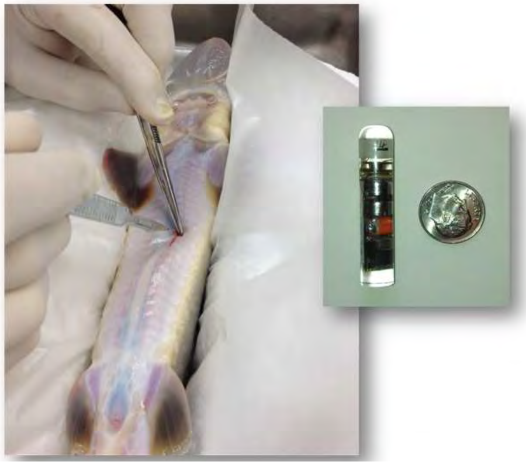
Sound map of different sources created and a 4-turbine MHK array at proposed site on the Mississippi River.

SOUND EXPOSURE STUDIES

- Behavioral response of fish to recorded HK device sound was evaluated in net pens in ORNL ponds.
- Largemouth bass, paddlefish, and pallid sturgeon (7-10 at a time).
- Pre-recorded device noise replayed at different volumes representing distances of 0-60 m from device.
- Fish movement tracked by surgically implanted transmitters and submersible acoustic receivers.
- Location data used to evaluate attraction, avoidance, and change in activity.



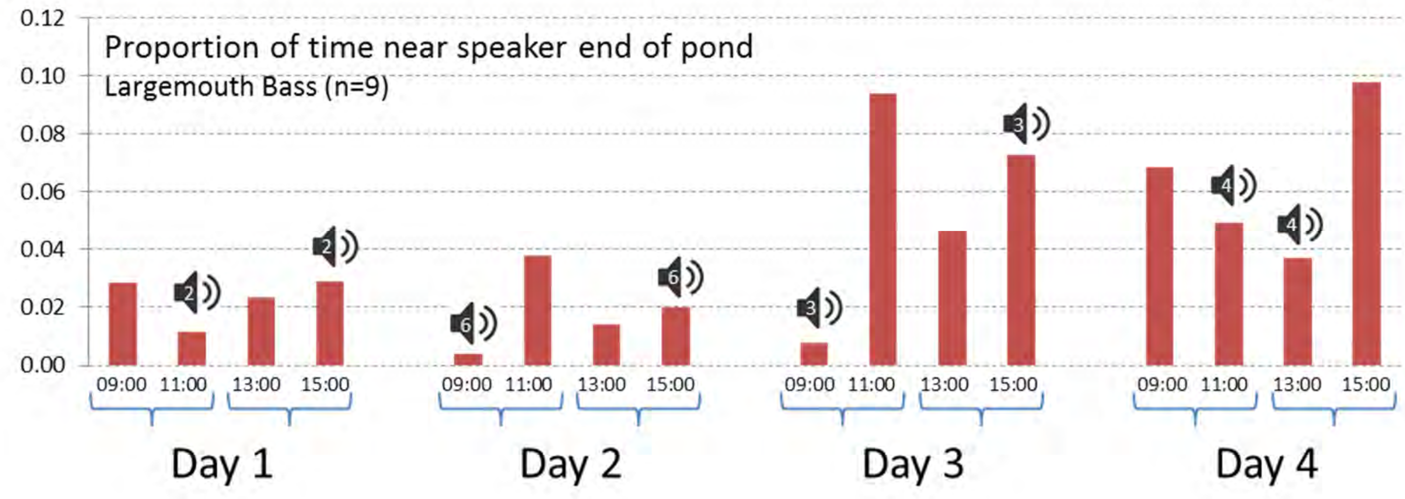
Floating Net Pen (6m wide x 20m long x 1.5m deep)



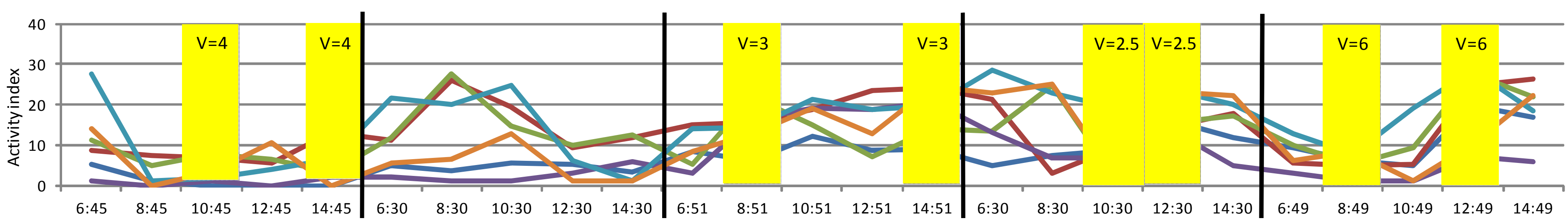
Transmitter being surgically implanted in pallid sturgeon for continuous tracking.

SOUND EXPOSURE STUDIES

- No consistent trends of attraction or avoidance to the sound at any volume.



- No consistent change in activity in response to sound at any volume.



Activity patterns of 6 paddlefish in response to random 2-hr blocks (yellow) of MHK turbine noise at 4 volumes relative to periods of no sound.

Accomplishments and Progress

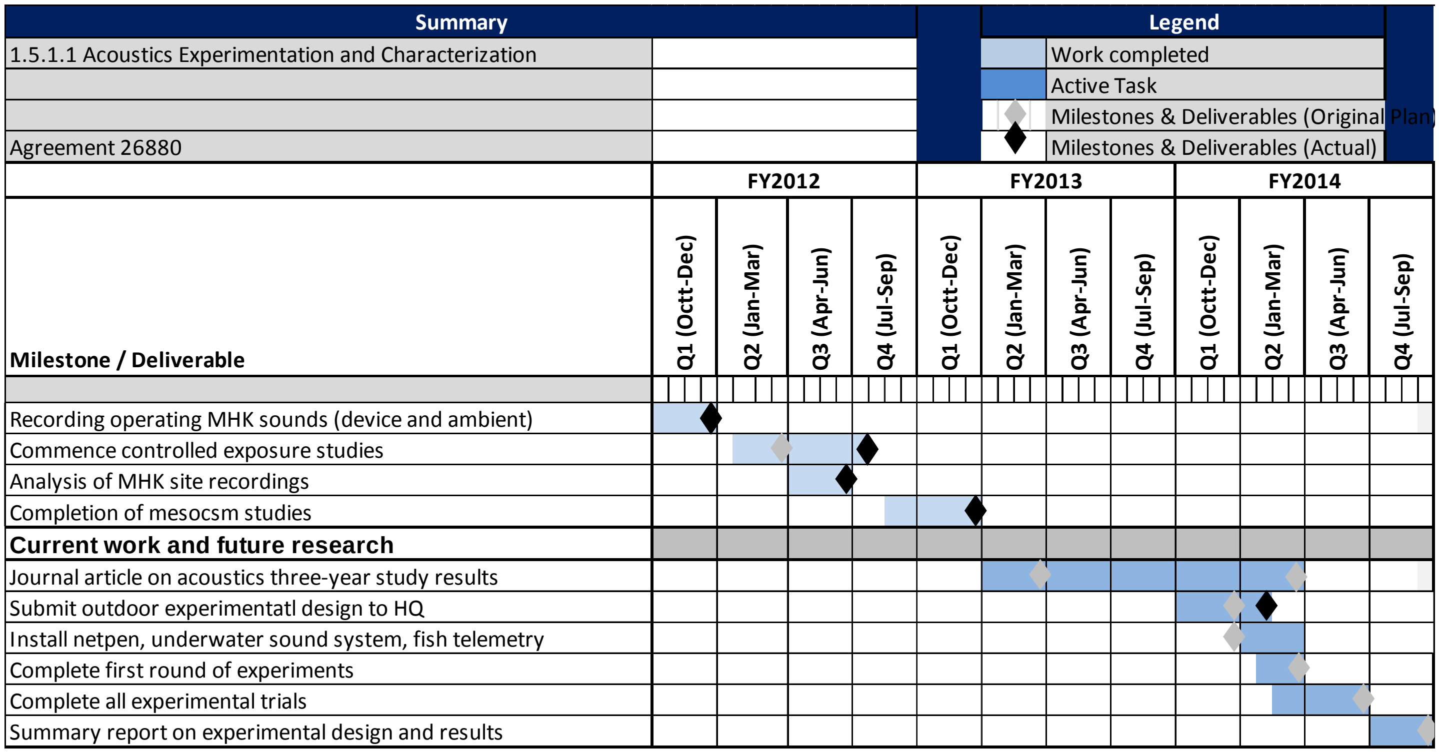
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PRELIMINARY CONCLUSIONS

- At 20 meters distance the sound created by the ORPC TidGen turbine is probably not even audible to most fish species
- Sound created by the ORPC turbine is less than a 25 HP outboard motor
- The sounds created by other anthropogenic sources in the Mississippi River far exceed that projected from an array of turbines
- During controlled pond experiments three freshwater species of fish showed no response to recorded sounds that simulated exposure to a turbine at distances of 0, 20, and 40 m.

Project Plan & Schedule

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



Comments

- Progress on FY2014 tasks was delayed early on due to delay in receiving money, but that has been rectified and completion of experiments by end of Q3 is still expected.

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$300K		$60K		$300K	

- The $60K funding in 2013 was intended to support a sound output characterization effort with the University of Washington at an operating MHK site (specifically the ORPC site in Eastport ME). The field component of this effort was postponed indefinitely when the turbine encountered technical problems. Progress was made on developing computer code to extract turbine sound from background sound from co-located recordings.

Partners, Subcontractors, and Collaborators:

- PNNL (underwater recording system; sound analysis software)
- Oak Ridge Associated Universities (student interns)
- Free Flow Power (site access at Mississippi River site; tech difficulties)
- Ocean Renewable Power Company - (site access at Eastport, Maine site; tech difficulties)

Communications and Technology Transfer:

Journal article in preparation to be submitted in March 2014

Presentations

- Global Marine Renewable Energy Conference – Washington, DC (poster)
- Hydrovision International – Denver, CO
- Southern Division American Fisheries Society – Nashville, TN
- University of Tennessee Departmental Seminar – Knoxville, TN

Next Steps and Future Research

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

FY14/Current research:

Second round of mesocosm exposure studies

- Different species
- Additional turbine recordings

Sound output characterization of simulated turbine array

- Multiple underwater speakers
- Recordings from multiple distances

Proposed future research:

Current funding ends in FY2014. Need for additional studies will be assessed after conclusion of 2014 experiments in discussions with DOE managers.

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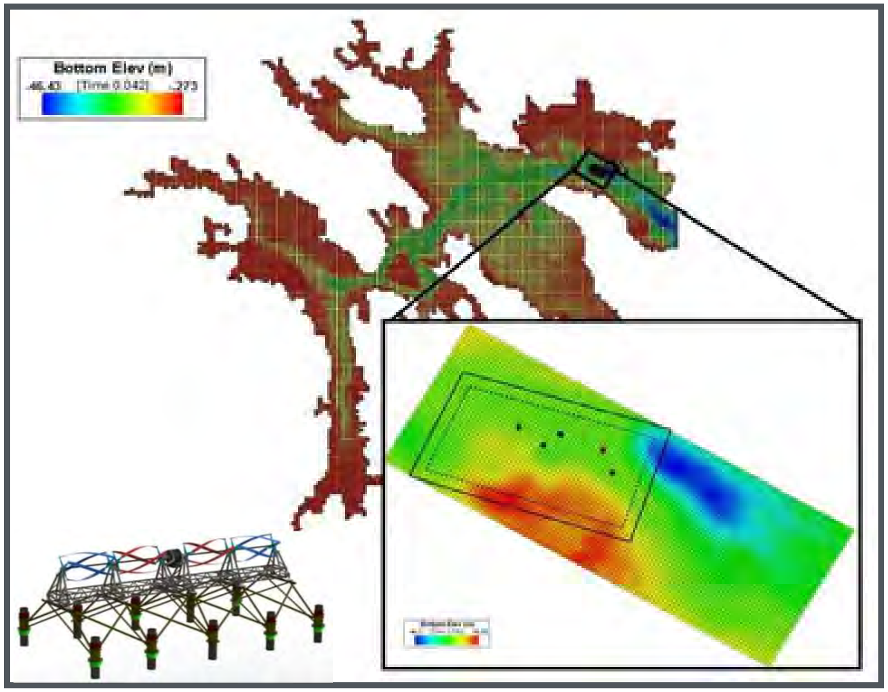

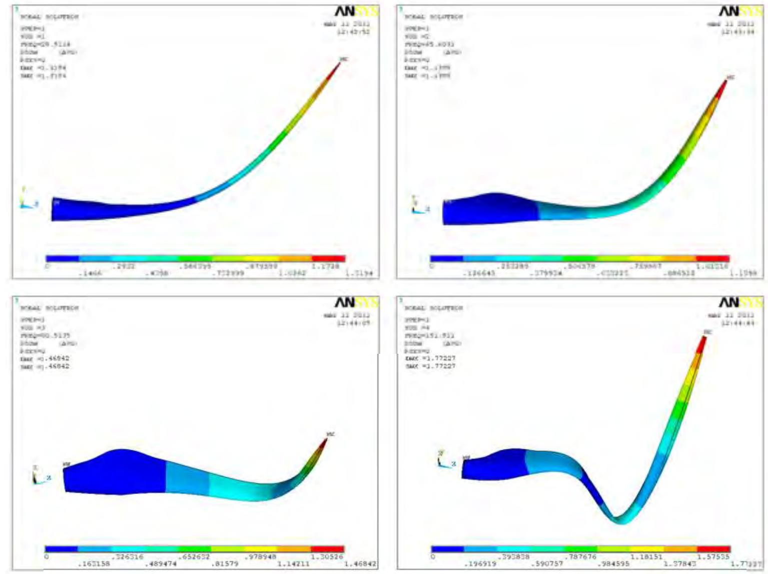

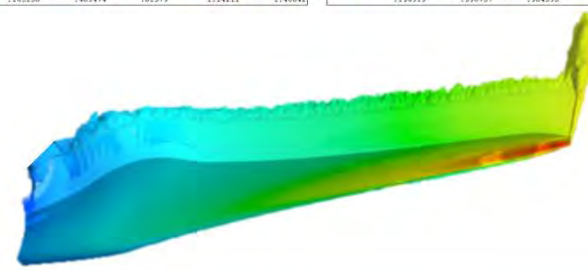

Tidal Modeling, User Manual, Validation, and Acoustics Package

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February 27, 2014

Purpose & Objectives

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

Problem Statement:

- Noise and disruption of natural flow processes are key environmental regulatory considerations
- Developers must balance power production with environmental compliance.

Impact of Project:

- Reduce levelized cost of energy (LCOE) and accelerate permitting by balancing environmental vs. performance considerations
- Product: MHK-specific tools to enable accurate environmental evaluation and responsible device design while maximizing power production and minimizing environmental effects.

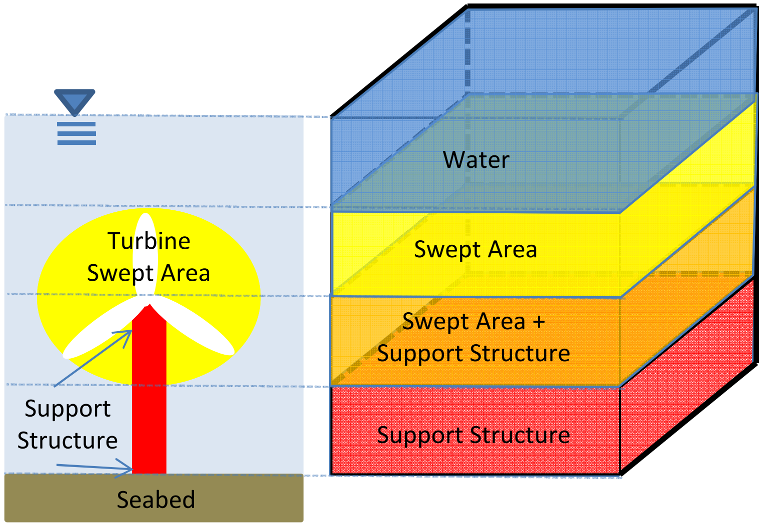
Aligns with these DOE Program objectives and priorities:

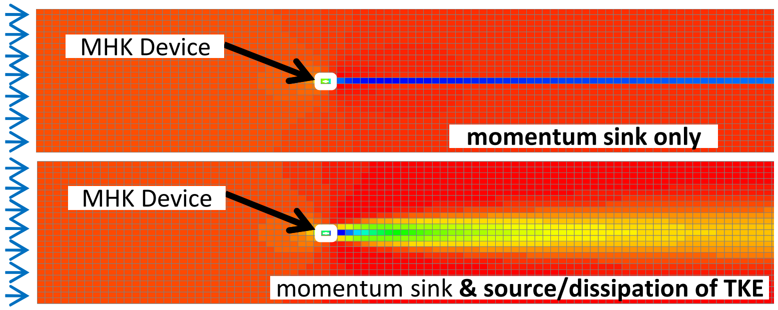
- Reduce deployment barriers and environmental impacts of MHK technologies
- Advance the state of MHK technology
- Characterize and increase access to high resource sites

Allow developers to **design quieter devices** and support **optimal device placement** to reduce LCOE and accelerate deployment

Technical Approach

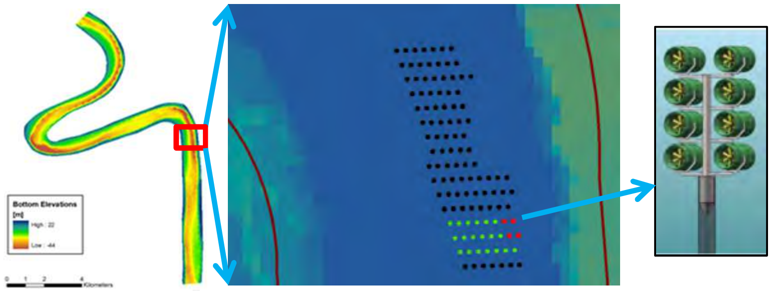
- SNL-EFDC: Optimal siting of CEC devices to maximize array power production and minimize environmental effects
  - Enhance highly respected US EPA code to include:
    - **CEC module (simulates energy conversion and wake generation - dissipation)**
    - Sediment dynamics module (3D sediment bed, morphological feedback, deposition/consolidation)
    - Augmented water quality module (algal growth)
  - Validate against available data sets
  - Apply SNL-EFDC to evaluate CEC array size vs. environmental effects
  - Develop array optimization framework (3D siting)
  - Technical Outreach
    - User's Manual, Training courses and materials





Develop, apply, and enable industry use of MHK-specific assessment tools/techniques

Leverage decades of hydrodynamic model development



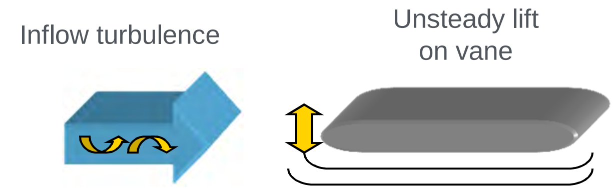
Technical Approach

Acoustic Models

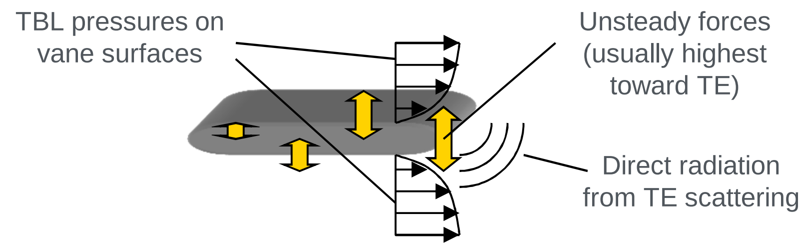
- MHK Noise Generation
  - Build upon pre-existing models to predict marine propeller noise (CHAMP using BEM)
    - BEM leverages structural and fluids analysis already in the device design process
  - Predict noise spectra (CEC devices first)
  - Compare numerical results with test data
- MHK Noise Propagation (begun August, 2013)
  - Evaluate pre-existing propagation models
  - Develop acoustic propagation code
    - Integrate with SNL-EFDC (represent marine env.)
    - Incorporate bathymetry, seabed & sea surface properties, salinity, temperature, flow, etc…
  - Compare predictions with data/analytical solutions
  - Evaluate sound levels vs MHK device location(s) and acoustic generation

Develop 'first ever' MHK-specific acoustic evaluation tools that leverage decades of related research

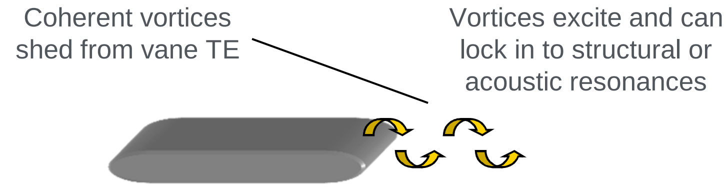
Leading Edge Noise (Turbulence Ingestion)



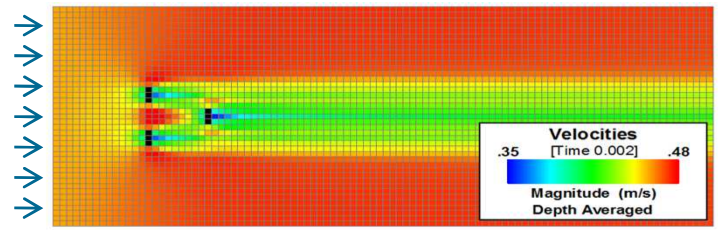
Trailing Edge Noise

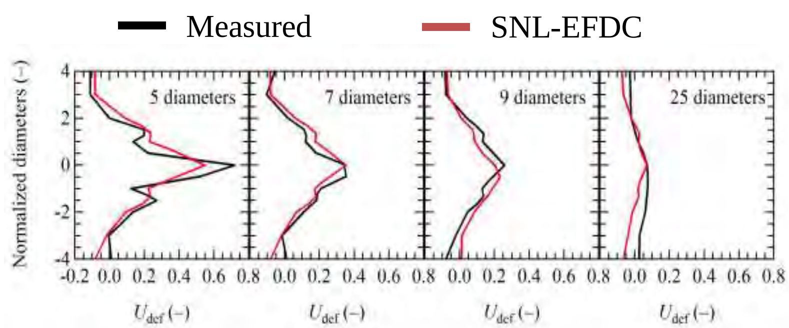


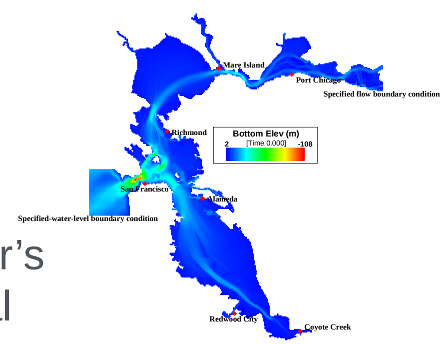
Vortex Shedding (VS) Noise

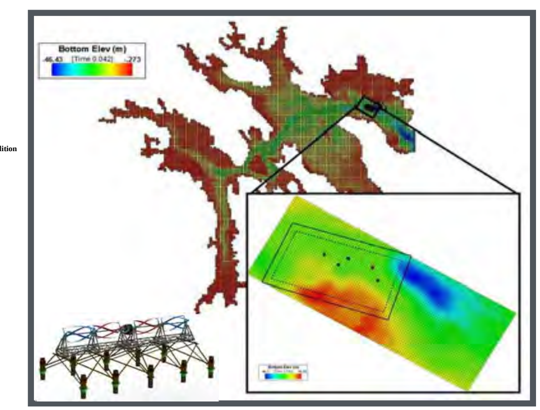


- SNL-EFDC
  - Validation against flume-scale turbine tests
  - Application to San Francisco Bay
    - Evaluated **tidal flushing and range** for 30, 150, & 300 CEC arrays. **Minor effects** observed for **largest CEC array**.
  - Application to Mississippi River
    - Evaluated **performance, flood hazard, and sedimentation** concerns for 12, 132, 534 CEC arrays (FFP)
  - Application to Cobscook Bay
    - Evaluated **tidal flushing and range** for 5 CEC array (ORPC). Almost **no discernible effects**.
    - **ORPC included SNL report in FERC application**
  - Developed CEC optimization framework
    - Applied to Cobscook Bay and demonstrated ~20% increase in power generation over baseline layout
  - Completed 4 training courses:
    - Verdant Power
    - Ocean Renewable Power Company
    - Free Flow Power
    - Group of Navy, FERC, BOEM, and DOE
  - Completed 1st edition of SNL-EFDC User's Manual and Self-Guided training material









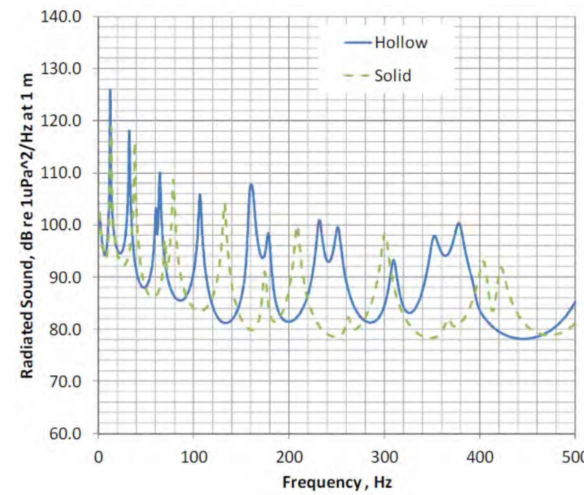
SNL-EFDC is effective and actively being used by industry

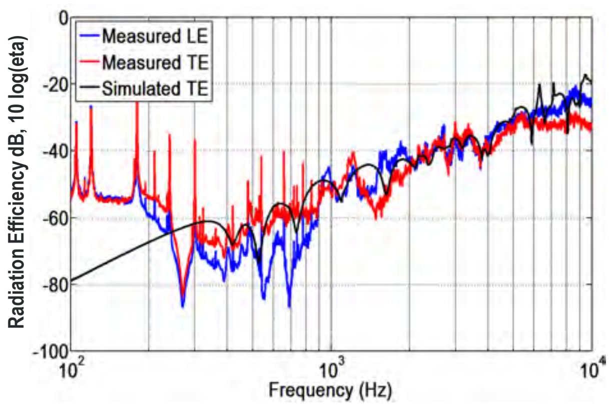
Accomplishments and Progress

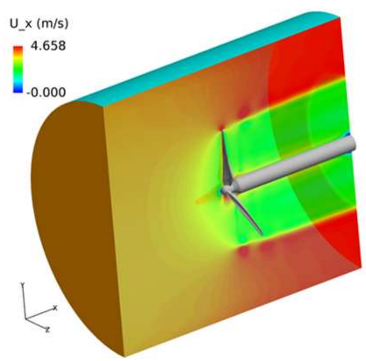
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

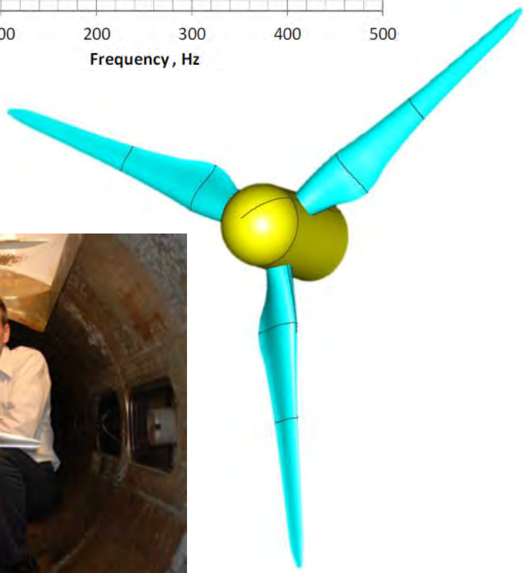
dll3

- Acoustic Models
  - Predicted acoustic signature for 5-m, 3-bladed, horizontal axis CEC device
    - Hollow and solid rotor
  - Measured noise generation around a scaled CEC device (described above)
  - Initial comparison of noise generation model against scaled turbine tests (of device above)
    - Vibration forcing and noise match experiment
    - Trailing edge forcing function is under predicted which leads to under predicted noise









Acoustic models are progressing on schedule

Slide 6

dll3 Mention how successful the ARL test was. Developers are clamoring for the results. The rotor actually performed better than all other MHK rotors tested at that facility (check with Arnie).
Daniel Laird, 1/12/2014

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1	FY2012 Q2	FY2012 Q3	FY2012 Q4	FY2013 Q1	FY2013 Q2	FY2013 Q3	FY2013 Q4	FY2014 Q1	FY2014 Q2	FY2014 Q3	FY2014 Q4
Project Name: Wind Energy Forecasting Methods and Validation for Tall Turbine Resource Assessment												
Q1 Milestone: SNL-EFDC validation against lab-scale single turbine/disk												
Q2 Milestone: Representative MHK turbine acoustic predictions (full-scale)												
Q3 Milestone: SNL-EFDC validation against lab-scale array												
Q4 MS: Balancing CEC array efficiency and environmental effects at realworld sites												
Q1 Milestone: Develop local-scale refined grid model of Cobscook Bay												
Q2 Milestone: Evaluate local environmental effects vs. power production (SNL-EFDC)												
Q3 Milestone: Comparison of noise generation data and numerical predictions												
Q4 Milestone: Complete SNL-EFDC training courses and Draft User's Manual												
Q4 Milestone: Acoustic propagation modeling literature review												
Q4 Milestone: Complete first iteration of CEC Array Optimization Framework												
Current work and future research												
Acoustic propagation model selection and development												
Acoustic generation model refinement and comparison to test data												
SNL-EFDC technical outreach and training material development												

Comments

- Project initiated 2010 – Ongoing
- SNL-EFDC: All milestones completed on time
- Acoustics: Model to data comparison was 1Q behind (now caught up).
  - Delays in testing and staff turnover

All work is progressing according to plan

Project Budget

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

	Budget History					
	FY2012		FY2013		FY2014	
	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
SNL-EFDC (multiple tasks)	$410K	-	$625K	-	$360K	-
Acoustics	$85K	-	$125K	-	$250K	-
Total	$505K	-	$740K	-	$610K	-

- No variances from project budget
- FY12 costed 100% of Spend Plan
- FY13 costed 99% of Spend Plan

Annual costs have consistently met Spend Plan targets

Research Integration & Collaboration

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

Partners, Subcontractors, and Collaborators:

Lab Partners: PNNL, ORNL, and ANL.

- Direct collaboration between FY10 - FY12, as part of a collaborative FOA award
- FY13 collaborations on MHK environmental considerations

Contractors: Sea Engineering

- Supports SNL-EFDC model development, application, and technical outreach

Universities: Penn State University – Applied Research Lab

- Supports MHK-specific acoustic generation model development and testing

Communications and Technology Transfer:

SNL-EFDC:

- Directly Distributed to ~50 MHK stakeholders (developers, regulators, and researchers)
- Web portal for broader distribution (OPEN EI, SNL website)
- 4 - hands on training courses; 1 – webinar/seminar hosted by FERC/DOE
- Presented at several conferences: GMREC, EWTEC, Oceans, AGU
- Publications: 9 technical reports, 3 conference proceedings, 1 journal publication

Acoustics Modeling:

- 4 technical reports, 2 conference proceedings, 2 conference presentations

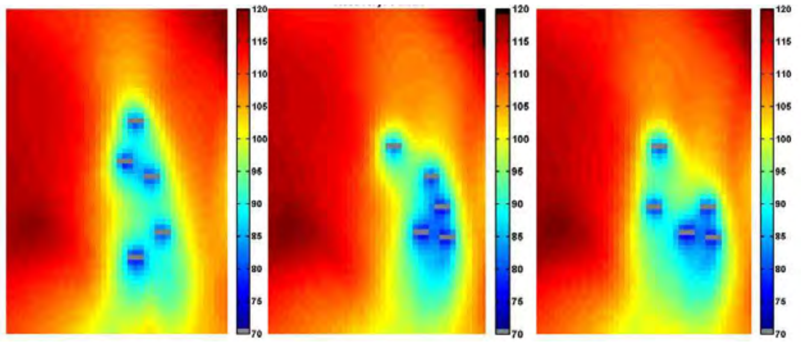
Publish, Pro-active outreach and web portal for broader distribution

Next Steps and Future Research

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

FY14/Current research:

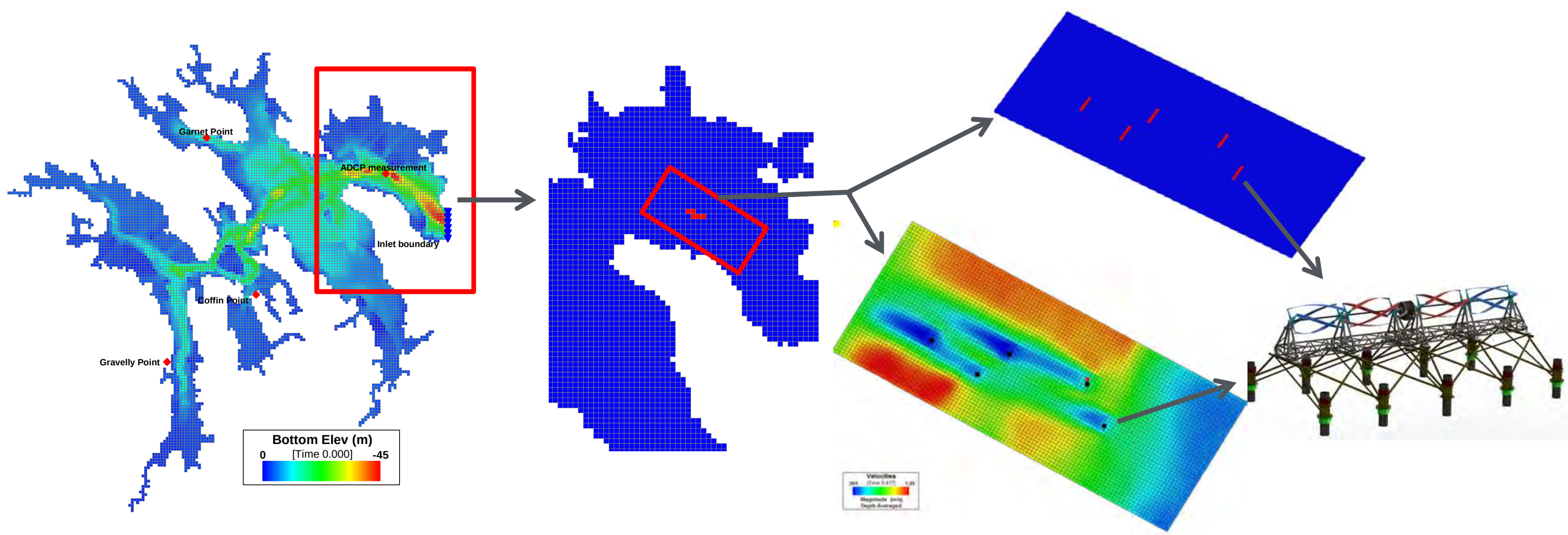
- SNL-EFDC
    - Establish web portal for access to code and relevant documents
    - Develop and distribute training materials and manuals
    - Provide hands-on and web based training courses
    - Continue model validation against new test cases
- Acoustics (multi-year effort)
    - Use experience with proprietary BEM noise generation tool to develop an open source version
    - Modify a suitable acoustic propagation source code and integrate with SNL-EFDC to represent marine environment
    - Initiate validation/verification studies for both models

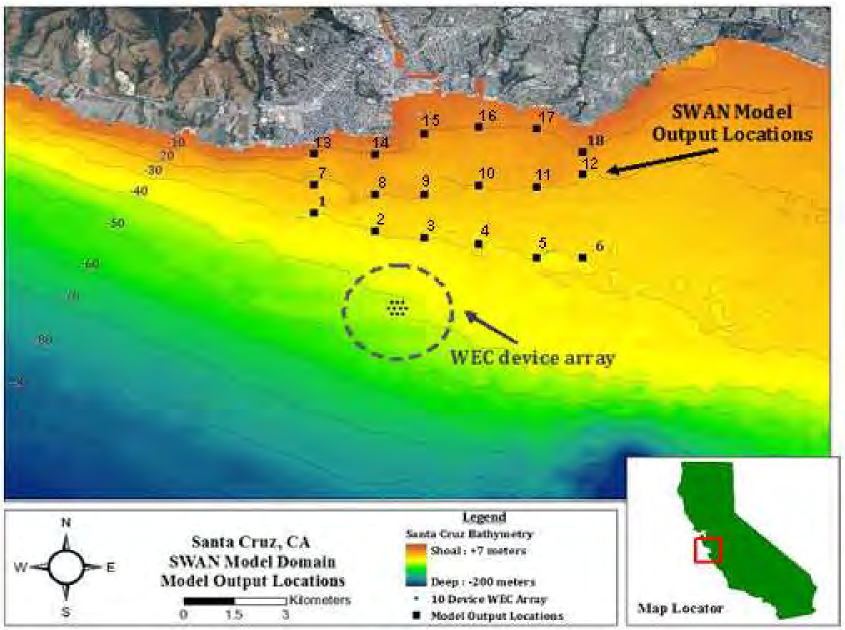


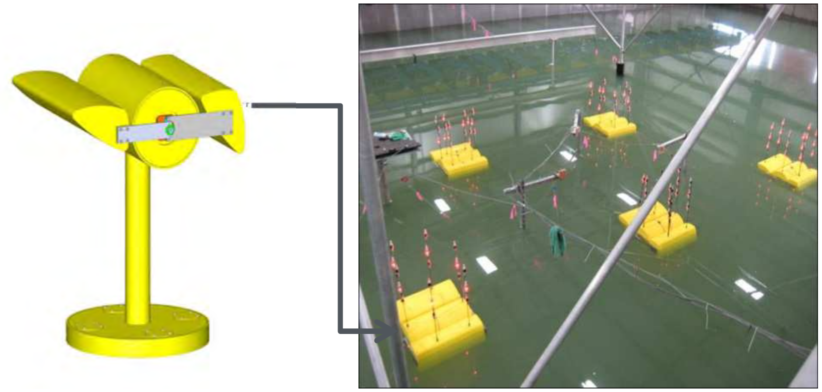
Increase functionality, availability, ease of use, and confidence in developed tools

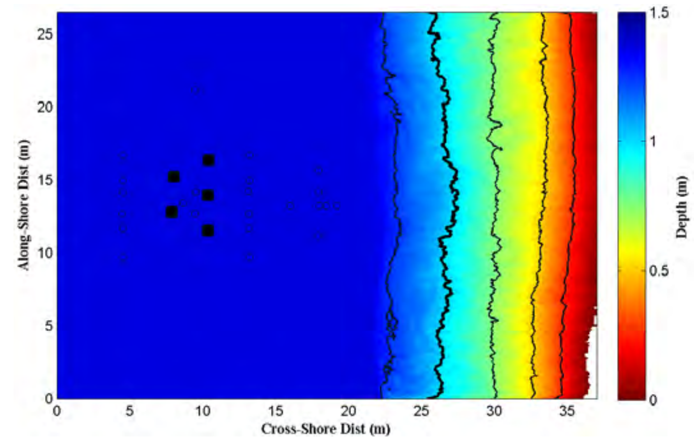
Proposed future research:

- Measure flow and noise around field deployed MHK devices
  - Benefits- Model validation and increased confidence in tools developed
- Refine and automate SNL-EFDC array optimization framework
  - Benefits- User friendly and speed up array optimization









WEC Array Modeling Improvements to Assess Far-Field Environmental Effects

Jesse Roberts

Sandia National Laboratories

jdrober@sandia.gov (505) 844 5730

Thursday 2/28/2014

Purpose & Objectives

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

Problem Statement:

- US permitting requires projects to perform an Environmental Assessment, proving little to no environmental impact
  - No existing deployments {means no industry/historic data to leverage}
  - Stakeholders can halt projects
  - **Must rely on numerical models**
- Large-scale wave models are currently limited in their ability to model changes in propagation due to Wave Energy Converters (WECs)
  - Do not accurately model energy removal

Project Impact:

- **Accelerate WEC deployments** by accurately informing developers and regulators on site-specific available wave power and realistic generation potential based on quantifiable environmental effects
- Product: **SNL-SWAN** will be a publicly available, verified and validated WEC friendly large-scale wave propagation model to assess environmental impact vs. WEC array performance

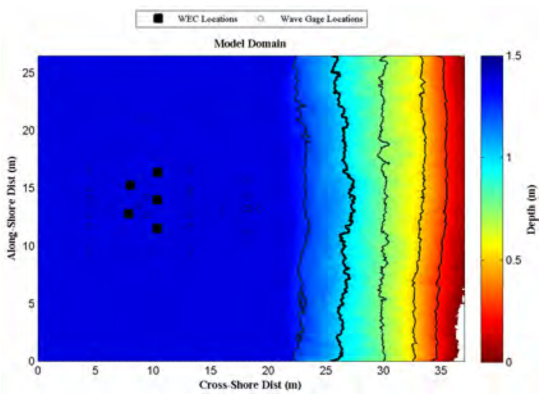
DOE Program Alignment for MHK:

- Reduce deployment barriers and environmental impacts of MHK technologies
- Characterize and increase access to high resource sites

SNL-SWAN Development:

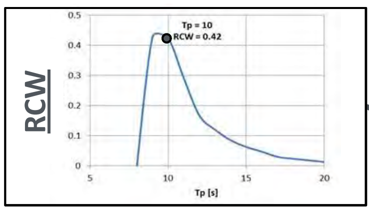
- Evaluate existing WEC array modeling tools & techniques
  - o SWAN is industry standard, freely available, open source, accounts for bathymetry and wave propagation
- Create alpha version of SNL-SWAN'WEC Module'
  - o Energy sink based on WEC power performance
- Verify code functionality
- Validate code by comparisons to experimental data from OSU tsunami wave basin
  - o 1/33 scale Manta 3.1 (CPT)
  - o 1, 3, & 5 WEC arrays
- Refine SNL-SWAN as needed (beta version)

OSU TWB SWAN Model Domain



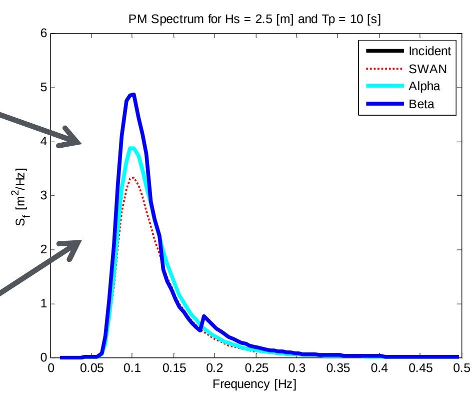
OSU TWB Array Experiments

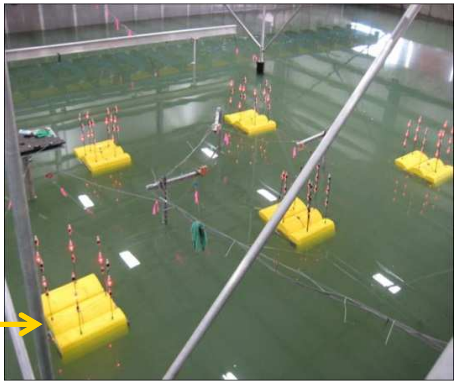
RCW



Power Matrix

		Tp (s)							
		6	7	8	9	10	11	12	13
Hs (m)	0.5	0.49	0.67	0.69	0.48	0.37	0.26	0.18	0.16
	1	1.88	2.26	2.10	1.49	1.15	0.79	0.66	0.52
	1.5	3.69	4.43	4.38	2.60	2.24	1.54	1.16	0.88
	2	6.03	8.04	6.60	4.21	[illegible]	2.35	2.09	1.62
	2.5	9.67	10.47	9.05	6.65	4.71	3.32	2.79	2.30
	3	12.77	14.88	13.09	8.44	6.08	4.66	3.75	3.02
	3.5	17.44	20.13	16.31	11.71	8.13	5.93	4.62	3.71
	4	22.15	21.61	20.85	14.22	10.43	7.67	5.77	4.91
	4.5	25.82	29.85	23.47	15.15	12.09	9.46	7.59	6.18
	5	31.85	37.05	27.79	19.44	13.64	11.48	8.46	6.71
	5.5	37.58	38.19	32.32	24.12	17.18	13.72	9.25	8.06

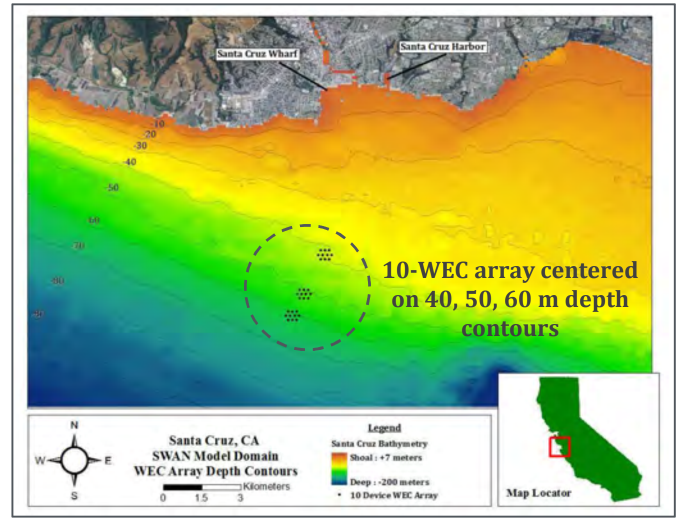


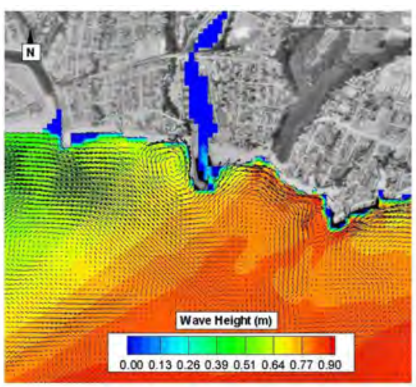


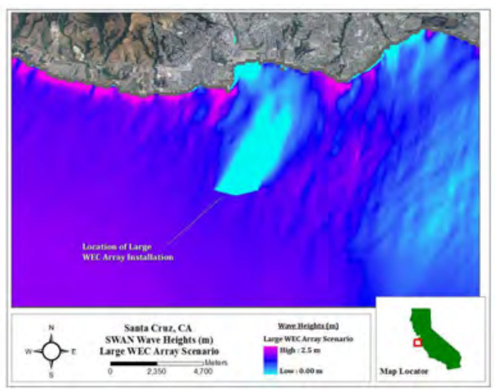
Develop accurate model to assess WEC influence on wave propagation

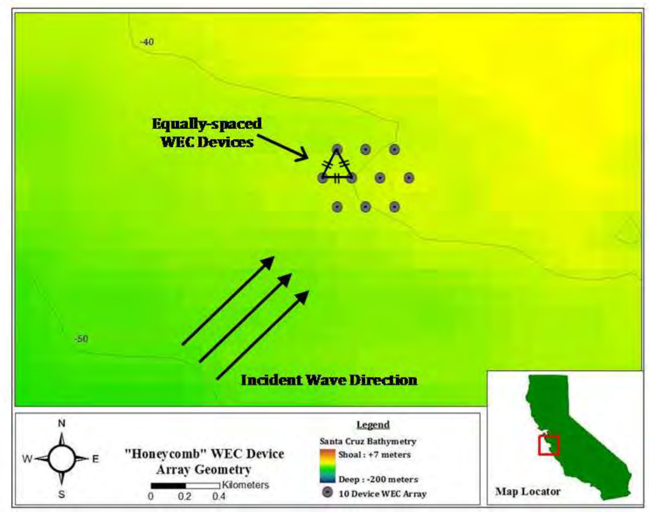
Environmental Evaluation:

- Evaluate *baseline* SWAN to model WEC arrays
    - Develop and validate wave model of real world site (*without* WECs)
    - Determine wave & obstruction parameter sensitivity (*with* WECs)
    - Evaluate WEC array size, location, and spacing
    - Link SWAN with SNL-EFDC to evaluate WEC changes to circulation and sediment transport
- Apply alpha version of SNL-SWAN
    - Provide usability feedback
    - Evaluate numerous WEC device types using realistic power data





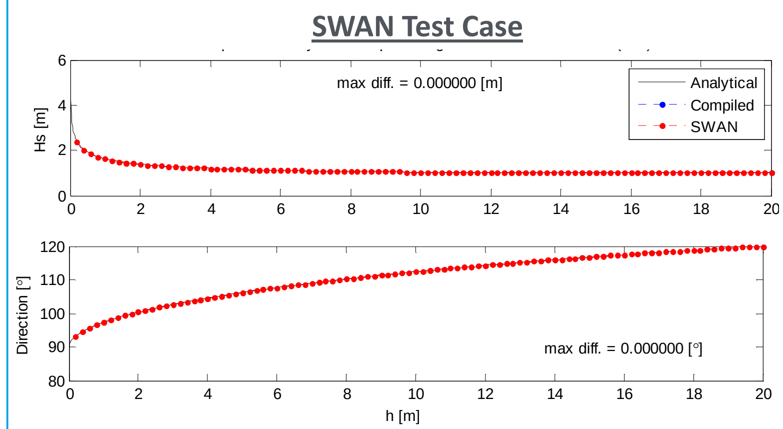




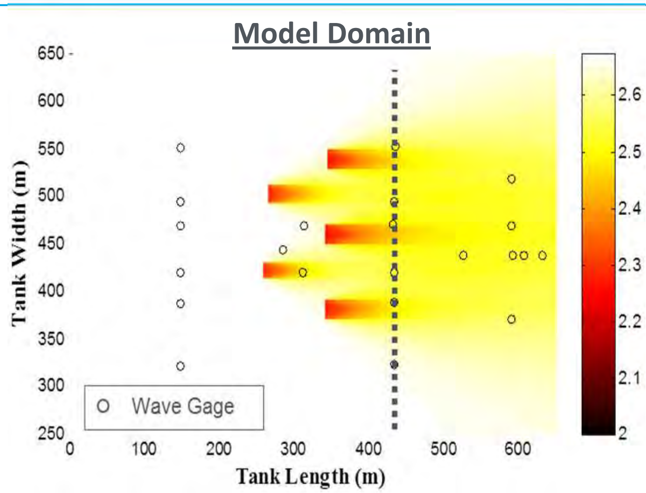
Develop relationship between WEC array configuration and environmental effects

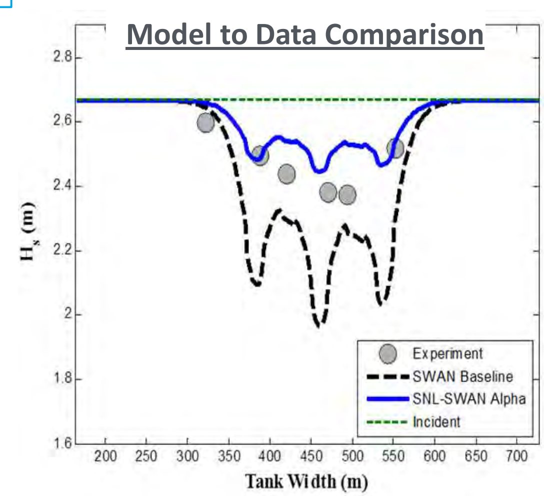
SNL-SWAN Development:

- Completed base SWAN model to data comparison
  - o Indicated need for 'WEC module'
- Created and verified *alpha version* of SNL-SWAN
  - o Baseline SWAN obstacle
  - o Relative capture width curve, based on Hs
  - o Power matrix, based on Hs and Tp
- Completed SNL-SWAN model to data comparison
  - o Indicated need for a *beta version* of SNL-SWAN
  - o Energy absorption vs. frequency bin
- Completed plan for development of *beta version*



❖ **Test data and model results presented at field-scale**





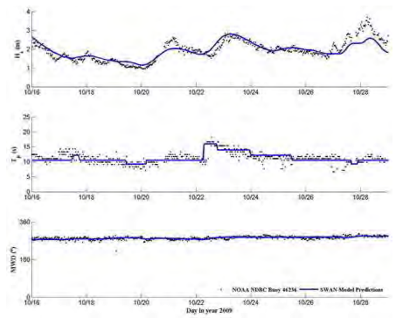
SNL-SWAN alpha version completed with verification and experimental comparison

Environmental Evaluation:

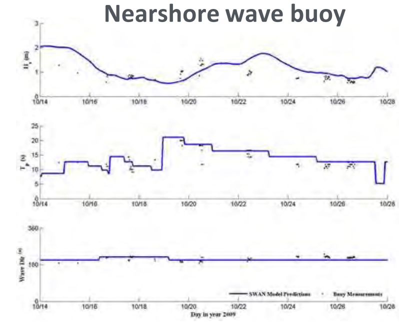
- Validated baseline wave and circulation model of Monterey Bay
  - o Leveraged field data collection from other sources
- Completed over 600 sensitivity model runs:
  - o Evaluated wave and obstruction parameters
    - ✓ Transmission coefficient dominates Hs changes
  - o Evaluated WEC array size, location, and spacing
    - ✓ 10, 50, 100, and 200 WEC devices in array
    - ✓ 40, 50, 60 m contour lines (~4-5 miles offshore)
    - ✓ Dense arrays have larger local effect
    - ✓ Porous arrays show effects further from array

Monterey Bay Model Validation

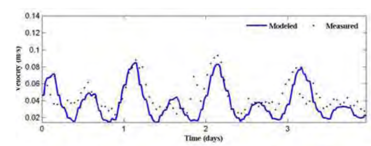
Offshore wave buoy



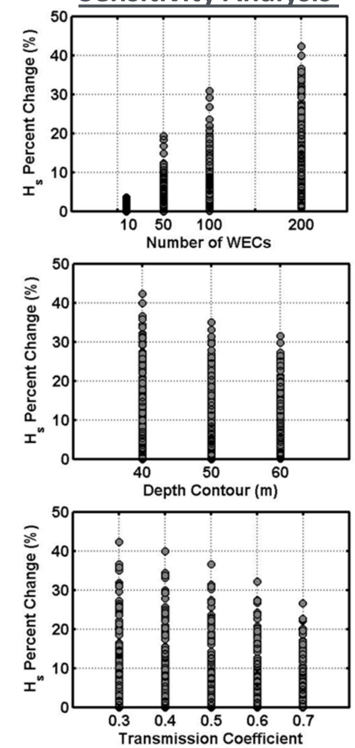
Nearshore wave buoy

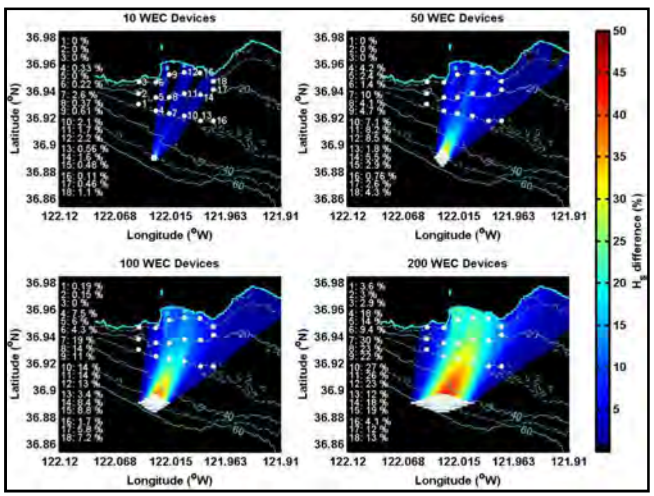


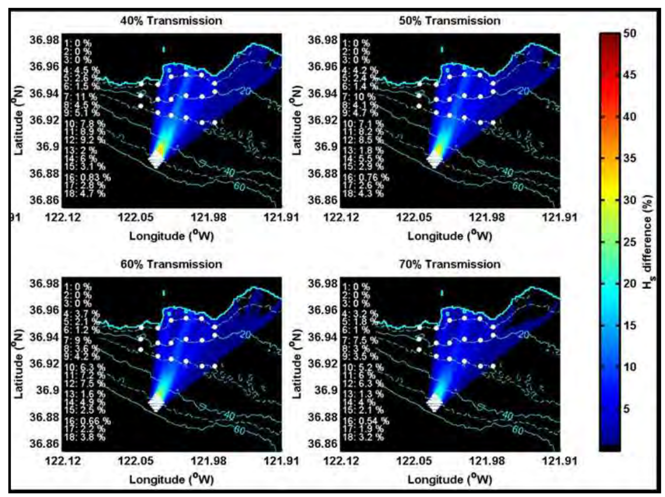
Nearshore velocity via ADCP



Sensitivity Analysis



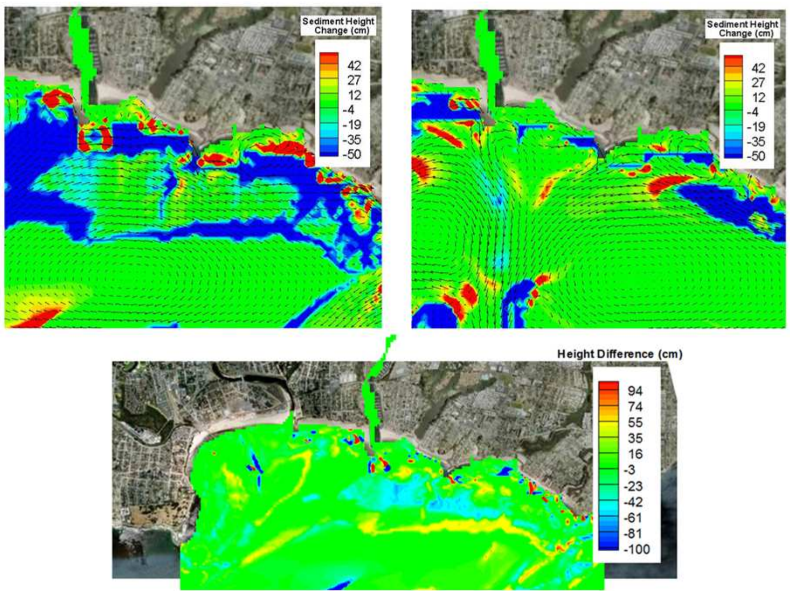


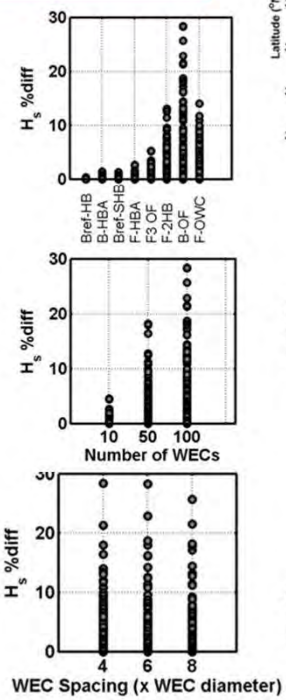


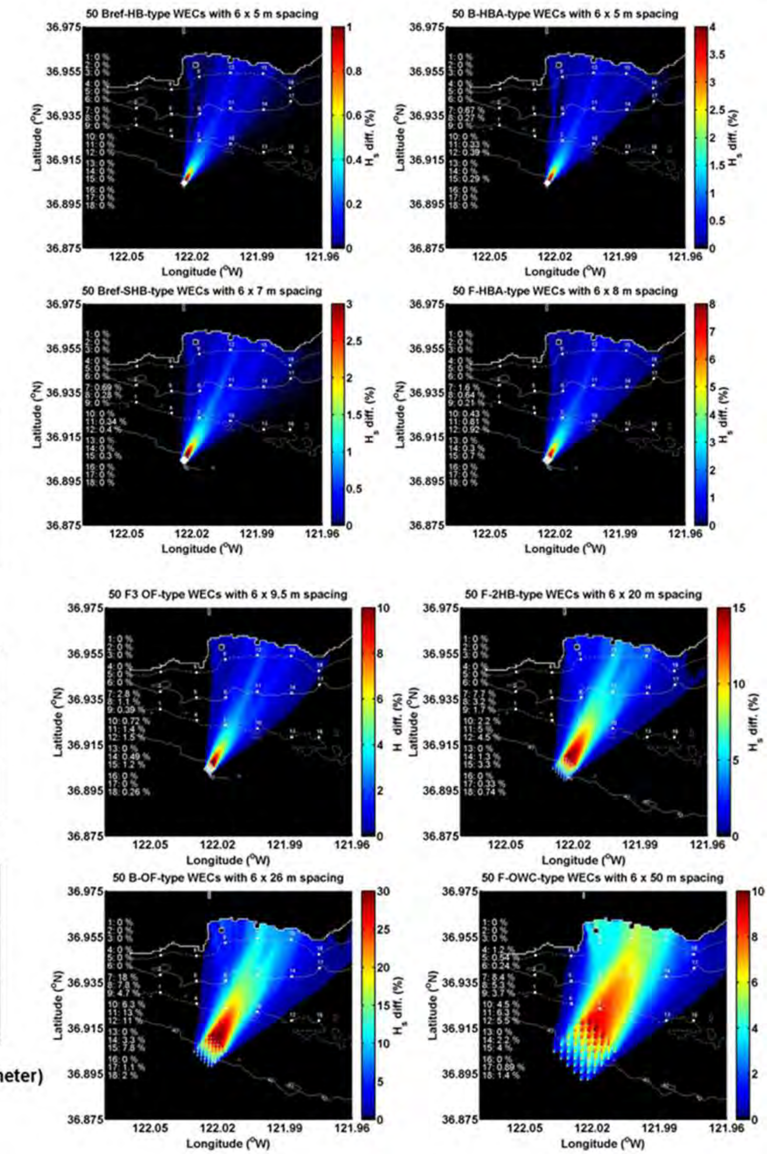
Evaluated baseline SWAN capabilities to model WEC arrays in real world setting

Environmental Evaluation:

- Evaluated changes to circulation and sediment transport for 200 WEC array (40m, 7X)
  - o Modified currents and dampened sediment dynamics
  - o Reduced deposition at harbor mouth
- Evaluated 8 WEC types with *alpha* SNL-SWAN
  - o Hs most sensitive to device type and array size







Developed relationships between array configuration and environmental effects

Project Plan & Schedule

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

WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
◇	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: WEC Array Modeling for Far-Field Env. Effects												
Q1 Milestone: SWAN sensitivity of WEC farm representation in Monterey Bay	◆											
Q2 Milestone: Develop WEC energy sink formulations		◆										
Q4 Milestone: 1) SWAN model sensitivity analysis of lab test cases; 2) WEC array effects to wave, current, and sediment circulation				◆ ◆								
Q1 Milestone: SWAN simulations of differing numbers and configurations of WECs					◆							
Q2 Milestone: Compile and initial verification of alpha version of SNL-SWAN						◆						
Q3 Milestone: SNL-SWAN sensitivity of WEC arrays in Monterey Bay model domain							◆					
Q4 Milestone: Compare SNL-SWAN with lab test data and outline pathforward								◆				
Current work and future research												
Compile beta version of SNL-SWAN										◇		
Seasonal effects to wave propagation due to WEC arrays											◇	
Comparison of beta version of SNL-SWAN with test data												◇
Journal publication SNL SWAN development and application												◇

Comments

- WEC environmental evaluation initiated in 2010 – Ongoing
- SNL-SWAN development initiated in 2012 – Ongoing
- All milestones completed on time

All work is progressing according to plan

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$414K	N/A	$450K	N/A	$500K	N/A

- No variances from project budget
- FY12 costed 100% of Spend Plan
- FY13 costed 96% of Spend Plan

Annual costs have consistently met Spend Plan targets

Research Integration & Collaboration

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

Subcontractors:

- Sea Engineering: SNL-SWAN development and application
- Coast and Harbor: SNL-SWAN development and validation

Collaborators/Partners:

- Oregon State University: WEC array wave tank experiments for code validation
- Columbia Power: WEC performance characterization for code validation

Communications and Technology Transfer:

- Technical Reports:
  - 6 DOE/SNL technical reports
- Conference Proceedings:
  - AGU 2012 presentation in San Francisco, CA
  - Oceans 2012 publication and presentation in Virginia Beach, VA
  - EWTEC 2013 publication and presentation in Aalborg, Denmark
  - Ocean Sciences 2014, 2 presentations in Honolulu, HI
  - GMREC 2014 (planned) publication and presentation in Seattle, WA
- Web portal for code and manual distribution (Open EI, SNL website)
- Direct training and manual development (future activity)

Publish, pro-active outreach, and web portal for broader distribution

Next Steps and Future Research

FY14/Current Research:

- Compile beta version on SNL-SWAN
- Validation of SNL-SWAN by comparison to OSU TWB experimental data
- Beta version of SNL-SWAN, planned limited release Fall 2014
- Utilize SNL-SWAN to investigate seasonal effects to wave propagation and ocean circulation due to WEC arrays

Proposed Future Research:

- Public release of SNL-SWAN with validation [Fall 2014]
- Application of SNL-SWAN at potential deployment sites
- Technical outreach to enable use by industry stakeholders
  - **Benefit: Help developers get devices in the water!** Ease permitting process
- Expansion of SNL-SWAN to model offshore wind

2014 Water Power Program Peer Review

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

Introduction to the MHK Environmental FOA

Wind and Water Power Technologies Office
Hoyt Battey and Jocelyn Brown Saracino
2/26/14

Purpose & Objectives

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

Problem Statement:

- Data collection and experimentation are essential to reducing uncertainty regarding the environmental effects of MHK technologies. This uncertainty is driving lengthy and costly MHK project permitting process which represent significant barriers to deployment - can reach up to $6.5M, equal to or exceeding deployment costs for some projects.

- To date, the opportunities to monitor for environmental effects around deployed MHK devices have been limited due to a relatively small number of deployments.

Impact of FOA:

- This FOA aims to reduce environmental risk for future projects by collecting data around operational devices, by developing and testing effective environmental monitoring technology, and by supporting the evaluation of risk from surrogate technologies to reduce the need for novel research at MHK devices. This data will inform future industry efforts, while simultaneously supporting pioneer MHK projects in their environmental data collection efforts.

This FOA aligns with the following DOE Program objectives and priorities

MHK

- Reduce deployment barriers and environmental impacts of MHK technologies

FOA Definition & Selection Process

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

- Over the past two years, the MHK MA&D team conducted a rigorous analysis to identify the greatest industry environmental needs, identify gaps remaining from previous efforts, rank those gaps, and develop a plan to strategically reduce environmental barriers to deployment. These efforts led to the development of this FOA .

- The team also worked with a host of regulatory and resource agencies to align priorities, coordinate on strategies.

- As a result, awards were made under two topic areas:
  - Environmental Monitoring of MHK Projects (EM)
  - Analysis of Environmental Effects of MHK Surrogate Technologies (S)

- The solicitation was co-funded by the Bureau of Ocean Energy Management (BOEM). BOEM lead the development of the surrogate topic and provided funding for these projects. They also contributed to the funding of one environmental monitoring project.

- The FOA required a letter of intent and a full merit review process was conducted.

FOA Timeline

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

- FOA Issue Date: 3/19/2013
- Letter of Intent (LOI) Due Date: 4/18/2013
- Application Due Date: 5/16/2013
- GFO Compliance Review of Applications: 5/21/2013
- Independent and Federal Consensus Merit Review Panels: 6/17/2013 – 6/21/2013
- Award announcement: August 28
- Project duration:
  - Environmental monitoring projects: 24-36 months
  - Surrogate projects: 12-18 months

Awardee Summary

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

Topic	Recipient Name	Project Title	Award Amount (Federal allocations only, * denotes full or partial BOEM funding)
EM	University of Maine	Interactions of Aquatic Animals with ORPC OcGen®…	$393,593
EM	Oak Ridge National Lab	Informing a Tidal Turbine Strike Probability Model…	$150,000
EM	Oregon State University	Using Multiple In Situ Approaches to Assess Fish…	$397,381
EM	Oregon State University	Measuring Changes in Ambient Noise Levels…	$149,613
EM	University of Washington	Marine Mammal Behavioral Response to Tidal Turbine Sound	$399,572
EM	Electric Power Research Institute (EPRI)	Potential Impact of EMF Fields from Undersea Cables on Migratory Fish…	$400,000
EM	Florida Atlantic University	Effects of EMF Emissions from Cables and Junction Boxes	$399,469
S	H.T. Harvey & Associates	Evaluating the Potential for Devices to Become Artificial Reefs…	$74,502*
S	Vantuna Research Group	Impacts of Electromagnetic Fields Associated with MHK	$69,935*
		Total	$2,434,065

University of Maine

Interactions of Aquatic Animals with ORPC OcGen® in Cobscook Bay, ME: Monitoring Behavior Change and Assessing the Probability of Encounter with a Deployed MHK Device

DOE Funding	Cost Share	Total Project Cost
$393,593	$100,000	$493,593

Proposed Partners:

Ocean Renewable Power Company
Army Corps of Engineers

Project Outcome and Impact Potential:

- Produce data on fish interactions with deployed tidal turbine
- Produce enhanced data processing techniques and encounter probability model which can be utilized by other projects

Project Summary:

- Perform "After" component of Before-After-Control Impact experiment to evaluate fish behavior near ORPC OcGen® turbine system
- Apply new analytical method to acoustic data to improve fish species identification based on swim bladder morphology
- Develop probability encounter model to assess natural interactions of fish with MHK device

Oak Ridge National Laboratory

Informing a Tidal Turbine Strike Probability Model through Characterization of Fish Behavioral Response using Multibeam Sonar Output

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

Project Outcome and Impact Potential:

- Provide data on fish interactions with a deployed tidal turbine
- Refine risk estimates and validate a fish behavioral model
- Advise which methods are most effective for predicting and monitoring effects of turbines

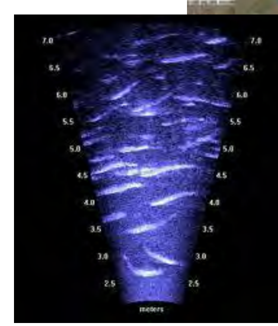
Project Summary:

- Utilize video data and multibeam sonar to characterize both near- and far-field fish behavior in relation to turbines at Verdant Power's Roosevelt Island Tidal Energy Project in the East River, NY
- Use observed fish behavior to update fish interaction model

DOE Funding	Cost Share	Total Project Cost
$150,000	$37,500	$187,500

Proposed Partners:

Verdant Power
Kleinschmidt Associates



Oregon State University

Using Multiple In Situ Approaches to Assess Fish Communities and their Connectivity in the Vicinity of Natural Rocky Outcrops and an Adjacent Active WEC Site in the Pacific Northwest

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

Project Outcome and Impact Potential:

- Compare fish and macrofaunal invertebrate communities between a wave energy conversion (WEC) device and natural reefing structures
- Address concerns that WEC devices will alter ecosystem dynamics

Project Summary:

- Use hook and line surveys and videographic observations to assess fish communities on a small natural reef and a WEC device
- Use acoustic telemetry to track fish habitat preference and movement between natural reefs and WEC devices
- Quantify difference in fish attraction between energized and non-energized WEC platforms

DOE Funding	Cost Share	Total Project Cost
$397,381	$101,392	$498,773

Proposed Partners:

Colombia Power Technologies
Oregon Wave Energy Trust
BioSonics Inc.
NOAA Northwest Fisheries Science Center
Pacific States Marine Fisheries Commission

Oregon State University

Measuring Changes in Ambient Noise Levels From the Installation and Operation of a Wave Energy Converter in the Coastal Ocean

DOE Funding	Cost Share	Total Project Cost
$149,613	$38,000	$187,613

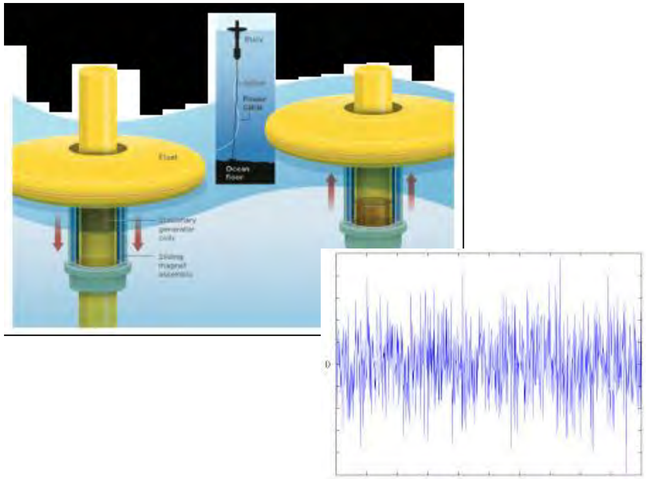
Proposed Partners:
Colombia Power Technologies

Project Outcome and Impact Potential:

- Increase understanding of noise produced by wave energy conversion (WEC) devices under a range of environmental conditions
- Data will help inform risk modelling efforts and provide relative comparison of WEC produced noise to ambient and other anthropogenic noise sources

Project Summary:

- Deploy seafloor mounted and autonomous drifting hydrophones to monitor noise levels before, during and after testing of WEC device at NNMREC ocean test facility off Newport, Oregon



University of Washington

Marine Mammal Behavioral Response to Tidal Turbine Sound

DOE Funding	Cost Share	Total Project Cost
$399,572	$100,000	$499,572

Project Outcome and Impact Potential:

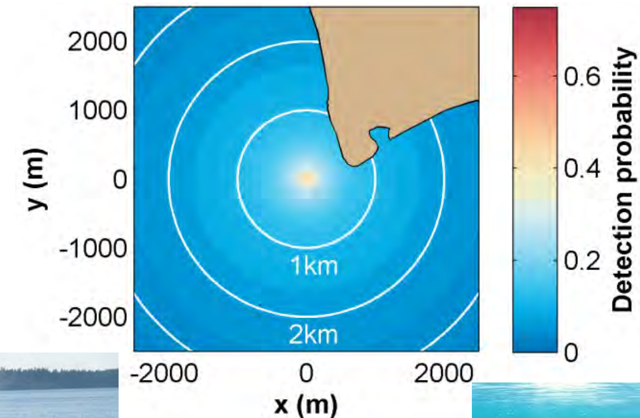
- Increase understanding of marine mammal responses to sound produced by tidal turbines, a high priority regulatory issue
- Address potential risks of tidal turbines to resident killer whales

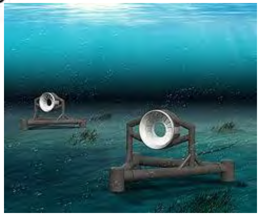
Project Summary:

- Use drifting hydrophones to quantify spatial and temporal noise patterns produced by two Open Hydro tidal turbines in Puget Sound, WA
- Utilize shore-based observers and hydrophone arrays to monitor marine mammal responses to turbine noise

Proposed Partners:

Sea Mammal Research Unit
Pacific Northwest National Laboratory





EPRI

Assessment of Potential Impact of the Magnetic Fields from Undersea Cable on Migratory Fish Behavior

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

Project Outcome and Impact Potential:

- Provide data on electromagnetic fields (EMF) produced by underwater cables and organismal response to EMFs
- Contributes valuable data to fields of regulatory concern

Project Summary:

- Monitor, model & map EMFs produced by high voltage, direct current undersea cable in San Francisco Bay
- Utilize existing fish-tag data to analyze movement of a number of migratory species
- Evaluate if EMFs produced by high voltage, direct current undersea cables alter fish migration behavior

DOE and BOEM Funding	Cost Share	Total Project Cost
$400,000	$312,279	$712,279

Proposed Partners:
University of California- Davis

Florida Atlantic University

Effects of EMF Emissions from Cables and Junction Boxes on Marine Species

DOE Funding	Cost Share	Total Project Cost
$399,469	$99,891	$499,360

Proposed Partners:

Naval Surface Warfare Center
Nova Southeastern University

Project Outcome and Impact Potential:

- Provide data on electromagnetic fields (EMF) produced by underwater cables and junction boxes
- Assess behavioral & community response of marine species to these EMFs
- Contributes valuable data to fields of regulatory concern

Project Summary:

- Characterize EMF produced by cables and junction boxes in the Navy's South Florida Ocean Measurement Facility
- Use SCUBA divers, camera-equipped AUVs and aerial surveys to monitor behavioral and community level response of aquatic animals to EMFs

Evaluating the Potential for Devices to Become Artificial Reefs or Fish Aggregating Devices Based on Analysis of Surrogates …

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

Project Outcome and Impact Potential:

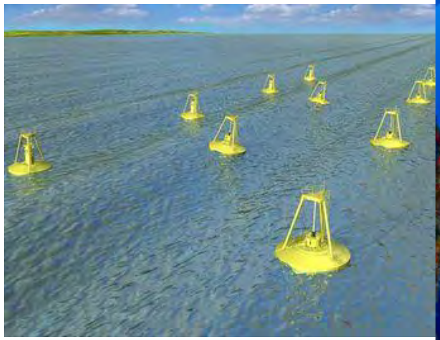
- Determine potential for MHK technologies to cause reefing effects and consequent beneficial or detrimental changes to marine species of regulatory concern

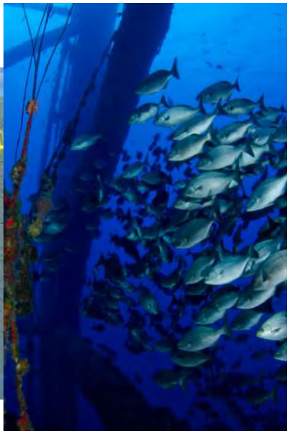
Project Summary:

- Perform comprehensive literature review and interview regional field managers
- Evaluate impact of size, shape, and configuration of surrogate deployments on fish and invertebrate communities
- Analyze impacts and risks for specific fish species and artificial reefs in five Pacific subregions

BOEM Funding	Cost Share	Total Project Cost
$74,502	$0	$74,502

Proposed Partners:
Collaborative Fisheries Research West National Marine Fisheries Service





Vantuna Research Group

Impacts of Electromagnetic Fields Associated with MHK Surrogate Technologies on Fish Movements

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

BOEM Funding	Cost Share	Total Project Cost
$69,935	$0	$69,935

Project Outcome and Impact Potential:

- Fill in gaps in current knowledge of impacts of electromagnetic fields (EMF) created by MHK surrogates on marine organisms

Project Summary:

- Compile and analyze existing information related to the impacts of EMF produced by MHK surrogate technologies on fish behaviors
- Generate a risk assessment model for interactions of specific fish species with EMFs produced by MHK surrogates

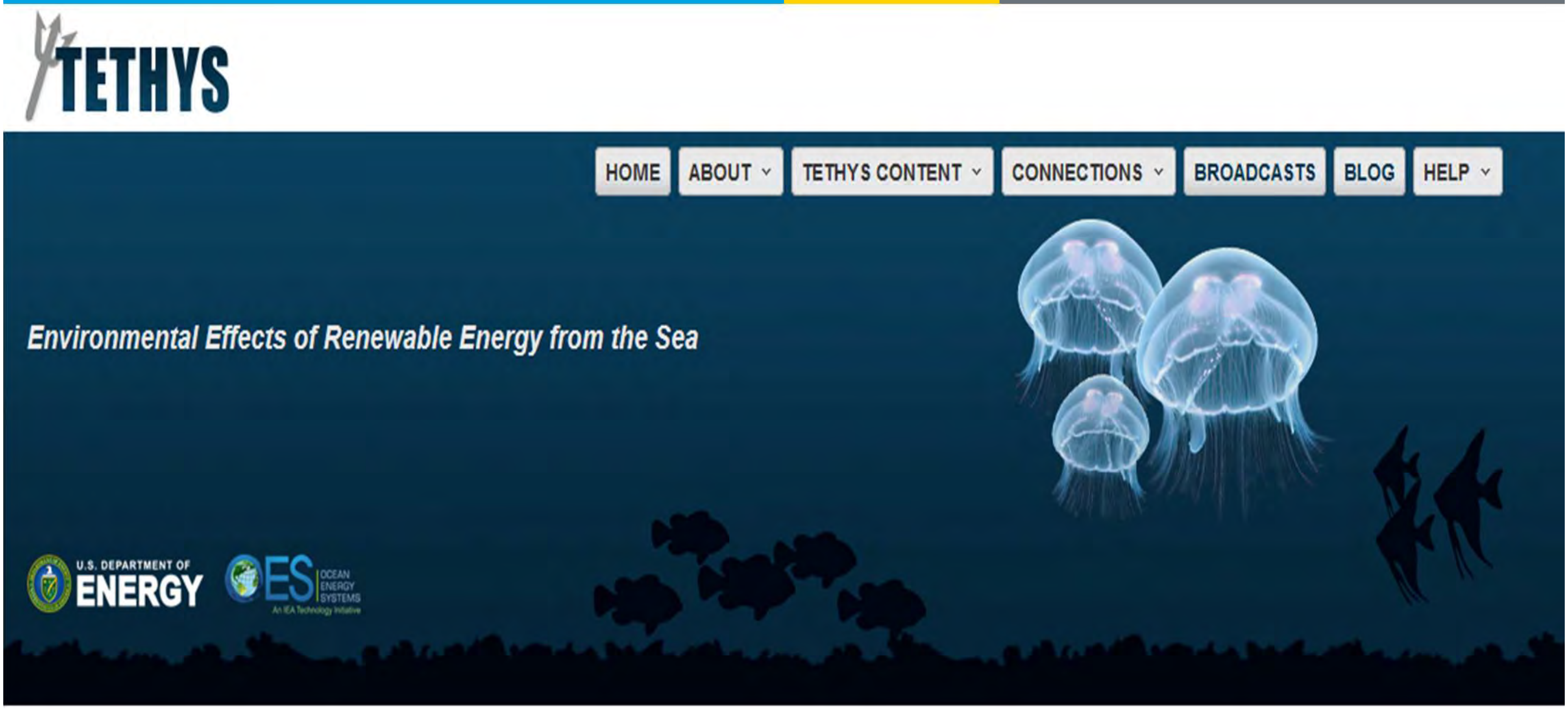
Proposed Partners:
None

Communications and Technology Transfer Plans:

- The MA&D portfolio has 3 major thrust areas. One of these three is Information Sharing and Education.
- Information from these projects will be broadly distributed by the program through our Tethys website and through Annex IV activities, including webinars, workshops, and conferences.
- Additionally, information from these projects will be included in meta-analyses of environmental impacts of MHK technologies.
- All projects are highly encouraged to submit research articles to peer reviewed journals for publication.

Water Power Peer Review

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



IEA OES Annex IV Support and *Tethys* Database Development

Andrea Copping
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February 27, 2014

Purpose & Objectives

Problem Statement:

- MHK technologies environmental effects data are dispersed amongst different countries and developers, or held as proprietary
- Access to these data could support efficient siting and permitting to accelerate the industry

Impact of Project:

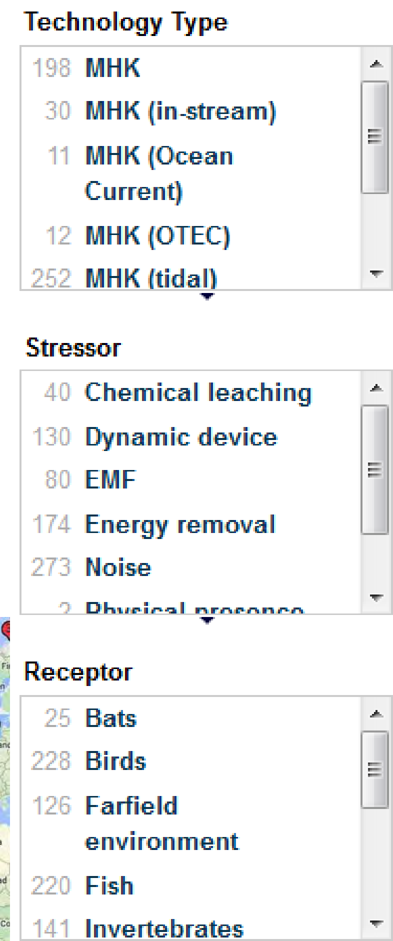
- *Tethys* makes information on environmental effects accessible to developers, regulators and researchers, provides common base of knowledge
- Annex IV bring together nations to share knowledge, learn from each other, reduce duplication of effort

This project aligns with the following DOE Program objectives and priorities Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

- *Tethys* aggregates information, literature, and metadata dealing with environmental effects of MHK projects:
  - Marine Animals
  - Marine Habitats
  - Ecosystem processes
- Organizes content into a searchable and comprehensive knowledge base
  - Enhance accessibility of information
- Audience: MHK researchers, regulators, developers, and other stakeholders

- *Tethys* is a web-based knowledge management system
  - Individual files tagged and searchable
    - Stressors, receptors, technology types
  - Sortable tables and interactive map views
- Knowledge Encapsulation Framework (KEF)
  - Website is a flexible tool responsive to user feedback
- Annex IV metadata collection
  - Metadata have been collected from project sites and research studies worldwide
  - Carried out by networking with developers and researchers internationally



Technical Approach

- As information and metadata are collected, there is enhanced cumulative understanding of current knowledge and research
- International MHK community are coming together around *Tethys* and Annex IV effort
- Tethys is becoming an effective tool to:
  - Assist with siting, monitoring, and mitigation decisions for MHK projects.
  - Foster efficient and timely government oversight and public acceptance

Tethys is commonly used by industry, academia, and government, and has received praise for the level of clarity and extensive coverage of data.

- *Tethys* metrics and goals
  - Delineate key performance metrics
  - Develop quarterly reporting process to monitor and improve performance of *Tethys*
- Content has expanded from 91 to 1163 media in 2 years
- Captures nearly all seminal documents in the field
- Peer review process carried out annually
- Recognized as Wiki of the Month in April 2013
  - Highlights the success of the technical infrastructure

Annex IV brings international practitioners together with information on environmental effects of marine energy development

- Annex IV metadata collection
  - **76** project sites and **49** research studies from **18** different countries
  - Constantly seeking to acquire new metadata and updates of Annex IV information; metadata fully integrated into *Tethys*
- Annex IV Experts' Workshops
  - Dublin Ireland; 2010 and 2012
  - Provided guidance and review of the program
- Final Annex IV Report (phase 1) case studies:
  - Physical interaction between animals and turbine blades;
  - Acoustic impact from wave and tidal devices on marine animals; and
  - Effects of energy removal on physical systems

Project Plan & Schedule - Tethys

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

Summary		Legend	
WBS Number or Agreement Number	1.5.3.1		Work completed
Project Number	64210		Active Task
Agreement Number	20072		Milestones & Deliverables (Original Plan)
			Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Development of Knowledge Management System												
Q1 Milestones: Update FY11 data collection plan												
Q2 Milestone: Complete website measurement plan												
Q3 Milestone: Trial dataset entered into Tethys to demonstrate functionality												
Q4 Milestone: Robust collection of documents (+40 per quarter)												
Q1 Milestone: Combine the MHK and Annex IV views into one database												
Q3 Milestone: Peer review by a minimum of 5 experts from Annex IV nations												
Milestones: Quarterly reports on nine Tethys metrics												
Current work and future research												
Tethys migration from the MediaWiki platform to the Drupal platform												
Annual peer review												

- FY12 - Funds were received late in Q1, so the collection plan was completed in early Q2.
- FY13 - Per guidance from DOE, the peer review was postponed a year until Annex IV country analysts have been recruited by DOE and the switch to the Drupal platform is complete.

Go/no-go

- In cooperation with DOE WWPTO, Go/No Go decisions have been made before each release of *Tethys*.

Project Plan & Schedule – Annex IV

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

Summary	
WBS Number or Agreement Number	1.5.3.1
Project Number	64210
Agreement Number	20078

Legend	
(light blue)	Work completed
(blue)	Active Task
◇	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Development of International Impacts Database (Annex IV)												
Q1 Milestone: Environmental effects metadata collection from Annex IV nations	◆											
Q2 Milestone: Develop and hold webinars for member nations on Tethys functions		◆										
Q1 Milestone: Final IV report report with case studies					◆							
Q1 Milestone: Update Tethys based on feedback from experts' workshop					◆							
Current work and future research												
Member nations' analysts will help plan annual activities and in collection									◇			
Further planning for Tethys/Annex IV commons										◇		
Engagement with EIMR										◇		

Comments

Variances:

- FY12 - The Annex IV metadata collection effort was conducted in Q1, but is an active ongoing task.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$162K		$450K		$475K	

- No variances from planned budget. FY13 funds received late in year, carryover for FY14
- 65% of budget expended to date
- No other funding sources.

Research Integration & Collaboration -Tethys

Partners, Subcontractors, and Collaborators:

- Pacific Energy Ventures
  - Assisted with data collection, curation efforts
- National Labs - SNL, NREL, and ORNL
  - Contributed material and feedback for Tethys
- Northwest National Marine Renewable Energy Center (NNMREC) - UW and OSU
  - Contributed material and participated in peer review of Tethys
- Peer reviewers of Tethys
  - Provide feedback and suggestions for enhancing Tethys functionality and content

Research Integration & Collaboration – Annex IV

Partners, Subcontractors, and Collaborators:

- Annex IV is an initiative under IEA Ocean Energy Systems (OES), led by DOE with federal partners FERC, BOEM, and NOAA.

- Annex IV phase 1:
  - Wave Energy Centre (Portugal and University of Plymouth assisted in metadata collection.
  - Seven Annex IV nations involved: US, Canada, Ireland, Spain, Norway, New Zealand, Republic of Korea

- Annex IV phase 2:
  - Scottish-based Aquatera Ltd. assisting in metadata collection effort.
  - Up to 14 member nations

Communications and Technology Transfer:

- Ongoing communication with international representatives, and targeted outreach efforts including the following:

- Presentations of *Tethys* and Annex IV at:
  - ICOE 2012 (Dublin IE);
  - Oregon Marine Renewable Energy Science Conference in 2012 ;
  - Recent Developments in Research on the Environmental Effects of MHK Technologies series 2013;
  - GMREC 2013
  - EWTEC 2013

- Peer reviewed paper in the International Journal of Marine Energy, 2013.
- Paper is in review with the Journal of Ocean and Coastal Management.

- Information on Tethys and Annex IV circulated at:
  - GMREC 2012 and 2013
  - Monitoring Instrumentation Workshop 2013
  - EWTEC 2013

Communications and Technology Transfer:

- Two Experts' Workshops held in Dublin Ireland in 2010 and 2012
- Report was published for the first phase of Annex IV by OES.

Annex IV Workshop 2012, Dublin

Next Steps and Future Research

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

F14/Current research:

- Migration of Tethys to new platform (Drupal)

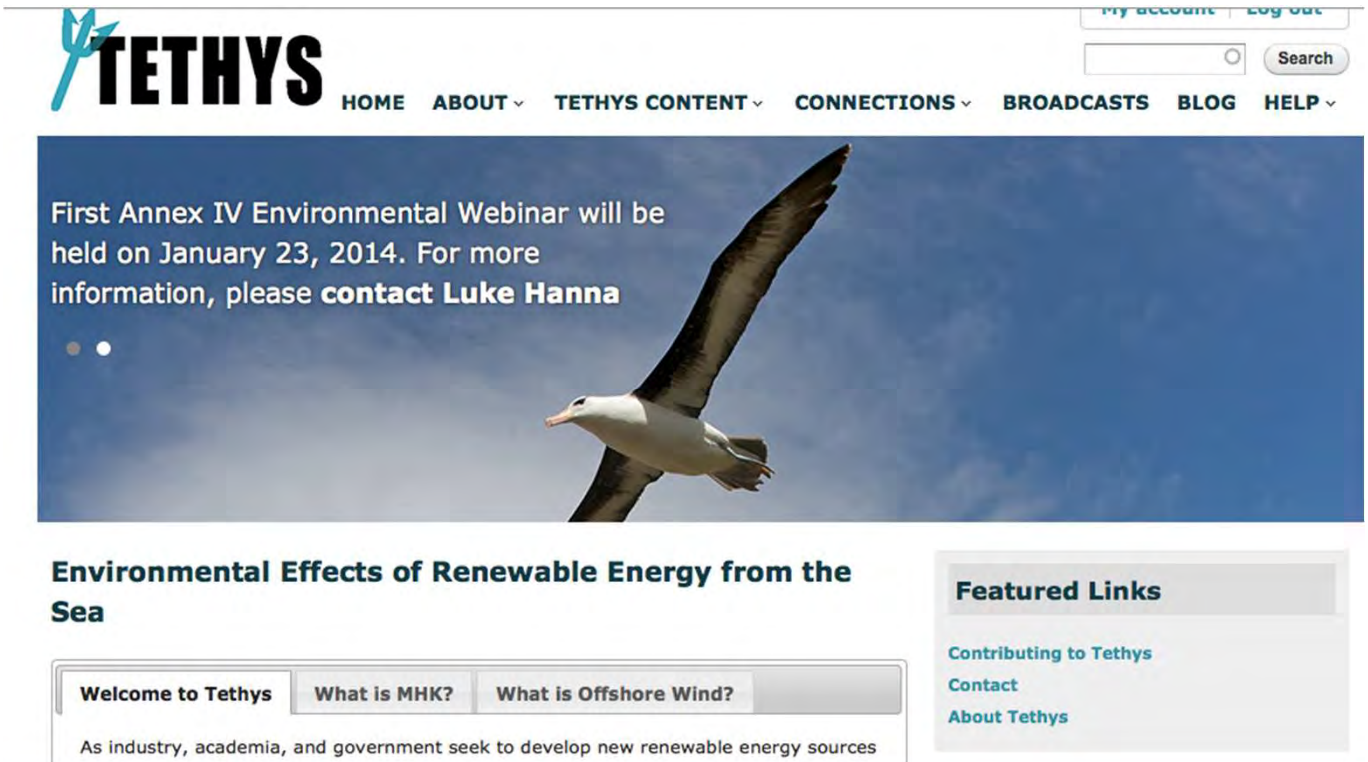
- Annex IV phase 2: renewed for next three years
  - Country analysts identified to help collection effort

- Creating a commons for MHK practitioners:
  - Outreach, online forums
  - Recorded expert online discussions
  - Quarterly environmental webinars
  - Blog, news blast
  - Social media
  - User profiles for interaction among users

- Annual peer review of *Tethys* for content and functionality
- Annex IV workshop on Best Practices to be held at EIMR, support for EIMR international conference (April 2014)
- Paper accepted for METS at GMREC
- Planning for State of the Science report and international conference (2015-16)

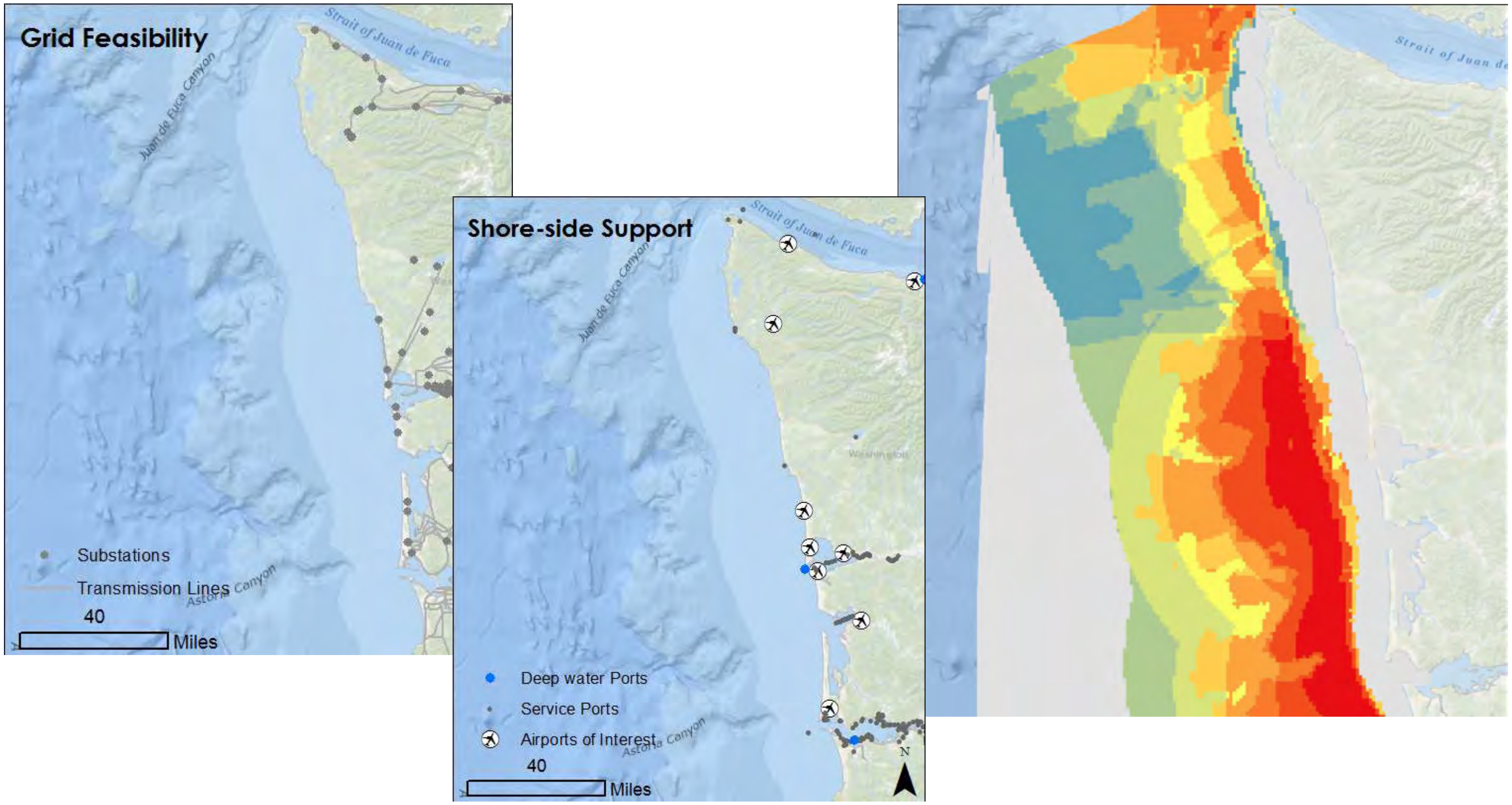
Proposed future research:

- Continued updates of Annex IV project site and research info
- Continued expansion of *Tethys* content and functionality
- Measures of effectiveness of various outreach activities
- Annual review of *Tethys*, Annex IV content and usefulness



Water Power Peer Review

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



West Coast Coastal and Marine Spatial Planning Support

Simon Geerlofs
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Pacific Northwest National Laboratory
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February 26, 2014

Purpose & Objectives

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

Problem Statement: MHK is an emerging industry--specific requirements and priorities of the industry are not always considered and effectively integrated into CMSP. May limit space and flexibility for future industry growth.

Impact of Project: Ensure that CMSP processes adequately consider the value of renewable energy among other uses of ocean space through:

- Direct engagement in planning processes to support WWPTO
- Partner with industry, states, BOEM, and DOE on West Coast suitability analyses

This project aligns with the following DOE Program objectives and priorities Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach--Engagement

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

Augment WWPTO engagement in West Coast CMSP planning processes (*boots on the ground);* information conduit between WWPTO and west coast stakeholders

Venues include:

- West Coast Governor's Agreement on Ocean Health
- BOEM/OR State Task Force
- Washington State Marine Advisory Committee
- Attend other meetings, workshops, events on CMSP at the direction of the WWPTO.

Technical Approach—Suitability

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

Partner with states, agencies, industry and others to carry out initial geospatial suitability analyses—focus on technical and economic suitability, informed by industry siting needs assessment.

- Expansion of approach developed for Oregon Territorial Sea Plan by OWET and Parametrix
- Multi-criteria decision analysis framework of weighted additive algorithms to evaluate site suitability
- Attributes of suitability represent fundamental economic and technical feasibility considerations (energy potential, water depth, proximity to shore, ports, and transmission infrastructure).

Technical Approach—Suitability

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MODEL	SUB- MODELS	ATTRIBUTES
Site Suitability	**Site Quality** **Grid Connection** **Shore-side Support**	•Energy resource potential •Depth •Substrate •Distance to Substation •Distance to Shore •Distance to Transmission Line •Distance to Service Port /Airport •Distance to Deepwater Port

1. Sub-model Score= $\sum \left(\frac{\text{attribute score*weight}}{\text{potential score}}\right)$

2. Suitability Score= $\sum \left(\frac{\text{sub-model score*weight}}{\text{potential score}}\right)$

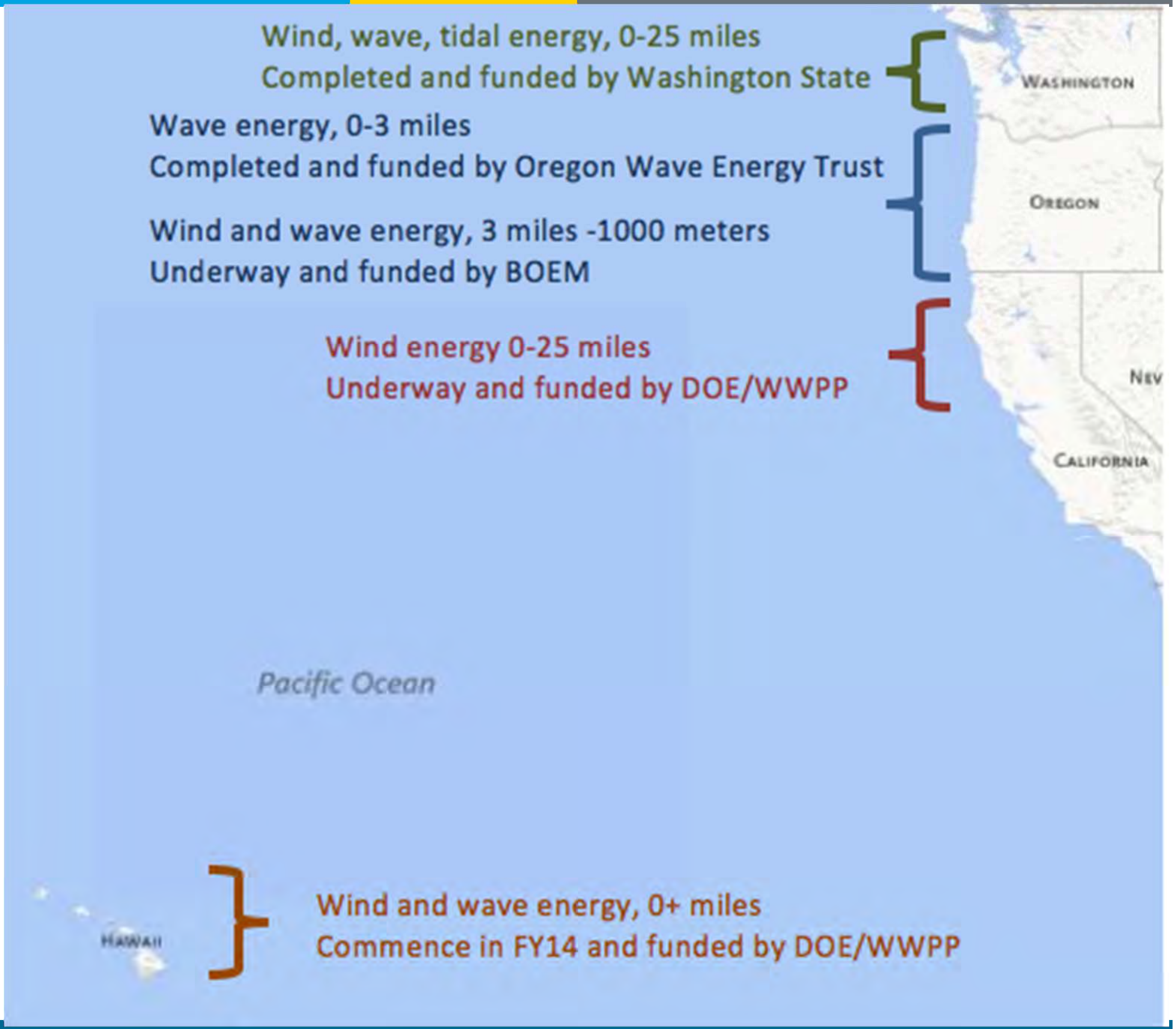
Accomplishments and Progress

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

West Coast suitability analyses for wave and wind completed or underway (2013-2014)

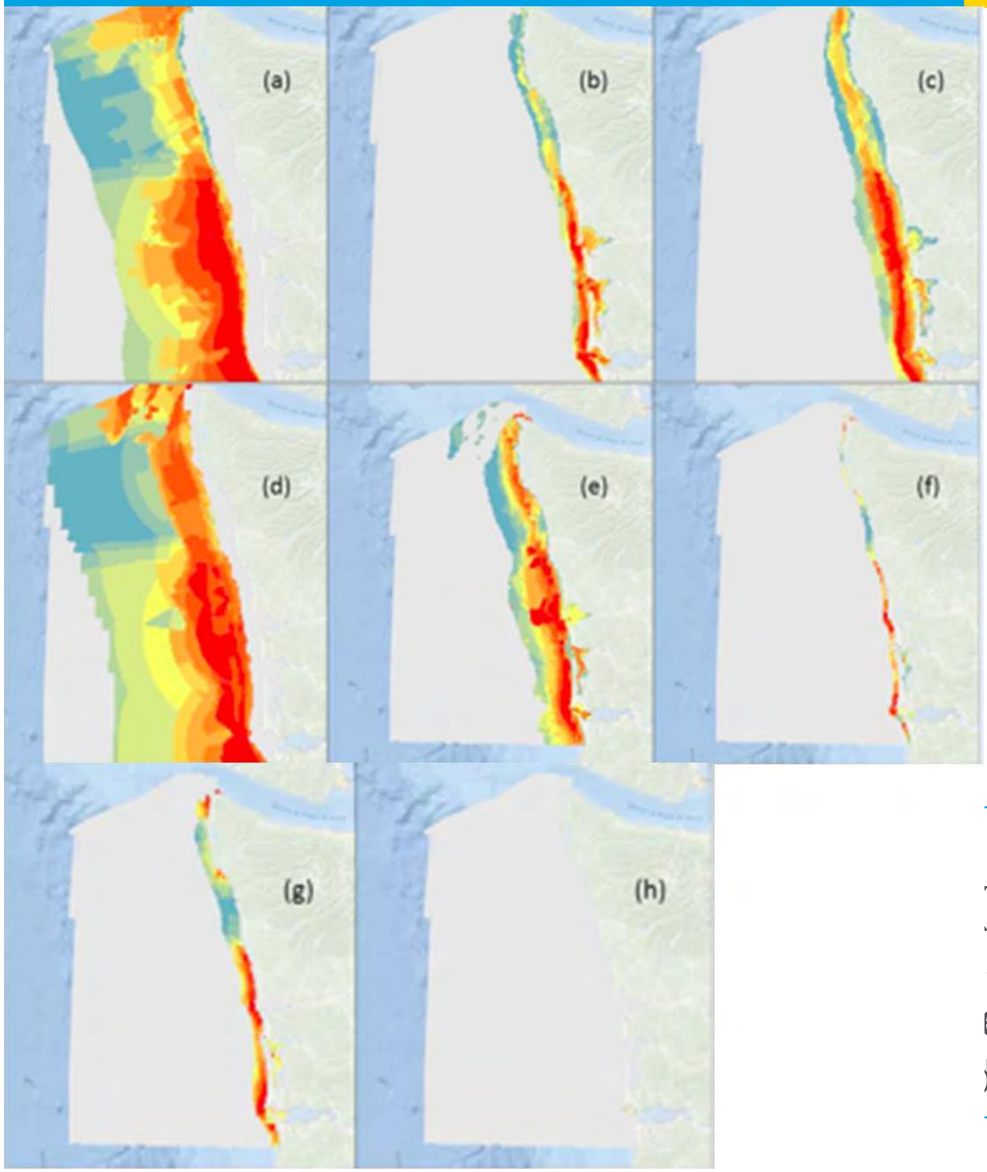
Consistent Methodology/Multiple Partners and Funders

- PNNL
- OWET
- Parametrix
- Oregon
- Washington
- DOE
- BOEM



Accomplishments and Progress

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



- **Example of results from WA state suitability mapping—**
- **PNNL, Parametrix, WA, and DOE partnership**
- **WA-state funded analysis to provide base layer for energy suitability to inform planning**
- **Warmer colors indicate better technical and economic suitability**

ility shown for floating wind (a), monopiles (b), jacket or tripod s (c), deepwater wave (d), mid-e (e), nearshore wave (f), nearshore levice (g), and tidal energy (h).

Project Plan & Schedule

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

Summary	
WBS Number: 1.5.3.2	
Project Number	
Agreement Number: 23469	

Legend	
(light blue)	Work completed
(blue)	Active Task
◇ (grey)	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Octt-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: West Coast Marine Spatial Planning Support												
Q1 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA.	◆											
Q2 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA.		◆										
Q3 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA.			◆									
Q4 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA. CMSP Case Study				◆								
Q1 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA, WCMAC					◆							
Q2 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA, WCMAC						◆						
Q3 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA, WCMAC							◆					
Q4 Milestone: Attendance at BOEM/OR Task Force Meetings, WCGA, WCMAX. Report on suitability analyses								(work completed)	◆			

Comments

- Work initiated in FY 2011, planned completion in FY 2014

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
60k		60k		100k	

- No major budget variances
- FY 13 budget was fully spent (both DOE funds as well as WA cost share). FY 14 funds received late December, 2013.
- PNNL is leveraging outside funding to carry out suitability analyses—BOEM (Oregon) and WA state. WWPTO funds targeted for Hawaii suitability in FY 14.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: This is a multi partner project, with multiple funding sources. Project team consists of PNNL, OWET, and Parametrix, with funding from DOE, BOEM, and WA state.

Industry is a primary partner through interviews, surveys, and advisory team.

Communications and Technology Transfer: WA state suitability analyses presented to Coastal Advisory Committee; BOEM funded OR analysis described at OWET conference; presentations to Marine Advisory Committee in WA; FY14 present Hawaii Analysis to BOEM/HI Task Force

Next Steps and Future Research

FY14/Current research: Expansion of suitability analysis to Hawaii (WWPTO-Funded); complete BOEM-funded analysis in Oregon; engage more fully with California stakeholders; challenges consist of short timeframes for execution; Multi partner teams and multiple funders require careful project management.

Proposed future research: Work is guided by the needs of the WWPTO and industry on the West Coast—future research will be targeted to advance integration of renewable energy integration into ongoing CMSP processes.

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

EERE Post-doctoral Fellowship (MHK)

Hoyt Battey

DOE Wind and Water Power Technologies Office

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2/26/2014

Purpose & Objectives

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

Problem Statement: The U.S. can benefit from providing opportunities for highly qualified researchers in the MHK industry to conduct R&D in parts of the world with active commercial MHK markets and thus improve the U.S. workforce.

Impact of Project: Encourage highly-qualified researchers to enter and remain in the MHK industry, fund high-priority R&D projects, give U.S. researchers exposure to more active commercial MHK markets (Europe), and strengthen linkages and facilitate collaboration between U.S. researchers and foreign counterparts.

This project aligns with the following DOE Program objectives and priorities

MHK

- Advance the state of MHK technology
- Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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

- Project operates as part of larger EERE program for post-doctoral researchers
- WWPTO is piloting this opportunity for MHK
- Research awardees are competitively selected for up to 2-year research projects at host institutions
  - IMERC (Ireland) identified as first partner institution
- Funding goes towards yearly living stipend, research allowance, research stipend for mentors' participation, health insurance, and expenses for relocation
- No other opportunities were identified for U.S. researchers to conduct R&D outside the U.S. and gain access to testing infrastructure and data from abroad.

Accomplishments and Progress

- To date, 3 research awards have been made
  - 1 beginning in calendar year 2012
    - Ari Posner, PhD in Hydrology and Water Resources, Arizona State.
      - Validation of a hydrodynamic and sediment model to simulate WEC arrays in conjunction with cost of energy analysis
  - 2 beginning in calendar year 2014
    - Bret Bosma, PhD in Electrical Engineering, Oregon State
      - Reducing the levelized cost of energy through advanced control techniques for ocean wave energy converters
    - Robert Cavagnaro, pursuing PhD in Mechanical Engineering, U. Wash
      - Preview-based control of marine hydrokinetic turbines for load mitigation and performance optimization

- Had hoped to make an award for calendar year 2013, but responses to the opportunity announcement were weak

Project Plan / Budget

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

- FY2013 funding will cover all research activities for current awardees (end of calendar year 2015 for longest award)

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0k	$0k	$360k	$0k	$0k	$0k

- Proposals were evaluated and selected during FY2013, and funding was allocated then, though research projects did not begin until January of 2014.
- Less than 10% of FY2013 funds have been expended as of February 2014.

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

- Irish Maritime and Energy Resource Cluster (IMERC)
  - Hydraulics and Maritime Research Centre (HMRC)
  - Coastal and Marine Research Centre (CMRC)
  - Cork Institute of Technology
  - Irish Naval Service

Communications and Technology Transfer:

- All awardees are required to submit research results to peer-reviewed publications if possible
  - Dr. Posner's work included in a 2013 edition of the Journal of Coastal Research
- WWPTO aid in making connections between awardees and other similar projects within the portfolio
- If program were continued/expanded, a centralized catalogue of results would likely be warranted

Next Steps and Future Research

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

FY14/Current research: WWPTO staff will review 6-month research results in summer of 2014 and meet with 2 current researchers at the International Conference on Ocean Energy in November 2014 to evaluate progress.

Proposed future research: Overall project will be evaluated during FY2014 to determine future strategy for this type of program in the context of the entire Water Power Program portfolio

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

MHK Regulator Training

E. Ian Baring-Gould

NREL

Ian.baring gould@nrel.gov 303 384 7021

February 27, 2014

Purpose and Objectives

Problem statement: Due to the current status of U.S. MHK power technology deployment, many state and federal regulators do not have a good understanding of water power technologies and the regulation process around their implementation. Consequently when projects are proposed, they typically face difficult approval processes due to this lack of basic understanding.

Impact of project: A better understanding of MHK technologies and their impacts will allow regulatory organizations to better prepare for, evaluate, and support the implementation of ocean-based energy technologies. This training will provide a level of knowledge and present a forum for more informal discussions around current ocean energy technologies, how they should be regulated and, more importantly, recent research on the environmental and other impacts of ocean energy development.

This project aligns with the following DOE Program objectives and priorities:

- Reduce deployment barriers and environmental impacts of MHK technologies.

Technical Approach

1) Develop basic workshop outline based on series of Offshore Renewable Energy workshops conducted by NREL for BOEM on the west coast in FY13
2) Conduct interviews with federal and state regulatory officials, industry representatives, and engaged parties to focus workshop content and identify appropriate participants
3) Develop content building from a strong base of current work
4) Conduct workshops:
   - Workshops tentatively set for the Pacific Northwest/Alaska, Northeast, and Washington, D.C. area
   - Refine content between workshops based on surveys
   - Hold one workshop as a recorded web meeting, allowing people to participate virtually
5) Publish materials:
   - Recorded web presentations made available online for future use
   - Presentations published, providing content for general use

Project Plan and Schedule

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

Summary	Legend	
WBS Number: 1.5.3.1		Work completed
Project Number:		Active Task
Agreement Number 26467		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: MHK Regulator Training								
Q1 Milestone: Draft Workshop Agenda and materials								
Q2 Milestone: Hold first workshop								
Q3 Milestone: Hold second and third workshop								
Q4 Milestone: Webinar recordings and presentations on the web								
Current work and future research								
Interviews with State and Federal Regulators								
Review and finalization of Workshop Agenda								
Develop and revise presentation content								
Publish content - webcast posting and presentation materials								

Comments

- Project builds on Offshore Renewable Energy workshop series funded by BOEM in FY13.
- Project initiated in late September 2013 and is expected to be completed September of 2014.
- Survey work slow to start up, but is getting back on track.
- No defined follow-on work after completion of this activity, but could be continued on an as-needed basis. At this time, since the Coast Guard, Navy, and other agencies rotate staff every 3 years, continuing education may be needed.

Project Budget

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

Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$200k	n/a	$198k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY13	Spend Plan FY14
$1.5K	$198.5k

- Received $200k at the end of FY13; spending has been minimal in the first quarter as project is ramped up
- FY14 project costs as of December 31st: $6k.

Research Integration and Collaboration

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

Partners, Subcontractors, and Collaborators: Partner with PNNL and interviewing many other people. Collaboration with industry and other federal partners is expanding and we are hoping to use federal or state facilities to conduct the workshops which will reduce costs and allow expanded attendance. Plan to engage content specific experts through honoraria or subcontracts, although specific people have not been finalized.

Communications and Technology Transfer: Three 1-2 day workshops, one webinar that will be recorded and put on the web (OpenEI), Publications-approved PowerPoint slides for all content that can be used more widely (available on OpenEI). Attendance of between 150 and 250 regulators directly with more viewing online and recorded versions is expected.

Next Steps and Future Research

Proposed future research:

- Future workshops with updated and additional content could be held as needed

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

National Marine Renewable Energy Centers

Wind and Water Power Technologies Office
Jim Ahlgrimm
Thursday, February 27, 2014

Goals – Develop centers of excellence and educa-tion undertaking research, development, demonstration, and commercial applica-tions of marine renewable energy tech-nologies.

Priorities – Development of testing infrastructure; support device design, environmental monitoring, and resource assessment; educate the next generation of ocean energy scientists.

FY 14 Budget: No new funds in FY14. Being funded by previous year balances.

DOE Unique Role – Research, development, and testing activities benefit the industry as a whole and accelerate the technology viability.

MHK Organizational Structure

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

Marine and Hydrokinetic Technologies

- Computational Modeling and Analysis
- Technology Advancement and Demonstration
- Resource Characterization
- Testing Infrastructure and Instrumentation
- Market Acceleration and Deployment

Key Counterparts and Collaborators

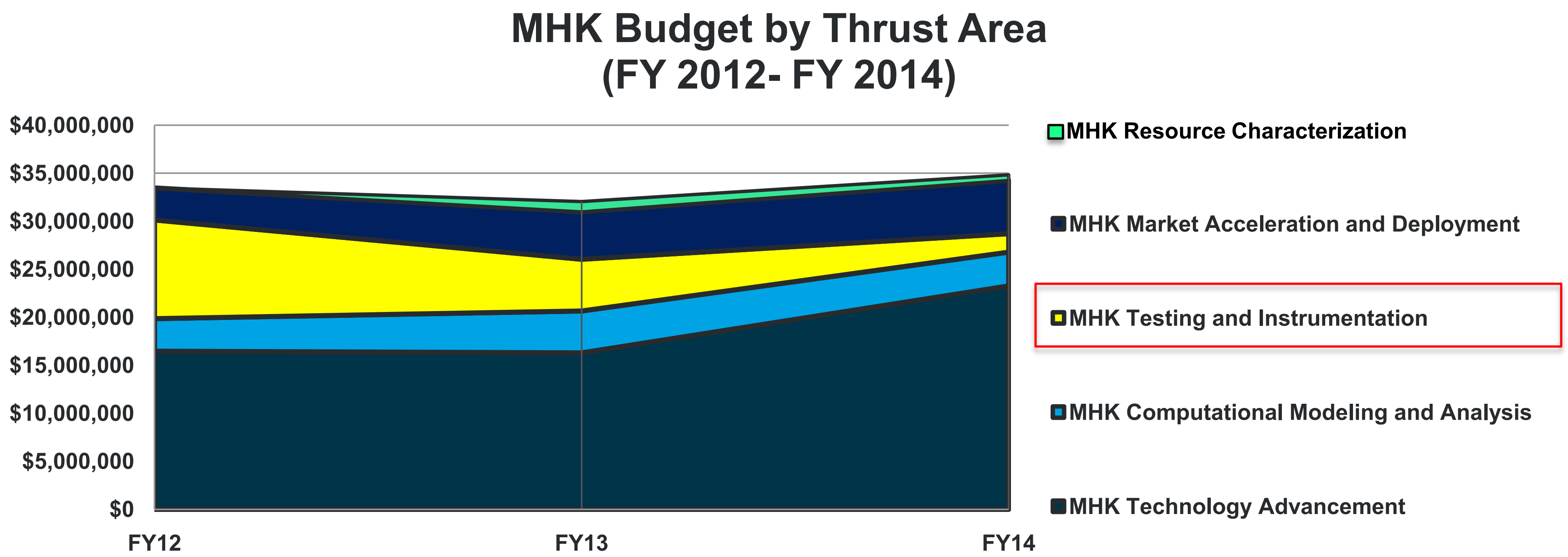
- National Renewable Energy Laboratory
- Sandia National Laboratories
- Florida Atlantic University
- Oregon State University/U. Washington
- University of Hawaii, U.S. Navy

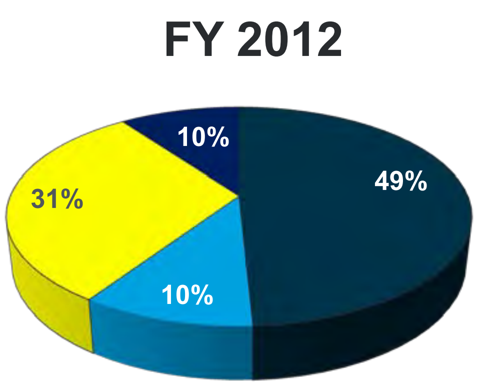
Portfolio Priorities – MHK

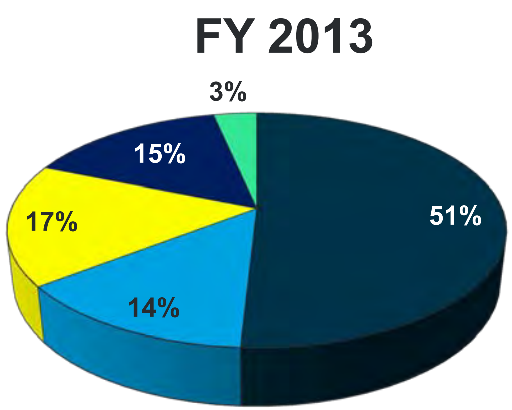
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

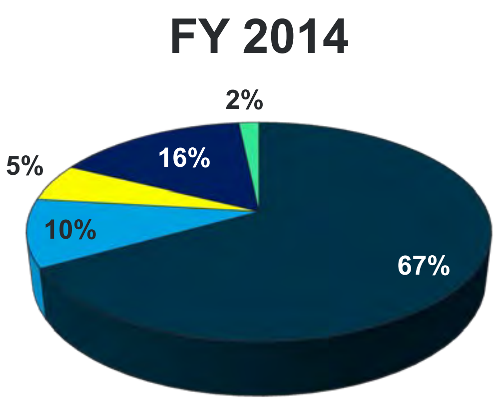
The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.	
Advance the state of MHK technology	• Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26

MHK Budget
(FY 2012 – FY 2014)









National Marine Renewable Energy Centers

- Authorized by Energy Independence and Security Act of 2007 (EISA 2007)
- Purpose
  - Advance the commercial application and viability of marine renewable energy
  - Serve as an integrated, standardized test center for developers
  - Serve as an information clearinghouse for the marine renewable energy industry, collecting and disseminating information on best practices
- Three selections
  - Northwest National Marine Renewable Energy Center
  - Hawaii National Marine Renewable Energy Center
  - Southeast National Marine Renewable Energy Center

Main Elements of the Testing Infrastructure & Instrumentation Portfolio – NMREC's

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

Marine Center Key Contributions	**Key Projects/Activities**
Southeast National Marine Renewable Energy Center	- Ocean current testing infrastructure - Ocean current technology and environmental research
Northwest National Marine Renewable Energy Center	- Full scale, open ocean wave testing infrastructure - Wave and tidal technology and environmental research
Hawaii National Marine Renewable Energy Center	- Sheltered wave testing infrastructure - Navy test site collaboration - Wave and ocean thermal technology and environmental research

Water Power Program Priorities in FY14 and Beyond

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

Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Include key collaborators	Upcoming milestones
Southeast National Marine Renewable Energy Center	Test site planning and development, including permitting and environmental research	Florida Atlantic University, Embry Riddle Aeronautical University, NREL	Preparation of test berth for scale ocean current testing
Northwest National Marine Renewable Energy Center	Open water wave testing infrastructure site selection and development	Oregon State University, University of Washington, NREL	Submittal of test site license documents to FERC
Hawaii National Marine Renewable Energy Center	Collaborative activities with Navy wave energy test site	Department of the Navy, State of Hawaii, Sea Engineering, Makai Ocean Engineering, Lockheed Martin	Initiate activities to evaluate the performance of wave energy device at 30 meter test berth

Evolution of the NMREC Portfolio

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

2008 **2010** **2012** **2014**

2008

- DOE selects two National Marine Renewable Energy Centers
    - Univ of Hawaii
    - Oregon St. / Univ of Wash
- Wave, tidal, OTEC
- Test infrastructure development
- R&D to advance and accelerate industry

2010

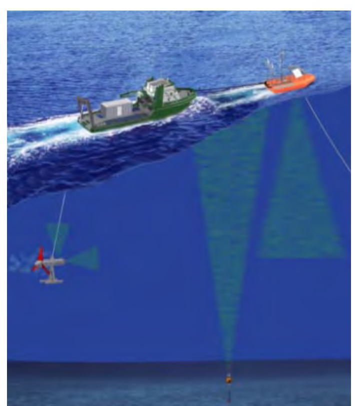
- DOE selects third National Marine Renewable Energy Center at Florida Atlantic Univ
- Ocean current and OTEC
- Test infrastructure development
- R&D to advance and accelerate industry

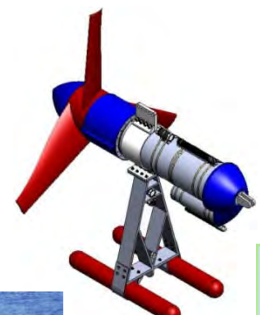
2012

- Congress directs DOE to provide not less than $10 million to build necessary infrastructure, including environmental performance monitoring, at MHK industry testing sites

2014

- No new funds in FY14 for any of the three NMREC's





NNMREC's Ocean Sentinel, Sept. 2012

Questions for Peer Reviewers

- Were the activities performed at the National Marine Renewable Energy Centers relevant to the industry?
- Do the National Marine Renewable Energy Center activities reflect the right mix of wave, tidal, current, and OTEC research, development, and testing?
- Did we adequately integrate the research being done at the National Marine Renewable Energy Centers with other program research being done at the national laboratories?

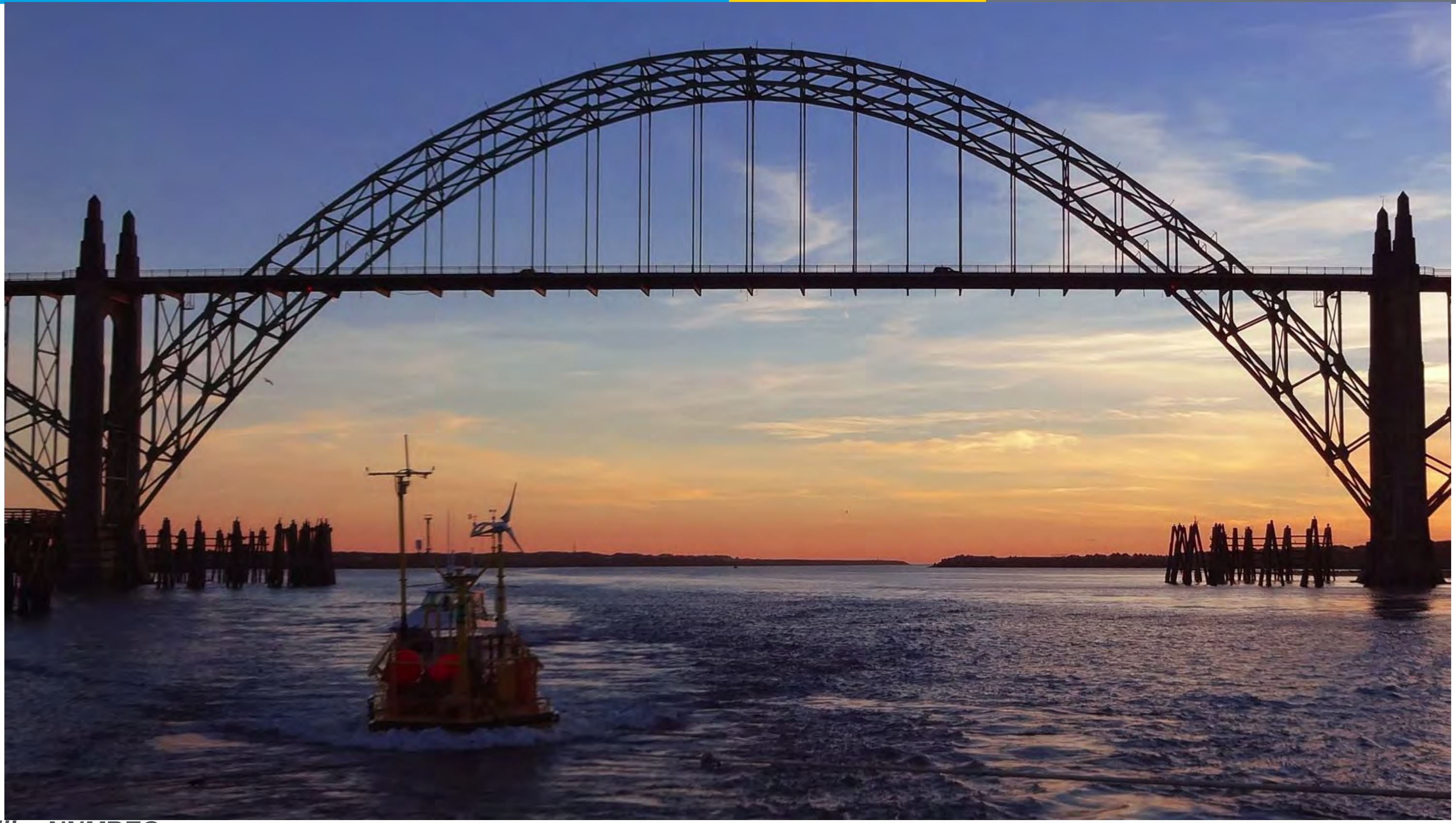


Photo: Dan Hellin, NNMREC

Northwest National Marine Renewable Energy Center

Belinda A. Batten

Oregon State University

belinda.batten@oregonstate.edu, 541.737.9492

XX February 2014

Purpose & Objectives

Problem Statement: NNMREC's mission is to facilitate the commercialization of marine energy technology, inform regulatory and policy decisions, and to close key gaps in scientific understanding with a focus on student growth and development.

Project Objectives:

- Develop facilities to serve as integrated test Center for wave & tidal energy developers
- Evaluate potential environmental and ecosystem impacts
- Optimize devices and arrays for deployment
- Improve forecasting
- Increase reliability and survivability

Purpose & Objectives

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

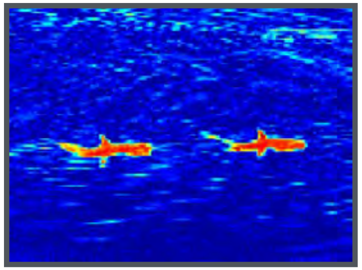
Impact of Project: NNMREC is a unique “go-to” team for industry, regulators, and funders that advances understanding of marine renewable energy, provides integrated research & testing, and provides access to world-class faculty and students.

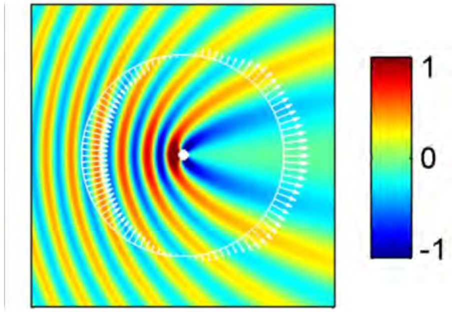
This project aligns with the following DOE Program objectives and priorities :

- Advance the state of MHK technology
- Develop key MHK testing infrastructure, instrumentation, and/or standards
- Characterize and increase access to high resource sites
- Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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

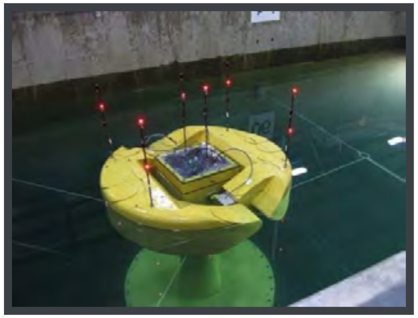


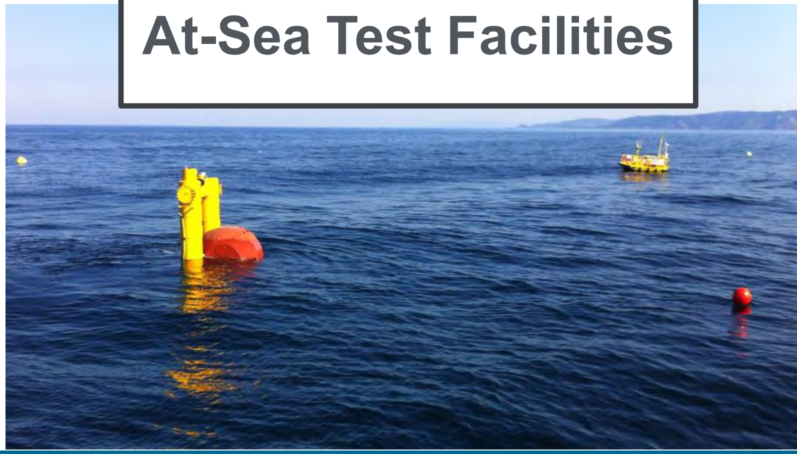


Field Studies ↔ **Numerical Modeling**

↕ ↕

Laboratory/Scale Model Tests ↔ **At-Sea Test Facilities**





Technical Approach

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

Environmental

Site Characterization

Marine Mammals

Benthic Ecosystems

EMF and Acoustics

Sediment Transport

Technical

Testing/Demonstration

Resource Forecasting

Survivability/Reliability

Advanced Materials

Device/Array Optimization

Social

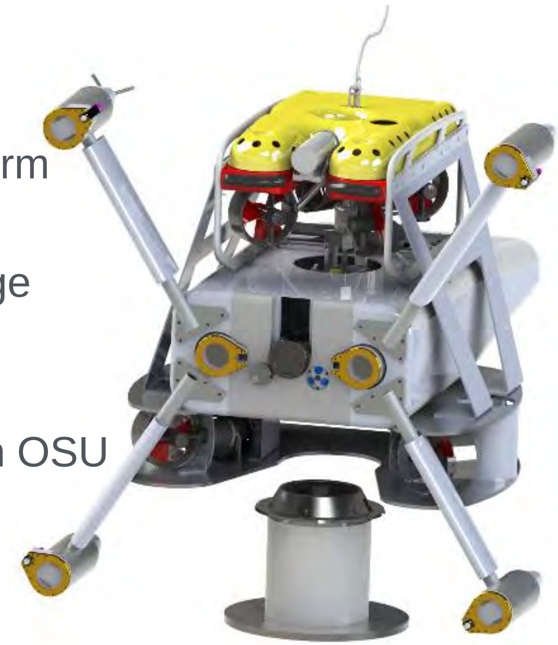
Fisheries/Crabbing

Outreach/Engagement

Existing Ocean Users

Local/State Economy

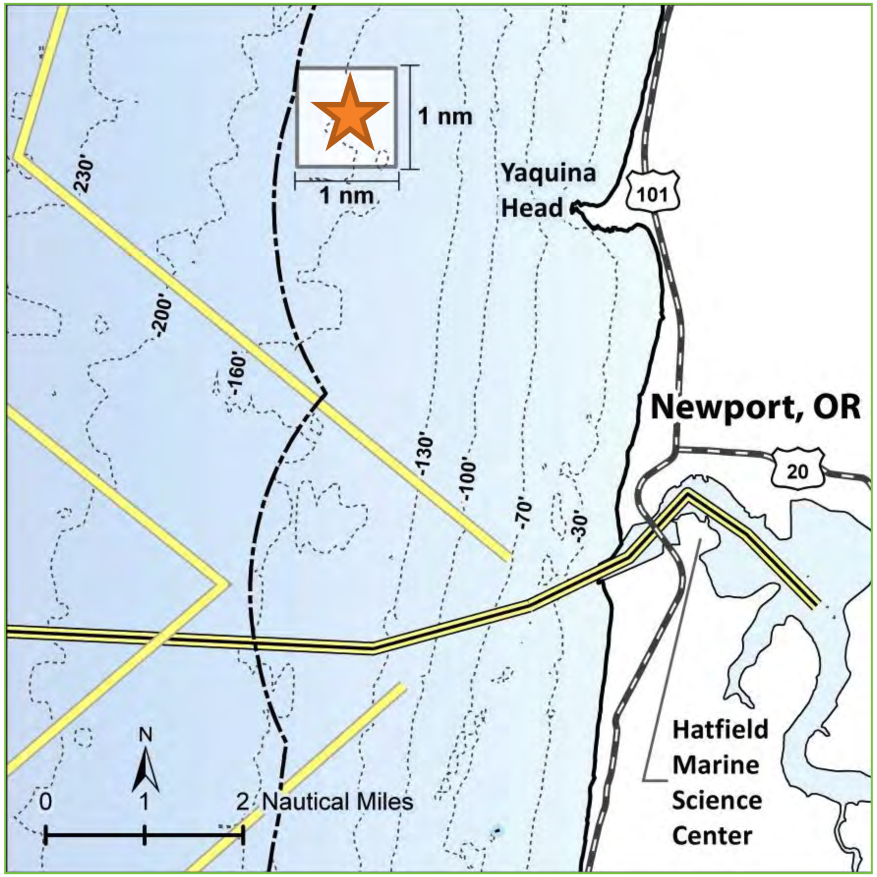
Develop Facilities to Serve as Integrated Test Center for Wave & Tidal Energy Developers

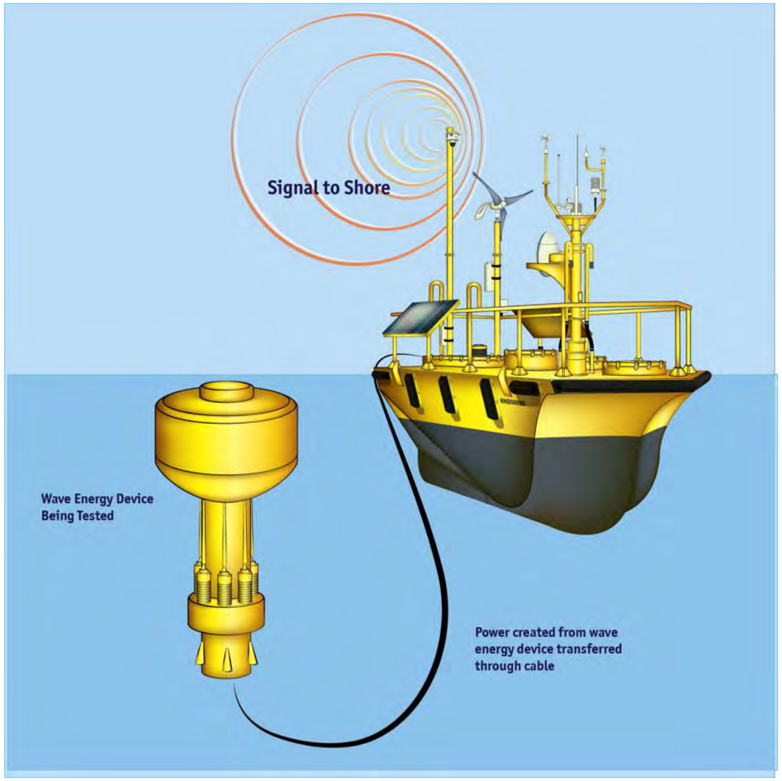


- Field test infrastructure:
  - Concluded 4.5 years of data collection using the Sea Spider platform *without any loss of equipment*
  - Developed prototype concept for the Adaptable Monitoring Package
- Scaled testing:
  - Tested WET-NZ, M3, new Columbia Power Technologies design in OSU wave tank; tested Shift Power in WESRF power electronics facility
- Intermediate open water testing:
  - Developed Puget Sound and Lake Washington as an intermediate scale wave test site, with 3 years of data collection on Lake Washington; tested Oscilla WEC in Lake Washington
- Worked with NREL on testing protocol and instrumentation development processes

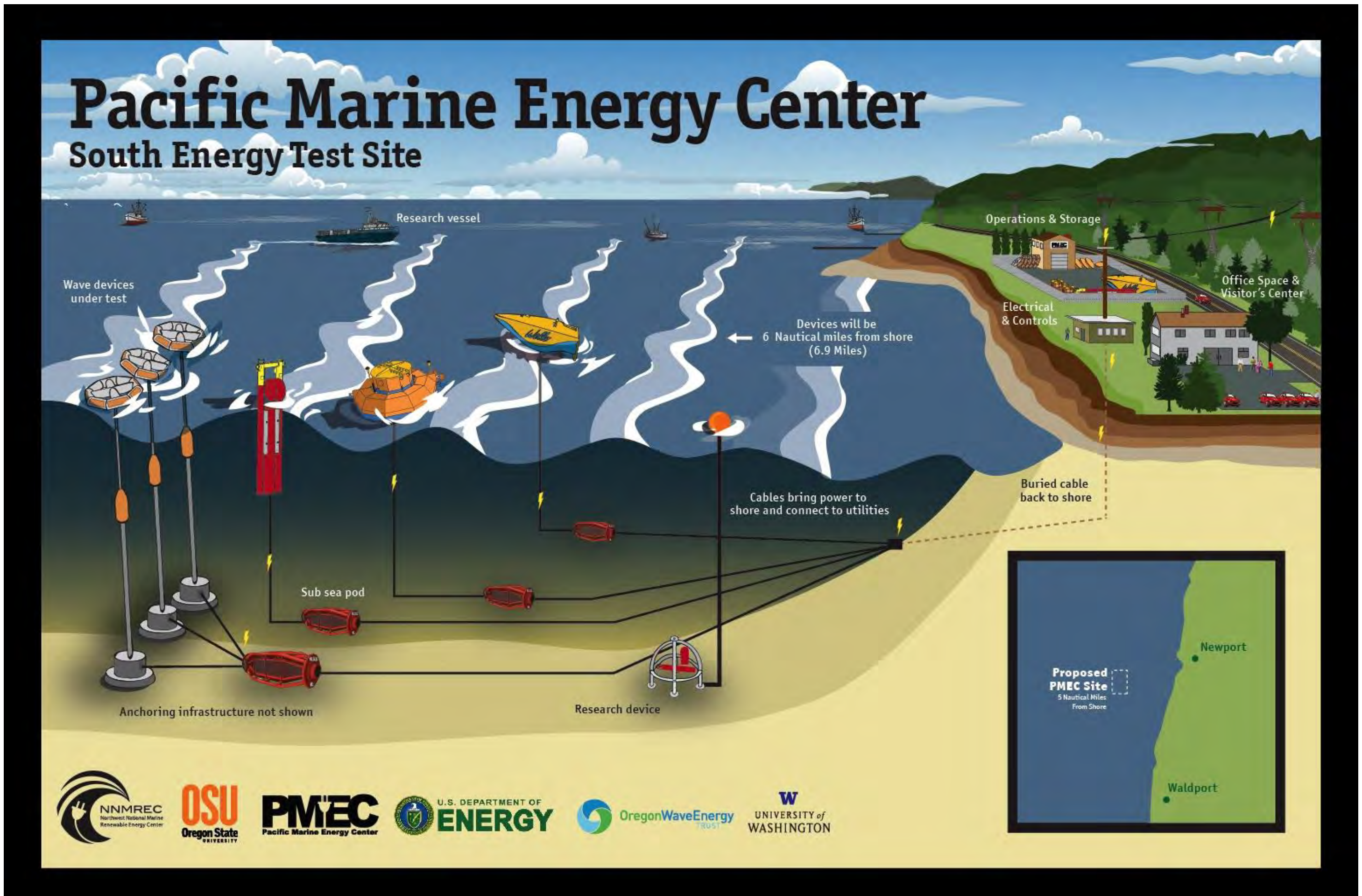
Develop Facilities to Serve as Integrated Test Center for Wave & Tidal Energy Developers

Pacific Marine Energy Center North Energy Test Site (PMEC-NETS):





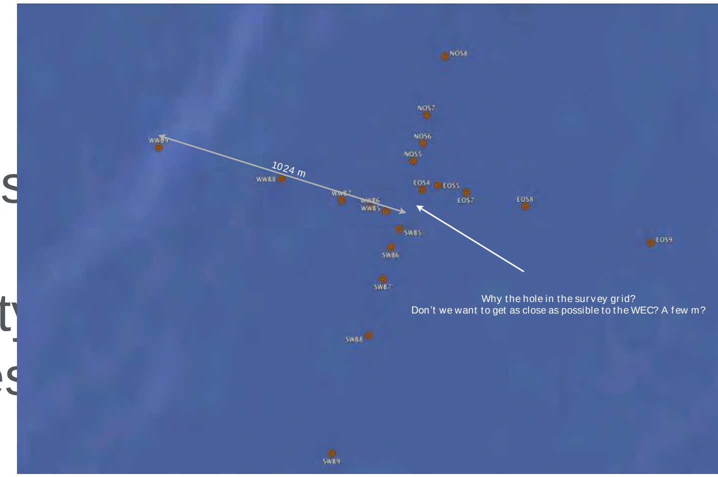
Develop Facilities to Serve as Integrated Test Center for Wave & Tidal Energy Developers

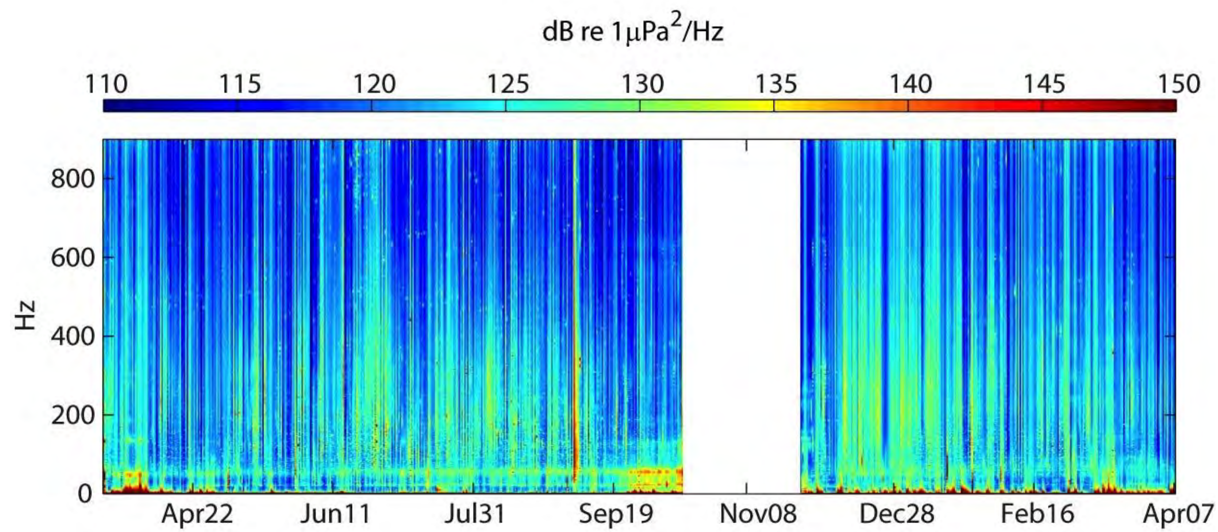


Evaluate Potential Environmental and Ecosystem Impacts

Completed baseline studies at PMEC-NETS;

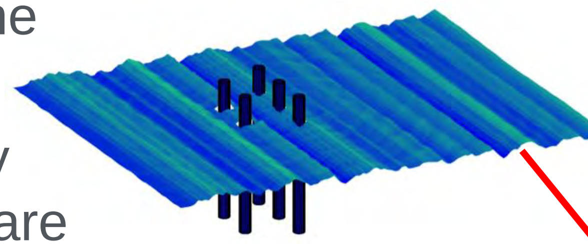
- Measured and analyzed acoustic, benthic, and EMF effects of WEC device distributions
- Developed thorough understanding of baseline seasonal and inter-annual variability in benthic habitat characteristics and species

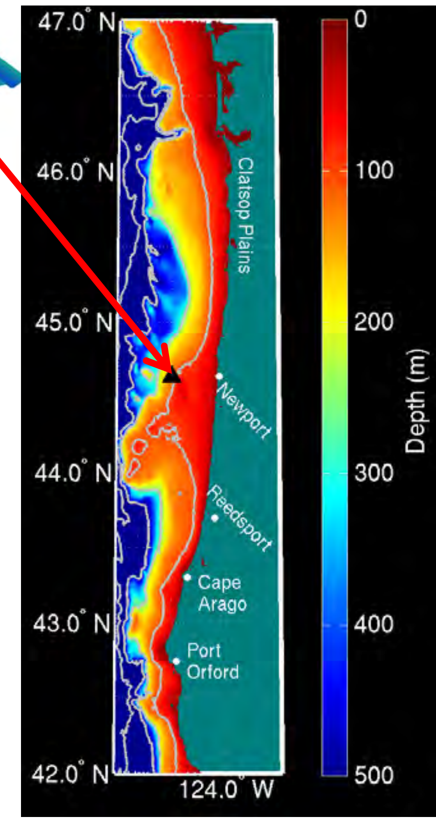


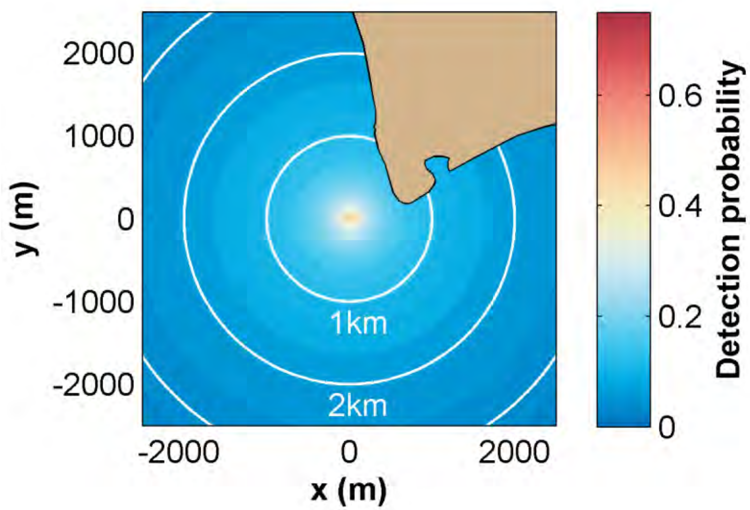


Evaluate Potential Environmental and Ecosystem Impacts

- Developed wave-WEC interaction simulations to assess effects on the wave field in the lee of a device
- Probabilistic framework to quantify extent to which marine mammals are likely to detect sound from tidal turbines against ambient noise

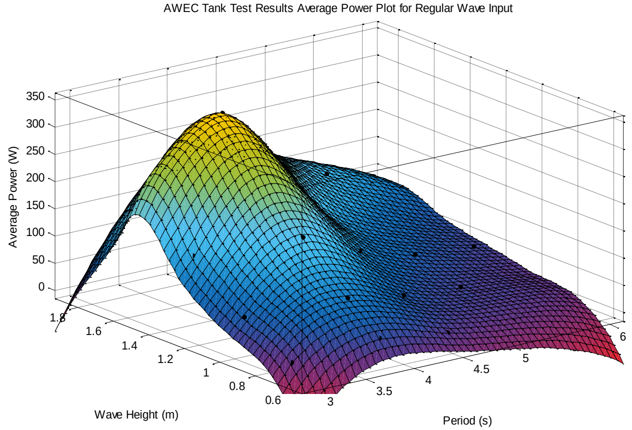






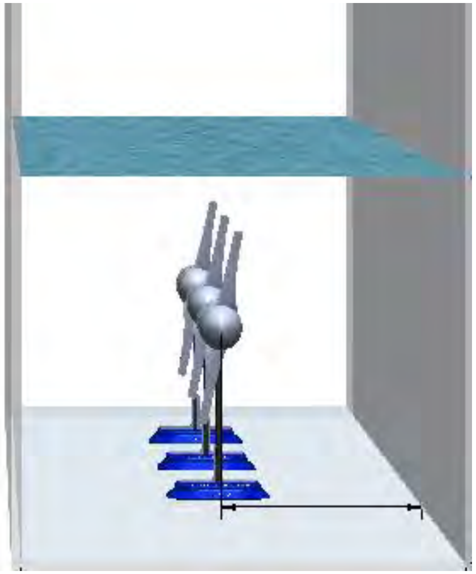
Optimize Devices and Arrays for Development – Wave

- Designed, built, and tested an autonomous WEC at OSU's scaled test facilities. Developed WEC software model validated against tank testing.
- Established a framework for computation of total power output from a WEC array, given information about offshore wave conditions.
- Developed and validated a WEC-array parameterization for spectral wave models, providing additional tools for array design.
- Developed an algorithm for estimating high-resolution time series power output from a WEC array



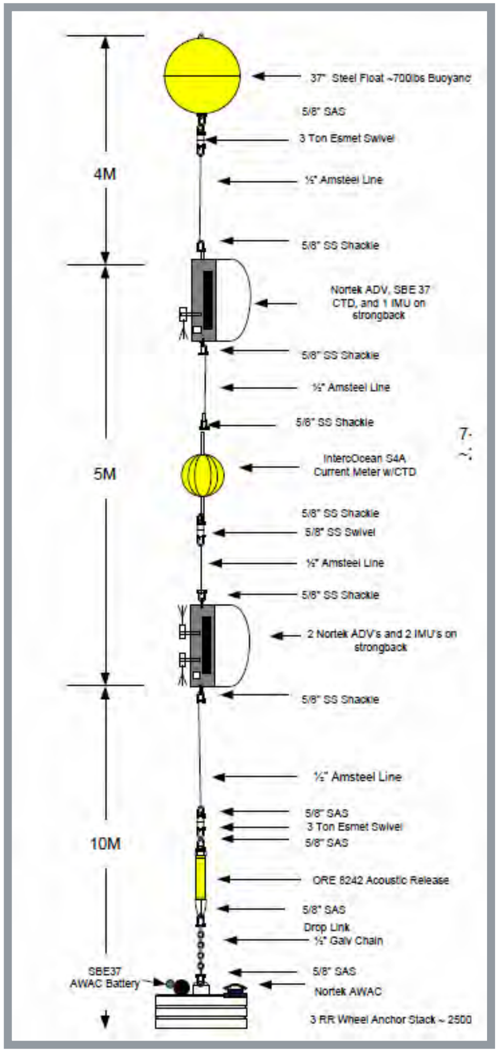
Optimize Devices and Arrays for Development – Current

- Computational tools for the static and dynamic analysis of slack moored tidal arrays
- Computational protocol for estimating performance of large arrays using BEM and an eight-turbine elementary array unit
- Laboratory-scale array of three axial-flow turbines (RM1 variant) used to study wake interactions
- Laboratory-scale cross-flow turbine (helical) used to study effects of blockage
- Field-scale cross-flow turbine used to study wake propagation and turbulence (w/ Sandia National Laboratories)



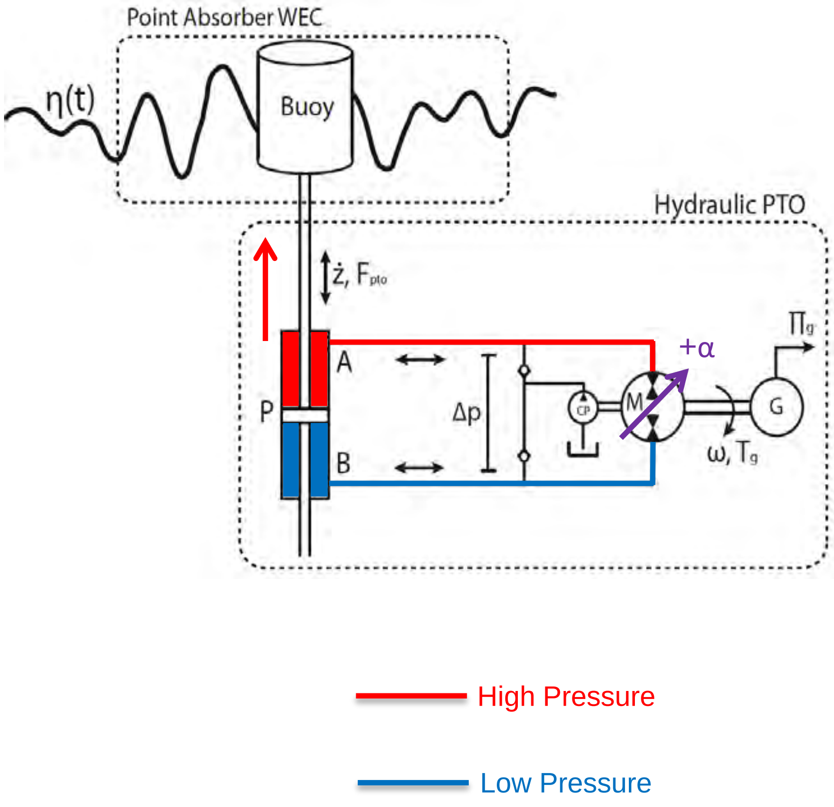
Improve Forecasting and Resource Characterization

- Developed and implemented wave forecasting model for the Oregon coast and carried out a 7-year hindcast to characterize detailed wave energy resource in Oregon.
- Demonstrated the effect of limited-domain representations of tidal systems –up to 25% uncertainty in theoretical resource
- Approaches to characterize the spatial and temporal variability in tidal current resources, including uncertainty in Annual Energy Production (incorporated into TC 114 standards development)
- Quantified ambient turbulence in the field, including a novel mooring for hub-height measurements (w/ NREL and PNNL)



Reliability and Survivability

- Designed and manufactured instrumented breaking wave measurement buoy
- Modeled and analyzed passively and actively controlled power take off architectures and the effect on component life
- Demonstrated electrochemical foul prevention coatings including numerical modeling and experimental validation



Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number: DE-FG36-08GO18179	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2009		FY2010		FY2011		FY2012		FY2013		FY2014		FY2015	
Task / Event	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)	Q1-Q2 (Sep-Mar)	Q3-Q4 (Mar-Sep)
Project Name: Northwest National Marine Renewable Energy Center														
Phase I Deliverables														
Phase II Deliverables														
Phase III Deliverables														
PMEC - SETS Deliverables														

Comments

- Project contracted from 3/15/09 – 3/14/15
- Detailed Deliverables in Back-up Slides

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$3,622K	$5,901K	$5,588K	$7,517K	$9,250K	$10,000K

- Initial funding: $6,250K from DOE in 3/09; added $4M from DOE in 12/12 and contract end date changed to 2015.
- Additional funding via cost match provided by: State of Oregon, State of Washington, Oregon Wave Energy Trust, Portland General Electric, Oregon Department of Energy, Oregon Built Environment and Sustainable Technologies Center, Snohomish PUD, and private donors

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators: University of Washington, National Renewable Energy Laboratory, Sandia National Laboratories, Pacific Northwest National Laboratory, Pacific Energy Ventures, Oregon Wave Energy Trust

Communications and Technology Transfer:

From 10/2011 – 10/2013, the project has resulted in:

- 112 presentations (77 technical, 35 outreach) at conferences, workshops and universities
- 62 publications in archival journals, conference proceedings, and books (searchable reference list available at nnmrec.oregonstate.edu/biblio)

Full details in summary document

Next Steps and Future Research

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

FY14/Current research:

Resource Characterization/Forecasting

- Deploy TRIAXYS and AWAC wave monitoring assets, at both PMEC-NETS and PMEC-SETS to gather wave resource data and simulate wave installation power outputs for an entire year
- Augment wave forecast with satellite wave data to improve wave power forecasts for grid integration of wave power

Device/Array Optimization

- Develop framework and recommendations for ocean WEC systems modeling within the generic framework developed by the IEEE renewable integration working group.
- Complete numerical model development for wave forcing on WECs, study of numerical predictive tools and their validation with experimental and field data from PMEC-NETS.

Next Steps and Future Research

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

FY14/Current research:

Environmental Effects of Devices

- Complete parametric study on nearshore impact of WEC-arrays using SWAN with field validation

Reliability and Survivability

- Validate design of breaking wave buoy
- Complete analysis of biofouling studies

Testing Infrastructure and Field Testing:

- Collect wake and acoustic data from the ORPC RivGen turbine (August 2014) to compare with experiments and simulations (*originally planned for TideGen in September 2013*)
- Complete Adaptable Monitoring Package prototype and test in the field

Next Steps and Future Research

FY14/Current research:

PMEC-SETS

- Continue environmental permitting and licensing tasks: (FERC NOI-PAD submission, environmental documents),
- Complete cable routing study
- Initiate baseline studies: benthic, acoustic, EMF, seabirds
- Determine grid emulator specifications for PMEC SETS based on industry needs, product availability, testing requirements, and facility siting / grid interconnect requirements.

Next Steps and Future Research

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Proposed future research:

- **Field Testing**: Support for WEC testing in 2014 at PMEC-NETS – *Collect performance and environmental data to advance technology readiness and improve market acceptance*
- **PTO Optimization and Control:** Experiments and simulations on PTO architecture to enhance water-to-wire efficiency, including preview control – *Reduce cost of energy*
- **Advanced Moorings**: Develop active mooring systems that reduce seabed footprint and cost relative to existing moorings, while playing an integral role in converter performance enhancement and survivability – *Reduce cost of energy and social acceptability*
- **Environmental Scale-up**: Develop approaches for scaling environmental results from early-stage pilot projects to commercial-scale arrays in high priority areas (e.g., direct interactions with marine mammals) – *Reduce permitting timelines and uncertainty*

Backup Slides

Project Plan & Schedule: Phase I Deliverables

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

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number: DE-FG36-08GO18179	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2009 Q3-Q4 (Apr-Sep)	FY2010 Q1-Q2 (Oct-Mar)	FY2010 Q3-Q4 (Apr-Sep)	FY2011	FY2012	FY2013	FY2014	FY2015
Project Name: Northwest National Marine Renewable Energy Center								
Phase I Deliverables								
Initial simulations with physics-based near shore wave model	Work completed	Work completed, ◆						
A coupled fluid-structure interaction model for prediction of near-field dynamics of a single WEC device	Work completed	Work completed, ◆						
A near shore wave model for the test berth site, incorporating a simplified representation of WEC devices, with testing as wave observations come online	Work completed	Work completed, ◆						
An initial fluid/structure interaction module for motion of WEC device and local flow properties	Work completed	Work completed, ◆						
An initial generalized control model (W)	Work completed	Work completed, ◆						
An initial numerical model of wakes and flow (T)	Work completed	Work completed, ◆						
An investigation of turbine depth on device performance in a sheared flow (T)	Work completed	Work completed, ◆						
A report documenting potentials for cross-fertilization between other renewable energy technologies and hydrokinetic technology	Work completed	Work completed, ◆						
Results of international ocean energy market survey (W)	Work completed	Work completed, ◆						
Design of full scale mobile PADA test berth (W)	Work completed	Work completed, ◆						
Initial ship-board deployment of radar wave imaging system for site characterization	Work completed	Work completed, ◆						
trialing of stand-along packages for over-the-side and bottom mounted monitoring (T)	Work completed	Work completed, ◆						
Published guidelines for best practices in instrumentation and monitoring (T)	Work completed	Work completed, ◆						
Initial environmental site characterization work for Center demonstration facility (W)	Work completed	Work completed, ◆						
Utilize area wave model to transform wave field affected by a WEC device toward shore	Work completed	Work completed, ◆						
Evaluation of existing high-sea state survival mechanisms applicable to WEC devices	Work completed	Work completed, ◆						
Evaluation of existing coating and electrochemical approaches	Work completed	Work completed, ◆						
An initial experimental approach to test electrochemical antifouling systems	Work completed	Work completed, ◆						

Phase II Deliverables

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Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number: DE-FG36-08GO18179	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2009	FY2010 Q1-Q2 (Oct-Mar)	FY2010 Q3-Q4 (Apr-Sep)	FY2011 Q1-Q2 (Oct-Mar)	FY2011 Q3-Q4 (Apr-Sep)	FY2012 Q1-Q2 (Oct-Mar)	FY2012 Q3-Q4 (Apr-Sep)	FY2013	FY2014	FY2015
Project Name: Northwest National Marine Renewable Energy Center										
Phase II Deliverables										
Simulations over the Oregon shelf with physics-based model and assessment of forecast accuracy with in situ and wave radar observations										
Incorporation of artifical neural networks to correct forecast errors from physcs based model										
Simulations and parametric studies of field-deployed WEC devices (W)										
Complete fluid-structure interaction module and simulations of near-field wave scattering from single WEC device with field data (W)										
Initial simulatios involving multiple devices using near-shore wave model (W)										
Assessment of level of interaction between devices and the nature of constructive/destructive effects as a function of separation scales and wave characteristics (W)										
Incorporation of more sophisticated representation of WEC devices into area wave models using results from wave-structure interaction module. (W)										
Initla interconnection of mechanical/electrical modeling tools to hydrodynamic modeling toos for modeling a single WEC device. (W)										
A numerical model of wakes and flow redirection (T)										
Calibration of wake models by field and flume data (T)										
Engineering rules for flow redirection in large arrays (T)										
A report documeneting the potential of hybrid renewable systems to accelerate deployment and evelopment of economies of scale (W)										
Construction and deployment of full-scale mobile PADA test bert. Results from wave monitors and WEC devices placed at the Center demonstration site (W)										
Radar deployments and analysis of radar/AWAC/Waverider observations (W)										

Phase II Deliverables, Continued

Summary		Legend
WBS Number or Agreement Number		Work completed
Project Number		Active Task
Agreement Number: DE-FG36-08GO18179		Milestones & Deliverables (Original Plan)
		Milestones & Deliverables (Actual)

Task / Event	FY2009	FY2010 Q1-Q2 (Oct-Mar)	FY2010 Q3-Q4 (Apr-Sep)	FY2011 Q1-Q2 (Oct-Mar)	FY2011 Q3-Q4 (Apr-Sep)	FY2012 Q1-Q2 (Oct-Mar)	FY2012 Q3-Q4 (Apr-Sep)	FY2013	FY2014	FY2015
Project Name: Northwest National Marine Renewable Energy Center										
Phase II Deliverables										
Design and bid process for multiple full-scale test berths (W)										
Free-stream turbulence measurements and correlation of turbulence with device performance (T)										
Wake measurements (T)										
Website and electronic document repository for environmental information										
Initial acoustic assessment of existing wave energy facilities; advise industry, agencies and other stakeholders on environmental effects (continuing activity) (W)										
Annotated bibliography of environmental effects pertinent to wave energy development (W)										
Initial simulations on effects of WEC device arrays and feed information back to array design to minimize shoreline effects (W)										
Develop, model and test survival mechanism for direct drive WEC devices (W)										
Develop low cost, robust electrochemical protection system capable of field deployment										
Short and long term deployment of test samples in Yaquina Bay for system evaluation										
Initial report on benefits of composite materials for tidal turbines and ocean energy systems										

Phase III Deliverables

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

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number: DE-FG36-08GO18179	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2009	FY2010	FY2011	FY2012 Q1-Q2 (Oct-Mar)	FY2012 Q3-Q4 (Apr-Sep)	FY2013 Q1-Q2 (Oct-Mar)	FY2013 Q3-Q4 (Apr-Sep)	FY2014 Q1-Q2 (Oct-Mar)	FY2014 Q3-Q4 (Apr-Sep)	FY2015
Project Name: Northwest National Marine Renewable Energy Center										
Phase III Deliverables										
Routine wave power forecasts to aid in design and implementation of test berth										
Assessment of total errors associate with hybrid (physics/ANN) technique										
Simulations and parametric studies of the physical WEC array deployed in the field										
Design, development and optimization of a WEC device array model										
Finalize development of an optimized array of WEC devices based on field data analysis and numerical parametric studies										
Complete assembly of integrated modeling framework (W)										
Explore feedbacks between hydrodynamics, power capture and device efficiency (W)										
Documentation, manual, tutorial, and example cases for the resulting modeling tool (W)										
Conduct Doppler profiling measurements to characterize the wake from a full-scale turbine (T)										
Verify and validate numerical models for wake propagation using field and laboratory wake measurements in order to develop empirical device spacing rules										
Assess the stability of tidal turbines with moorings using numerical simulations (T)										
Protocols, instrumentation and accreditation plans for WEC testing (W)										
Routine radar and in situ deployments and analysis, support for model validation										
Planning documents for design of multiple cable-to-sore test berths and related on-shore infrastructure										
Results form wave monitors and WEC devices placed at the NETS site										
Results of wave observation analysis										
Report describing options for cost-effective monitoring of commercial arrays (T)										
Continue field data collection from Admiralty Inlet until June 2013 (T)										

Phase III Deliverables, Continued

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Summary		Legend	
WBS Number or Agreement Number			Work completed
Project Number			Active Task
Agreement Number: DE-FG36-08GO18179			Milestones & Deliverables (Original Plan)
			Milestones & Deliverables (Actual)

Task / Event	FY2009	FY2010	FY2011	FY2012		FY2013		FY2014		FY2015
				Q1-Q2 (Oct-Mar)	Q3-Q4 (Apr-Sep)	Q1-Q2 (Oct-Mar)	Q3-Q4 (Apr-Sep)	Q1-Q2 (Oct-Mar)	Q3-Q4 (Apr-Sep)	
Project Name: Northwest National Marine Renewable Energy Center										
Phase III Deliverables										
Develop protocols to quantify design velocities at tidal energy sites from current measurements and meteorological data (T)										
Workshop on EMF effects related to grid marine energy devices (W)										
Post installation sampling at NETS										
Test various WEC array designs to assess range of possible shoreline impacts. Identify configurations with least or no impact. (W)										
Complete work on potential shoreline effects of WEC arrays (W)										
Conduct passive acoustic characterization of a full-scale tidal turbine to assess relationship between noise and power generation state (T)										
Develop simple, open-source models for reinstallation estimates of acoustic effects from tidal turbines (T)										
Develop a framework/checklist for local modelers to verify the fitness of their models to evaluate and quantify the extractable tidal resource.										
Identification of best antifouling performers in real ocean energy system geometries										
Models and engineering protocols for predicting coatings behaviors in long-term deployments										
Model and simulate effects of breaking waves on WECs (W)										
Investigate WEC device topologies for increased reliability and survivability (W)										

PMEC-SETS Deliverables

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Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number: DE-FG36-08GO18179	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2009	FY2010	FY2011	FY2012	FY2013 Q1-Q2 (Oct-Mar)	FY2013 Q3-Q4 (Apr-Sep)	FY2014 Q1-Q2 (Oct-Mar)	FY2014 Q3-Q4 (Apr-Sep)	FY2015 Q1-Q2 (Oct-Mar)	FY2015 Q3-Q4 (Apr-Sep)
Project Name: Northwest National Marine Renewable Energy Center										
PMEC - SETS Deliverables										
GPS Coordinates of the PMEC site that meet the needs of the industry as defined by engineering analysis and requirements and accepted by the local community										
Market Analysis for user needs										
Supply Chain Analysis										
PMEC Development Plan										
Pre-design documents, detailed cost estimates, operation and management plan										
PMEC business plan										
Quarterly reporting of outreach and engagement activities										
Working relationships established with necessary permitting agencies										
Permitting applications filed										
Baseline characteristics of PMEC site for key parameters										
Report outlining strategy for utility interconnect										
Prototype instrumentation payload system (AMP)										
Pre-design for grid emulator										
Dynamic model for slack moored WECs										
Research report on composite mono-cables										

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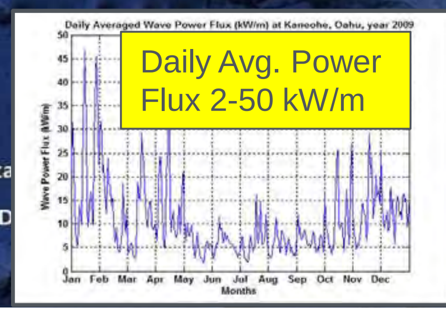
Hawaii Wave Energy Test Site

- 30m berth in place (~1km offshore)
  - Hosted OPT device
- 60, 80m berths by Dec 2014 (~2km offshore)
- Grid connected
- HNEI/HINMREC to measure environmental impacts and provide independent performance evaluation



Hawaii National Marine Renewable Energy Center (HINMREC)

Richard Rocheleau

Hawaii Natural Energy Institute (HNEI)

rochelea@hawaii.edu, (808) 956 8346

27 February 2014

Purpose & Objectives: OTEC

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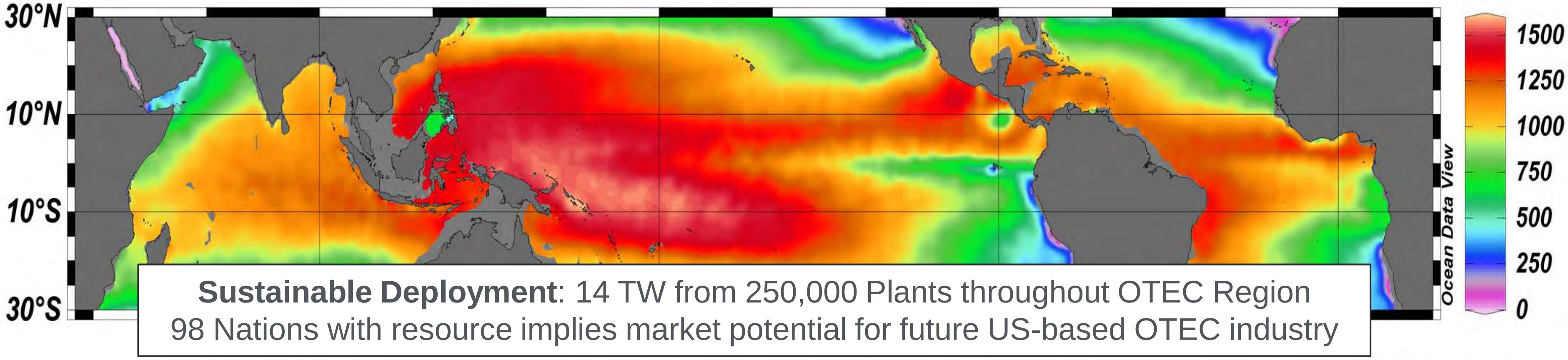
Problem Statement: Economic models indicate that ocean thermal energy conversion can be cost competitive at scales of 50 MW or more. However, commercialization is hampered by high capital cost, technical risk, lack of long-term operational records, and environmental impact uncertainty.

Impact of Project: HNEI/HINMREC has leveraged ONR and Navy investment to improve understanding of the environmental risks and to support development of a fully operational OTEC test facility to conduct materials research and component testing to reduce technical risk.

This project aligns with all four DOE program objectives.

- Resource Mapping Complete

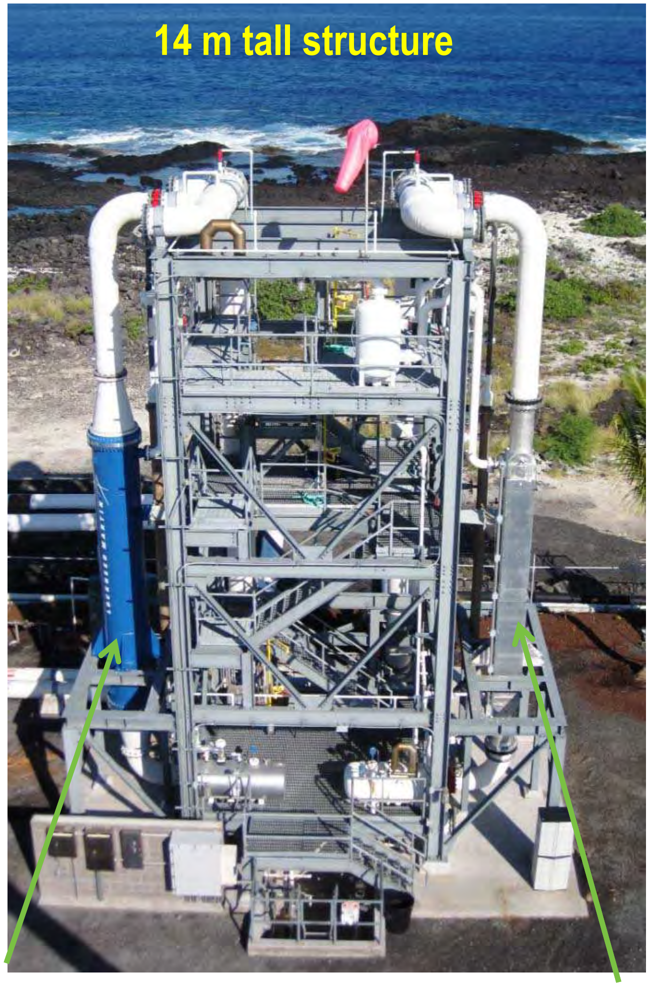


Technical Resource: 100 MW OTEC Plant Annual Electricity Generation (GWh)

Baseline: 877 GWh/year @ $\Delta T = 20$ ℃

- Kahe Point Plume Studies Complete
  - Models (UH and Makai Ocean Engineering) agree that plume equilibrium is below photic layer (~120m in Hawaii)
  - Identified parameters to monitor during plant operation to assess impact (Chlorophyll a, temperature/salinity/oxygen, pH and dissolved inorganic carbon)
  - Results provided to NOAA, currently used to guide baseline measurements for seawater air conditioning projects

Photo courtesy of MOE



S&T Condenser (by LM)

Brazed Fin Evaporator (by CHART)

OTEC Test Facility at NELHA

- Designed & operated by Makai Ocean Engineering
  - Infrastructure funded by NAVFAC
  - Materials and testing of advanced aluminum heat exchangers funded by Office of Naval Research via grant to HNEI
  - Corrosion testing supported by HINMREC
- Fully integrated plant
  - Integrated NH_3 system
  - Deep (600 m or 900m) & surface seawater system
  - 100kW turbine to be installed 2014
- Establishing performance of *cost-effective* aluminum heat exchangers

Purpose & Objectives: Wave Energy

Problem Statement: The US lacks infrastructure for the testing of 'large demonstration scale' wave energy conversion (WEC) devices to evaluate performance, durability, and environmental impacts; needed by developers to achieve commercialization (TRL 8/9).

Impact of Project: HNEI/HINMREC has worked with Navy/DOE to develop a 3-berth, grid-connected wave energy test site off Marine Corps Base Hawaii. Berths at 30m, 60 and 80m expected to be operational in 2014, allowing testing of devices up to ~ 1MW peak.

This project aligns with all four DOE program objectives.

Integrate DOE and Navy Objectives for Wave Energy Testing

Department of Energy

- Site Preparation
  - Assist Navy with design of 3-berth Test Site
  - Facilitate environmental permitting process
- Conduct Environmental Impact Measurements
  - Acoustic, EMF, Ecological, Sediment Transport
- Conduct Independent Performance Assessments
  - Characterize wave resource (forecast/hindcast)
  - Assess device durability
  - Develop power matrices to correlate performance with sea state
  - Evaluate alternative modeling approaches to enhance value of device performance evaluations
- Provide Marine Services to Developers (funded by Navy)

Expected NAVFAC Funds

Accomplishments and Progress
(Site Preparation)

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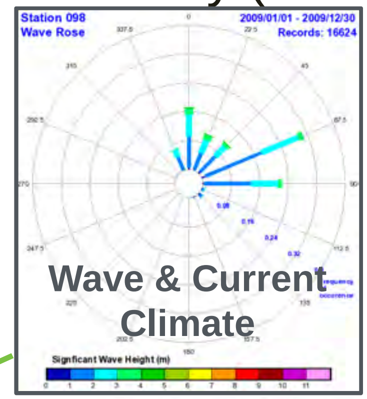
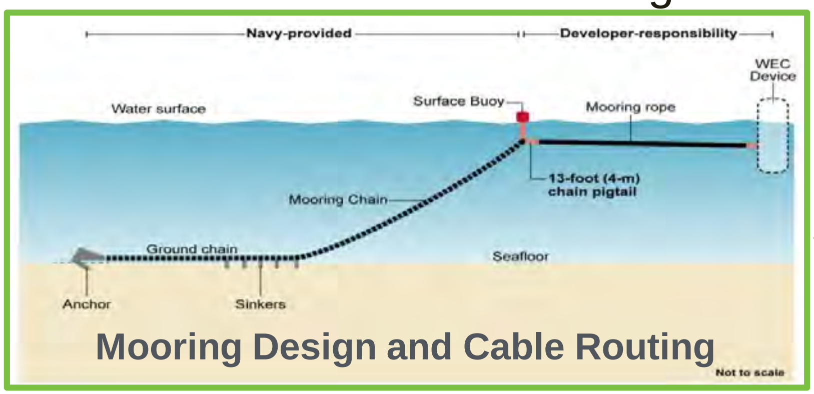
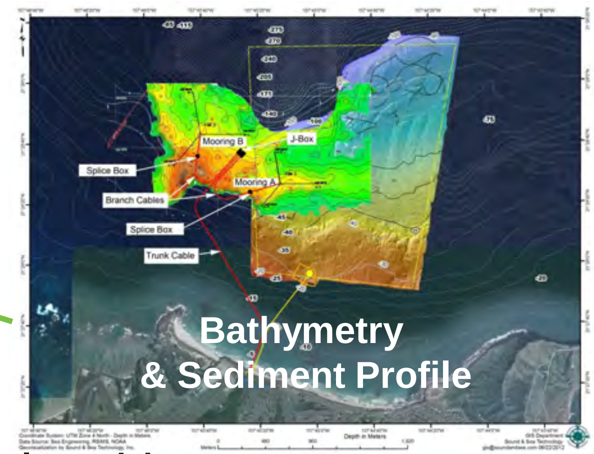
- Site Design (60m and 80m berths) Complete
  - Design by Sound and Sea Technology for US Navy (NAVFAC)
  - HNEI/HINMREC Support
    - Wave/current analysis
    - Bathymetry and sediment survey
    - Frequent participation in design planning discussions/meetings







- Navy EA Complete, FONSI Imminent
  - HNEI/HINMREC served in regular advisory role with NAVFAC, NOAA, DOE, Marine Corps for over 2 years

WETS Design Complete

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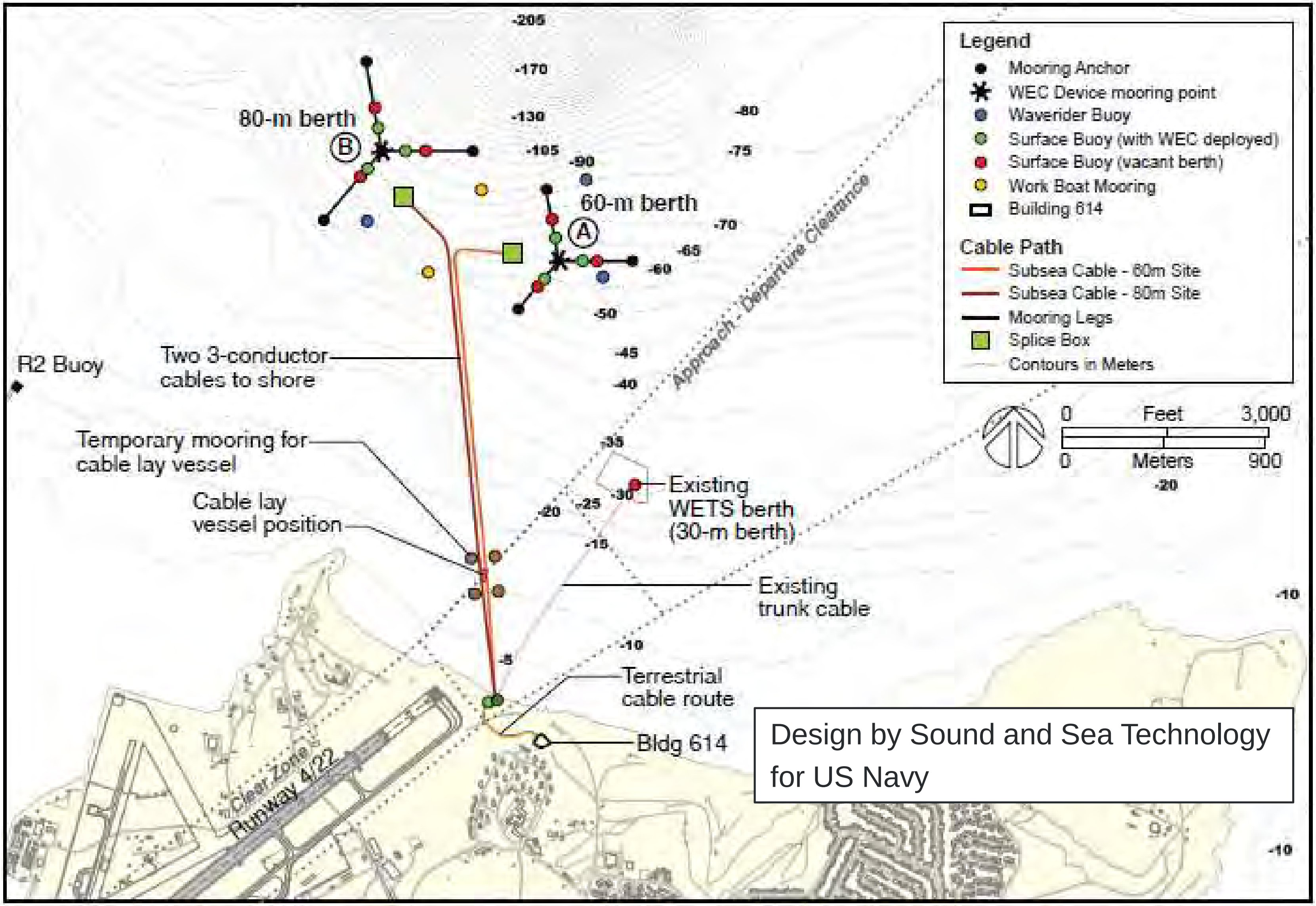


Design by Sound and Sea Technology for US Navy

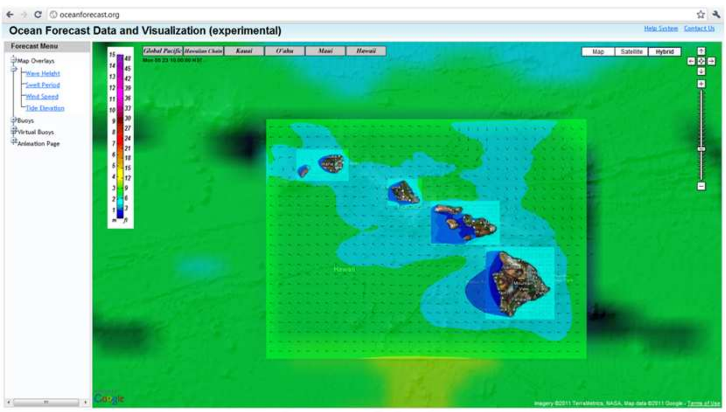
Plans in Place for Acoustic, EMF, Ecological, and Sediment Transport Measurements

- Hydrophone stations for each berth designed, fabrication and testing in progress
- Agreement in principal reached with UW for floating hydrophone system to be deployed periodically
- Agreement in principal reached with OSU for regular deployments of EMF measurement system
- Agreement in principal with Sea Engineering, Inc. to conduct periodic diver and ROV ecological surveys
- Agreement in principal with Sea Engineering to continue sediment profile measurements after deployment of deep moorings and WEC devices

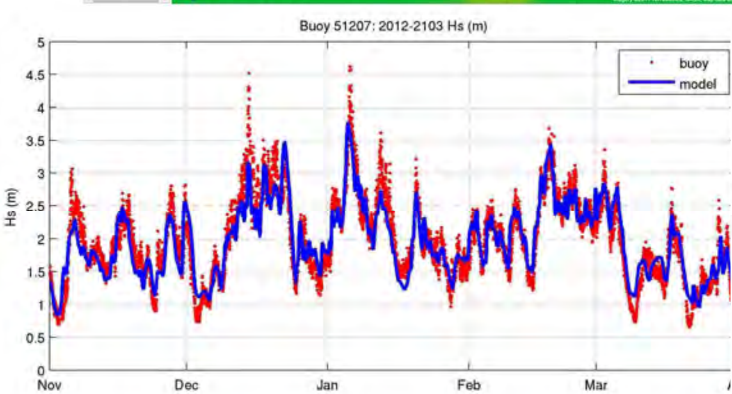
Measurements to begin after final Navy approval of EA

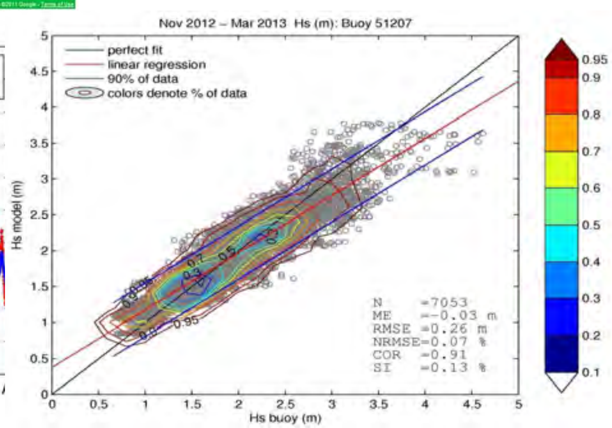
Accomplishments and Progress
(Independent Performance Assessment)

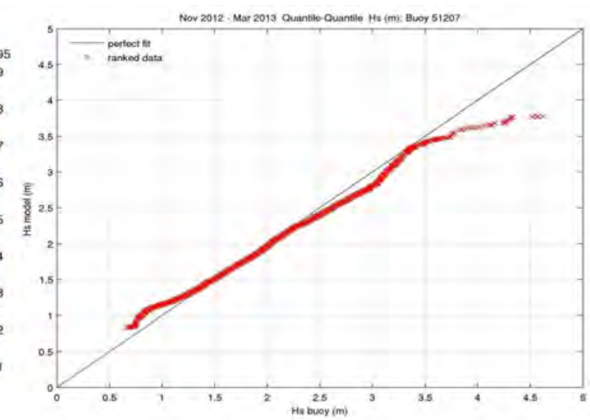
- Wave Hindcast Database Developed, and Growing
- Running Daily 7.5-day Wave Forecasts with High-res Model
  - Calibrated using WaveRider buoy deployed in October 2012
  - 80% of data within 10% of model



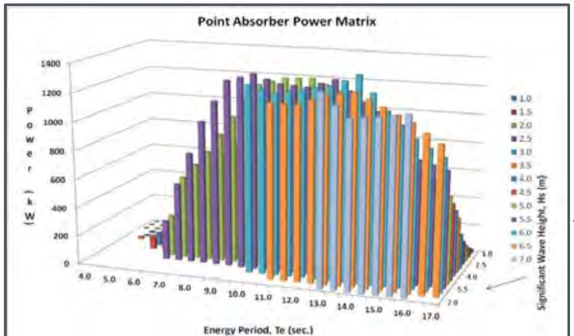
- RMSE ~0.26 m
- Swell event peaks are underestimated
- Overestimates small waves
- Underestimates large waves





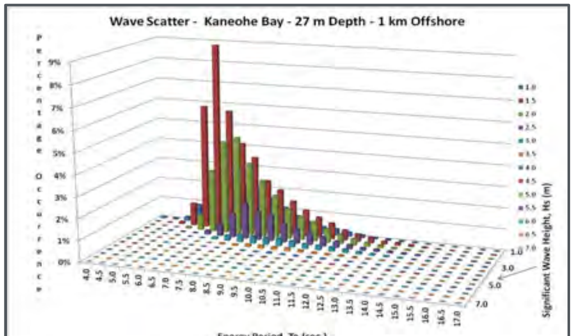


- Plan Developed for WEC Device Durability Assessment
  - Monthly, then quarterly, diver inspections of devices/connections
  - Monthly, then quarterly, diver/ROV inspections of moorings
- Methodology Developed for Device Power Matrices (electrical output vs. wave parameters)



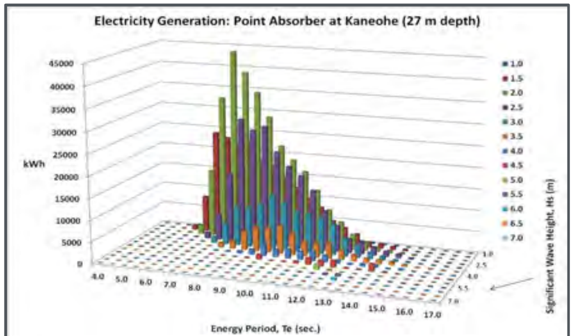
Power Matrix: kW vs. Hs/Te

X



Wave Scatter: Occurrence vs. Hs/Te

=



Electricity Generation: kWh vs. Hs/Te

- Developed device modeling capabilities
  - “Numerical wave tank” model, with enhanced non-linear physics, is under development
  - WEC array modeling ongoing, array wave power extraction and required ocean area can be assessed

Project Plan & Schedule - WETS

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• Deploy ADCP near 30m berth	March 2014
• Begin quarterly ecological surveys	April 2014
• Begin monthly/quarterly device and mooring inspections	April 2014
• Begin independent power output data collection	May 2014
• Initial acoustic recordings w/NWEI device	May 2014
• Begin sediment transport/water sample baseline surveys	June 2014
• OSU conduct initial EMF measurements w/NWEI device	Summer 2014
• Begin baseline acoustic recordings at deep sites	Summer 2014
• UW SWIFT hydrophone deployment #1	Summer 2014
• Upgrade hindcast database w/newly released wind data	September 2014
• Deploy WaveRider buoys #2 and 3	October 2014
• Additional EMF measurements w/multiple devices	Summer 2015

Dates based on Navy schedule

FONSI (2/14), 30m berth occupied by NWEI (4/14), deep berths complete (9/14), tenants (TBD) at deep berths (12/14)

Summary

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<u>OTEC</u> – All DOE activities to be completed in 2014

<u>WETS</u>

- Focus shifting from preparation to execution
- HNEI helping to link between DOE and Navy objectives
  - Expected Navy funds will extend and expand HINMREC effort
- Emphasis will be on supporting grid-connected in-water testing
  - Environmental impact measurements (acoustic/EMF/ecological)
  - Independent performance analysis
  - Marine support services
- Proposed Navy effort provides for smooth transition from HINMREC and continued operations through 2017

Project Budget

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Budget History					
FY2012		**FY2013**		**FY2014 & FY2015 (with Carryover)**	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$947K	**$950K**	**$1,449K**	**$1,450K**	**$5,009K**	**$5,009K**

- Original 5-Year Project from 09/08 to 09/13
- Cumulative 2-year no-cost extension to 09/15 due to NEPA Compliance and Permitting Process requirements
- Two-Year FY'14 and FY'15 includes carryover
- Expenditures minimized to support future in-water testing
  - FY'13 Actual Expenses were $787K vs. $1,449K
  - Through 12/13 DOE expenditures of $3,248.6K out of the total $7,999.6K multiple-year contract
  - Keeping team together while minimizing current expenditures was challenging
- In addition to cost-share above, $500K awarded by the State of Hawaii
- NAVFAC will spend >$10M to commission Wave Energy Test Site, not including current negotiations with HNEI
- DOE funding distribution: Management/EA 15%; UH Research 20%; Test Sites 65%

NWEI Device Under Test in Oregon

Photo courtesy of NWEI

Partners, Subcontractors, and Collaborators

- **Academic & Research Institutions**

University of Hawaii: Yi-Leng Chen (*Meteorology*); Kwok Fai Cheung (*Wave Resource*); Gerard Nihous (*Ocean Thermal Resource & WEC Modeling*); Eva-Marie Nosal (*Acoustics*); Mark Merrifield (*Waveriders*)

NNMREC: Brian Polagye (*Acoustics*); Adam Schultz (*EMF*)

- **Private Sector Subcontractors**

Sea Engineering (*Ocean field work & Diver/ROV Surveys*); Makai Ocean Engineering (*Corrosion & Heat Exchangers*); Garrad Hassan (*WEC Protocols & Modeling*)

- **Federal**

NAVFAC (*Wave Energy Test Site*); ONR (*Env. Studies; System Design*)

NOAA (*OTEC*)

- **State of Hawaii**

Dpt. of Business, Economic Development, and Tourism (*Policy & Support*)

Communications and Technology Transfer:

- All information available at **http://hinmrec.hnei.hawaii.edu/** with 50 daily visitors on average
- Wave resource assessment provided directly to developers
- Bathymetry, sediment, wave and ocean current data transferred to NAVFAC for WETS design
- Presentations at GMREC; Energy Ocean & other Conferences
- Academic degrees: Ph. D. *"Periodicity and Patterns of the Global and Wave Climate"*, J. Stopa (2013); MS *"Geometric Effects on Maximum Power Absorption Efficiency for a Single, 2D Heaving Body"*, R. Hager (2012); MS *"Numerical Simulations and Observations of Airflow through the 'Alenuihaha Channel, Hawaii"* D. Hitzel (2013)

Technology Transfer (Representative Publications):

- Arinaga, R.A. and Cheung, K.F. (2012). *"Atlas of global wave energy from 10 years of reanalysis and hindcast data"*. Renewable Energy, **39**, 49-64.
- Stopa, J.E., Filipot, J.-F., Li, N., Cheung, K.F., Chen, Y.-L., and Vega, L. (2013). *"Wave energy resources along the Hawaiian Islands chain"*. Renewable Energy, **55**, 305-321.
- Rajagopalan, K. and G.C. Nihous, (2013) *"An Assessment of global Ocean Thermal Energy Conversion Resources under broad geographical constraints," Journal of Renewable and Sustainable Energy*, **5**, 063124, 11 p.
- Rajagopalan, K. and G.C. Nihous, (2013) *"An assessment of Global Ocean Thermal Energy Conversion (OTEC) resources with a high-resolution Ocean General Circulation Model," Journal of Energy Resources Technology*, **135**, 041202, 9 p.
- Nihous, G.C., (2012) *"Wave power extraction by arbitrary arrays of non-diffracting oscillating water columns," Ocean Engineering*, **51**, 94-105.
- Nihous, G.C., (2013) *"Maximum wave power absorption by flexible line attenuators," Applied Ocean Research*, **43**, 68-70.

FY14/Current research:

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Resource Assessment & Forecasting

- Include coupled ocean-atmosphere into world thermal resource model (FY'14 completion)
- Upgrade Hawaii wave hindcast with newly released 30-year wind data (FY'14 completion)
- Ongoing analysis of Waverider data; and, 7.5 day on-line WETS forecast

Computer Models

- Array of multiple flexible line attenuators (FY'14 completion)
- Numerical Wave Tank for WEC device performance (continued into FY'15)

Environmental Impact Monitoring of Devices at WETS (FY'14: NWEI; beyond FY'14: TBD)

- In-situ baseline acoustic and EMF emission at WETS (FY'14)
- Acoustic and EMF emission measurements with WEC devices operational
- Develop semi-empirical model of emissions as a function of device operating phase
- Quarterly surveys: ecological & water quality ; sediment transport; mooring/cable hardware

WEC Device Electrical Performance at WETS

- Develop test protocol and implement data acquisition system (FY'14 completion)
- Wave and ocean current in-situ measurements (continued into FY'15)
- Document Power Matrix (wave parameters vs. electrical output) of WEC devices deployed at WETS (continued into FY'15)

Aluminum Corrosion

- Complete multiple-year corrosion tests at the Hawaii OTEC Test facility

FY14/Current research :
Theoretical WEC *Performance Evaluation*

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	"Name Plate"	Kaneohe, Oahu	Kilauea, Kauai	Pauwela, Maui	Kaneohe, Oahu
Wave Scatter Data (Year)		**2009**	**2009**	**1990-2009**	**1990-2009**
Site Depth		**58 m**	**53 m**	**73 m**	**86 m**
Wave Power Flux: Po *(from HINMREC)*		**13.8 kW/m**	**21.6 kW/m**	**23.1 kW/m**	**12.1 kW/m**
WEC Device *(Power Matrix by others)*		**Annual MWh:**	**Annual MWh:**	**Annual MWh:**	**Annual MWh:**
*** Point Absorber IEC/TS 62600-100 Annex A** www.iec.ch	1000 kW	**1048 MWh CF: 0.12**	**1343 MWh CF: 0.15**	**1951 MWh CF: 0.22**	**1105 MWh CF: 0.13**
*** Pelamis** www.pelamiswave.com	750 kW	**826 MWh CF: 0.13**	**743 MWh CF: 0.11**		
*** Wavestar C5 (Terminator)** http://wavestarenergy.com	600 kW	**2494 MWh CF: 0.47** Curtail 4 days	**2331 MWh CF: 0.44** Curtail 22 days		

Theoretical Resource

Technical Resource

Project Plan & Schedule

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

Project Schedule & Milestones: Hawaii National Marine Renewable Energy Center (HINMREC)						DE-FG36-08GO18180
SOPO Task	Title / Task Description	Task Completion Date				Progress Notes
			Planned	Actual	Percent Complete	
1.0	**Project Management**		NA	NA	NA	Go/No-Go process led to project continuation and budget balance approval (01/17/12). Ongoing work: Quarterly Progress Reports delivered and all technical findings uploaded to http://hinmrec.hnei.hawaii.edu/
2.0	**OTEC Resource Assessment & Sustainability**		09/14/13	09/14/13	100%	Global resource to 1/4° x 1/4° (Lat/Long) posted 09/30/12; Sustainable OTEC power model resolution upgraded from 4° to 1° (Lat/Long); and Interactive OTEC Power Atlas posted.
3.0	**Wave Resource Assessment** 3.1) Wave Models High Resolution update and calibration with WETS data 3.2) WETS Wave Measurements, Analysis & Forecasting		09/14/14		70%	- Hawaii wave resource from hindcast model with 20-year NOAA wind data completed and posted 09/14/12; - Hindcast model to be upgraded with higher resolution 30-year wind data by 09/14; - Task 3.2 underway with 12 moths record available from the Waverider installed December 2012.
4.0	**Environmental Impact Monitoring at WETS** 4.1) WEC Device Acoustic Emissions 4.2) Device & Power Cable EMF Emissions 4.3) Ocean currents/waves AWAC measurements 4.4) Sediment Transport Field Measurements 4.5) Ecological & Water Quality Field Surveys		Progress Report: One year after NEPA Compliance (12/14) Final Report: 09/15		0%	No activities were allowed pending NEPA Compliance achieved December 2013. No-cost extension extended project through 09/14/15.
5.0	**WEC Device Electrical Performance at WETS** 5.1) Test Protocol & Data Acquisition System 5.2) Performance Analysis & Hardware Surveys		Progress Report: One year after NEPA Compliance (12/14) Final Report: 09/15		0%	No activities were allowed pending NEPA Compliance achieved December 2013. No-cost extension extended project through 09/14/15; Task 5.1 is now underway and to be completed by April 2014 on time for first tenant at the 30 m site (NWEI)
6.0	**Supporting Studies** 6.1) WEC Numerical Models 6.2) Alternate Mooring Design 6.3) Aluminum Corrosion and Biocorrosion		Progress report: 09/14/13 Final report: 09/14/14		30%	No activity was allowed under tasks 6.2 pending NEPA Compliance Determination. Task 6.3 is continuation of previous tasks that had been determined to be in compliance of NEPA.

Southeast National Marine Renewable Energy Center

Susan H. Skemp

Florida Atlantic University

sskemp@fau.edu, 561 297 2339

February 28, 2014

Purpose & Objectives

Problem Statement:

To advance the immature MHK industry and achieve grid-scale economically-viable and environmentally responsible penetration into the U.S. domestic energy portfolio, assistance is needed with technology development, environmental assessments, regulatory guidance, and system reliability through research, testing, and outreach/workforce training.

Impact of Project:

This project will make available solutions and infrastructure for the MHK industry to advance energy capture products through TRLs 5/6. This award prepares the world's first ocean current offshore test berth (not grid-connected), a research turbine for component testing, various technology solutions in prognostics, instrumentation, and rotors, and collects resource measurements, including turbulence characterization.

This project aligns with the following DOE Program objectives and priorities:

MHK

- Advance the state of MHK technology
- Develop key MHK testing infrastructure, instrumentation, and/or standards
- Characterize and increase access to high resource sites
- Reduce deployment barriers and environmental impacts of MHK technologies

Technical Approach

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NEPA Hold until Q1 FY14

(except regulatory tasks – 1st hold lifted Q3 FY13)

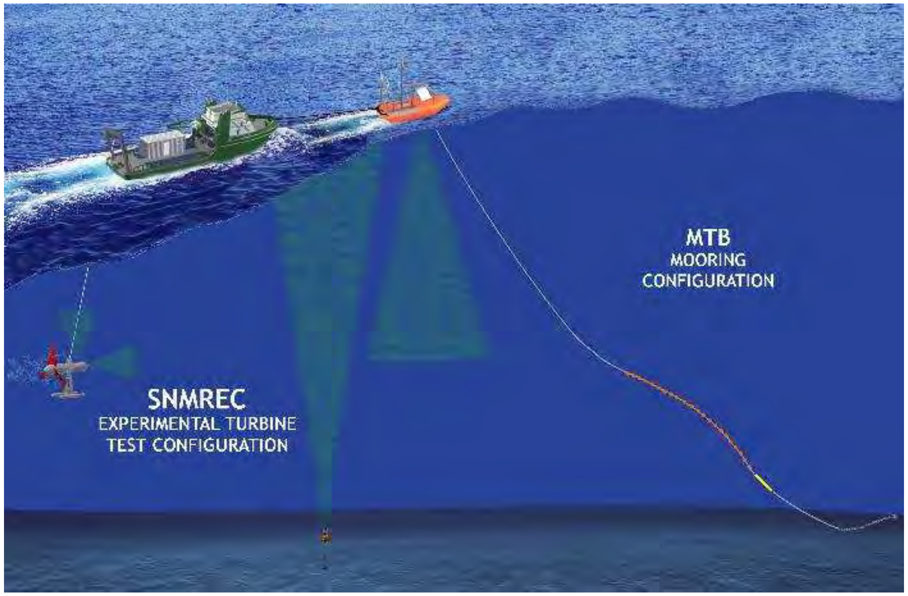
TRL 5/6 Demonstration-scale Turbine Test Berth

Technical Approach: Install mooring buoy for barge or vessel to deploy turbines (up to 100 kW or 7 meter rotor diameter) for surface-tethered validation tests.

Key Issues Addressed: Opportunity for industry to validate/explore energy conversion concepts and system dynamics prior to scale-up.

Unique Aspects:

- Relevant environment
- Fully characterized inflow
- Pre-permitted
- Standards-compliant measurements
- Simple management of generated power
- Vetted protocols and support infrastructure



NEPA Hold until Q1 FY14

(except non-wetted build – 1st hold lifted Q3 FY13)

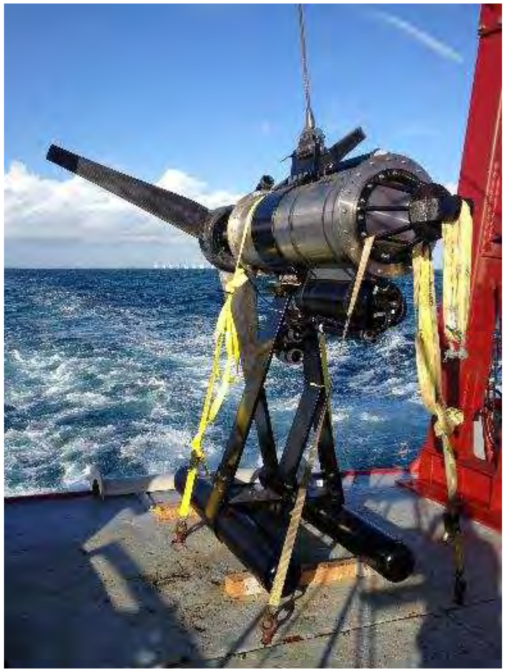
20 kW 3-meter Rotor Research Turbine

Technical Approach: Build small-scale research turbine with features representative of industry concepts.

Key Issues Addressed: Validate numerical tools, evaluate commercial component performance, develop and test prognostics systems, research rotor design and performance, and document environmental interaction.

Unique Aspects:

- Open-source and public design
- Many off-the-shelf reconfigurable components
- Standard tools used for design (NREL CAE Tools)
- Negative, positive, or neutral buoyancy configuration
- Comprehensively measured powertrain health, inflow, and turbine motion



NEPA Hold until Q1 FY14

Ocean Current Resource Characterization

Technical Approach: Install moored ADCPs to collect long term large-scale ocean current measurements and perform monthly turbulence characterization measurements for one year as a baseline data set.

Key Issues Addressed: Offshore test berth condition pre-characterization, ocean current numerical tool validation/verification, commercial site evaluation measurement techniques, and collection of design input data for turbines.

Unique Aspects:

- Builds on past legacy and data sets
- Adaptive approach (subsequent deployments re-configurable)
- Comprehensive: large and small scales measured
- Repeatable methods
- Consistent with oceanographic best-practice
- Most cost-effective approach
- Turbulence approach consistent with and in cooperation with NREL/NNMREC

Accomplishments and Progress

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Major Tech Accomplishments FY12-13:

- First MHK Environmental Assessment and FONSI on OCS in U.S. (Q4 FY2013, originally expected Q2 FY12)
- Turbine rotor designed and non-instrumented blades delivered
- Turbine assembled and components tested
- PHM system concept completed and vibration analysis software beta tested
- Turbulence instrumentation lab tested/benchmarked (DE-EE0000319)
- Four years of moored ADCP data collected (DE-EE0000319)

Major Tech Accomplishments FY14:

- MTB sea trials complete and design verified
- Preliminary turbine tow tests complete (without generator, with rotor)

Project Plan & Schedule

Summary	
WBS Number or Agreement Number	EE0004200
Project Number	NA
Agreement Number	EE0004200

Legend
- Work completed
- Active Task
- Milestones & Deliverables (Original Plan)
- Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: SNMREC Offshore Testing Facility - Small Scale Turbine Testing and Development												
Task 1.1: Turbine design, fabrication, and assembly												
Task 1.2: Turbine component testing and initial system tests												
Task 2.1: PHM data fusion techniques												
Task 2.2: PHM vibration measurement and analysis												
Task 2.3: PHM system architecture and data management												
Task 3.1: Design and testing of non-instrumented rotor												
Task 3.2: Composite rotor structures and tools												
Task 4.1: BOEM Project Plan (BOEM EA/FONSI, Project Plan draft)												
Task 4.4: Data certification and test center accreditation (preliminary study)												
Current work and future research												
Task 3.1: Design and testing of instrumented rotor												
Task 4.1: BOEM Project Plan (complete Project Plan)												
Task 4.2: Site selection and survey												
Task 4.3: MTB installation												
Task 4.4: Test center accreditation (organization implementation)												
Task 5.1: Turbine system integration and testing												
Task 5.2: Turbine auxiliary support infrastructure												
Task 6.1: Ocean current characterization												
Task 6.2: Turbulence characterization												

Comments

- All tasks under NEPA hold until Q3 FY13 when some non-wetted tasks released
- All remaining NEPA holds removed Q1 FY14

Project Budget

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Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,250K	$1,250K	$250K	$250K	$0K	$0K

- No variances to date on project budget
- $337,160 expended through FY13
  (19% of total, 57% of allowable)
- $125,580 cost share committed through FY13
  (7% of total, 54% of allowable)

Partners, Subcontractors, and Collaborators: Two explicit subcontractors: Embry-Riddle Aeronautical University and TBD (selected via public bid). In addition, separate NREL sCRADA aligned with many project tasks.

Communications and Technology Transfer:
All of SNMREC's publications, achievements, meetings, and additional information are listed online at: http://snmrec.fau.edu.

Next Steps and Future Research

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FY14/Current research plan:

Begin tasks previously under NEPA hold. Final installation of MTB dependent on BOEM lease process (possible barrier and/or delay), but majority of uncoupled tasks to finish by Q1 FY15:

- Turbine electrical and mechanical systems integrated Q4 FY14
- PHM research (preliminary designs, software, and data collection, and integration) to conclude Q3 FY14
- Instrumented rotor blades to be delivered Q3 FY14
- Moored ADCPs to be deployed Q2 FY14-Q1 FY15
- Turbulence measurements (1 year) completed Q2 FY15

Proposed future research:

- Deploy integrated research turbine for performance data measurement and tool validation
- As demand evolves, install additional test berths
- Customize and test PHM systems with commercial systems
- Continue resource characterization and evolve into now/fore-casting tools
- Leverage offshore testing and infrastructure for environmental interaction studies and further baseline population characterizations
- Mature modeling and analysis tools with commercial product evolution
- Begin grid-connected full scale test berth design/planning and leasing

2014 Water Power Program Peer Review

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

Testing Infrastructure & Instrumentation

Wind and Water Power Technologies Office
Jim Ahlgrimm

Thursday, February 27, 2014

Overview – Testing Infrastructure & Instrumentation

Goals – Reduce the cost and risk of technology demonstration for developers by providing access to testing facilities that enable a systematic progression through technology readiness and performance towards commercialization.

Priorities – Address gaps in testing capabilities, with wave energy as highest priority.

FY 14 Budget: $1.6 M

DOE Unique Role – Companies cannot afford to establish test facilities on their own. DOE cost share can attract funding from others to develop facilities that span MHK technology development.

MHK Organizational Structure

- Marine and Hydrokinetic Technologies
  - Computational Modeling and Analysis
  - Technology Advancement and Demonstration
  - Resource Characterization
  - Testing Infrastructure and Instrumentation
  - Market Acceleration and Deployment

Key Counterparts and Collaborators

- National Renewable Energy Laboratory
- Naval Facilities Engineering Command
- National Marine Renewable Energy Centers
- Sandia National Laboratories

Portfolio Priorities – MHK

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.	
Advance the state of MHK technology	• Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26

MHK Budget (FY 2012 – FY 2014)

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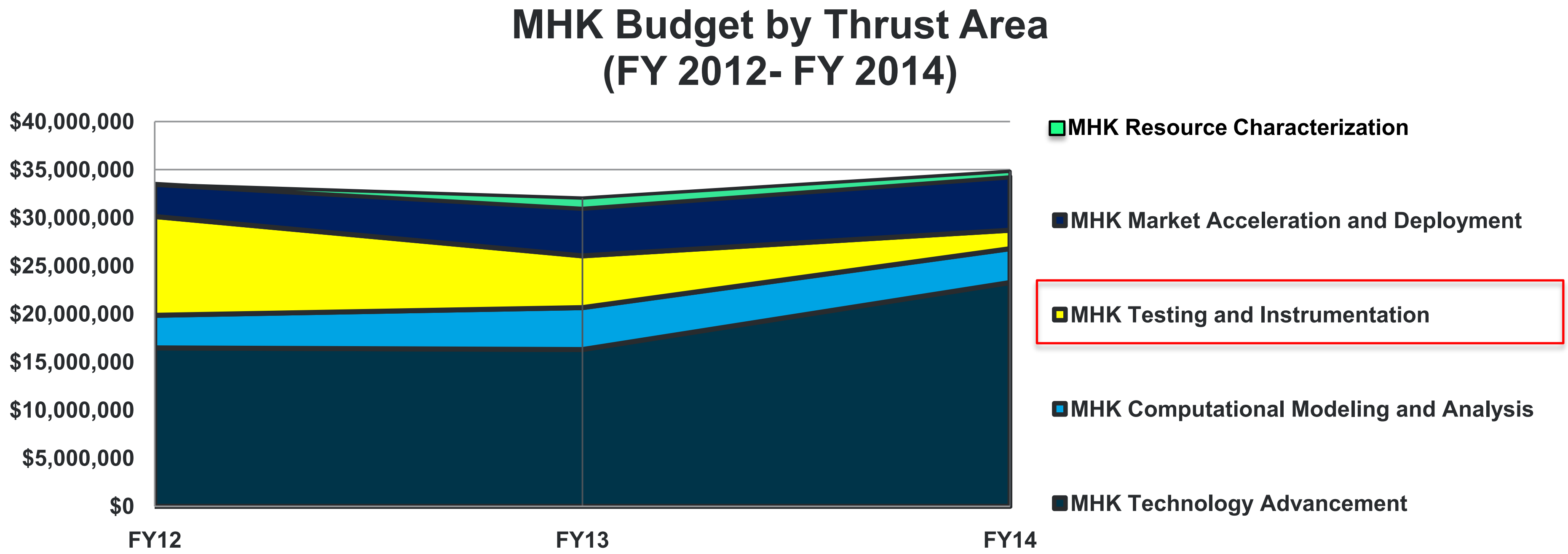

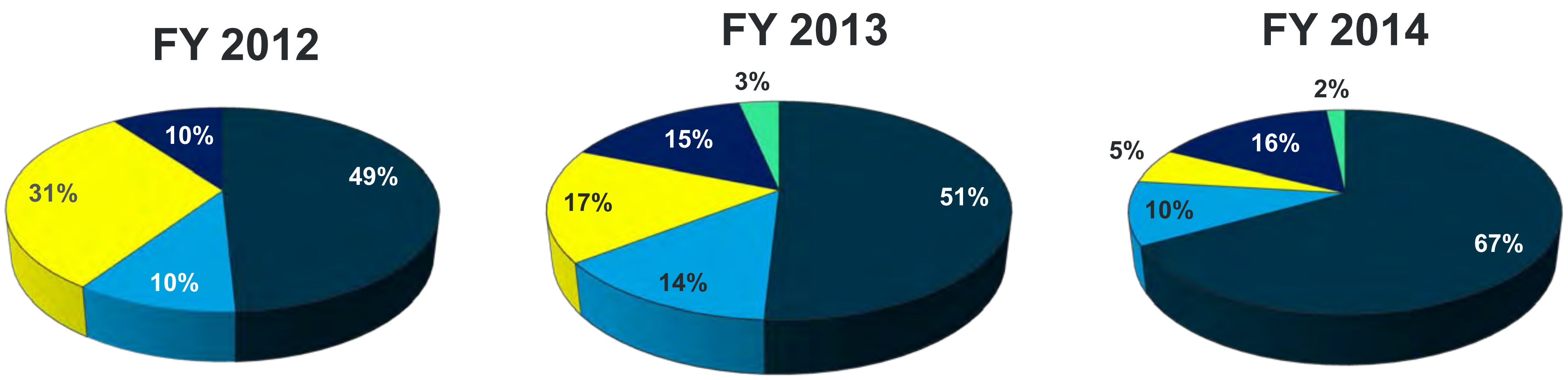

Main Elements of the Testing Infrastructure & Instrumentation Portfolio

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Technical Area	Key Projects/Activities
Test Facility Support & Construction	- Test infrastructure gap analysis - Open ocean wave energy test sites - Ocean current test site
Testing Instrumentation	- Modular instrumentation system for MHK data collection - Advance turbulence instrumentation - Structural loads and system response instrumentation
Standards & Certification	- U.S. engagement in international standards development

Priorities in FY14 and Beyond

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Technical Area	**Priorities or Changes in Portfolio FY11 vs FY14**	**Include key collaborators**	**Upcoming milestones**
Test Facility Support & Construction	- MHK wave testing - Collaboration with Navy - Testing needs assessment completed - Open-water test facility FOA	• U.S. Navy • NMREC's • OSU, Cal Poly • NREL, SNL	• Complete open-water prelim design FOA negotiations • Navy deep water test berths
Testing Instrumentati on	• High resolution data acquisition systems to support validation of performance, design, control, and numerical models	• NREL, SNL	• Deliver open source instrumentation framework to industry
Standards & Certification	• Work with U.S. industry partners to ensure representation in international standards	• NREL • Industry subject matter experts	• Annual meeting of MHK standards group in April

Technology: Wave and Tidal / Current Infrastructure

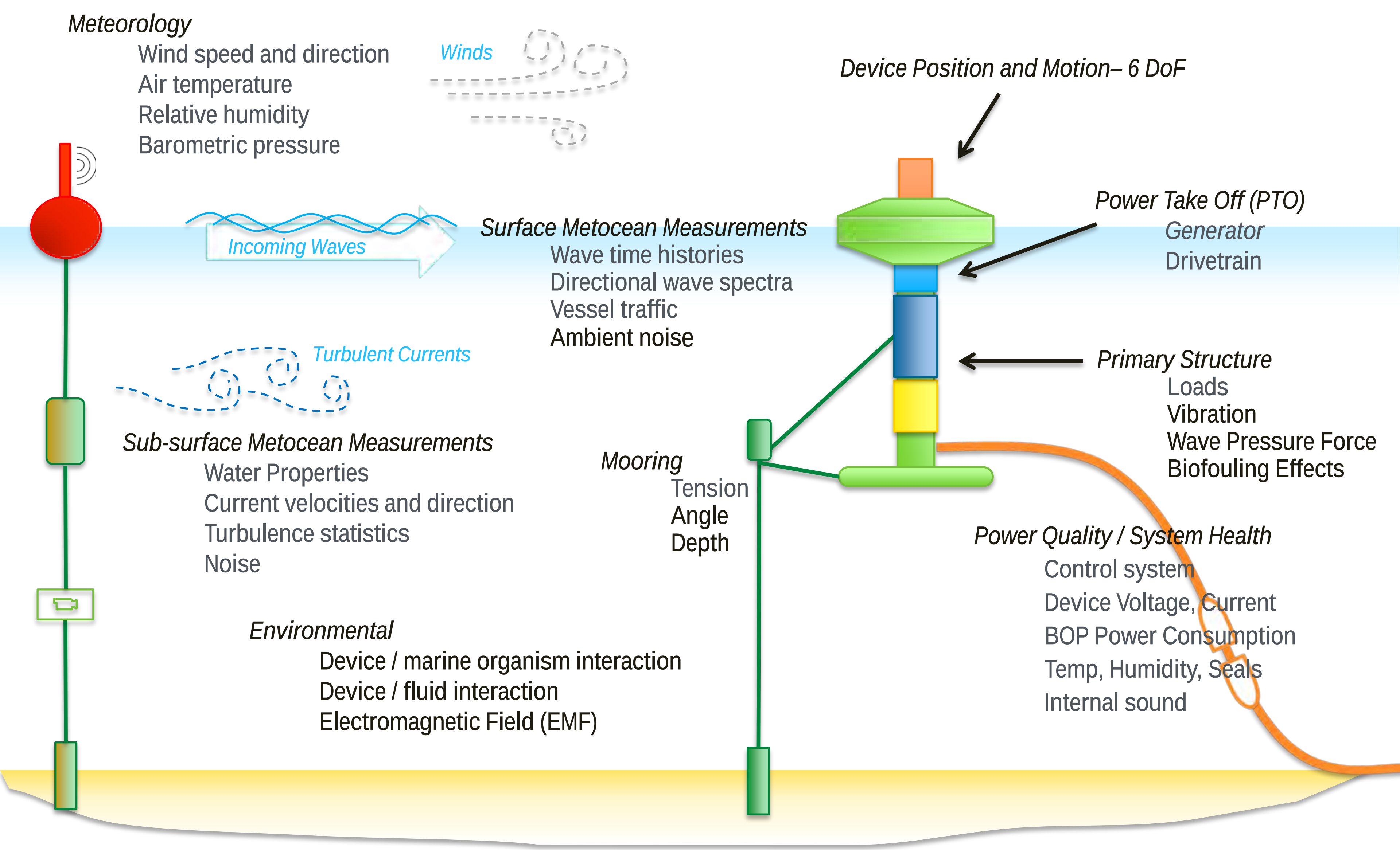
- Testing facilities that span TRL levels will accelerate the technology design cycle and reduce design iterations and cost
- Unavailability of U.S. testing infrastructure for TRL 5 -8 wave energy devices

TRL	Approx. Scale	Infrastructure Requirements	High Cap-Ex Gaps	Approximate Leveraged Cost to Fill Gap ($M)
1-4	$^{1}/_{50}$ - $^{1}/_{10}$	Small oscillating drivetrain simulator Wave basin/flume (1-5m deep, .1-1m Hs)	No gap	-
5/6	$^{1}/_{5}$ - 1	Med. oscillating drivetrain simulator (2 MNm) Wave basin/flume (5-10m deep, 1-2m Hs) Wave basin/flume (10-20+m deep, 1-2m Hs) Nursery Berths (10-50+m deep, 1-2m Hs)	1 "mid-size" No gap 1 "deep lab" 2 nursery berths	1 – 3 - 8 – 23 1 – 3
7/8	½ - 1	Large oscillating drivetrain simulator (10 MNm) Open water berths with grid sim. / connection (20-100+m deep, 2-4+m Hs)	1 "large" 2 open water berths (critical)	5 - 15 8 - 23
9	Array	2 array strings, 3-5 berths each	2 array strings	15 - 45

Red: High priority investment Yellow: Medium priority investment Green: Low priority investment

(Use this slide as an opportunity to describe the evolution of your portfolio and its various priorities throughout time. This can be provided as a timeline (recommended) or other visual representation)

MHK Measurement Basics



Evolution of the Instrumentation Portfolio

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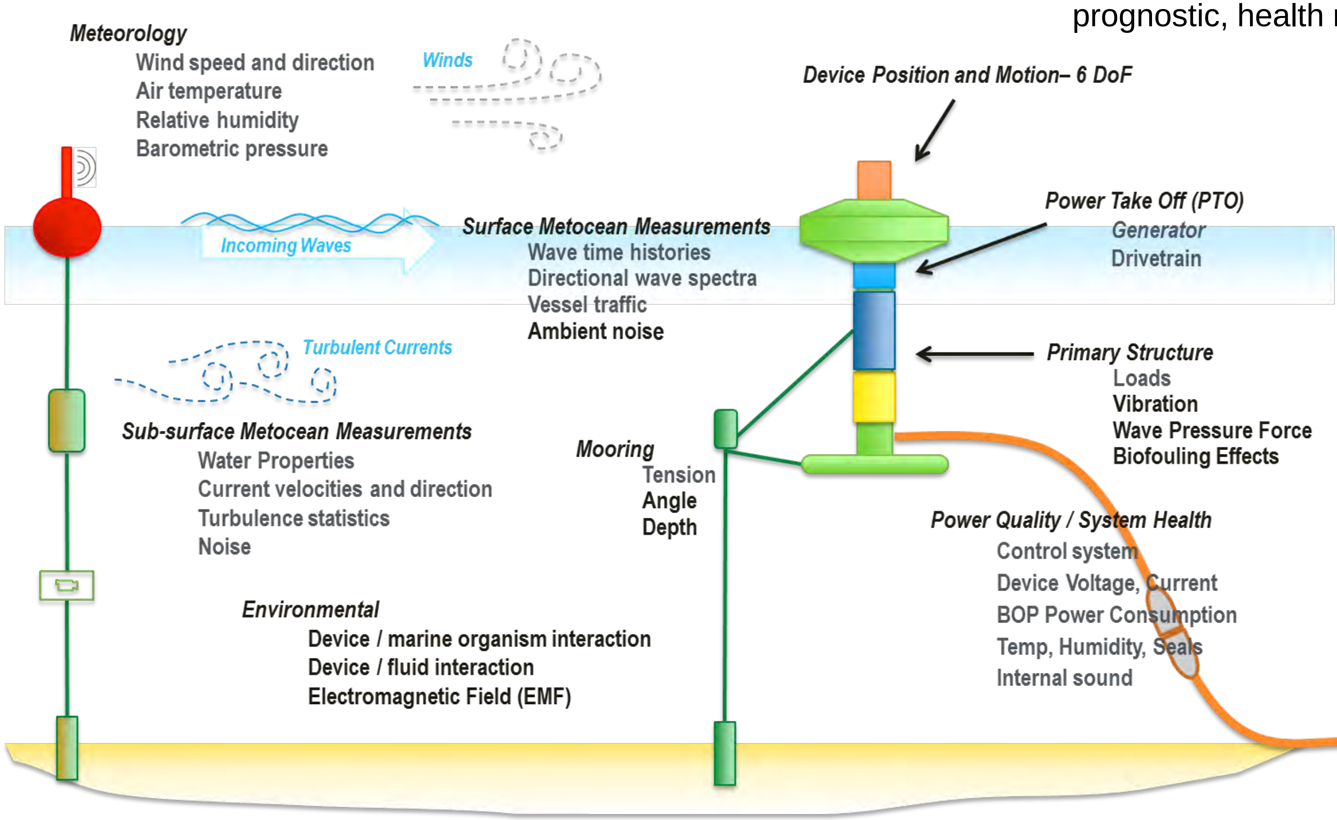
2011 **2012** **2014** **2020+**

- Data acquisition system to synchronize all measurements
- Fill specific measurement gaps to improve design and validate models and codes
- Develop instrumentation that improves performance and operation (i.e. wave sensing for controls, onboard sensors for prognostic, health monitoring)



Questions for Peer Reviewers

- Have we overlooked any test facility needs?
- Do we have the right priorities in addressing testing infrastructure gaps?
- Does the U.S. need its own unique test infrastructure?

Water Power Peer Review

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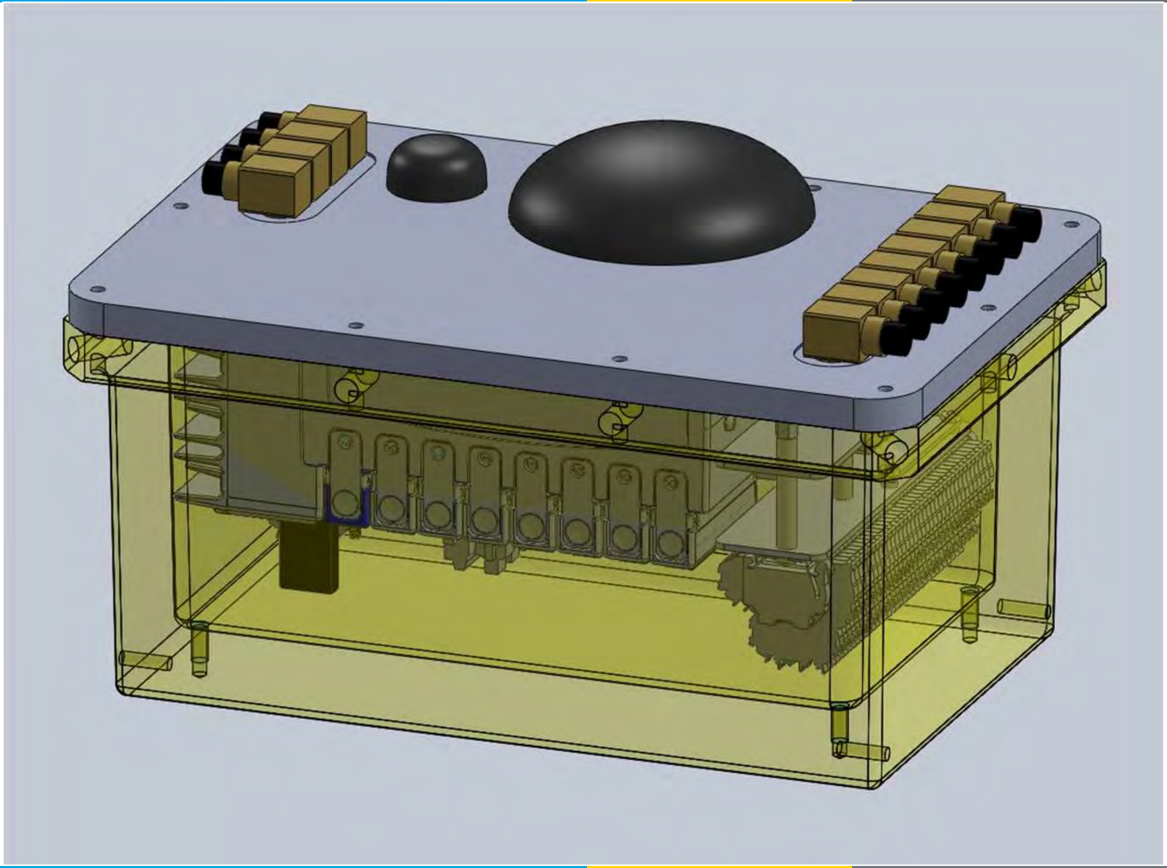


MOIS: Modular Ocean Instrumentation System

Eric Nelson

National Renewable Energy Laboratory
enelson@nrel.gov 303 384 7155

February 27, 2014

Purpose and Objectives

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

Problem statement: Develop an instrumentation system with open-source design for on-device testing for MHK devices, including tidal turbines and wave energy converters.

Impact of project: Measurements collected from system may be used to characterize device performance and accelerate the engineering process, validate modeling and analysis codes, assess and improve IEC standards, and develop device testing methodology for MHK devices.

This project aligns with the following DOE Program objectives and priorities:
Develop key MHK testing infrastructure, instrumentation, and/or standards

1. Gathered system requirements:

- Testing requirements survey of device developers
- IEC wind turbine standards
- IEC (draft) standards and other MHK references
- DOE MHK Instrumentation Workshop.

Instrumentation Requirements (Tidal Example)

Structural and Loads Measurement (e.g. blade/tower strain and vibration, mooring line tension, wave pressure force etc)

	Variable/Quantity	Data Requirements	# Channels	Preferred Instrument	Measurement Source	Level of Importance	Synchronized to Real-Time System?	Raw or Processed Data?
1	Vibration Structure and blades	10 Hz (maybe higher?)	10?		Device control system	Critical - Required	Synchronized to realtime system	Raw data
2	Internal Sound level (Device)	Depends on sound frequencies of interest - raw data	?		Measured	Useful	Synchronized to realtime system	Raw data

Motion/Response (e.g. geodtic position, velocity, acceleration, depth, orientation, angular velocity, etc)

	Variable/Quantity	Data Requirements	# Channels	Preferred	Measurement	Level of Importance	Synchronized to	Raw or
13	Device Orientation	Once every 15 minutes to 0.1 degrees	1		Device control system	Critical - Required	Not synchronized	Raw data
14	System Status	1/60 Hz	1		Device control system	Critical - Required	Asynchronous but within time window	Raw data

Mechanical (e.g. PTO RPM/linear position and velocity, blade pitch, temperature, shaft torque/tension/strain, water intrusion, humidity, etc)

	Variable/Quantity	Data Requirements	# Channels	Preferred	Measurement	Level of Importance	Synchronized to	Raw or
25	Water Intrusion	1/60 Hz	# of housings	Humidity sensor	Measured	Critical - Required	Not synchronized	Raw data
26	Generator Winding Temperature	1 Hz	5-10?		Device control system	Critical - Required	Asynchronous but within time window	Raw data
27	Shaft Torque	100 Hz	1	In-line rotary torque sensor, or mechanical/generator-based dynamometer	Measured	Useful	Asynchronous but within time window	Raw data
28	RPM - Generator/Rotor etc.	100 Hz	1	built-in into rotary torque cell, hall-effect, or optical	Device control system	Critical - Required	Synchronized to realtime system	Raw data
29	Blade loading	100 Hz	# blades		Measured	Useful	Synchronized to realtime system	Raw data
30	Blade Deflection	100 Hz	# blades x N positions		Measured	Useful	Synchronized to realtime system	Raw data
31	Blade Strike	1 Hz	# blades x N positions	Accelerometer	Measured	Useful	Synchronized to realtime system	Processed data
32	Gearbox Oil Temperature	1 Hz	1		Measured	Critical - Required	Asynchronous but within time window	Raw data
33	Sound Level	10000 Hz (w/ duty cycle)	1		Measured	Useful	Asynchronous but within time window	Raw data

Example of a testing requirements survey form

DOE MHK Instrumentation Workshop

2. Defined objectives and required functionality for MOIS:

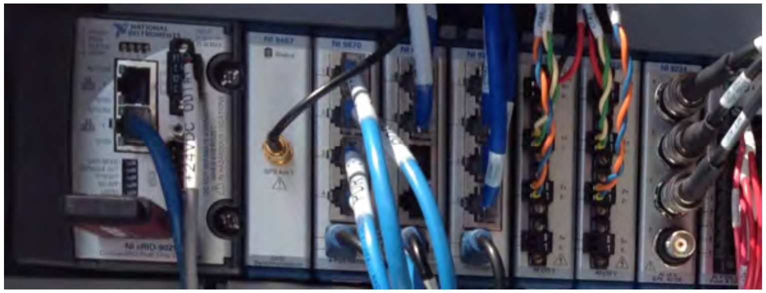
– Data collection for power performance, mechanical loads, power quality, and acoustic noise
– Data collection for design validation of MHK devices
– Data collection for modeling validation of MHK devices
– Ruggedized and robust for marine environment
– Reconfigurable for various testing
– Compact sized for installation on MHK devices
– Autonomous and continuous operation.

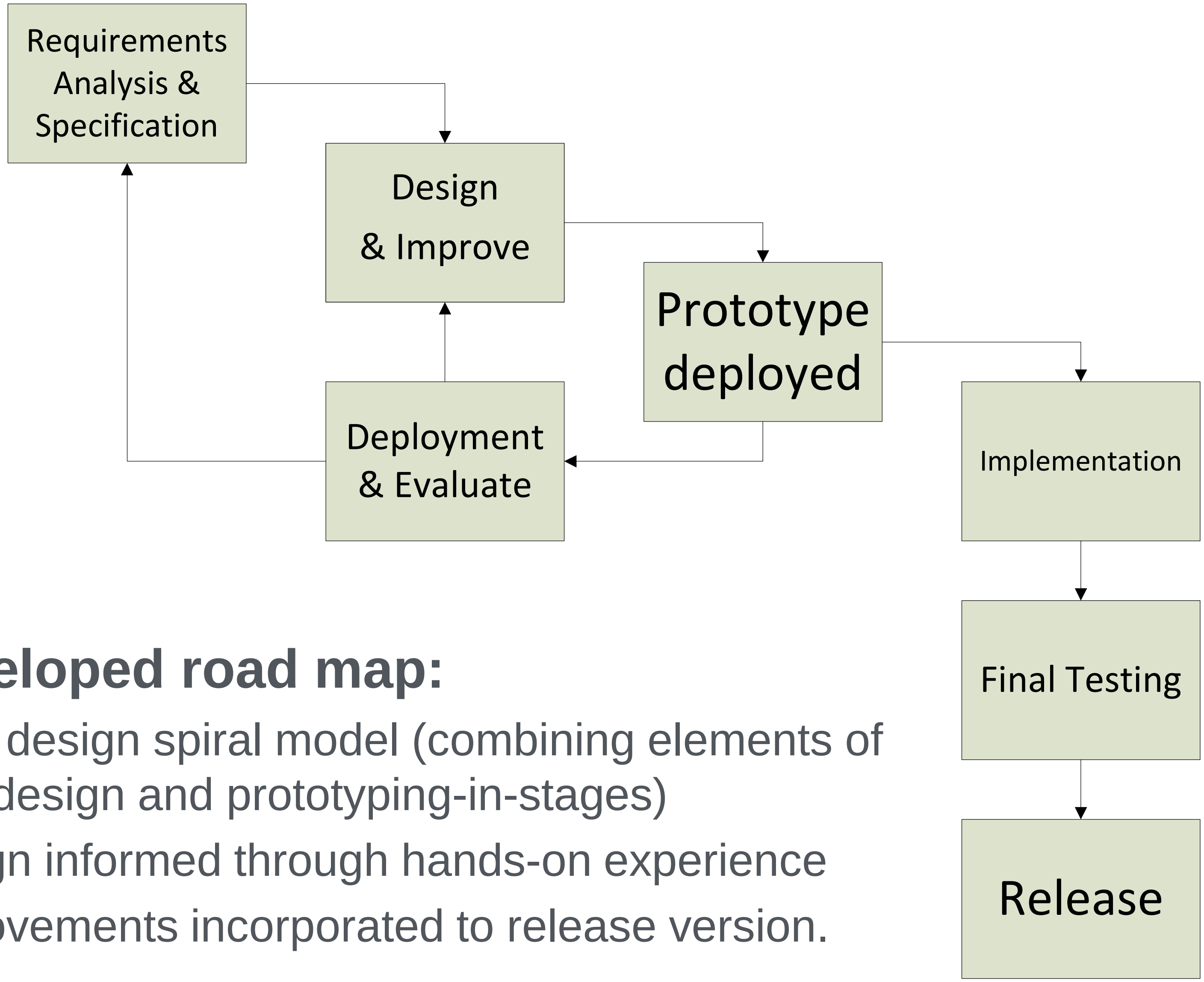
3. Assessed available data acquisition systems:

- Measurement types, precision, sample rate, etc.

4. Conclusion: National Instruments, Compact RIO hardware and custom LabVIEW software meets specifications

- Can be used for many types of measurements
- Flexible and configurable for testing most MHK devices
- LabVIEW software can be developed for a modular and scalable data acquisition system
- National Instruments offers supportability, training, calibration, and maintenance services.





5. Developed road map:

- Uses design spiral model (combining elements of both design and prototyping-in-stages)
- Design informed through hands-on experience
- Improvements incorporated to release version.

Accomplishments and Progress

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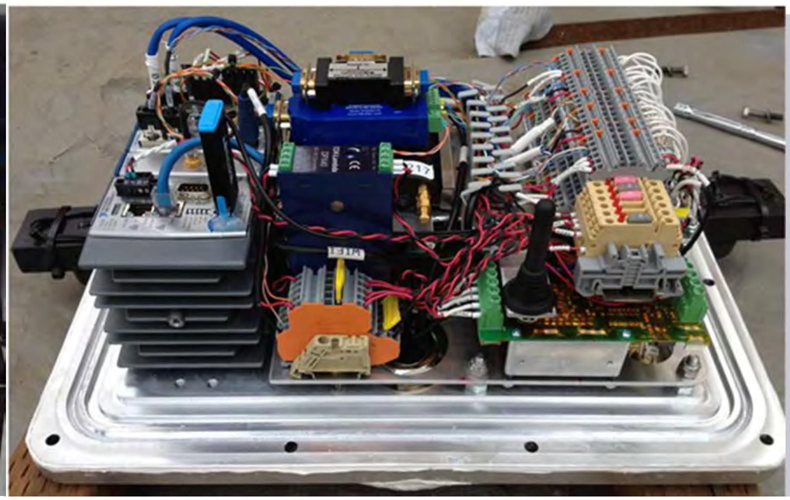
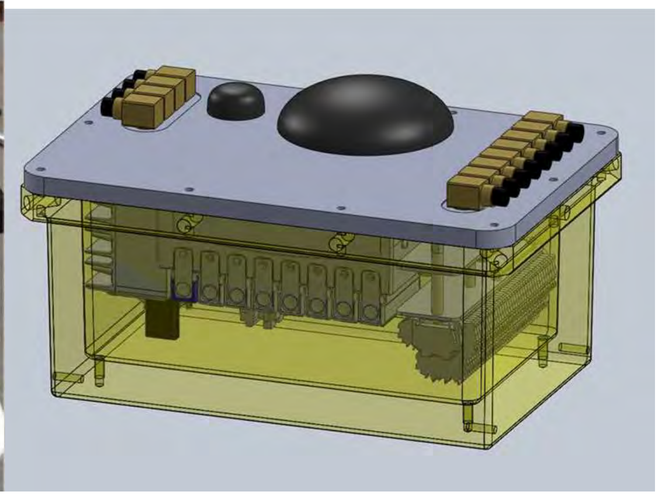
Two versions of MOIS have been built and deployed and the third is in progress.

Gen 1



Gen 2



Gen 3

Four in-water deployments of MOIS:

- Feb 2012: Free Flow Power, River Turbine, Mississippi River, LA
- Apr 2012: FloDesign, Tidal Turbine, Piscataqua River, NH
- June 2012: SWAY Offshore Wind Turbine, Kollsnes, Norway
- Aug 2012: WET-NZ, Wave Energy Converter, Oregon Coast.

Accomplishments and Progress

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

Free Flow Power, River Turbine, Mississippi River, LA, Feb 2012.

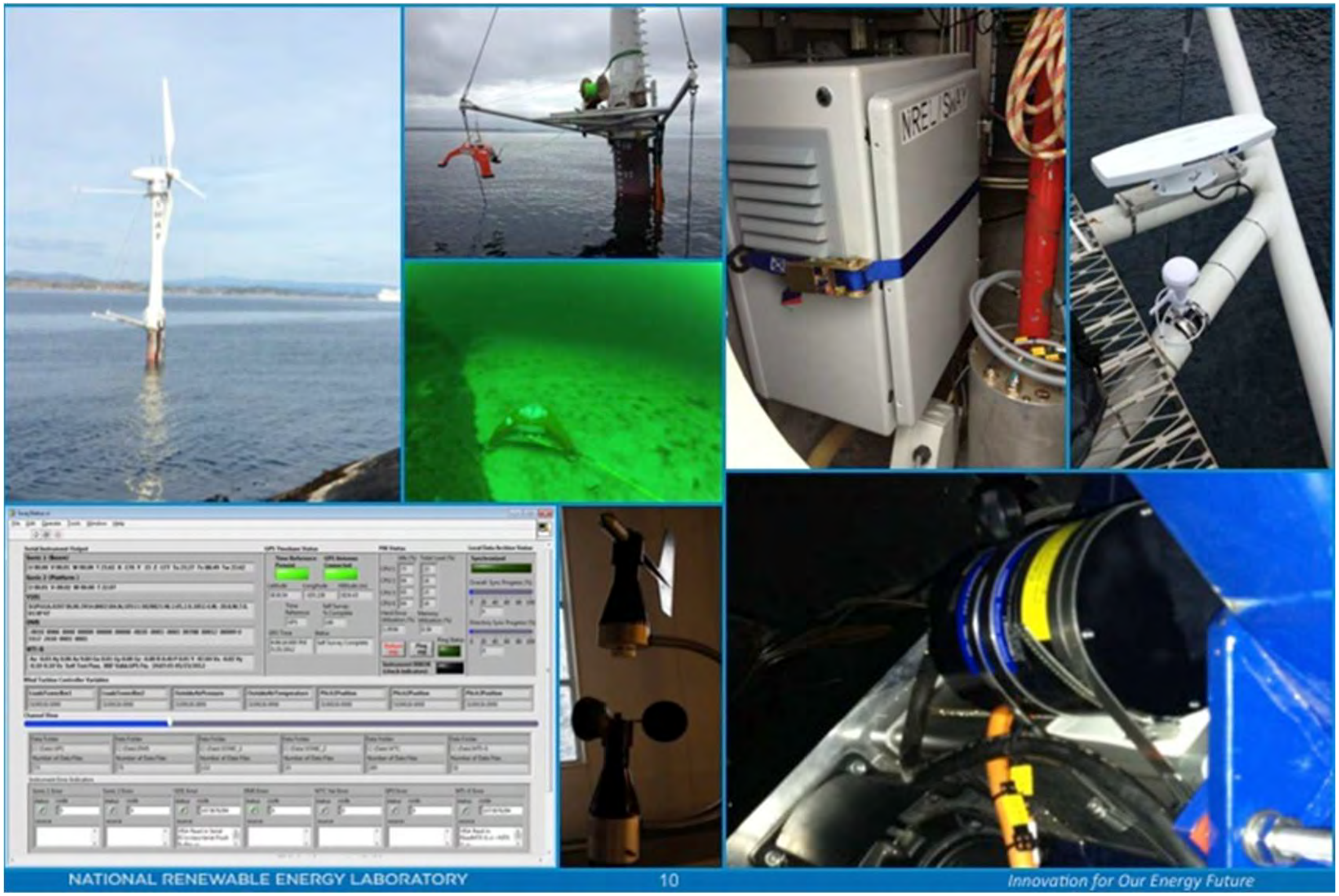
Accomplishments and Progress

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

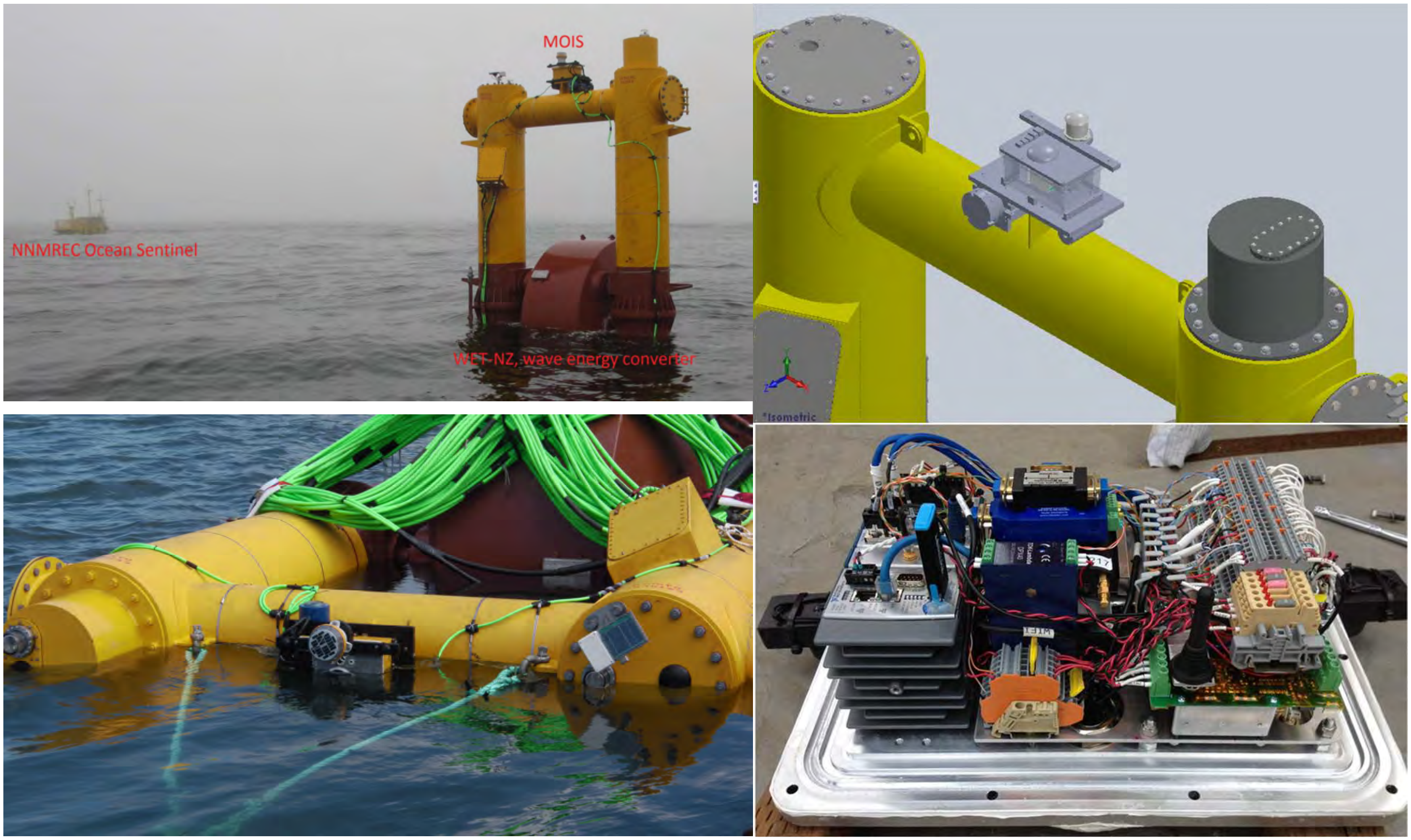
FloDesign, Tidal Turbine, Piscataqua River, NH, Apr 2012.

SWAY Floating Offshore Wind Turbine, June 2012

- Utilized a combination of MOIS and NREL Wind DAS components



WET-NZ, Wave Energy Converter, Oregon Coast, Aug 2012.



Accomplishments Summary

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MOIS version	Date	Outcome and Lessons Learned
Gen 1	Feb 2012	• Successfully installed MOIS on river device • MHK device failure during deployment, testing abandoned • Determined number of channels and sample rate that can be supported by a single system
Gen 1	Apr 2012	• Installed and deployed MOIS on tidal device • Data collected for many tidal cycles in "attended operation" • Software for long term "autonomous" deployment needed
Gen 2	Aug 2012	• Ruggedized in subsea enclosure • Software failure with little data collection due to battery fault • Hardware supporting remote system administration and recovery features must be added to MOIS • Hardware to provide buffered power for MOIS needed
Gen 2.1	Mar 2014	• To be installed on wave device for one year • Software improvements, remote administration and software recovery capability, improved MOIS power system • Long term bench test of full system with instruments underway
Gen 3	End of FY2014	• Expected to meet specifications (improvements on later slide).

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number 1.3.2.2	
Project Number	
Agreement Number 26498	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: MOISyt Modular Ocean Instrumentation												
Q1 Milestone: Completion of the protocol assessment & preliminary roadmap												
Deployment: Gen 1												
Q2 Milestone: Complete integration of measurement modules and primary computer system												
Deployment: Gen 1												
Q3 Milestone: Complete integration and testing of complete system												
Deployment: Gen 2												
Q4 Milestone:Design, testing, and deployment report of instrumentation system												
Q4 Milestone: Compile bibliography of existing testing protocols, outline for open-water WEC testing protocols												
Q1: Develop specifications for deployable WEC testing system												
Q2: Construct draft test plan for open ocean dployment WEC deployment												
Q3: Complete design of hardware for upgrades to advance MOIS												
Q4: Demonstrate function of all test channels & establish data process analysis procedure												
Q4: Perform data quality check on initial samples and verify data quality meets criteria												
Q1: Develop detailed specifications for MOIS Gen3 hardware and software												
Current work and future research												
Q2: Complete FMEA and reliability review of the MOIS Gen3 core hardware and software components												
Deployment: Gen 2.1												
Q3: Finalize MOIS Gen 3 System design with improvements as outlined in AOP												
Q4: Complete bench testing of MOIS Gen3 hardware & integrate new software												

Comments

Project is on track and all milestones have been met.

Project Budget

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,050k	n/a	$800k	n/a	$487k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$693K	$313K	$425k

- Received $400k at the end of FY13 for work in FY14
- FY14 project costs as of December 31st: $47,165.

Partners, Subcontractors, and Collaborators:

Partners: (2013) - Northwest Energy Innovations (NWEI), Industrial Research Limited, Naval Facilities Command, Marine Corps Base Hawaii

Partners: (2012) - FreeFlowPower, FloDesign, University of New Hampshire, NNMREC (OSU & UW), NWEI

Subcontract: Windward Engineering for technician support and Virtex, LLC for software development.

Communications and Technology Transfer: DOE MHK Modelling & Instrumentation Workshop (2012), presentation, Modular Ocean Instrumentation System (MOIS), presented by Eric Nelson, Offshore Wind and Ocean Power Systems section. Instrumentation system design to be made public.

Next Steps and Future Research

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

FY14/current research: MOIS Gen 2.1 will be deployed on NWEI's WET-NZ WEC planned deployment in March 2014. MOIS will measure motion, mooring loads, depth, and float (prime mover) position of the WEC. MOIS Gen 3 is under development and includes upgrades such as a higher channel count, more robust and compact enclosure, software improvements, and system documentation. Software allows for more reconfiguration for test specific requirements than earlier generations of MOIS.

Proposed future research: Utilize MOIS for in-water testing of MHK devices.

Water Power Peer Review

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

Figure 2 – Section of an ORPC-supplied foil,from which coupon substrates were cut.

Figure 3 – Cross-section of the ORPC-supplied foil showing the laminate layup.

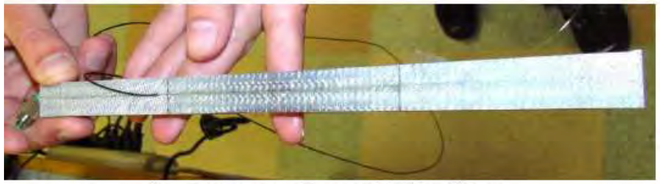

Figure 4 – Test specimen with a mounted MOI bare FBG sensor.

Figure 5 – Test specimen with a mounted MOI standard-package FBG sensor.

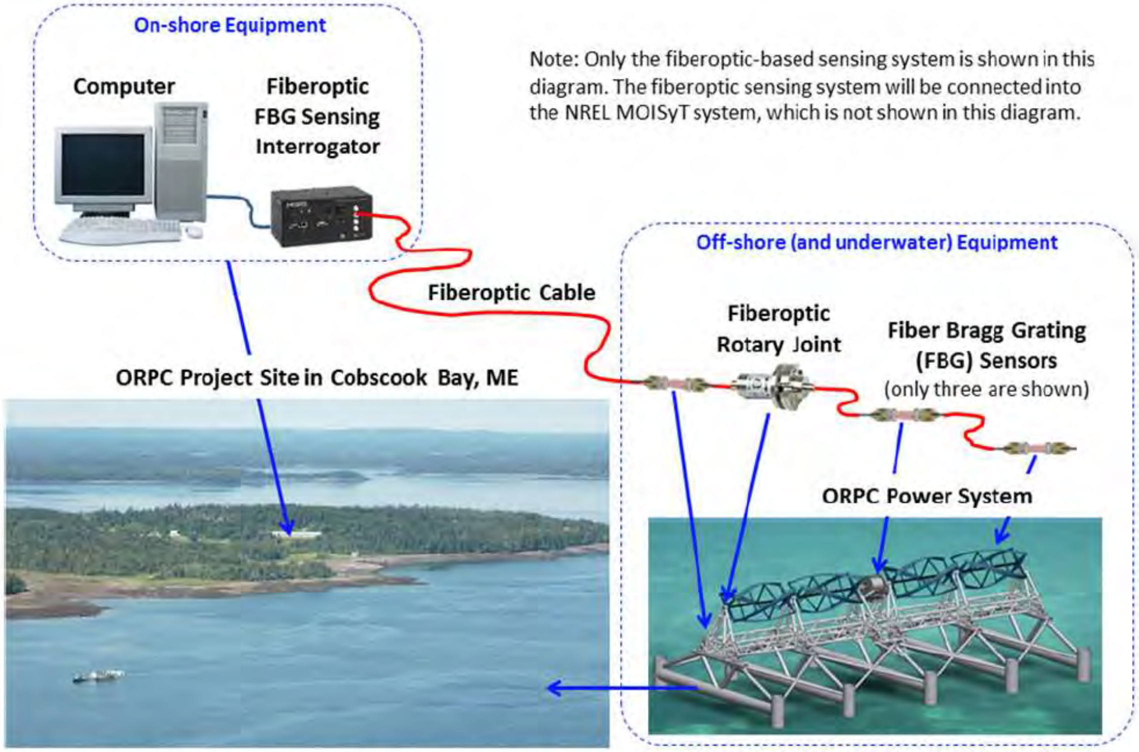

Figure 1 – Concept diagram of a fiberoptic-based sensing system for the ORPC MHK application.

Instrumentation System Development

Bernadette A. Hernandez-Sanchez

Sanda National Laboratories

baherna@sandia.gov 505 272 7656

February 2014

Purpose & Objectives

Problem Statement: Externally mounting sensors is the most practical option for a wide range of instrumentation applications; however, the effectiveness and lifespan of an adhesive bond at withstanding these environmental conditions on a system under fatigue has not been investigated.

Impact of Project: Leverage Sandia wind instrumentation. Provide instrumentation research and applications on specific issues identified by the technical staff at NREL and SNL that could be critical to the general success of Marine HydroKinetic (MHK) testing applications. Use the NREL-SNL-ORPC CRADA MHK project as the current and applicable application to focus research directions.

This project aligns with the following DOE Program objectives and priorities

Develop key MHK testing infrastructure, instrumentation, and/or standards

(materials & adhesive properties can impact on validity of structural health measurements by sensors, etc.)

Technical Approach

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- strain sensors were bonded to coupons.
- Fiber-optic Fiber Bragg Grating (FBG) sensors were selected
- FBG strain sensor types were provided by Micron Optics Inc. (MOI)
- coupons were cut from a foil sample provided by Ocean Renewable Power Company (ORPC) and the FBGs adhered using methodology provided by MOI.
- coupons were reserved as control for each of the sensor types and environmental conditions, *i.e.* they remained dry. The remaining sensors were to be soaked for 1 month
- static and fatigue testing in the 56kip Instron fatigue tester.

Leveraged Sandia Advanced Materials & DOE Wind Materials Research

Figure 2 – Section of an ORPC-supplied foil,from which coupon substrates were cut.

Figure 3 – Cross-section of the ORPC-supplied foil showing the laminate layup.

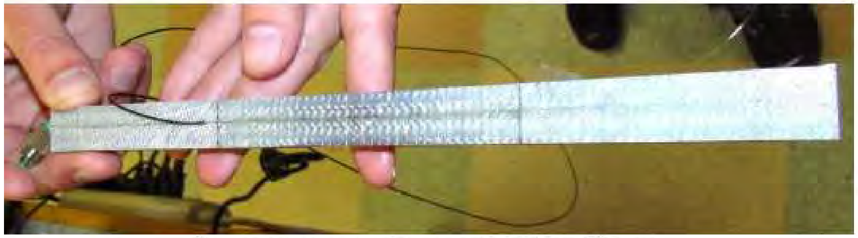
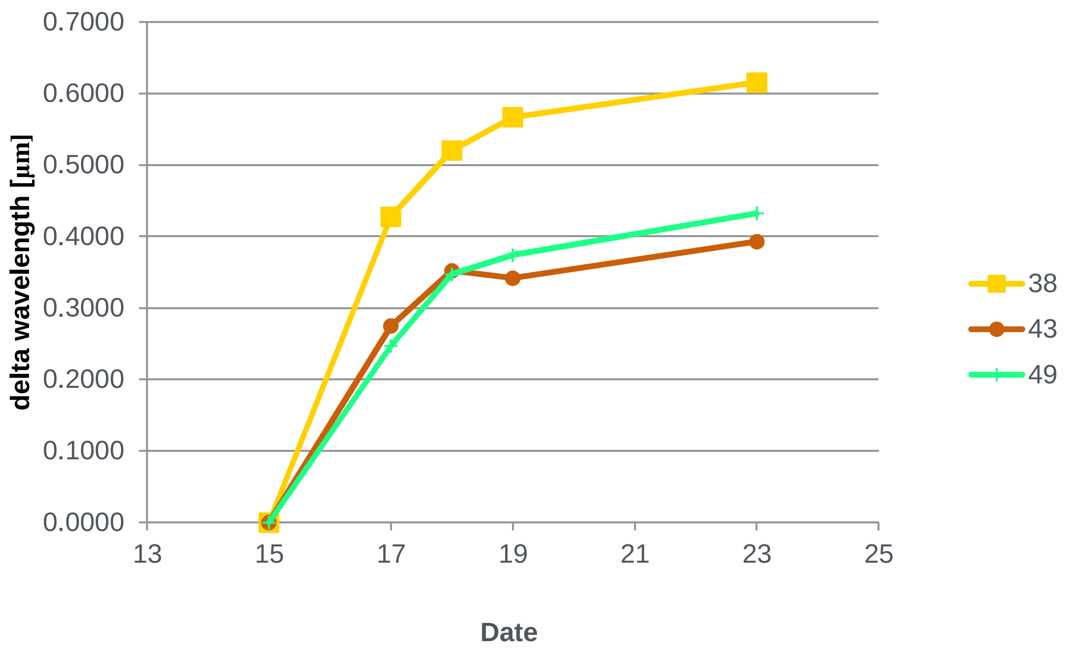


Figure 4 – Test specimen with a mounted MOI bare FBG sensor.

Figure 5 – Test specimen with a mounted MOI standard-package FBG sensor.

Water Conditioning Verification:

- Prepared & environmentally soaked samples/sensors
- Began static tensile tests for strength of sensor bonds and materials
- **Temperature-compensated change in wavelength of 3 FBG strain sensors during the first week of environmental soaking.**



Sandia is quantifying water uptake in MHK composites

Project Plan & Schedule

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

Summary	
WBS Number or Agreement Number	1.4.1.6
Project Number	20064
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Instrumentation System Development												
Q1 Milestone: SNL, NREL, and OPRC Meetings												
Q2 Milestone: Determine ORPC requirements												
Q4 Milestone: Technical Report delivered to DOE												
Q2 Milestone: Generate Coupons												
Q3 Milestone: Contion Test Coupons												
Q4 Milestone: Begin Static and Fatigue Testing												
Current work and future research												
Fatique Testing												

Comments

- FY12-FY14
- Instron broke during testing and require repair. This has been fixed and we are back on schedule to finalize testing.

Project Budget

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

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$140K		$33K		$3K	

- Carry over funding for FY 14 was needed to support testing due to equipment failure.
- Program has been closed out, final testing underway
- Leveraged DOE's Wind Materials along with Advanced Materials and Manufacturing Programs for fatigue testing.
- On target to finalize program tasks in FY14 Q2.

Partners, Subcontractors, and Collaborators: Sandia National Laboratories (Rumsey, Hernandez-Sanchez) Montana State University (Johnson) , Micron Optics (Constantine), Ocean Renewable Power Company (McEntee), National Renewable Energy Laboratory (Nelson)

Communications and Technology Transfer:

- Abstract submitted to 2014 GMREC METS Session
- Results will support instrumentation efforts using FBG fiber optics to other MHK deployments
- MSU and SNL Websites (http://energy.sandia.gov/?page_id=834); (http://www.coe.montana.edu/composites/)

Next Steps and Future Research

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FY14/Current research:

Finish fatigue testing of conditioned samples

Proposed future research:

- Embedding sensors is an intriguing alternative for integrating a health and performance monitoring system into MHK devices and is anticipated to be more robust, but has not been investigated. Once a structure can be accurately and efficiently instrumented, control strategies need to be implemented in order to inform operations and maintenance strategies and scheduling.

Water Power Peer Review

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

The Twenty Participating Countries in the Ocean Energy Systems Agreement of the International Energy Agency

Year	Country	Organisation
2001	DENMARK	Ministry of Transport and Energy, Danish Energy Authority
2001	PORTUGAL	Laboratorio Nacional de Energia e Geologia (LNEG)
2001	UNITED KINGDOM	Department of Energy and Climate Change (DECC)
2002	IRELAND	Sustainable Energy Authority of Ireland
2002	JAPAN	Saga University
2003	CANADA	Natural Resources Canada
2005	UNITED STATES OF AMERICA	United States Department of Energy (DOE)
2006	BELGIUM	Federal Public Service Economy
2007	GERMANY	The Government of the Federal Republic of Germany
2007	MEXICO	Institute of Engineering of the Mexico's National Autonomous University (UNAM)
2007	NORWAY	The Research Council of Norway
2008	ITALY	Gestore dei Servizi Energetici (GSE)
2008	NEW ZEALAND	Aotearoa Wave and Tidal Energy Association (AWATEA)
2008	SPAIN	TECNALIA
2008	SWEDEN	Swedish Energy Agency
2009	AUSTRALIA	The Commonwealth Scientific and Industrial Research Organisation (CSIRO)
2010	REPUBLIC OF KOREA	Ministry of Oceans and Fisheries
2010	SOUTH AFRICA	South African National Energy Institute (SANEDI)
2011	CHINA	Marine Renewable Energy Research, Development and Administration Center
2013	NIGERIA	Nigerian Institute for Oceanography and Marine Research

Standards Development: IEC TC114 and the Ocean Energy Systems Agreement of the IEA

Walt Musial

NREL

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February 25, 2014

Purpose and Objectives

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

Problem statement: Internationally recognized MHK standards are needed to ensure minimum levels of safety, remove market barriers, and provide high quality reproducible test results.

Impact of project: Participating in the development of standards helps to accelerate the development and deployment of ocean energy devices and allows the U.S. to collect critical information on the status of international ocean energy R&D to enable DOE to construct a targeted and well-informed ocean energy research program and to provide feedback to the U.S. industry on the status of international activities.

This project aligns with the following DOE Program objectives and priorities:

- Develop key MHK testing infrastructure, instrumentation, and/or standards.

Technical Approach

- Participate and have a leading role in the development of international and domestic standards related to marine hydrokinetic devices, including IEC TC114 and IEA OES

- NREL will serve as Administrator of the U.S. Technical Advisory Committee for TC114 and manage a subcontract with Cardinal Engineering to support industry participation. In addition, NREL will provide direct support to the TC114 Chairman, Neil Rondorf

- NREL will provide direct technical support to DOE by serving as the U.S. Alternate Member to the Ocean Energy Systems Agreement of the International Energy Agency (IEA) and also provide technical support to the U.S. Operating Agent of OES Annex V, which organizes and facilitates international information exchange workshops

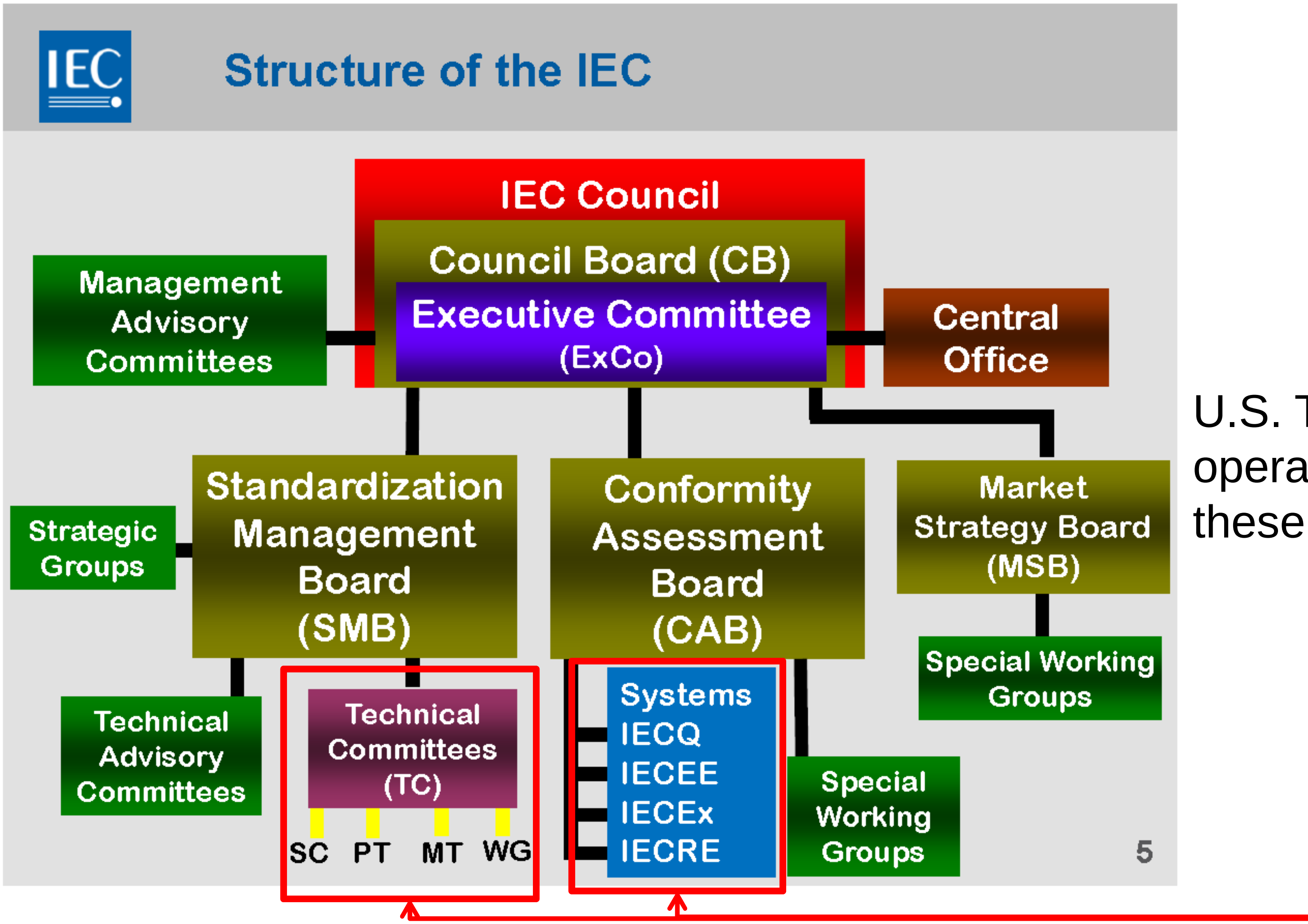
- Indirect benefit: Standards development meetings are a great platform to understand what issues the industry is struggling with and the boundaries of current knowledge to help define R&D needs.

IEC is the main focus of the activities.

- International Electrotechnical Commission (www.iec.ch)
- TC114 prepares standards for marine energy conversion systems
- TC114 has 14 participating countries and 8 observer countries
- NREL manages U.S. contributions through ANSI
- U.S. Technical Advisor Group (TAG) consists of roughly 57 members from industry, universities, government agencies, and national laboratories
- U.S. TAG members participate on the Conformity Assessment Board.

Country	Participating (P)/Observing (O) Status
Brazil	O-Member
Canada	P-Member
China	P-Member
Czech Republic	O-Member
Germany	P-Member
Denmark	P-Member
Spain	P-Member
France	P-Member
United Kingdom	P-Member
Ireland	P-Member
Iran	O-Member
Italy	O-Member
Japan	P-Member
Korea, Republic of	P-Member
Netherlands	P-Member
Norway	P-Member
Poland	O-Member
Portugal	O-Member
Romania	O-Member
Russian Federation	O-Member
Sweden	P-Member
Ukraine	O-Member
United States of America	P-Member

Structure of IEC



U.S. TAG operates in these areas

Structure of IEC TC114

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Chairman: Neil Rondorf (US)
Secretary: Danny Peacock (UK)
Technical Officer: Charles Jacquemart (IEC)

U.S. Technical Advisor (Chairman): Bill Staby
U.S. Deputy Technical Advisor: Roger Bagbey
U.S. TAG Administrator: Arielle Cardinal

WG/PT	Title	Convener
PT62600 1	Terminology	Ghanashyam Ranjitkar (CA)
PT62600 2	Design requirements for marine energy systems	Bob Paasch (US)
PT62600 10	The Assessment of Mooring Systems for Marine Energy Converters	Ryan Nicoll (CA)
PT62600 20	Guideline for design assessment of Ocean Thermal Energy Conversion (OTEC) system	Mann-Eung Kim (KR)
PT62600 30	Electrical power quality requirements for wave, tidal and other water current energy converters	Mohamed El-Hawary (CA)
PT62600 101	Wave energy resource assessment and characterization	Matt Folley (GB)
PT62600 102	Wave Energy Converter power performance assessment at a second location using measured assessment data	Kim Nielsen (DK)
PT62600 103	Guidelines for the early stage development of wave energy converters: Best practices and recommended procedures for the testing of pre-prototype scale devices	Brian Holmes (Ireland)
PT62600 201	Tidal energy resource assessment and characterisation	Andy Baldock (GB)
AHG 2	Power performance assessment of electricity producing river current energy converters	Ghanashyam Ranjitkar (Canada)
AHG 3	Assessment of information received on IEC TS 62600-100, Power performance assessment of electricity producing wave energy converters	Scott Beatty (Canada)
AHG 4	Assessment of information received on IEC TS 62600-200, Power performance assessment of electricity producing tidal energy converters	Jonathan Colby (US)

Cardinal Engineering Subcontract: Industry Support and TAG Management

- TAG Members who participate on an international level are given stipends to reimburse them for their efforts and encourage participation
  - TAG Members are required to submit deliverables to receive stipends
  - Currently 18 TAG Members qualify; all other participation is on a volunteer basis
- ANSI membership is paid for 22 TAG Members
- Website development and maintenance
- Support for annual face-to-face meeting.

OES Annex V on Information Exchange

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- Accelerate the development and deployment of ocean energy technology through a multi-country exchange
- Allow participants to understand the current state of knowledge in the field
- Develop a consistent method of assessing the performance and cost of ocean energy conversion systems.

Operating Agent	United States Department of Energy
Duration	October 1, 2011 – December 2015
Member Countries (20)	Denmark, Portugal, United Kingdom, Ireland, Japan, Canada, United States, Belgium, Germany, Mexico, Norway, Italy, New Zealand, Spain, Sweden, Australia, Republic of Korea, South Africa, China, Nigeria

Annex V Tasks:

Task I – Planning

Establish the structure and outcomes of the annex to include a plan of actions and milestones that identifies resource-specific meetings and product plans, potentially broken down to: 1) Wave; 2) Tidal Current; 3) River Current; 4) OTEC; 5) Hybrid; and others.

Task II – Identify Topics

Data definition working group meetings to identify eligible projects and data sets to be exchanged

Task III – Hold Workshops

Exchange workshops to present project information, experience, and data to the participating members.

NREL's Role - Participate in all tasks:

1. Technical expertise in planning Annex V and selecting U.S. and other country projects
2. Establishing data requirements and presentation formats for the exchange workshops
3. Coordination and logistical support to the country meeting hosts
4. Developing technical presentations for workshops
5. Analyzing and assessing workshop information

Accomplishments and Progress

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

TC 114

- Published 3 Technical Specifications to date: IECTS62600-1 Ed.; IEC TS 62600-100 Ed. 1; IEC TS 62600-200 Ed. 1
- Successful recruitment of subject matter experts
- Adequate staffing of all project teams and ad-hoc groups
- U.S. TAG Member Neil Rondorf voted to serve as international Chairman
- Created U.S. TAG website that is updated regularly
- Published 2 articles in "IEC e-tech" (monthly IEC newsletter): *IEC e-tech 2012-11: Marine Renewables* and *IEC e-tech 2013-03: A CA system for marine energy*
- U.S. TAG Members Jonathan Colby and Diana Bull winners of the IEC Young Professionals Competition

IEA OES Annex V

- Organized and held two workshops:
  - Workshop I – Open Ocean Testing of MHK Technologies
  - Workshop II – Numerical Modeling Methods for Wave and Current Technologies
- First Annual Report published

Project Plan and Schedule

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

Summary	
WBS Number or Agreement Number 1.3.3.1	
Project Number	
Agreement Number 17247	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Standards Development - IEC TC114, IEA-OES												
Q1 Milestone: Update IEC TC114 Membership Database												
Q2 Milestone: Fund IEA ExCO US Annual Contribution												
Q3 Milestone: Prepare for and partcicipate in IEA OE ExCO meetings												
Q4 Milestone: Produce letter report: summary of efforts and gaps												
Q1 Milestone: Execute new subcontract to administer TAG funding												
Q1 Milestone: Prepare for and participate in Fall IEA OES ExCO meeting												
Q2 Milestone: Develop initial design for US TAG website												
Q2 Milestone: Fund IEA ExCO US Annual Contribution												
Q3 Milestone: Prepare for and attend the IEC TC114 Plenary Meeting												
Q3 Milestone: Prepare for and participate in the IEA Spring OES ExCo Meeting												
Q4 Milestone: Produce letter report: summary of efforts and current status												
Q4 Milestone: Plan the IEA work program for 2014 and submit letter report												
Q1 Milestone: Organize and participate in US TAG annual meeting												
Q2 Milestone: Write the OES-IEA Annex V Workshop II draft report and submit to ExCo												
Q3 Milestone: Prepare for and attend the IEC TC114 Plenary Meeting												
Q4 Milestone: Plan the 2015 IEA work program and submit letter report												

Comments

The Standards task has been on track and there have been no significant delays.

Project Budget

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

Project Funding History

Budget History (Funding)					
FY2012		FY2013		DOE FY2014	
DOE	Cost-share	DOE	Cost-share		Cost-share
$934k	n/a	$769k	n/a	$883k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY12	Funds spent by end of FY13	Spend Plan FY14
$650K	$571K	$661k

- Spending has been on track given DOE guidance of preserving 25% of funds for carryover
- FY14 project costs to date as of December 30th: $144k.

Research Integration and Collaboration

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Partners, Subcontractors, and Collaborators:

IEC TC114: Subcontractor – Cardinal Engineering. NREL collaborates with 57 TAG Members from industry, academia, government, DOE, and national laboratories.

IEA OES: Member Countries and Cardinal Engineering, Annex V Operating Agent, in partnership with the U.S. Department of Energy.

Communications and Technology Transfer:

IEC TC114: Technical Specifications are published and available for purchase on the IEC website. IEC TC114 holds one Plenary Meeting annually and meeting minutes and presentations are available on the IEC website.

IEA OES: OES workshop reports will be published on the OES Web site at http://www.ocean-energy-systems.org/ when approved by the OES Executive Committee.

Next Steps and Future Research

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FY14/Current research:

IEC TC114: Continue to recruit subject matter experts to staff new project teams and manage day to day operations of the US TAG. Organize and attend US TAG and IEC TC114 Plenary Meetings.

IEA OES: Provide coordination and logistical support and develop technical presentations for workshops, analyze and assess workshop information, contribute to the annex's final report.

Proposed future research:

IEC TC114: Standards are evolving over time to address the needs of the end users and industry such as:

- Acoustic Characterization
- Development of CAB Renewable Energy System and Marine Renewable Energy Scheme

IEA OES: Annex V is currently planning additional Workshops and the OES is developing an Annex on the MHK Cost of Energy

Water Power Peer Review

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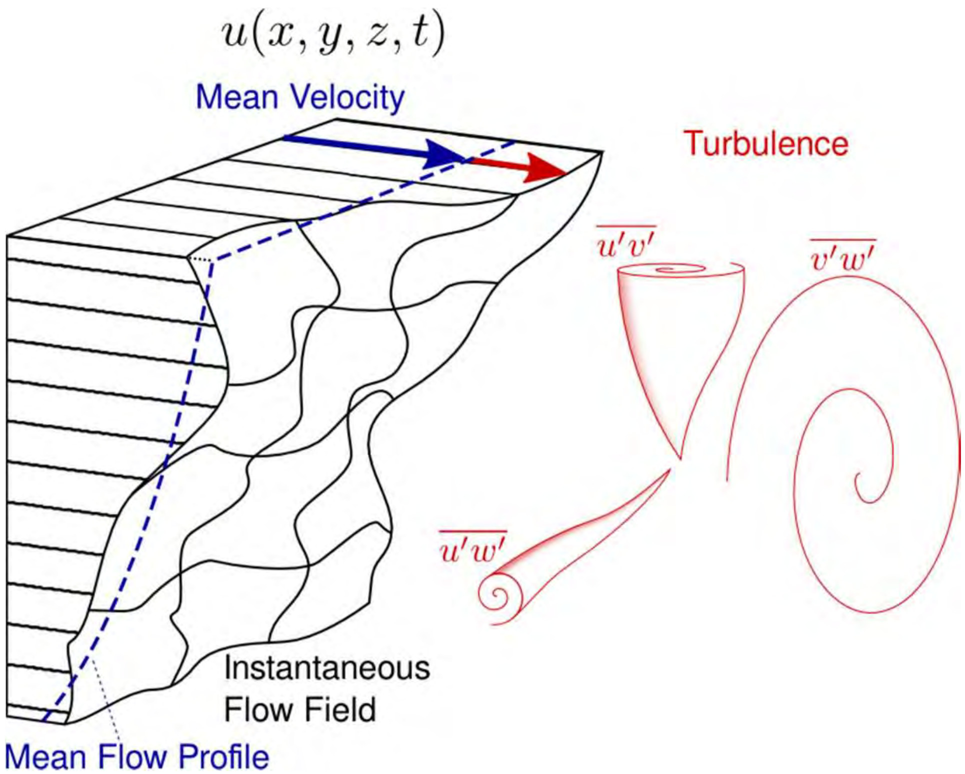

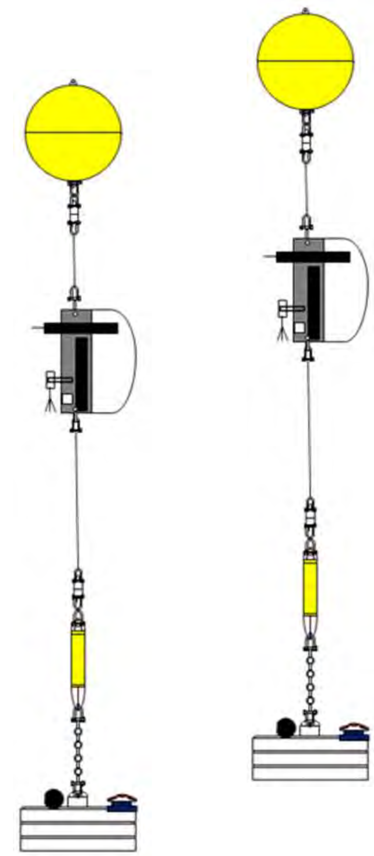

New Project: Advanced Turbulence Measurements Methodology Development

Levi Kilcher

National Renewable Energy Laboratory

levi.kilcher@nrel.gov

Wednesday February 26, 2014

Problem Statement: Device designers need accurate fatigue load predictions to meet device life goals. This requires accurate turbulence inflow measurements.

- Device simulation tools (e.g., HydroFAST, Tidal Bladed) require realistic inflow simulations based on accurate turbulence measurements.
- More inflow data is needed (i.e., lower cost of turbulence measurements).
- Detailed wake turbulence measurements will inform array design.

Impact of Project: Provide the MHK community with a low-cost methodology for quantifying the details of tidal, river, and ocean-current turbulence. This project will also produce a publically available inflow dataset of a tidal power site.

This project aligns with the following DOE Program objective:

- Developing key MHK instrumentation.

What do we need to measure?

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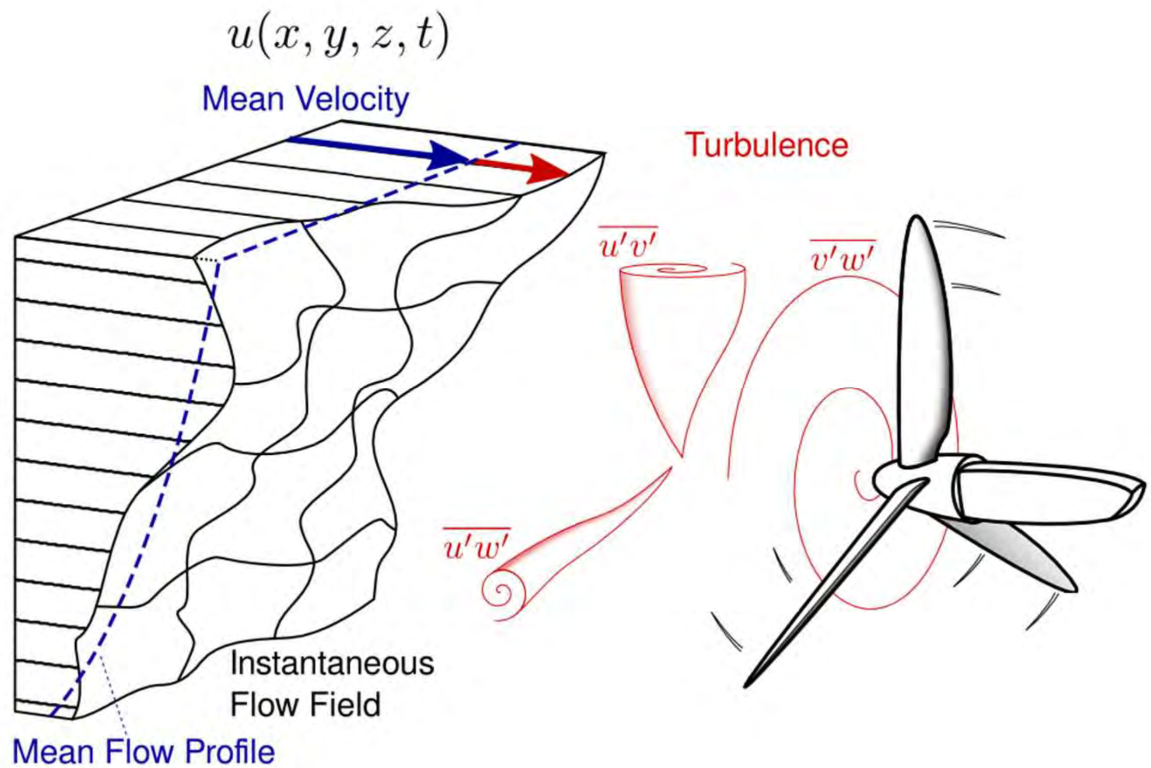
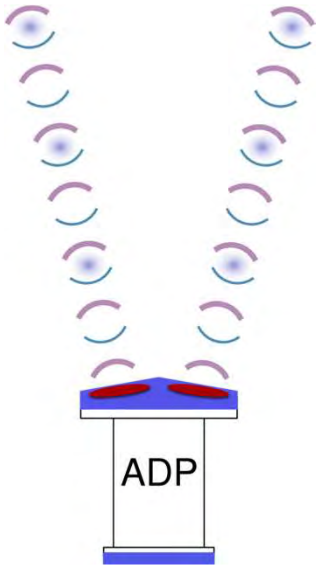
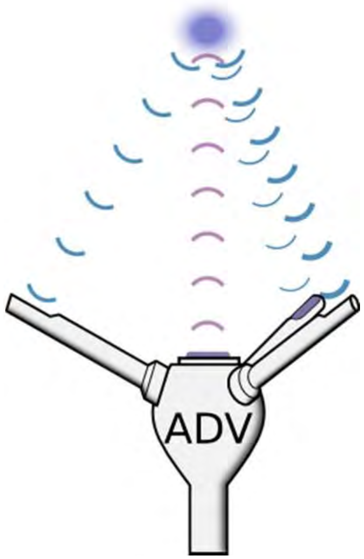
- Mean velocity profile
- Turbulent Kinetic Energy (TKE)
  turbulence intensity
- Turbulence Spectrum
  timescales of turbulence
- Reynold’s Stresses
- Spatial coherence
  length-scales of turbulence



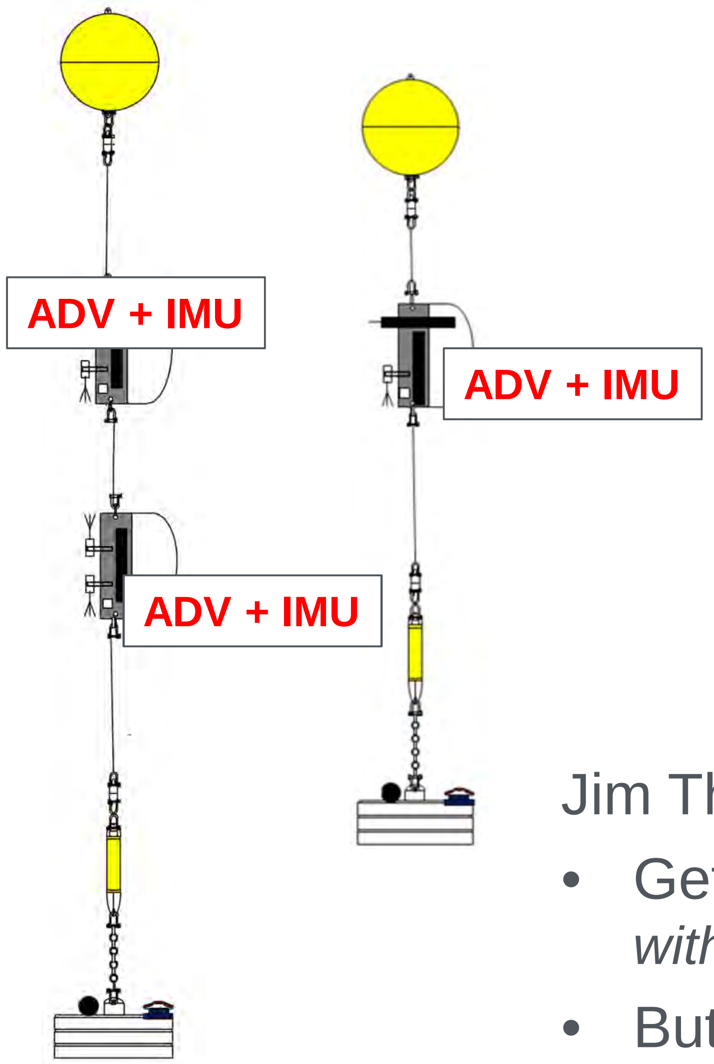


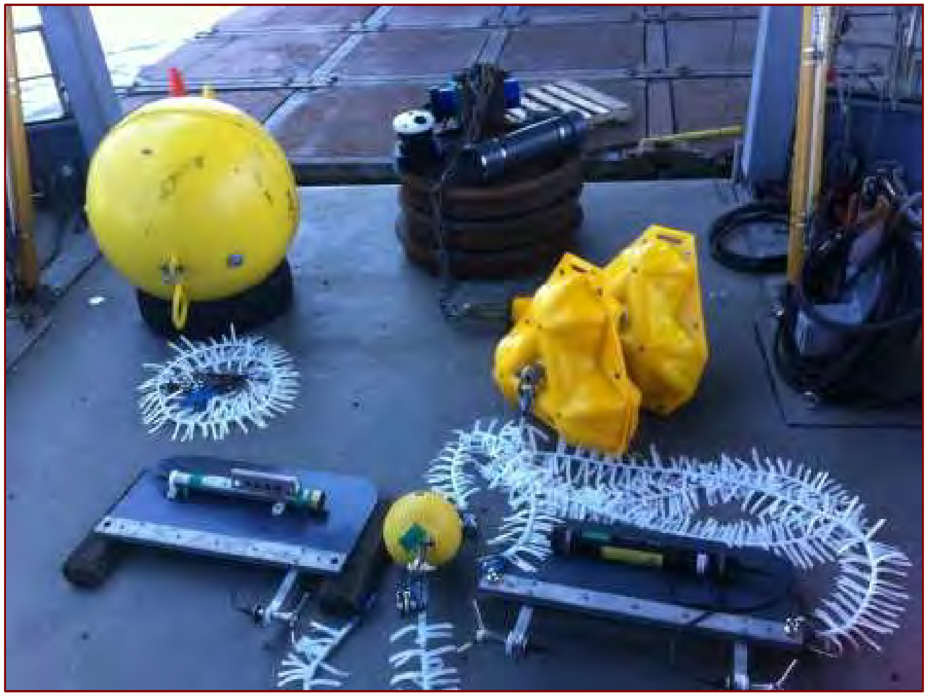
Doppler Profilers	Doppler Velocimeters
Poor precision *noise and spatial aliasing*	Excellent precision *coherent pulses*
Convenient deployment *deploy on seafloor*	Deployment challenges *must position at hub-height*
Measures: • Mean profile • Reynold's stress • TKE?	Measures: • TKE spectrum • Reynold's stress • Spatial coherence*



A low-cost, reliable system for deploying ADVs at hub-height is needed!

***: Must deploy multiple ADVs simultaneously.**





TTM components on the deck of the R/V Jack Robertson prior to deployment (photo courtesy of Jim Thomson).

Jim Thomson (UW-APL) developed TTM:

- Get ADVs farther above seabed
  without an expensive fixed-frame
- But what about motion contamination?
  Inertial Motion Units (IMUs) capture ADV motion

Can mooring motion be removed from ADV velocity measurements?

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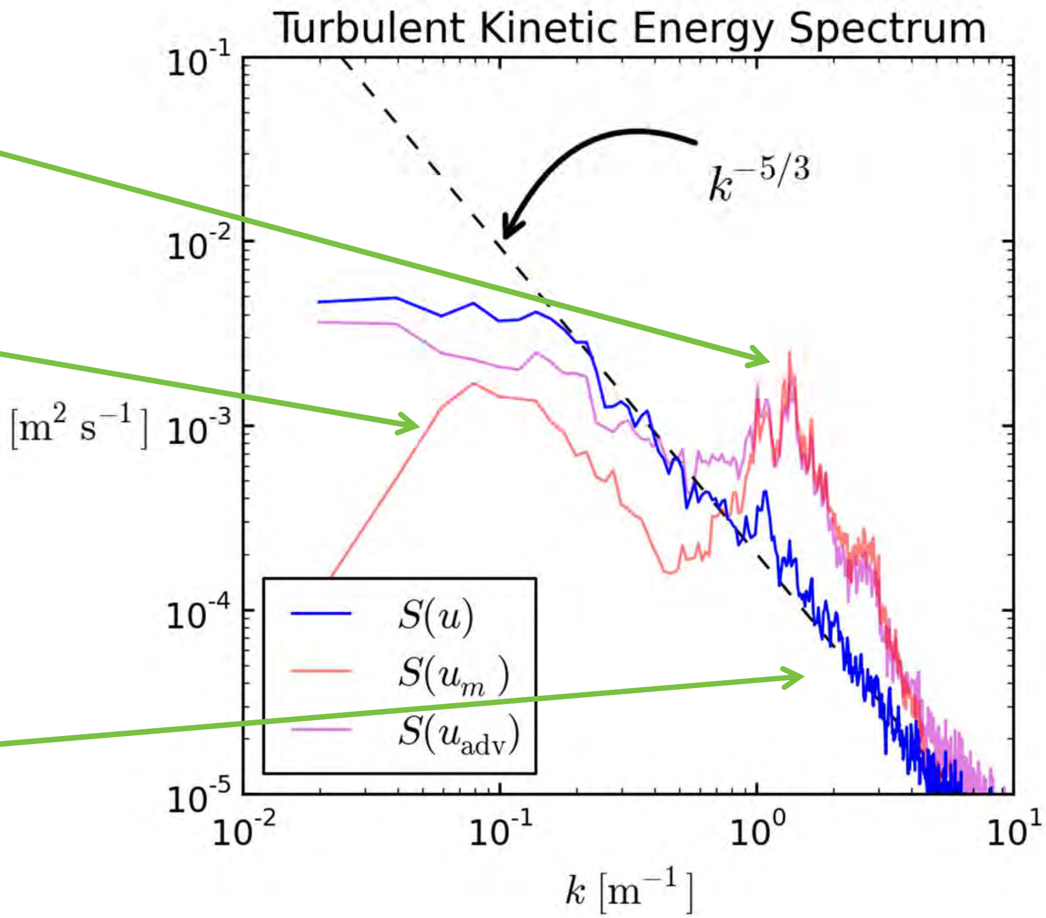
1. Uncorrected measurements are contaminated by motion.

2. Motion-induced velocity computed from IMU accelerometer and rotation-rate measurements:

$$\vec{u}_m = \vec{u}_a + \vec{u}_\omega$$

3. Motion-corrected spectrum agrees with fundamental turbulence theory:

$$\vec{u} = \vec{u}_{ADV} - \vec{u}_m$$



Wavenumber spectra of IMU-ADV measurements from Admiralty Inlet. Data collected in collaboration with Jim Thomson (University of Washington APL).

Spatial Coherence: Test Deployment

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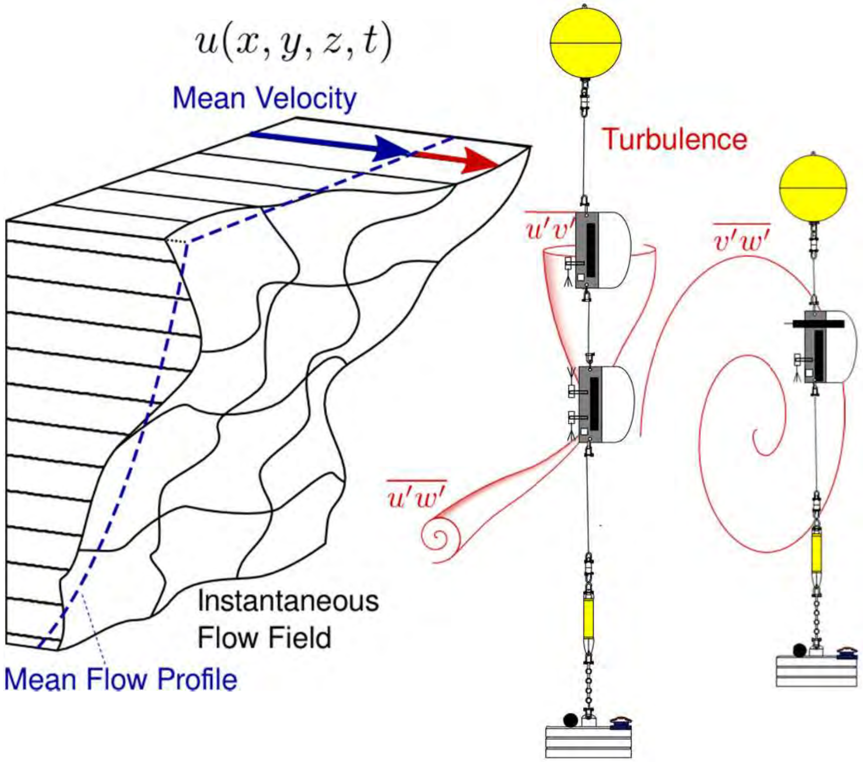

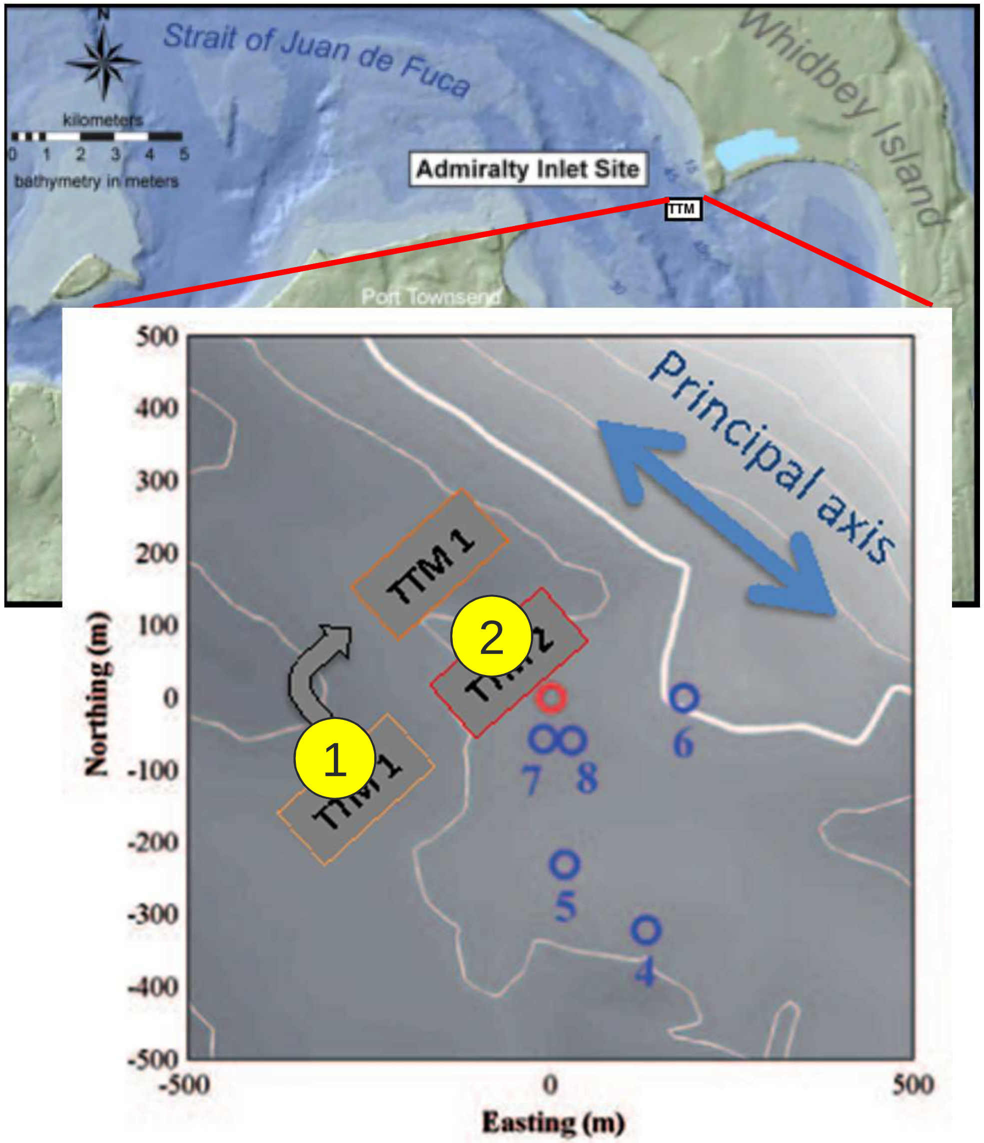

Two moorings (1 and 2) will be deployed in Puget Sound in two configurations:

a) Across the principal flow direction to capture ‘lateral coherence’, and

b) Along the principal flow direction to capture ‘streamwise coherence’.

How do we validate coherence estimates?

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1) Coherence follows an exponential decay:

$$Coh = Ae^{-\beta kr}$$

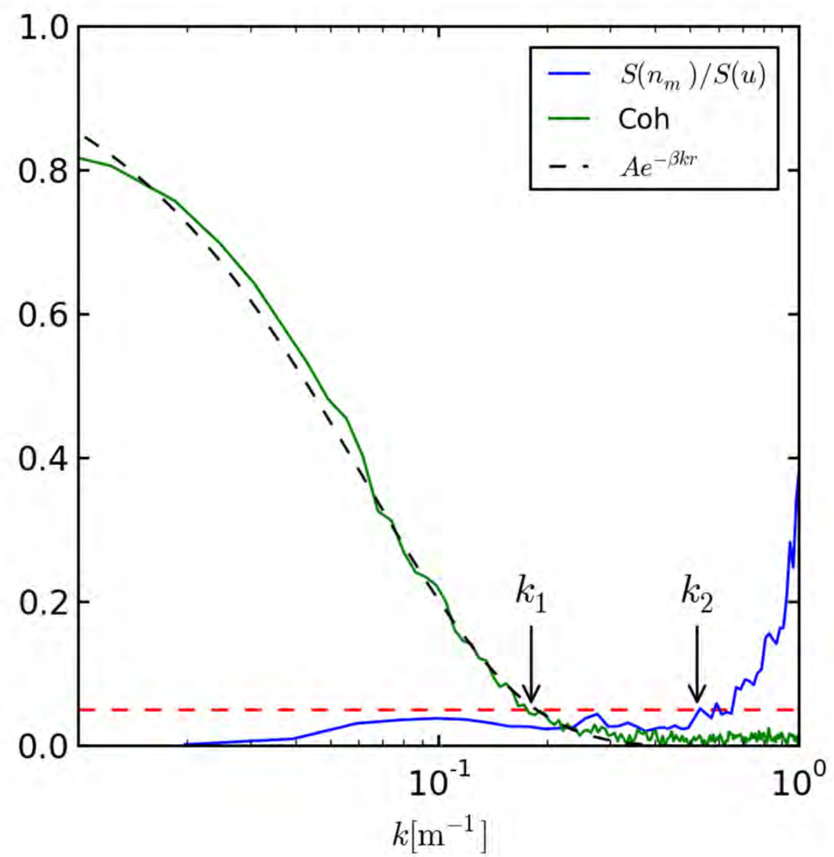
k – wavenumber

r – distance between points

Coefficients A and β are ~1, and site-specific.

2) To ensure IMU noise does not inaccurately reduce coherence:

$$k_2 > 2k_1$$



Hypothetical TTM-based IMU-ADV coherence (green) and IMU-noise spectra (blue). The dashed red line indicates the 0.05 threshold used to define the values k_1 and k_2.

Data Courtesy of Verdant Power and Oak Ridge National Lab.

Gunawan, B., Neary, V.S., and Colby, J. (2014) Tidal energy site resource assessment in the East River tidal strait, near Roosevelt Island, New York, NY (USA), in press, Renewable Energy.

Related efforts through FY13:

- Successfully deployed moored IMU-ADVs.
- Developed and validated motion-correction software.
  Thomson et.al. *Tidal turbulence spectra from a compliant mooring,* Marine Energy Technology Symposium (2013).
- Developed PyTurbSim ocean turbulence simulation tool (see poster).

Project Plan and Schedule

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Summary
WBS Number or Agreement Number 1.3.2.1
Project Number
Agreement Number 26837

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2014			
Task / Event	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Advanced Turbulence Measurement Techniques				
Q1 Milestone: Develop multi-TTM array layout and deployment plan				
Q2 Milestone: Assemble TTMs & configure instrumentation				
Q2 Milestone: Deliver memo that includes photos and results				
Q3 Milestone: Complete a multi-TTM test deployment				
Q3 Milestone: Deliver memo with perlimnary assessment for coherence measurements				
Q4 Milestone: Release test measurement data				
Q4 Milestone: Submit draft report that quanitifes capacity to measure coherence				
Current work and future research				

Comments

- Project Initiated: 10/1/2013
- Expected Completion Date: 9/30/2014

Project Budget

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Project Funding History

Budget History (Funding)			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$229k	n/a	$494k	n/a

Project Spending

Budget Actuals and Future Spend Plan		
Funds spent by end of FY 2012	Funds spent by end of FY 2013	Spend Plan FY14
$0k	$0k	$370k

- NREL received $229K in funding in late FY13 and no funds were spent until FY14.
- FY14 Project Costs as of December 31, 2013 are $17k.
- FY15 Carryover funding for TurbSim task to incorporate any new data sets into this project

Partners, Subcontractors, and Collaborators: Jim Thomson's team at University of Washington's Applied Physics Lab designed the TTM and will be constructing and deploying the moorings and collaborating on data analysis.

Communications and Technology Transfer:

- Thomson et.al. (2013) METS paper.
- A technical report or journal publication will detail the methodology for making these measurements and estimating coherence.
- Data will be released publicly: http://en.openei.org/wiki/Gateway:Water_Power.
- Data will be incorporated into pyTurbSim (see poster).

Next Steps and Future Research

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Proposed Future Research:

- Collaborate with academic and industry partners to make additional measurements using the multi-TTM system.
- Incorporate these data sets into PyTurbSim.
- Enable developers and researchers to characterize turbulent inflow environment at specific sites.

2014 Water Power Program Peer Review

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

Marine and Hydrokinetic Testing Infrastructure Development NEW

Wind and Water Power Technologies Office
Jim Ahlgrimm, DOE
February 27, 2014

Purpose & Objectives

Problem Statement:

- The US Industry is new and emerging. There are over 40 MHK concepts being developed in the U.S., and many more overseas.
- Pre-permitted test facilities are crucial to reduce development timelines and RDT&E costs.
- Federal investment is necessary as no one company has the resources to develop test facilities on their own.

Impact of FOA:

Investment in critical test infrastructure and standardized instrumentation packages benefits all US developers, speeds design evolutions and positions US developers for global market competition.

This FOA aligns with the following DOE Program objectives and priorities

MHK

- Advance the state of MHK technology
- Develop key MHK testing infrastructure, instrumentation, and/or standards

Open Water, Fully Energetic Wave Test Facility

The primary objective of this topic area is to identify possible site locations and evaluate the potential to establish a national wave testing facility within U.S. territorial waters. Project activities under this FOA include:

1. identify options for a national test site meeting the resource and testing criteria necessary to test full scale wave generation devices (specific minimum wave resource and facility support requirements are identified in the “Minimum Resource & Infrastructure Requirements” section below as well as in the Merit Review Criterion section of this FOA, Section V),

2. develop a preliminary facility design,

3. estimate cost and schedule for site development and facility construction,

4. estimate annual facility operating and maintenance cost, and

5. estimate testing fees required for full facility cost recovery inclusive of facility operation, maintenance, and test support based on a semi-annual lease of individual testing berths.

FOA Timeline

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- FOA Issue Date: 07/03/2013
- Letter of Intent (LOI) Due Date: 07/26/2013
  - LOIs were requested to aid in establishing the number of merit reviewers that would likely be needed, but not required in order to submit a full application
- Application Due Date: 08/13/2013
- GFO Compliance Review of Applications: 8/30/2013
- Federal Consensus Merit Review Panel: 09/23/2013
- Award Negotiation: In process (expected award date in 2nd Quarter of FY14
- Period of Performance: 12 Months

Test Facility Resource and Infrastructure Requirements

Any proposed test site and accompanying facility support infrastructure must meet or exceed the following resource and infrastructure support requirements:

Site Location & Resource:

- Located in U.S. territorial waters
- Test berths subject to full (unprotected) oceanic wave regimes
- Wave annual average power density ≥ 30 kW/m
- Testing berth water depths ≥50m

Site Capacity:

- A minimum of four (4) testing berths and sufficient infrastructure and support capacity to accommodate simultaneous testing of four (4) wave generation devices
- Rated test capacity of each berth to accommodate generation devices up to 1 MW
- Access & approval for grid interconnection with sufficient line capacity to operate all testing berths simultaneously at rated power

Awardee Summary

Applicant	Application	Federal Share
Oregon State University	1505 - The Pacific Marine Energy Center South Energy Test Site (PMEC-SETS)	$750,000
California Polytechnic State University, San Luis Obispo	1506 - California Wave Energy Test Center (CalWave)	$750,000
	Total	$1,500,000

- The Pacific Marine Energy Center will be a grid--connected test facility to evaluate utility scale wave energy conversion (WEC) device performance, environmental interactions, and survivability
- Builds on previous NNMREC test infrastructure work (NNMREC has received $10M from DOE since 2008 for MHK research as well as test infrastructure activities)

DOE Funding	Cost Share	Total Project Cost
$750K	$340K	$1,090K
Proposed Partners:		
OSU, U Wash, Univ College – Cork, Pacific Energy Ventures, NREL, SNL, Ore Wave Energy Trust		

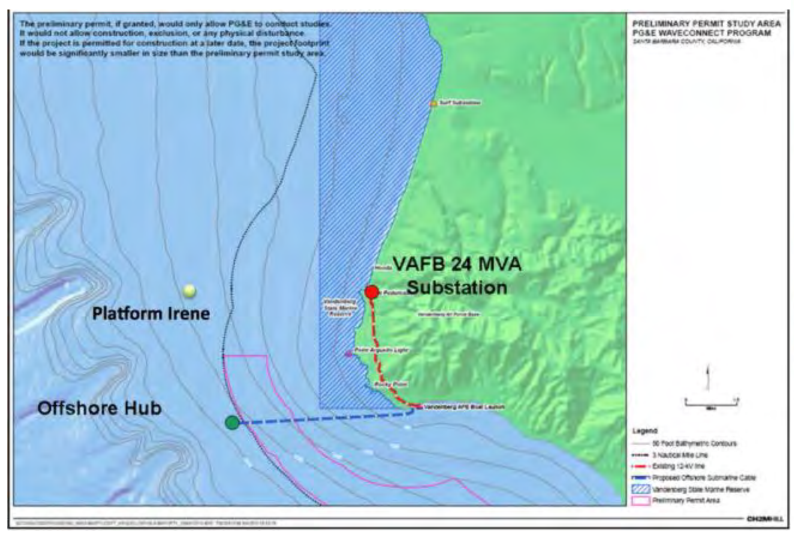
California Polytechnic State University

California Wave Energy Test Center (CalWave)

- The California Wave Energy Test Center (CalWave) will be an open water, grid connected full scale wave test site preliminary design.
- Cal Poly will select from two potential sites near Eureka and Vandenberg Air Force Base.
- Vandenberg AFB site leverages existing electrical infrastructure and could have significant cost savings.

DOE Funding	Cost Share	Total Project Cost
$750K	$400K	$1,150K

Proposed Partners:
Cal Poly, Burns & McDonnell, CH2M HILL, Kearns & West, EPRI, Glosten Assoc, Humboldt State, H.T. Harvey, Redwood Coast Energy Auth, Schatz Res Ctr, NREL, Oceanlinx, Pac Marine Renewables, SAIC, SNL, UC San Diego, Va Tech



Communications and Technology Transfer (Transition) Plans

The long-term technology transfer component of this project will be to develop and provide affordable access to world-class test facilities for emerging wave energy components and system in order to accelerate development and deployment of U.S. technologies.

Once fully developed, these test facilities will be available to industry and can contribute to:

1. Reducing the technical and financial risk of MHK technology deployment
2. Reducing the cost of testing for individual developers and the industry as a whole, and
3. Reducing the time-to-market of commercially ready systems.

2014 Water Power Program Peer Review

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






MHK Water Resource Characterization

Wind and Water Power Technologies Office
Joel Cline

Thursday, February 27, 2014

Overview: Resource Characterization

Goals – Enhance understanding of ocean energy resources that can contribute to U.S. energy needs.

Priorities

- Develop knowledge of the physical conditions potentially to be experienced by deployed MHK devices and arrays.
- Understand how these conditions determine deployment siting and scale of deployment, device selection for a given project site and potential levelized cost of energy of the MHK resource.

FY 14 Budget: $0.5M

DOE Unique Role – The Water Power Program can help identify new opportunities for developing renewable energy resources by providing high-level resource information to the public.

MHK Organizational Structure

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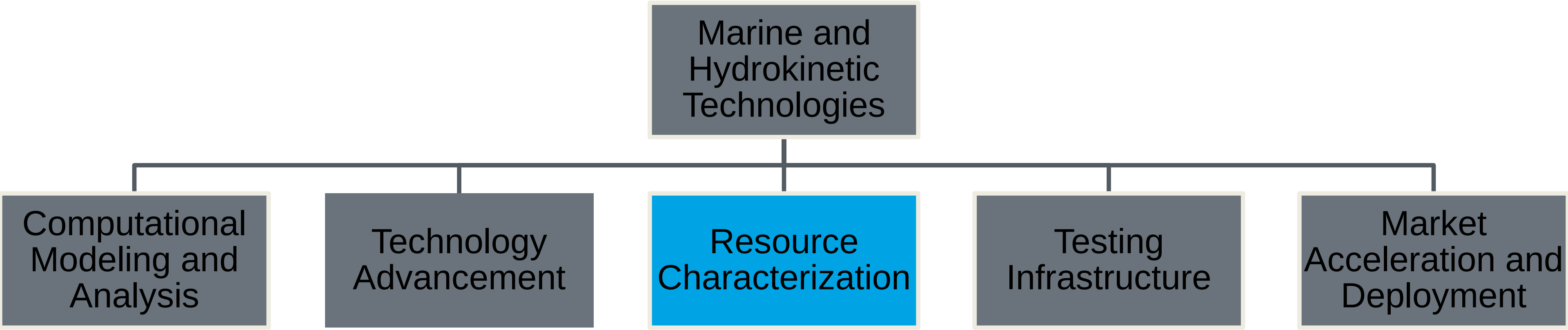

Key Counterparts and Collaborators

- National Renewable Energy Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories
- Industry
- National Marine Renewable Energy Centers

MHK Key Objectives

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The 2014 Water Program Peer Review Agenda has sessions that will cover projects and activities in these priority areas.	
Advance the state of MHK technology	• Tuesday, 2/25 • Wednesday, 2/26
Develop key MHK testing infrastructure, instrumentation, and/or standards	• Thursday, 2/27
Characterize and increase access to high resource sites	• Thursday, 2/27
Reduce deployment barriers and environmental impacts of MHK technologies	• Wednesday, 2/26

MHK Budget (FY 2012 – FY 2014)

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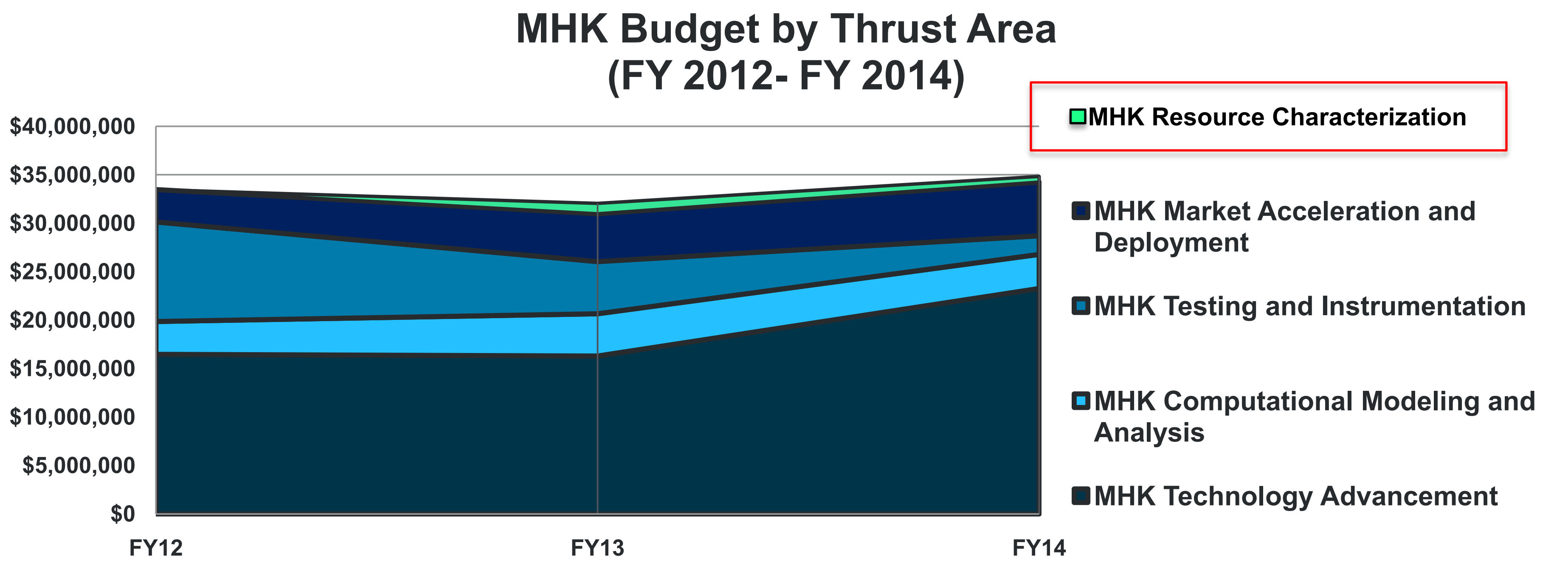

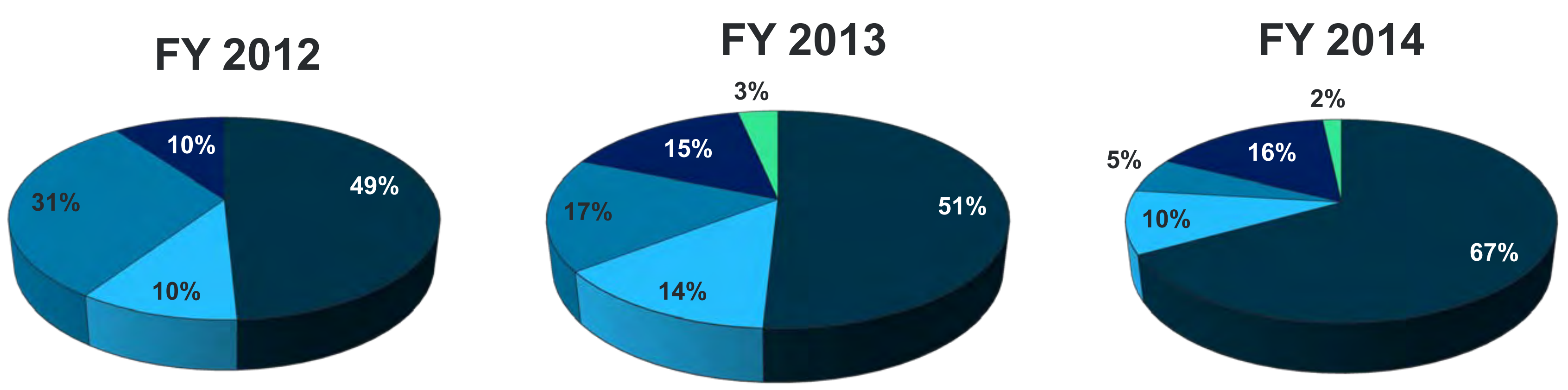

Main Elements of the Resource Characterization Portfolio

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Technical Area	Key Projects/Activities
4.1 Wave Resource Characterization	NREL: • Navy Installation Resource Characterization* • National Resource Refinement Using 30- Year Data* PNNL: • Wave Model Refinement for Resource Characterization of NAS Recommended Areas SNL: • Wave Environmental Characterization at Wave Test Sites* • Wave Resource Model Refinement for near shore and hot spots
4.2 Tidal & Current Resource Characterization	NREL: • Tidal, ocean, river current-resource assessment and hydropower addition to MHK Atlas*

* Indicates carryover project from FY13

Resource Characterization Priorities in FY14 and Beyond

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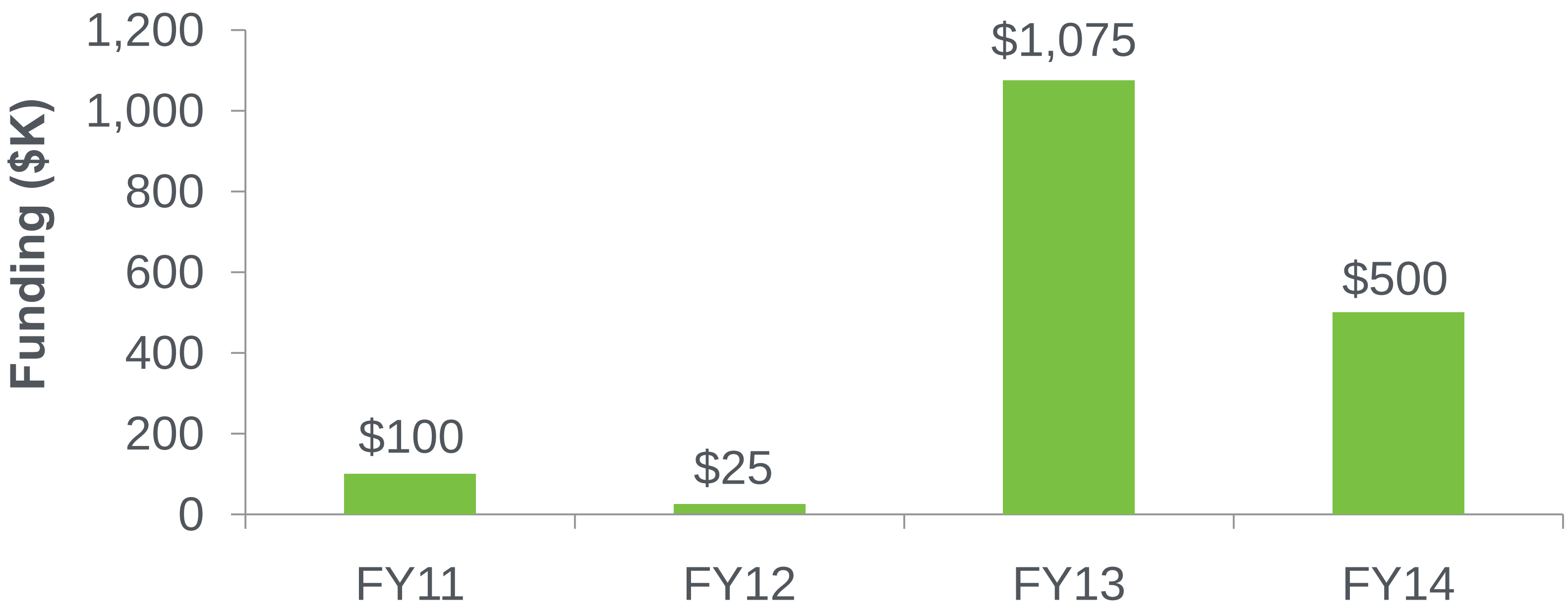
Technical Area	Priorities or Changes in Portfolio FY11 vs FY14	Key Collaborators	Upcoming milestones
4.1 Wave Resource Characterization	• Refinement of MHK resource assessments to address limitations • Emphasis on enhancing wave resource characterization • Looking at new models beyond Wavewatch III	NREL • Navy • Virginia Tech PNNL SNL: • Sea Engineering Inc.	• Add updated wave resource grid to MHK Resource Atlas • Complete wave energy assessments at various test sites
4.2 Tidal & Current Resource Characterization	• Additions to the MHK Atlas	NREL: • Georgia Tech	• Add ocean current and tidal resources to MHK Resource Atlas

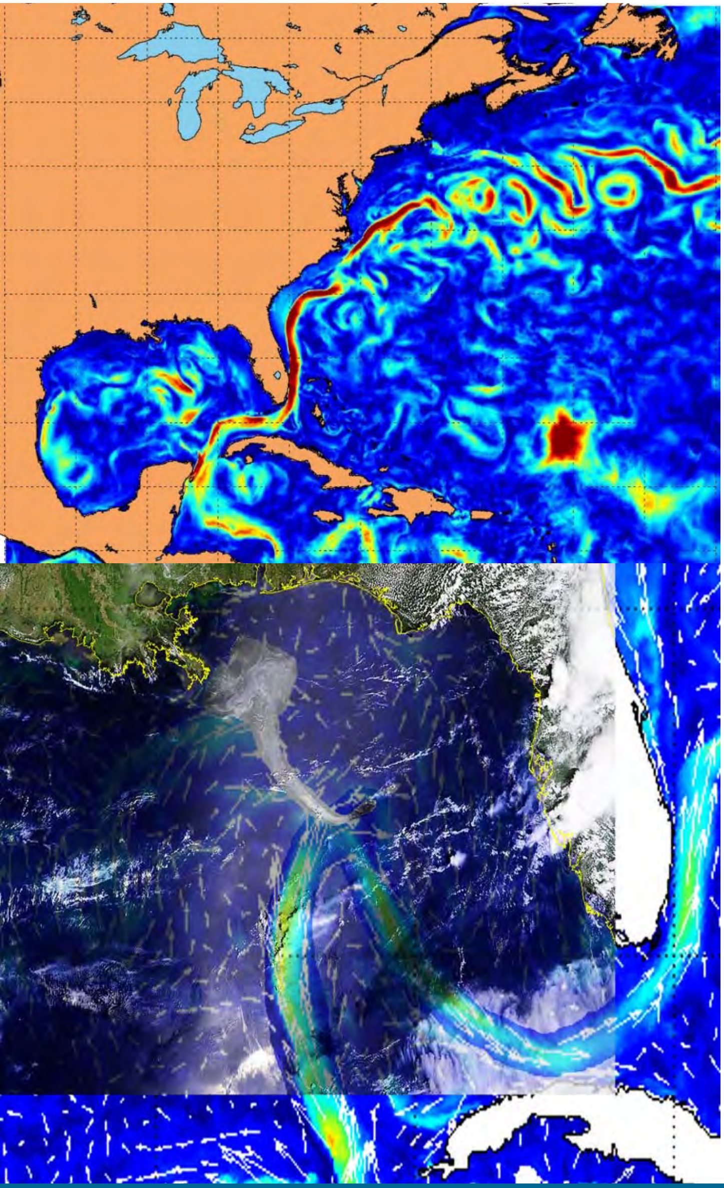
Evolution of the Resource Characterization Portfolio

MHK Resource Characterization Funding

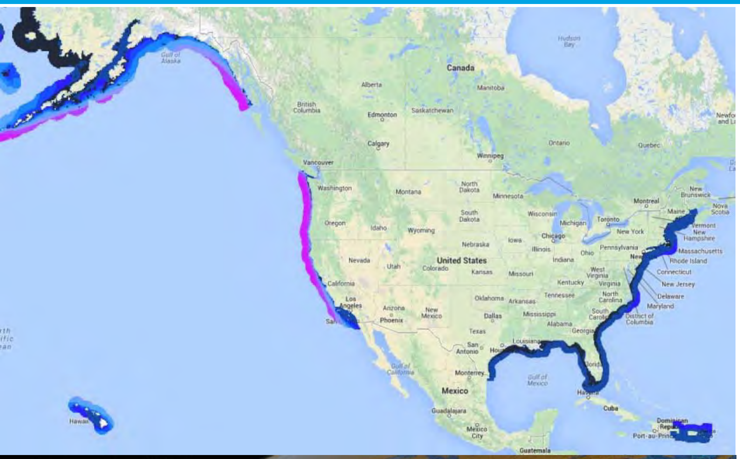


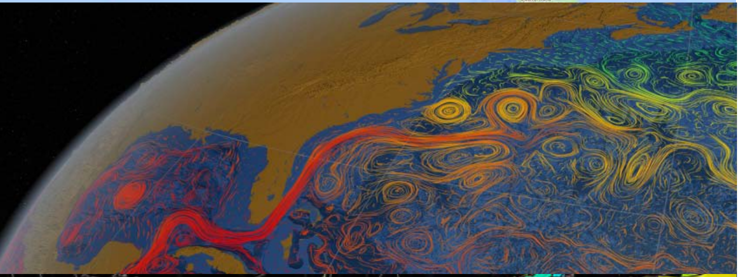
NOAA WAVEWATCH III®

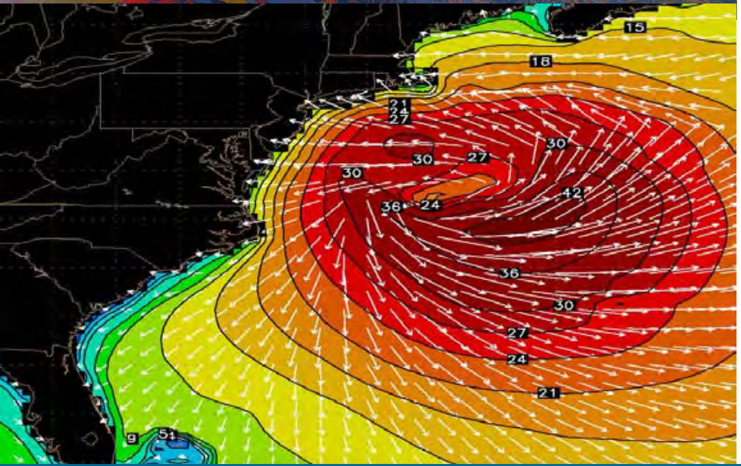
NREL NATIONAL RENEWABLE ENERGY LABORATORY MHK Atlas



- **Wave modeling efforts**
  - WW III
  - Swan
  - FVCOM
  - Others
- **Improved Wave Resource Characterization**
- **Work with DoD to highlight the areas they can begin work on**
- **Eventually lead to a Wave Classification Scheme**







- **Portfolio Pivot**
  - **From Resource Assessment on large scale to more refinement**
  - **Working with labs to discover the best of all and work together**
  - **Reduce duplication of effort and pool resources**
  - **Develop a single "best-practices" model – Is this the right path?**
  - **Work with DoD – fulfills their need and possible test areas – seems a great resource – thoughts?**
  - **Do you want a Wave Classification Scheme?**
  - **Portfolio priorities: Are they the right ones?**
  - **Portfolio shifts: Did we make the right call?**
  - **Are there items we haven't considered?**

Resource Characterization Agenda Overview

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Subject Area	Time	Topic	Presenter
Resource Characterization	2:15 PM	Flowfield Characterization for Tidal Energy Sites	Marshall Richmond, Pacific Northwest National Laboratory
	2:30 PM	DOD MHK Deployment Potential NEW	Joseph "Owen" Roberts, National Renewable Energy Laboratory
	2:45 PM	Wave Environmental Characterization at Wave Test Sites NEW	Vincent Neary, Sandia National Laboratories

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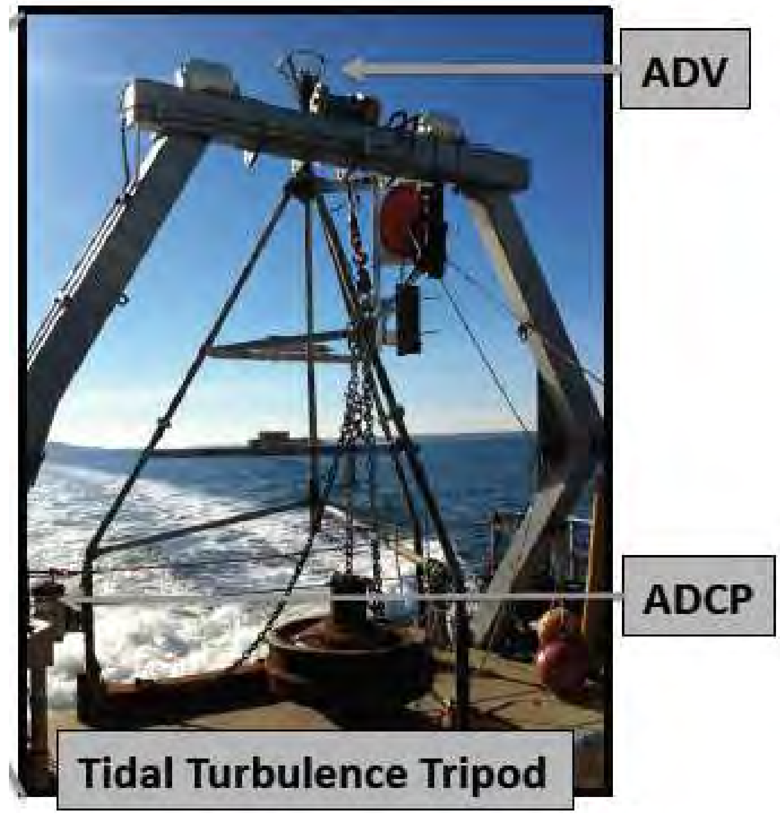

Flowfield Characterization for Tidal Energy Sites

Marshall Richmond
Pacific Northwest National Laboratory
marshall.richmond@pnnl.gov
February 24, 2014

Purpose & Objectives

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Problem Statement: Turbulent inflow conditions at installation sites is a critical need for engineering design of MHK devices to achieve desired power generation and mechanical reliability

Impact of Project: The project developed sampling methods and provided field measurements of tidal turbulence for use in MHK design tools

This project aligns with the following DOE Program objectives and priorities

- **Advance the state of MHK technology**
  - Data to inform machine design and power performance
- **Develop key MHK testing infrastructure, instrumentation, and/or standards**
  - Instrumentation packages and analysis methods

Technical Approach

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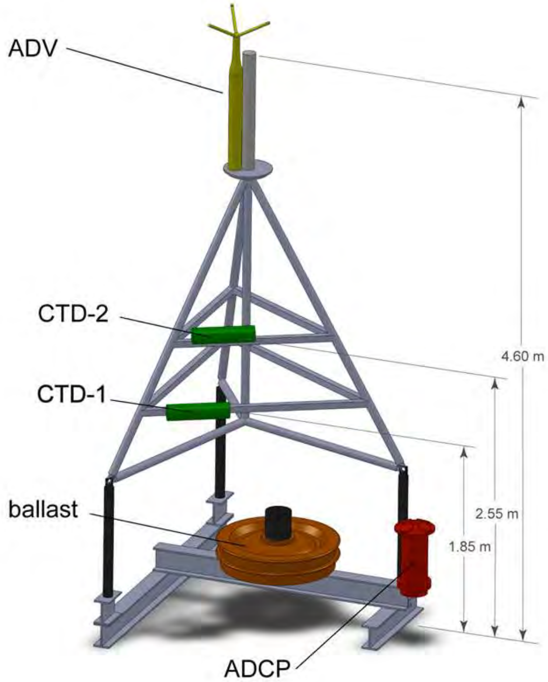
- Characterize turbulent water inflow conditions before and after the deployment of prototype MHK turbines
  - Mean flow
  - Turbulence intensity
  - Spectra
- Develop field instrumentation packages and analysis protocols
- Evaluate performance of oceanographic instrumentation (ADCP – Acoustic Doppler Current Profiler; ADV – Acoustic Doppler Velocimeter) for unique and energetic MHK site conditions
- Data to support the adaptation of NREL's turbulent inflow (TurbSim) and machine design codes to MHK devices

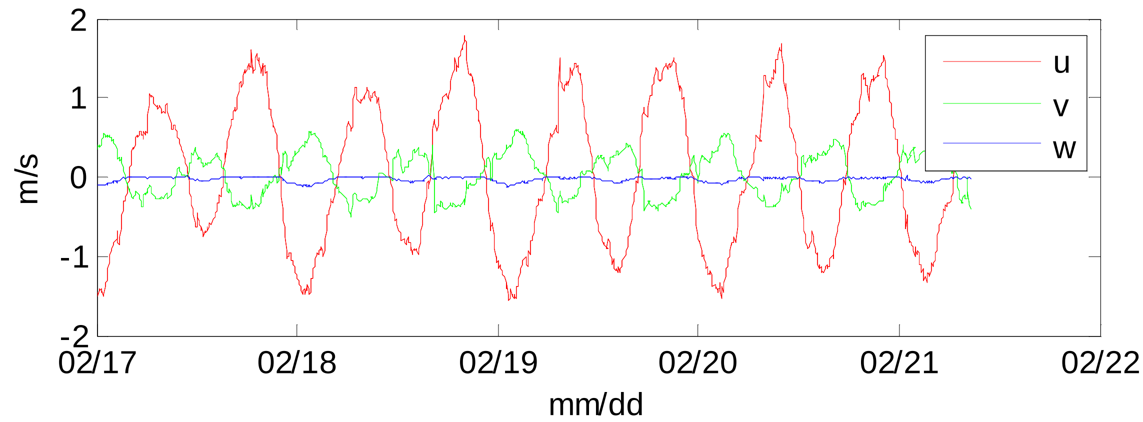
Puget Sound Sites

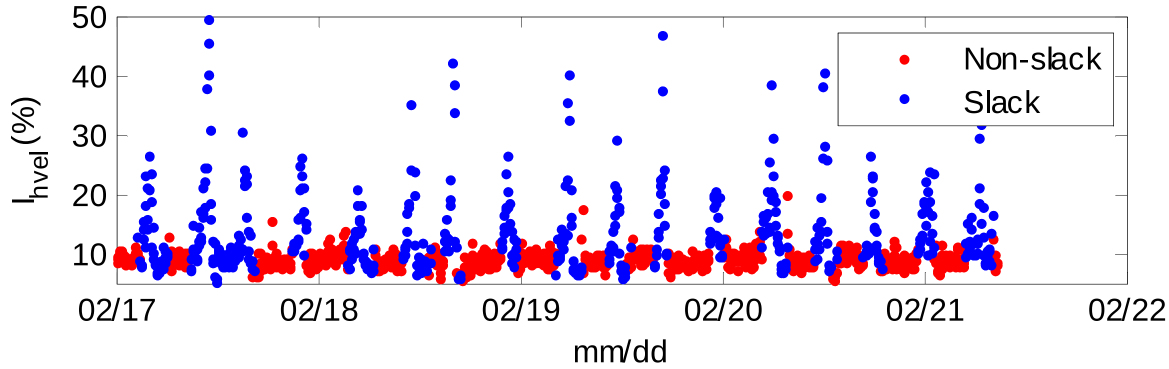


Turbulence Tripod

Tripod – Example Data

- ADV
  - Mean velocity u, v, w, and horizontal velocity
  - Turbulence intensity (%)
    - Average TI for for horizontal velocity for non-slack period is around 10%
    - Slack period has higher TI since mean velocity is significantly lower





Turbulence Mooring

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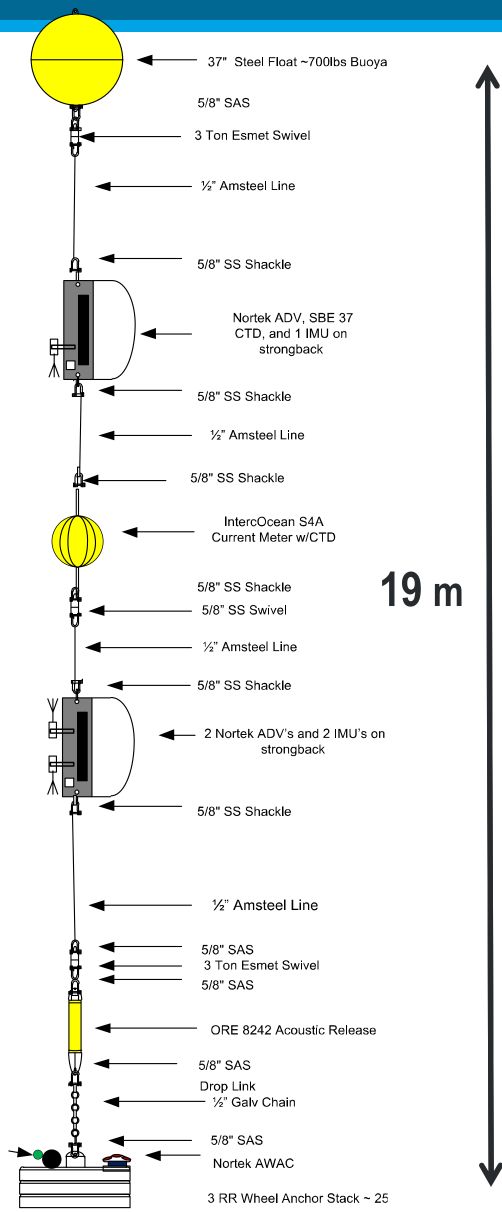

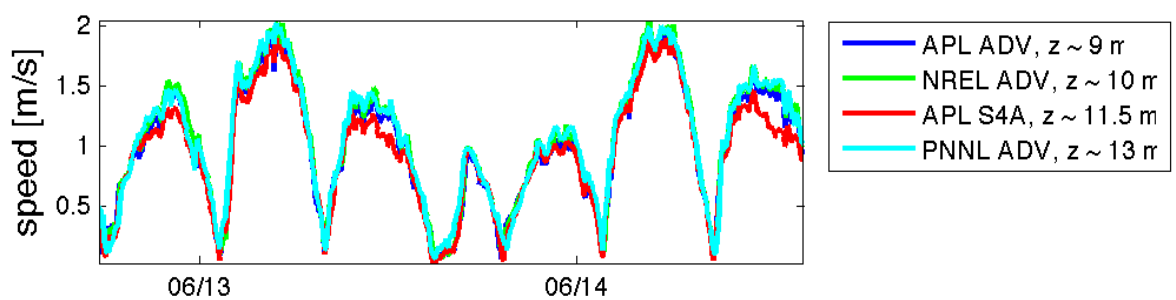

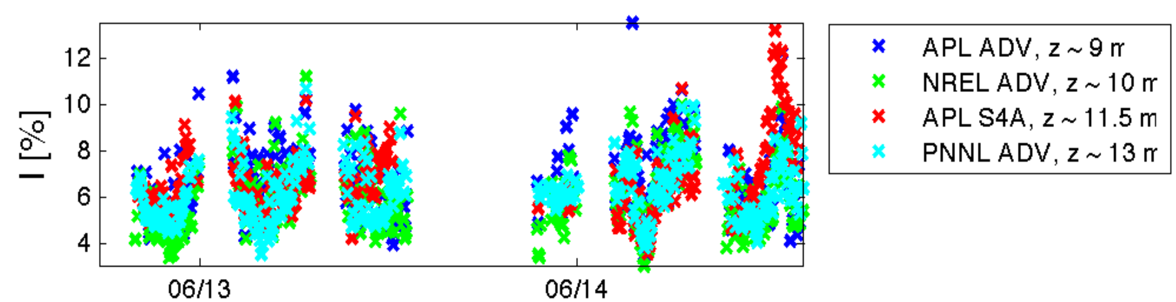

Technology Advances

- Characterized turbulent water inflow conditions prior the deployment of prototype MHK turbines
    - Mean flow
    - Turbulence intensity
    - Spectra
- Evaluated performance of oceanographic instrumentation
    - ADCP – Acoustic Doppler Current Profiler
    - ADV – Acoustic Doppler Velocimeter
    - deployment methods for unique and energetic MHK site conditions
- Contribution to MHK Technology Development
    - Field data to support adaption of NREL's turbulent inflow (hydro-TurbSim) and machine design codes to marine and hydrokinetic energy devices
    - Developed field instrumentation packages and analysis protocols that can be used by industry
- Validation data for near-field and far-field hydrodynamic and water quality models

Project Plan & Schedule

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Milestone/ Deliverable	FY10	FY11	FY12	FY13
Prototype turbulence tripod deployed	◆			
Turbulence tripod data @ Oceans 2010 conf	◆			
Modified turbulence tripod deployed		◆		
Data distribution to NREL		◆		
Turbulence tripod data analysis and publication		—	◆	
Tidal turbulence mooring concept development		—	◆	
Tidal Turbulence Mooring deployed			◆	
Turbulence Mooring Analysis in GMREC 2013			—	◆

Comments

- Project initiated in September 2009 (end of FY09)
- Completed in July 2013
- Work elements are being transitioned to Field Measurement Campaign

Project Budget

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

Budget History					
FY2010		FY2011		FY2012	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$200K	n/a	$200K	n/a	$160K	n/a

- Budget was reduced in FY2012 by $40K. Field work was reduced accordingly.

Partners, Subcontractors, and Collaborators:

- Pacific Northwest National Laboratory
  - Marshall Richmond, Vibhav Durgesh – post-doc
- University of Washington
  - Jim Thomson, Brian Polagye
- National Renewable Energy Laboratory
  - Eric Nelson, Levi Kilcher
- Sandia National Laboratories
  - Vince Neary

Communications and Tech Transfer

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- Work has been presented at Oceans, GMREC, AGU, EWTEC, NREL Workshops
- Data sets have been provided to researchers external to the project
- Journal articles, conference papers, technical reports:

  - Thomson J, L Kilcher, MC Richmond, J Talbert, A deKlerk, B Polagye, M Paris, and R Cienfuegos. 2013. "**Tidal Turbulence Spectra From A Compliant Mooring**." In Proceedings of the 1st Marine Energy Technology Symposium, METS2013. Global Marine Renewable Energy Conference (GMREC), Washington, DC.
  - Durgesh V, J Thomson, MC Richmond, and B Polagye. 2012. "**Noise correction of turbulent spectra obtained from Acoustic Doppler Velocimeters**." Submitted and in review.
  - Thomson, J., Polagye, B., Durgesh, V., & Richmond, MC (2012). **Measurements of turbulence at two tidal energy sites in Puget Sound, WA**. Oceanic Engineering, IEEE Journal of, 37(3), 363-374. doi:10.1109/JOE.2012.2191656
  - Thomson J, J Talbert, A deKlerk, MC Richmond, V Durgesh, B Polagye, L Kilcher, and E Nelson. 2012. "**Demonstration of a mid-water mooring for tidal turbulence measurements**." Presented at AGU Fall 2012 Meeting, San Francisco, CA. PNNL-SA-91564.
  - Richmond MC, J Thomson, V Durgesh, and B Polagye. 2011. "**Field measurements to characterize turbulent inflow for Marine Hydrokinetic devices - Marrowstone Island, WA**." AGU Fall Meeting 2011, San Francisco, CA. PNNL-SA-81904.
  - Richmond MC, J Thomson, V Durgesh, and B Polagye. 2011. **Inflow Characterization for Marine and Hydrokinetic Energy Devices. FY-2011**: Annual Progress Report . PNNL-20463.
  - Harding S, J Thomson, B Polagye, MC Richmond, V Durgesh, and I Bryden. 2011. "**Extreme Value Analysis of Tidal Stream Velocity Perturbations.**" In European Wave and Tidal Energy Conference.
  - Richmond MC, V Durgesh, J Thomson, and B Polagye. 2011. **Inflow Characterization for Marine and Hydrokinetic Energy Devices. FY-2010** Annual Progress Report . PNNL-19859.
  - Richmond MC. 2011. "**Inflow Characterization and Device Interaction Modeling for MHK Turbines**." Presented at 1st NREL Marine Hydrokinetic Device Modeling Workshop, Boulder, CO on March 2, 2011. PNNL-SA-79392.
  - Thomson J, MC Richmond, B Polagye, and V Durgesh. 2010. "**Quantifying Turbulence for Tidal Power Applications.**" In OCEANS 2010 MTS/IEEE: Innerspace: a Global Responsibility, pp. Paper No. 100514-042. IEEE.

Next Steps and Future Research

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Proposed future research:

Transitioning to new Field Measurement Campaign Project

Utilize collection and analysis methods developed in this work to characterize inflow and wake for an operating tidal turbine

- Bottom mounted tripods
- Moored instrument arrays
- Mobile surveys
- Coordinated with concurrent turbine performance data

Water Power Peer Review

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

DOD MHK Deployment Potential

Joseph "Owen" Roberts

NREL

Joseph.roberts@nrel.gov 303 384 7151

February 28, 2014

Purpose and Objectives

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

Problem statement: The U.S. Department of Defense (DOD) has a renewable energy goal of 25% by 2025, which equates to an installed capacity goal of 3 gigawatts (GW). DOD has conducted initial site screening for most renewables and is interested in the deployment possibilities for MHK to meet near and long term goals.

Impact of project: DOD is an early adopter and has already taken steps to host demonstration projects which could be expanded if suitable sites were identified. Navy has specific interest in MHK technologies that could be capitalized to the benefit of the MHK industry. This study will identify the most deployable sites while considering the energy resource for large scale prototype deployment to incorporate into DOD facility energy plans.

This project aligns with the following DOE Program objectives and priorities:

-Reduce deployment barriers and environmental impacts of MHK technologies

-Develop key MHK testing infrastructure, instrumentation, and/or standards.

Technical Approach

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

This project aims to identify the most likely deployable sites for all DOD facilities within the 50 states by combining current knowledge, new datasets, and expert site assessment.

Phase 1: All DOD-owned sites within the 50 states will be screened for viability using available data including known exclusion areas; current technology constraints; resource for tidal, wave, and ocean current; and interconnection capacity and viability.

Phase 2: High potentially deployable sites (~10) will be identified in collaboration with DOD and these sites will be visited to allow more detailed assessments of viability, including assessments of additional deployment constraints for both large scale and prototype testing deployments.

Data from both studies will be incorporated into facility-wide, long-range energy plans at the direction of base officials and DOD.

Methodology Example

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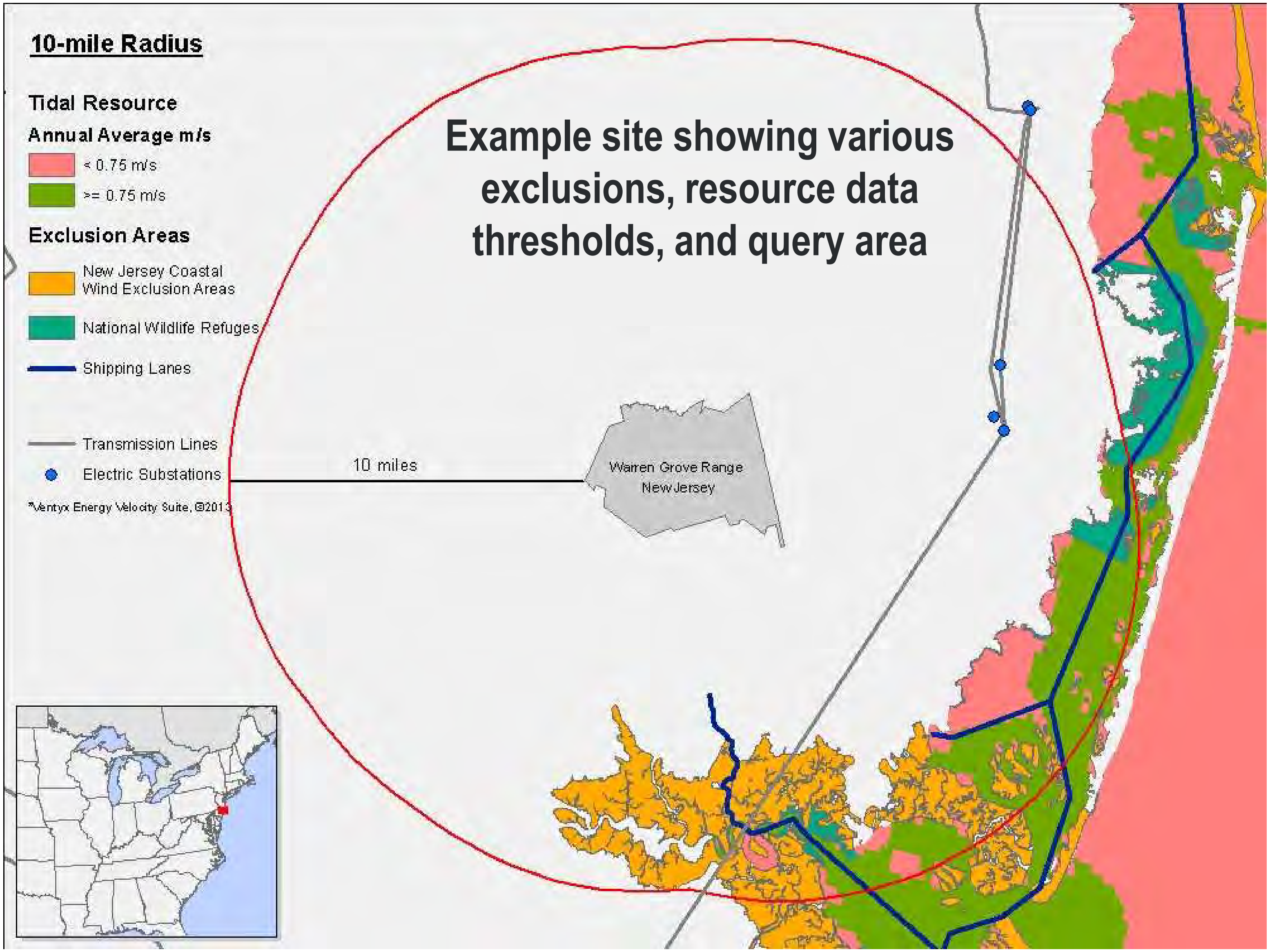


Summary	Legend
WBS Number 1.4.1.1	Work completed
	Active Task
Agreement Number 26499	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Navy Installation Resource Charicterization								
Q1 Milestone: Down Select 10 sites								
Q2 Milestone: 10 Site visits completed								
Q3 Milestone: Draft Report to DOE and DOD								
Q4 Milestone: Final report submitted to DOE and DOD								

Comments

- Scope expanded from just Navy to all DOD branches, but focuses on Navy sites
- Project initiation September 2013 with first round to be completed September 2014
- Second milestone delayed due to increase in available data for screening sites

Project Budget

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

Project Funding History

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$325k	n/a	$323k	n/a

Project Spending

Budget Actuals and Future Spend Plan	
Funds spent by end of FY 2013	Spend Plan FY14
$1.8K	$323k

- Received $325k at the end of FY13; spending was minimal
- FY14 project costs as of December 31st: $22k.

Research Integration and Collaboration

Partners, Subcontractors, and Collaborators: All branches of DOD, specifically the Navy, will be involved with screening sites to assist with identifying the most likely installations for MHK technologies. Potential partnership with others for site specific modeling.

Communications and Technology Transfer: To be determined by DOE and DOD based on sensitivity of information.

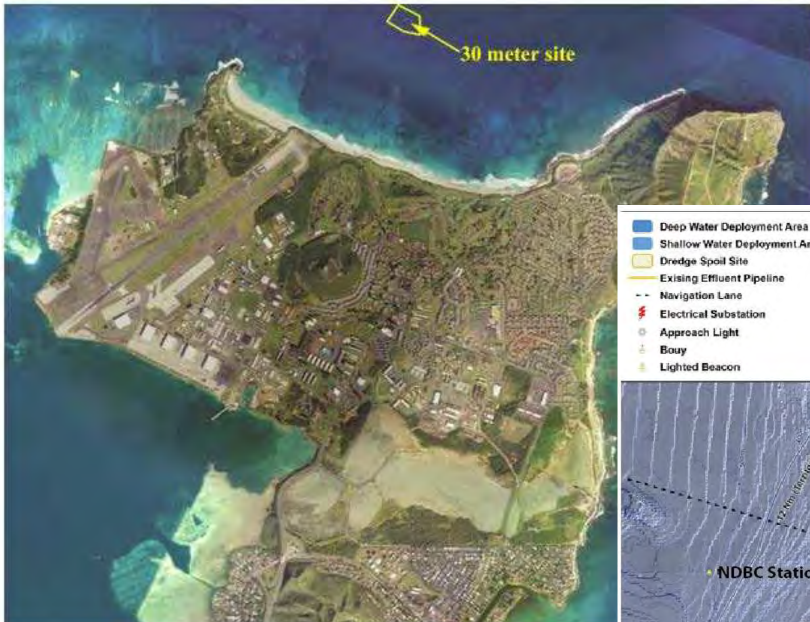
Potential future research:

Additional out year activities could include:

- Further investigation of the final ~3 sites by including higher resolution modeled data or even *in-situ* measurement data; more thorough understanding of mission considerations; and discussions with the base, local utilities, and impacted waterway users
- Expansion of screening investigation to additional sites not covered in current analysis
- Additional investigation of high likelihood sites.
- Future work could possibly include non-domestic DOD facilities

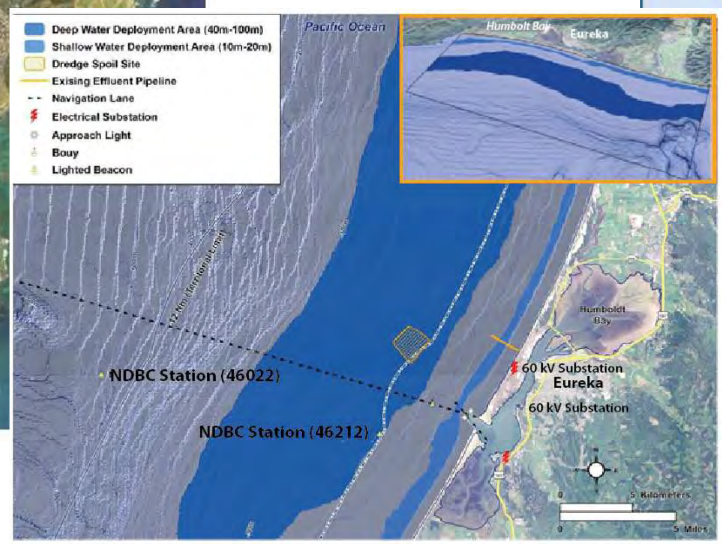
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WETS (Hawaii)

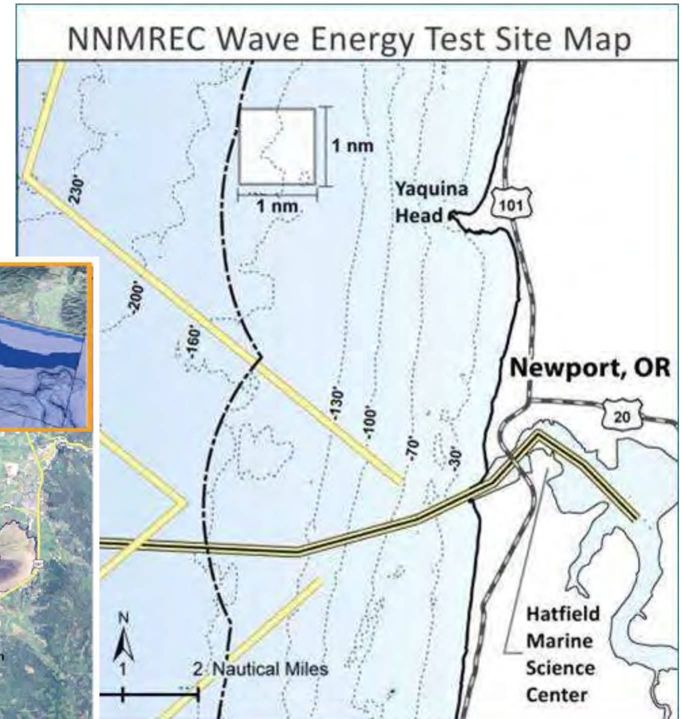


Source: http://azurawave.com/projects/hawaii/

Humboldt Bay (CA)



Source: Reference Model Report



Source: http://nnmrec.oregonstate.edu/pmec-facilities

New Project: Wave Environmental Characterization at Wave Test Sites

Vincent Neary

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February 27, 2014

Purpose & Objectives

Problem Statement:

- Lacking a single information source with well-documented and consistent approach that defines wave energy characteristics at different U.S. test sites
- A standard wave classification system is needed to promote technology advancement

Impact of Project:

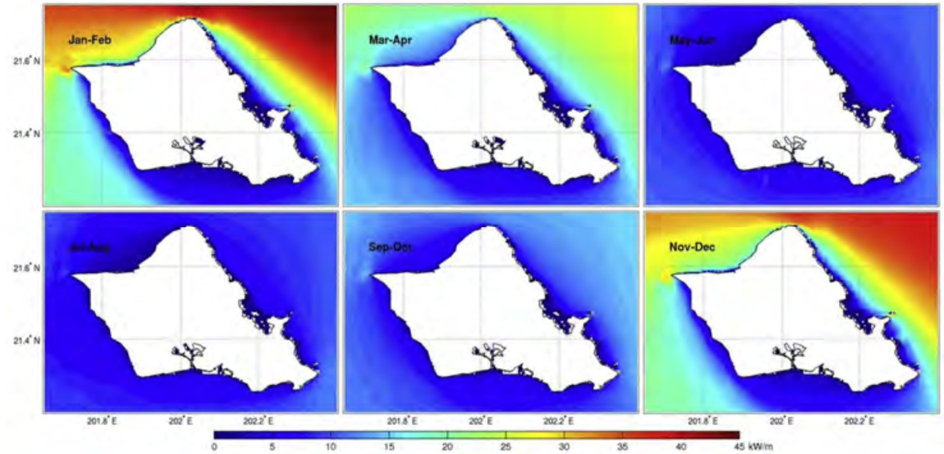
- MHK Industry will benefit from catalogue providing full wave resource characterization at 'tier 1' wave test sites (operational and extreme) – FY14
    - Allows WEC developers to compare & select test sites (design for and/or select most suitable test site)
    - Provides consistent analysis of available resource at high energy test sites
- Provides initial dataset and framework for wave classification system

This project aligns with the following DOE Program objectives and priorities:

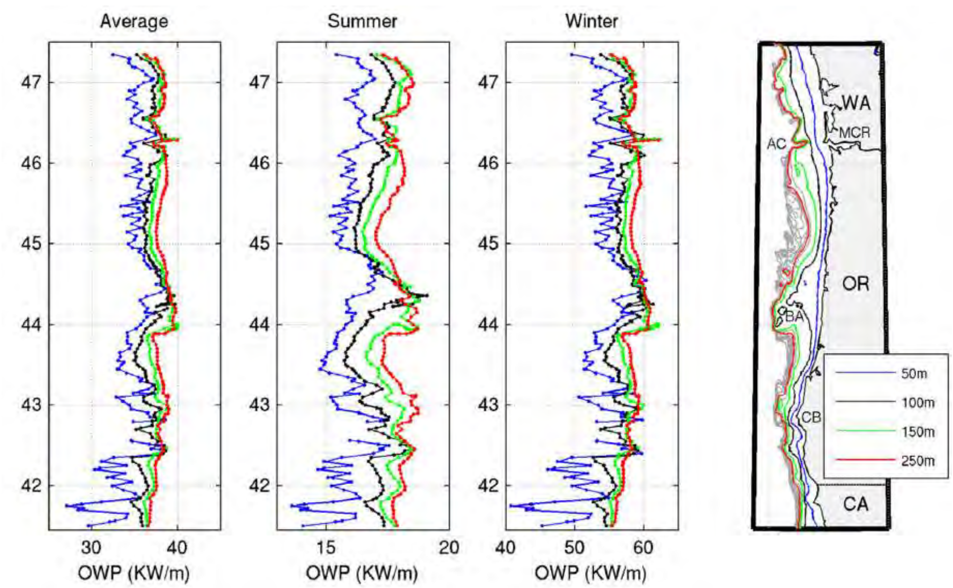
MHK: Characterize and increase access to high resource sites
MHK: Develop key MHK testing infrastructure (catalogue with consistent wave energy characterization for U.S. test sites will promote testing sites and assist developers)

Technical Approach

- Study emphasizes consistency in characterization & uniform presentation in order to directly compare sites
- Study leverages expertise and past efforts
- Wave statistics generated from hindcast simulations
- Key features:
  - Leverage IEC Technical Specification (draft)
  - Leverage hindcast simulations at NNMREC (PMEC site) & HINMREC (WETS)
  - Account for seasonal variation of wave characteristics
  - Estimate extreme sea states
  - Calculate cumulative probability distributions (weather windows)
  - Perform hindcast simulation for Humboldt Bay site



Source: Stopa et al. 2013 "Wave energy resources along the Hawaiian Island Chain"



Source: García-Medina et al. 2014 "Wave Resource Assessment in Oregon and southwest Washington, USA"

Project Plan & Schedule

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

Summary
WBS Number 1.4.1.1
Project Number 21857
Agreement Number 26924

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2013 Q1 (Octt-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Octt-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Wave Energy Characterization at Wave Test Sites								
FY14 Q1 Milestone: Identify & transfer >=60% measured & simulated data sets; develop MATLAB algorithms for post-processing & perform preliminary calculations								
Current work and future research								
FY14 Q2 Milestone: Complete preliminary wave resource classification scheme; identify key variables for resource and O&M classes								
FY14 Q3 Milestone: Complete transfer of all data sets; employ MATLAB algorithms to perform final calculations of wave energy resource statistics								
FY14 Q4 Milestone: Complete final catalogue of characterization at Tier 1 sites; deliver preliminary wave resource classification scheme & identify further work needed								

Comments

- Initiation date: 8/16/2013; proposed project completion date: 9/31/2014
- On schedule

Project Budget

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

Budget History			
FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share
$300k	$0	$0	$0

- Funding received late August 2013, so all carried over to FY14
- ~15% of budget expended
- Project is making progress as anticipated and no issues at this time

Partners, Subcontractors, and Collaborators:

- NNMREC researchers (Prof. Belinda Batten, Prof. Tuba Özkan-Haller, Prof. Merrick Haller, and Gabriel García-Medina)
- Humboldt Bay: Colin Sheppard (Humboldt State University), Troy Nicolini (NOAA's NWS Eureka location)
- Hawaii: HINMREC (Prof. Luis Vega), Sea Engineering Inc (Andrew Rocheleau – part of WETS marine operations management)

Communications and Technology Transfer:

1. Selected project results disseminated at national and international conferences
   a. Dallman A, Neary V, Gunawan B, "Initial characterization of the wave resource at several high energy U.S. sites," *Marine Energy Technology Symposium, 7th Annual Global Marine Renewable Energy Conference*, Seattle, WA, April 15-18, 2014
   b. Dallman A, Neary V, Gunawan B, "Wave environment characterization at wave energy converter (WEC) test sites," 2014 Ocean Science Meeting, Honolulu, HI, 23-28 February, 2014
2. Final catalogue will be advertised and available for download at SNL's Water Power Publications website, waterpower.sandia.gov/

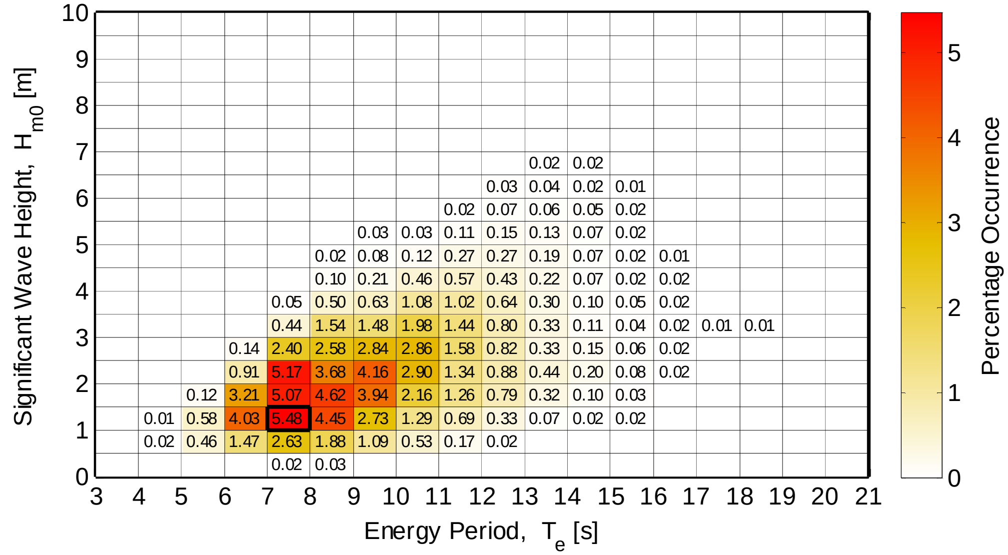
Next Steps and Future Research

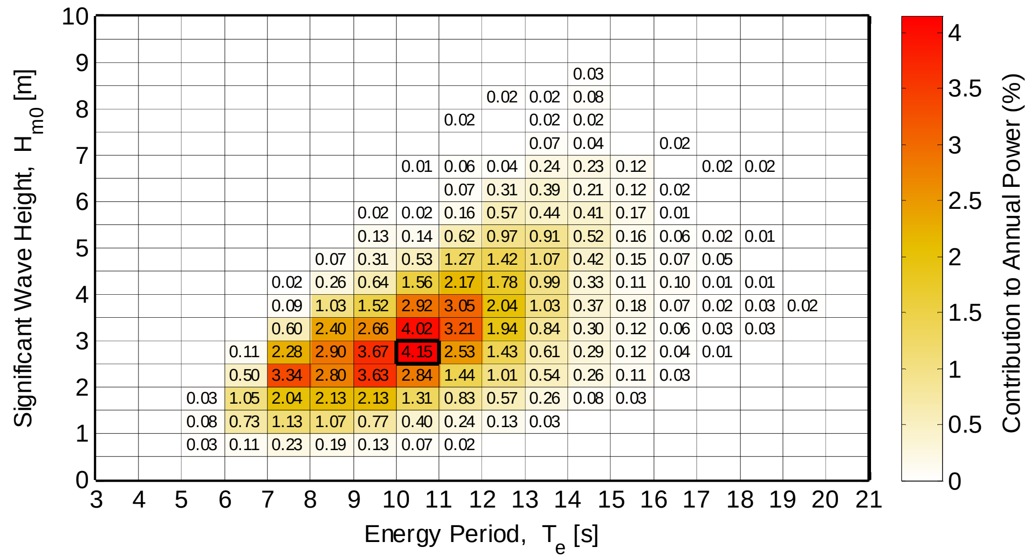
FY14/Current research:

- Reviewed past efforts on wave energy characterization
- Identified all data sources and past hindcast simulations available
- Investigating selection of additional wave variables
- Calculating 6 variables to characterize sea states using simulated hindcast spectral data (model must be validated with measured data)
  - omnidirectional wave power
  - significant wave height
  - energy period
  - spectral width
  - direction of maximum directionally resolved wave power
  - directionality coefficient

FY14/Current research:

- MATLAB algorithms developed to calculate JPDs, variables of interest
- Plots show initial results of JPDs from buoy 46212 (spectral data from 2004-2012) offshore of Eureka, CA
- Omnidirectional wave power: 30.2 kW/m





Next Steps and Future Research

FY14/Current research:

- Q2: Complete preliminary wave resource classification scheme; identify key variables for resource and O&M classes
- Q3: Complete transfer of all data sets; employ MATLAB algorithms to perform final calculations of wave energy resource statistics
- Q4: Complete final catalogue of characterization at Tier 1 sites; deliver preliminary wave resource classification scheme & identify further work needed