National Laboratory Activities to Support Marine Energy Technology Progress

January 12, 2012

Marine Energy Technology Advancement Partnership (METAP) Project

Hosted by Mark Sinclair, CESA

CleanEnergy States Alliance

Housekeeping

- All participants will be in listen-only mode throughout the broadcast.
- You can connect to the audio portion of the webinar using your computer's speakers or a headset. You can also connect by telephone.
- You can submit questions for today's event by typing them into the "Question Box" on the webinar console. Questions about today's topic will be answered, as time allows, following the presentation.
- This webinar is being recorded and will be made available after today's broadcast on the CESA website at

http://www.cleanenergystates.org/projects/marine-energy-technology-advancement-project/

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About the METAP Project

- The purpose of this project is to accelerate the overall pace of development and commercialization of marine renewable energy in the United States through a strategic, collaborative approach between state and federal agencies.
- METAP aims to link and coordinate the MHK technology support activities in states (through state energy offices, universities and clean energy funds) with the DOE Wind and Water Program's MHK activities. Specifically, METAP's goals are to accelerate support for the MHK industry in the U.S. and increase and leverage public funding for the most promising wave, current, and tidal devices through a collaborative State-Federal funding and solicitation process. METAP was contracted out to a group of state-membership organizations led by the Clean Energy States Alliance (CESA). This project is supported by the U.S. Department of Energy.

Today's Presentations

This webinar, the eighty in a series for the State/Federal Marine Energy Technology Advancement Project (METAP), will present the recent activities of the National Labs in support of marine energy technologies.

1. Hoyt Battey, U.S. Department of Energy
2. Rich Jepsen, Sandia National Laboratories
3. Al LiVecchi and Rick Driscoll, National Renewable Energy Laboratory
4. Andrea Copping, Pacific Northwest National Laboratory

http://www.cleanenergystates.org/projects/marine-energy-technology-advancement-project/

CleanEnergy States Alliance

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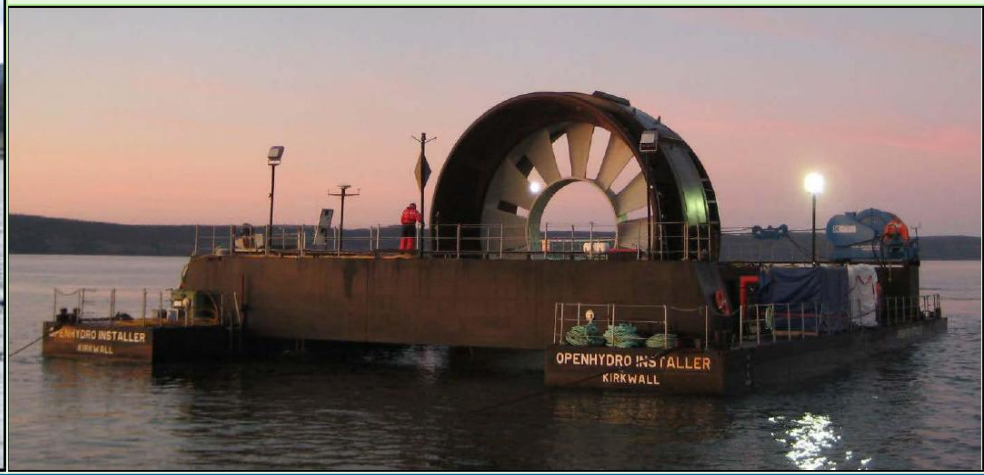
U.S. Department of Energy MHK Activities

Hoyt Battey
Water Power Program
U.S. Department of Energy



Marine and Hydrokinetic Priorities

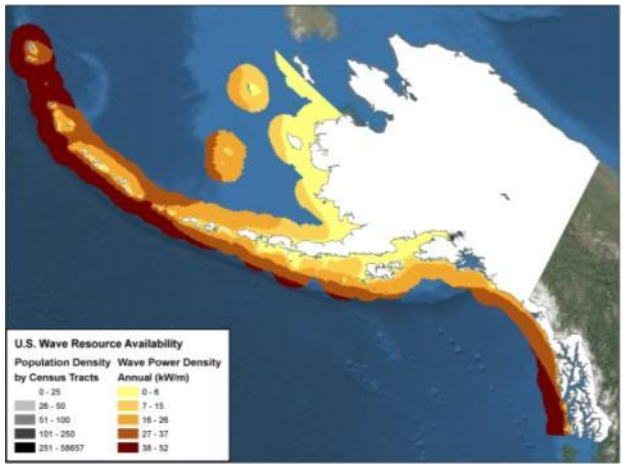
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

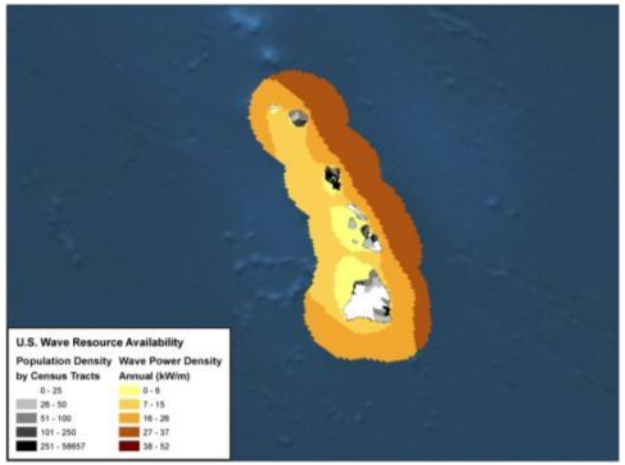
The Program is undertaking a rigorous assessment of available U.S. marine resources and evaluating the wide range of technologies available to tap these resources, while simultaneously seeking to address and resolve associated environmental challenges, and aiming to reduce the time and cost of licensing MHK systems.

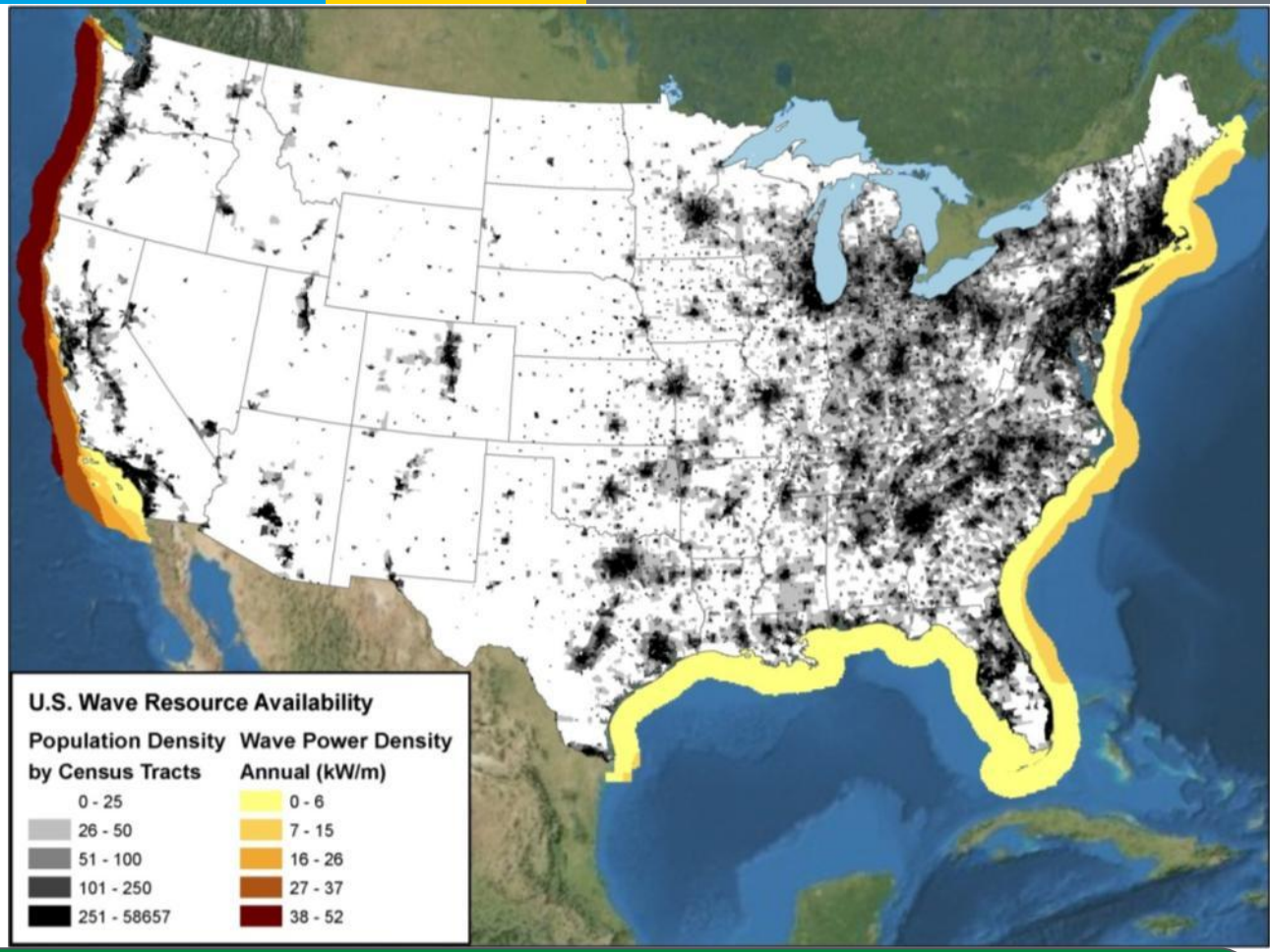
RDDD Priority	Program Projects
Assess the Resource: • Verify/Validate the potential contribution of these emerging technologies	• National Resource Assessments for wave and tidal are complete and being reviewed by NAS; ocean current, in-stream, and ocean thermal underway (TBC in 2012)
Determine Current LCOE and ID Technology Leaders: • Understand the full-range of technologies, their performance characteristics, LCOE and cost drivers • Investigate potential environmental impacts and how they can be mitigated or minimized	• MHK Technology Database…catalog of all device types and deployment status (US and global) • Reference Model Development • Apply/adapt existing tools/models from wind energy
Reduce Costs and Improve Performance: • Prototype deployment and testing • Scale and tank testing • Device/array design and modeling • Support integrated testing/RD&D Centers • Environmental Research to decrease deployment costs	• FY10 MHK Technology Readiness Advancement FOA • SBIR / STTR (Phase I and Phase II Awards) • National Marine Renewable Energy Centers (3) • Laboratory RDT&E
Coordinate Information-Sharing: • Facilitate/accelerate/reduce the cost of project planning, siting, and permitting (demonstrations and commercial systems) • Assemble technical and environmental performance data	• Guidebook - Siting Methods for Hydrokinetics • Tethys (knowledge management system) • MHK Environmental Webinar Series • Federal Renewable Ocean Energy Working Group
Leverage International Investments, Expertise, and Experience: • Cooperative development of international standards • Share device performance data	• IEC TC 114, Marine Energy – Wave and Tidal Energy Converters • IEA Ocean Energy Systems Implementing Agreement - Annex IV and Annex V introduced by US • Potential MOUs with key international partners

2011: Marine and Hydrokinetics Wave Energy Resource Assessment

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



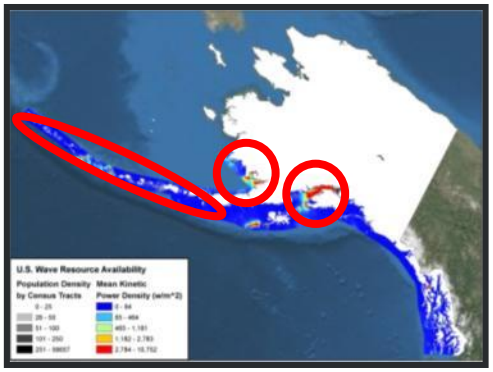




Wave Energy is the dominant MHK resource available to the United States

http://maps.nrel.gov/re_atlas

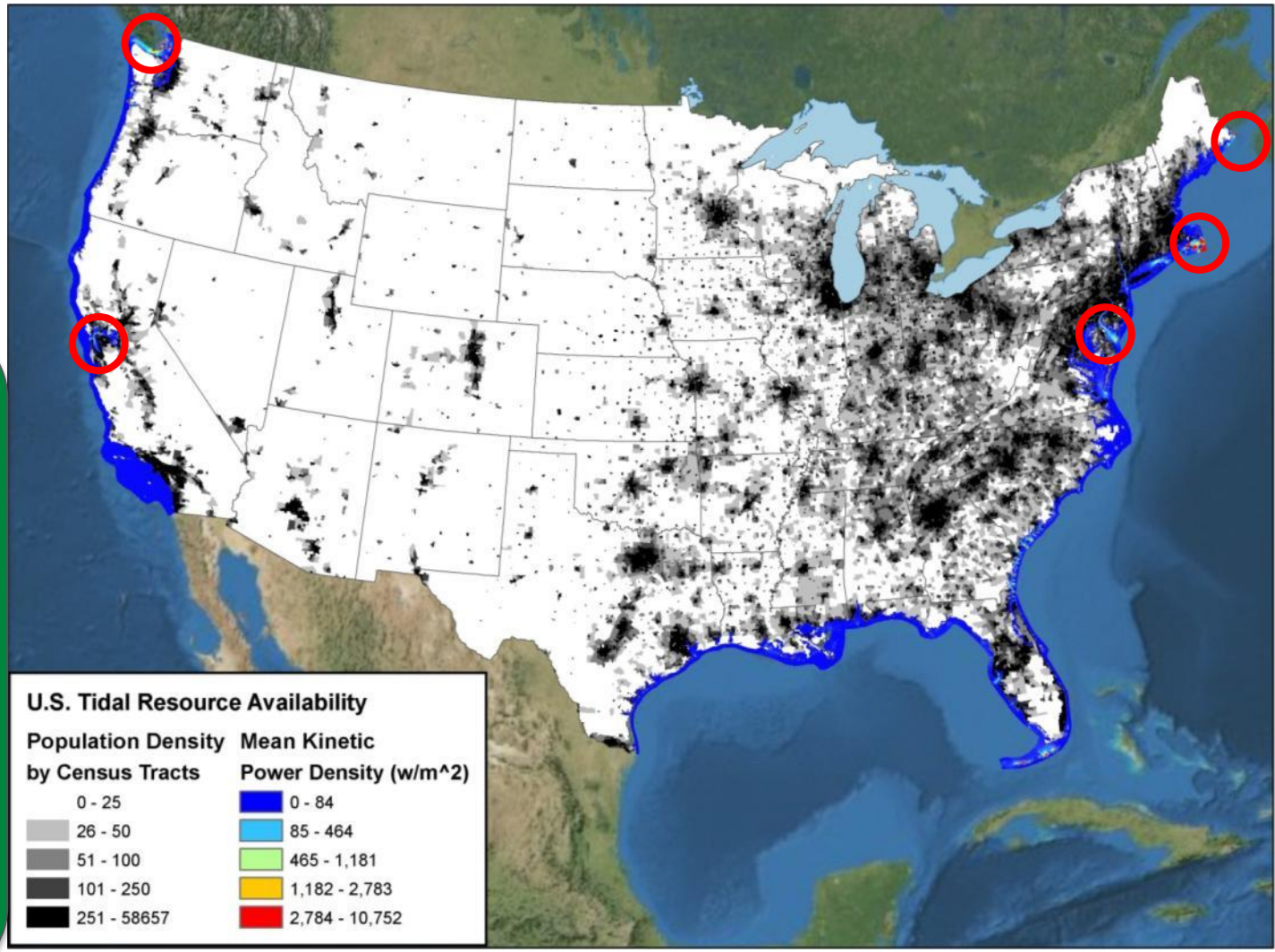
2011: Marine and Hydrokinetics Tidal Resource Assessment



CONUS tidal resources are concentrated and exist in close proximity to major coastal load centers…

However, over 90% of the overall resource is located in Alaska.

Magnitude of potential tidal power is significantly less than wave.



http://www.tidalstreampower.gatech.edu/

State of the Industry: Numerous Companies and Device Types

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

Wave

Australia
- oceanlinx

Finland
- WAVEROLLER®

Germany
- VOITH

Norway
- Fred. Olsen

Ireland
- OCEAN ENERGY
- wavebob™ blue energy

UK
- AQUAMARINE POWER
- AWS ocean energy
- pelamis wave power

New Zealand
- WAVENERGY TECHNOLOGY NEW ZEALAND

Denmark
- POSEIDON FLOATING POWER
- Wave Dragon

United States
- Resolute Marine Energy — Clean Power from Ocean Waves
- COLUMBIA POWER
- OPT OCEAN POWER TECHNOLOGIES

Tidal / River / Ocean Current

Australia
- ATLANTIS RESOURCES CORPORATION

Canada
- Clean Current® Renewable Energy Systems

Norway
- Hammerfest STRØM

United States
- VERDANT POWER
- Hydro Green Energy®
- FREE FLOW POWER
- ECOMERIT TECHNOLOGIES
- nc Natural Currents
- ORPC OCEAN RENEWABLE POWER COMPANY

UK
- Lunar Energy™ harnessing tidal power
- Marine Current Turbines Turning the tide

Ireland
- openhydro tidal technology

Sample of companies with significant investments, high TRL-level devices, and/or significant in-water deployments.

Ocean Thermal

United States
- OTEC International LLC
- OCEAN THERMAL ENERGY CORPORATION
- LOCKHEED MARTIN

Salinity Gradient

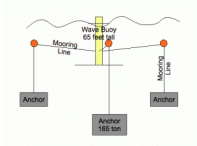
Norway
- Statkraft

MHK System Development

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

Technology Readiness Levels:
A Disciplined Protocol for Technology Development

DOE TRL 1-3
Discovery / Concept Definition / Early Stage Development, Design and Engineering



DOE TRL 4:
Proof of Concept

DOE TRL 5/6:
System Integration and Laboratory Demonstration

DOE TRL 7/8:
Open Water System Testing, Demonstration, and Operation

DOE TRL 9:
Array Testing

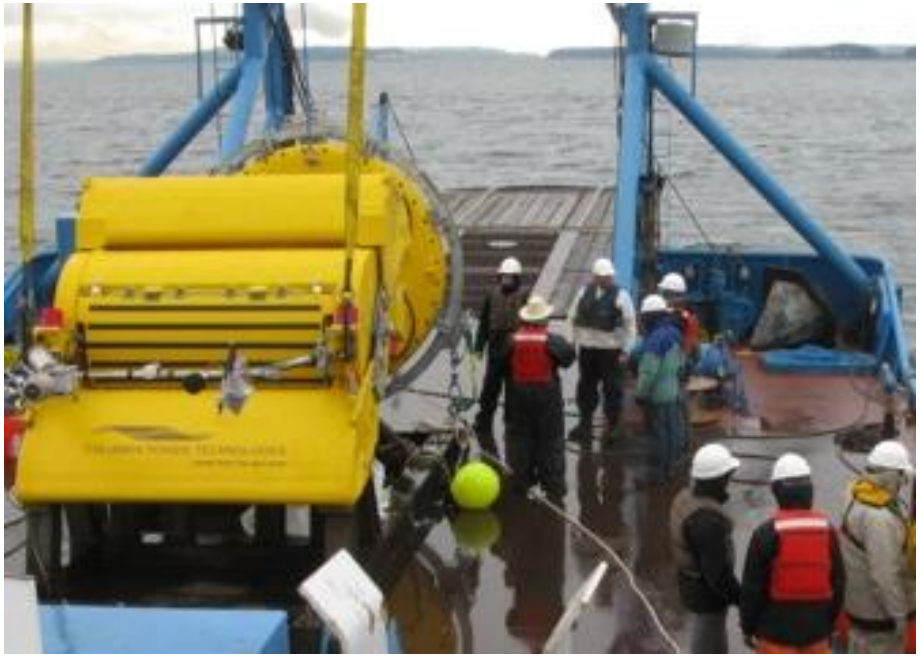
DOE TRL 10:
Commercialization

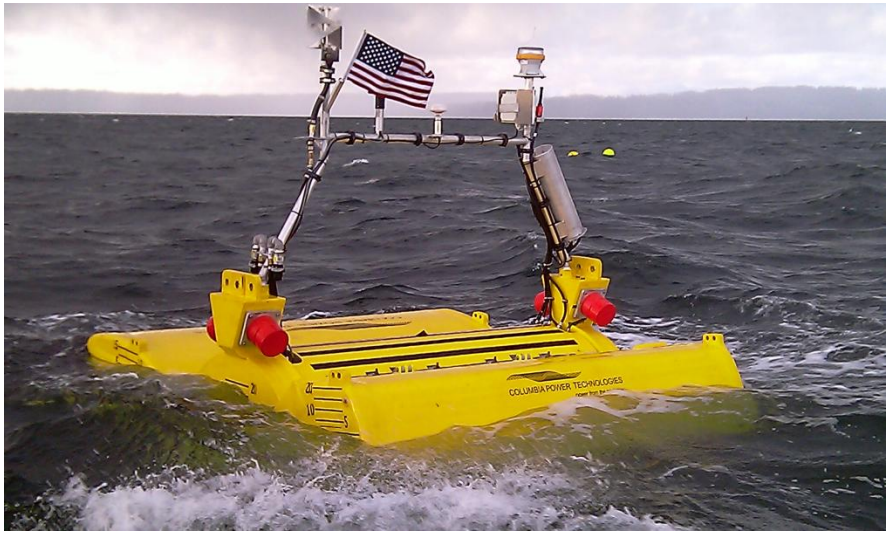
FY 2010: The Program committed up to $37 million over 4 years in order to accelerate the technological and commercial readiness of emerging marine and hydrokinetic (MHK) technologies. 27 projects were selected for funding, with individual awards ranging from $160,000 to up to $10 million.

U.S. Technology Demonstration Projects (2011-2013)

- ***Free Flow Power***
  - *40 kW river in-stream turbine deployed in the MS River on 6/20/2011.*
  - *2nd deployment achieved in MA on 8/15/2011*
- ***Columbia Power Technologies***
  - Wave energy converter was deployed in March 2011 in Puget Sound, WA. Presently in operation, controlled remotely from Corvallis, OR.
- ***Ocean Renewable Power Company***
  - The first of 5 150 kW tidal turbines in a grid connected array will be deployed in Maine's Western Passage during spring 2012.
- ***Ocean Power Technologies***
  - The first 150kW WEC of a 10 device array will be deployed in 2012 in Reedsport, OR. Final FERC application has been submitted.
- ***Snohomish Public Utility District***
  - Two grid connected 6-meter turbines planned for deployment in Admiralty Inlet in 2013.
  - Field measurements continued making this the best characterized tidal site in the US.

2011: Columbia Power Technologies Demo

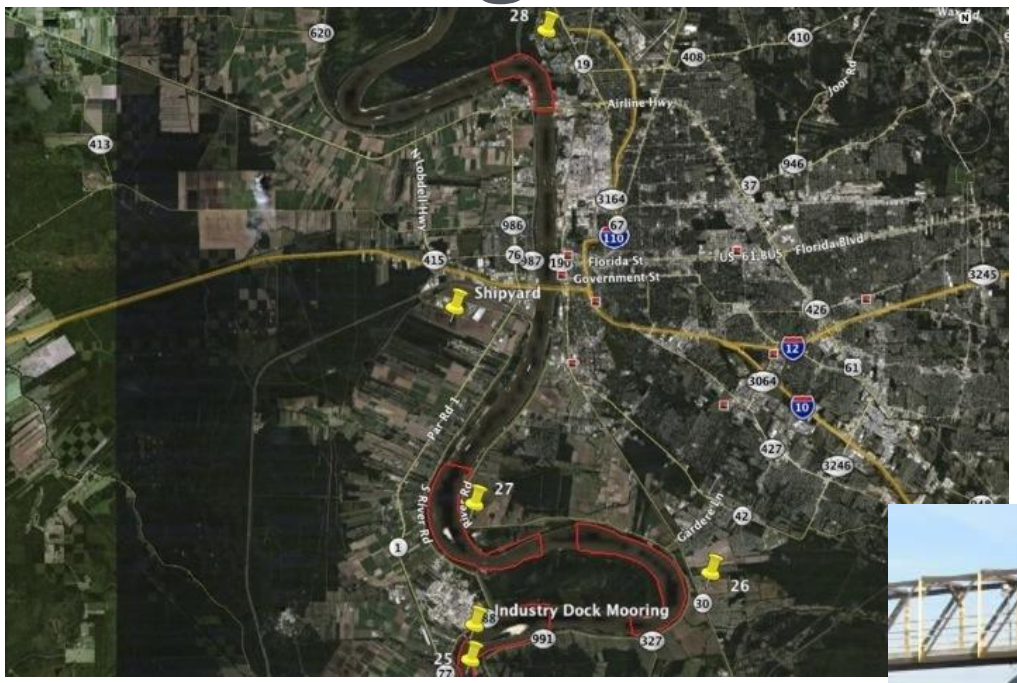




Video

http://www.columbiapwr.com/technology.asp

Baton Rouge Area Map



Video

http://free-flow-power.com/videos

2011: MHK Industry Projects

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

Project Title: Active Acoustic Deterrence of Migratory Whales

PI: Greg McMurray, PEV

Partners: Oregon State University Marine Mammal Institute, Ocean Power Technologies, Tillamook Public Utility District, and Pacific Gas and Electric.

Funding Level: $249,975

Objectives: Testing of a limited range acoustic deterrent system to discourage gray whales from entering wave energy parks and to minimize the risk of mortality. The project will test the effectiveness of an 'acoustic pinger' in the frequency range of 3-5 kHz at an amplitude of 60 dB above ambient noise. The project area is Yaquina Head, near Newport, OR.

Links to Lab Work: This is currently the Program's only work on mitigation strategies. Active acoustics could be tools used by labs in carrying out future research, and lessons learned in permitting and deploying this device could inform those studies.

2011: MHK Industry Projects

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

Project Title: Assessment of the Environmental Effects of Hydrokinetic Turbines on Fish: Desktop and Laboratory Flume Studies

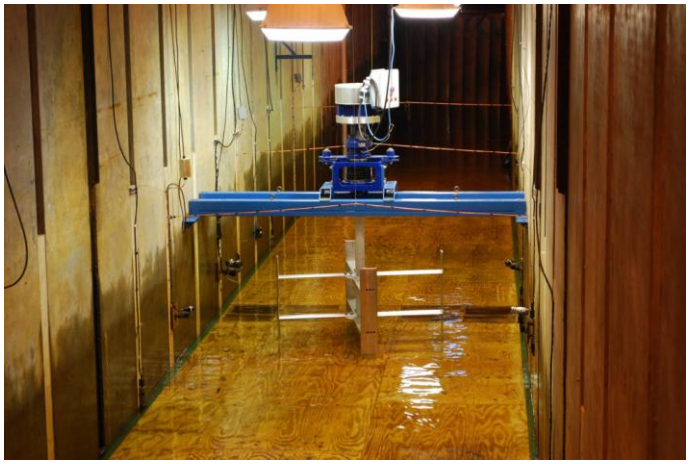
PI: Paul Jacobson, Doug Dixon, EPRI

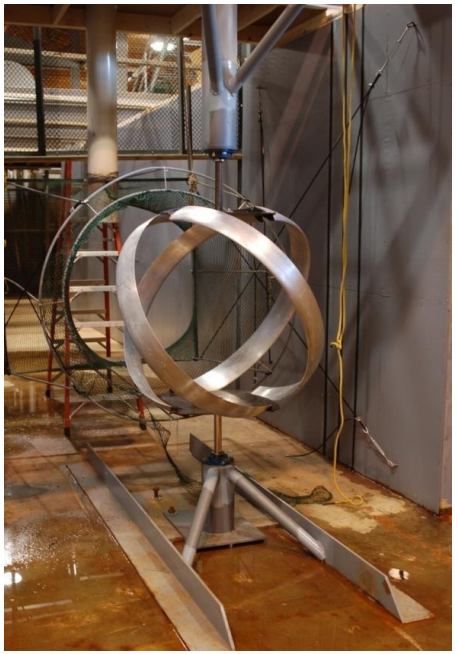
Partners: Alden Research Laboratory, USGS Conte Anadromous Fish Research Laboratory

Funding Level: $597,408

Objectives: Determining the probability of blade strike and injury, and the behavior of fish as they encounter hydrokinetic turbines. (1) assessment of potential injury mechanisms using available data from conventional hydro turbines; (2) theoretical models for predicting blade strike probabilities and mortality rates; and (3) performing flume testing with at least three turbine designs and several fish species

Links to Lab Work: Data integrated into Tethys database on environmental research, and project overlaps with other work on physical interactions and effects on aquatic organisms.





2011: DOE MHK Environmental Webinar Series

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

- Series developed by subgroup of the Federal Renewable Ocean Energy Working Group, including representatives from BOEM, DOE, EPA, and NOAA. PNNL provides technical assistance: http://mhk.pnnl.gov/wiki/index.php/DOE_MHK_Webinar_Series
- Series Goals:
  1. To identify gaps and priority areas for future research efforts.
  2. To communicate ongoing studies and results.
  3. To help inform siting and permitting efforts.
- Webinar Topics
  - July 27: MHK Environmental Data Management, Cumulative Impacts, and Risk Assessment
  - August 29: Research on Aquatic Animal Interaction with MHK Devices
  - September 14: Monitoring Technologies and Strategies for MHK Devices
  - December 14: Potential Acoustic Impacts
- Attendance:
  - About 150 in attendance at each webinar
  - Wide audience:
    - Government (State and Federal)=44%; Industry=31%; Academic Researchers=19%; NGO=4%
    - International participation accounted for 6% total attendance, including representatives from government, academia, and industry.

MHK Environmental Research at ORNL and ANL

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

Physical Interactions with Devices

-Evaluating potential for fish attraction and avoidance

-Modeling and experimentation to evaluate strike risk to fish

Electromagnetic Fields

-Experimentation to evaluate potential effects of EMF on fresh water fish and invertebrates

Acoustics

-Evaluating effects on MHK noise by increasing knowledge of noise in riverine environments. Planned device noise measurements and net-pen studies.

Toxicity

-Experimentation to measure the effects of antifouling coatings on aquatic organisms

Benthic Habitat Alteration

-Development of measurement methodology to evaluate effects of MHK devices on benthic habitat. Planned measurements around devices.

Conceptual Model Development

-Development of conceptual models to increase understanding of the ecological relationships between MHK stressors and biological receptors and the cumulative impacts of development.

Benthic Habitat Alteration

-Development of monitoring protocols

CLOSING

Thank you for your time!

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Sandia Water Power Program Update

Rich Jepsen,

January 12, 2011

METAP Webinar: National Laboratory Activities to Support Marine Energy Technology Progress

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

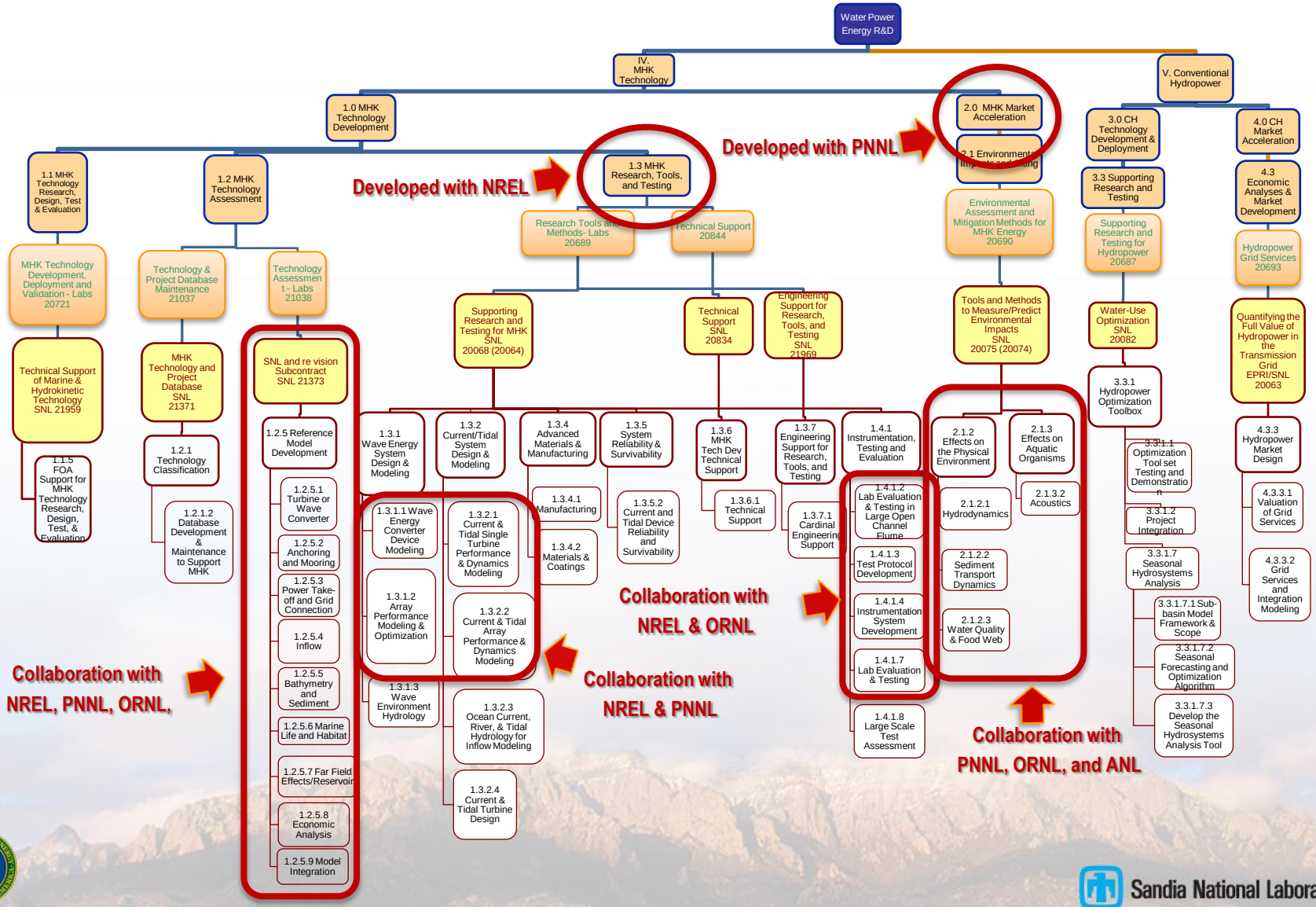
Topic Outline

- **Reference Models:** Develop a representative set of Reference Models (RM) for the MHK industry to develop baseline cost of energy (COE) and evaluate key cost component/system reduction pathways

- **Research Tools and Testing:** Analysis tools and methods to be developed, evaluated and validated. In addition, new materials and coatings will be developed, evaluated, and validated. Most importantly all these tools, formulations and test data will be accessible to industry.

- **Market Acceleration:** Assessment of changes to the physical (i.e. currents, waves, sediments, and water quality) & acoustic environment potentially incurred through operation of various types of MHK devices and arrays.

Water Power Program Chart: SNL Activities



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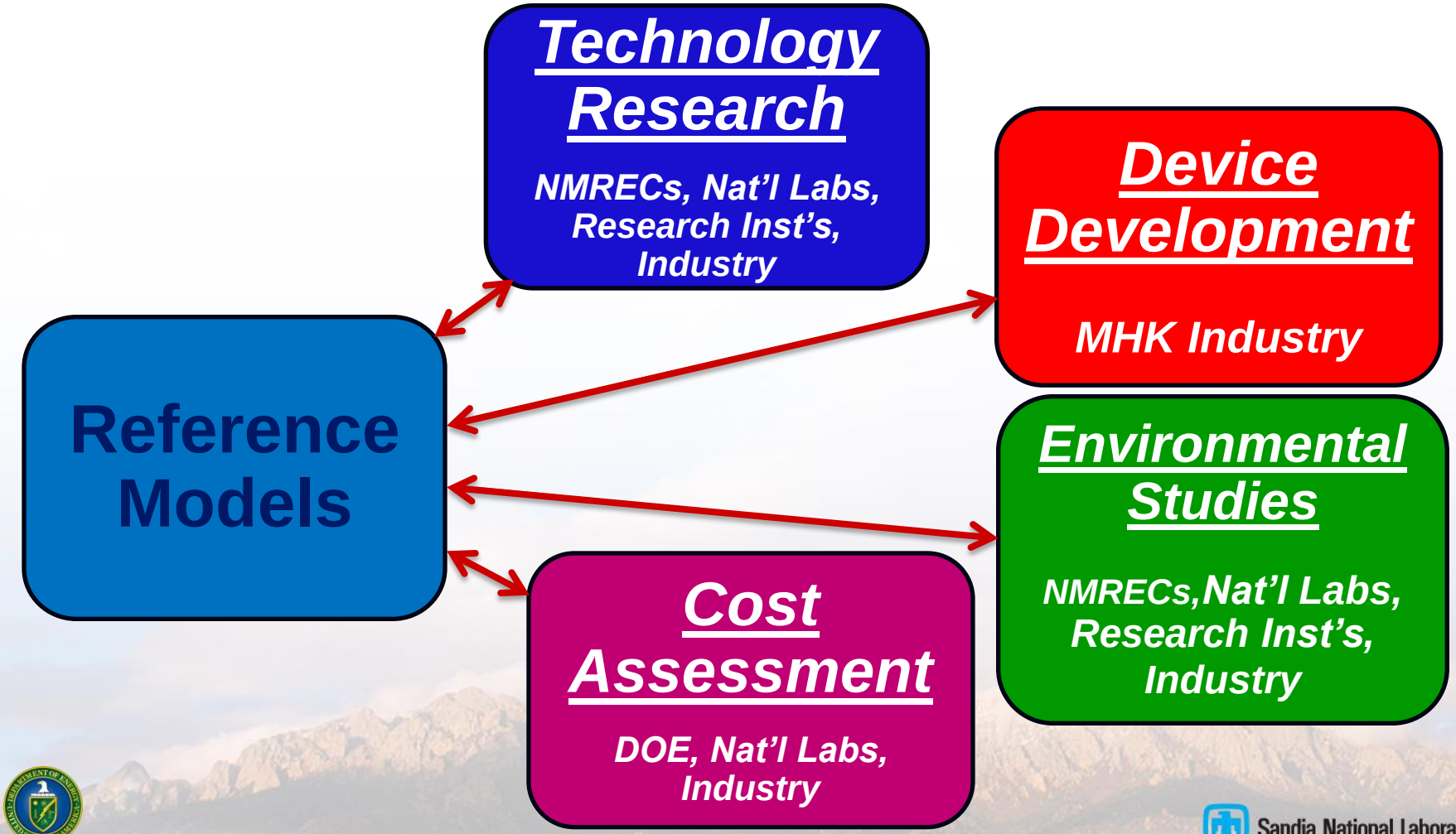
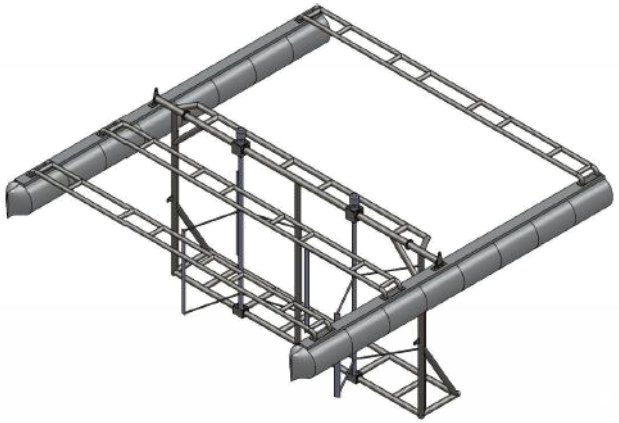
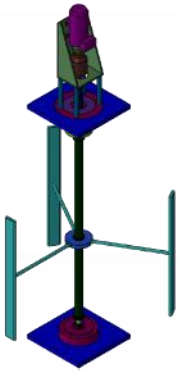
Reference Models: Integrate WP Program

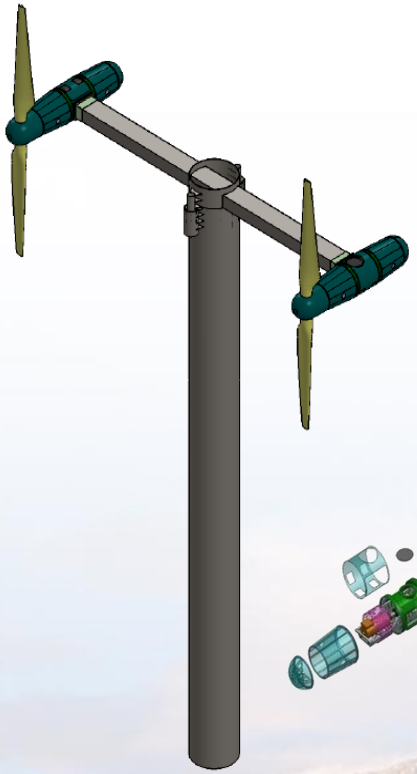


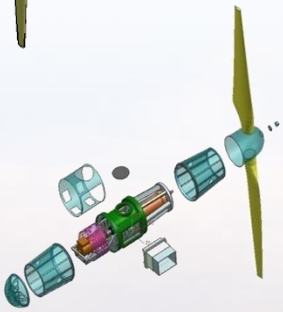
Reference Model Examples



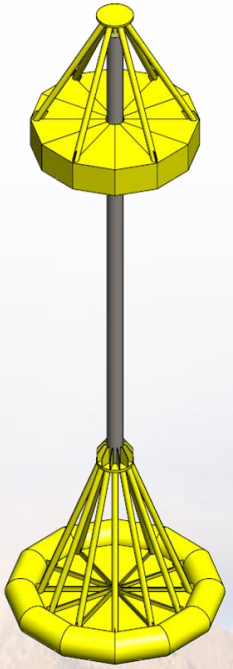


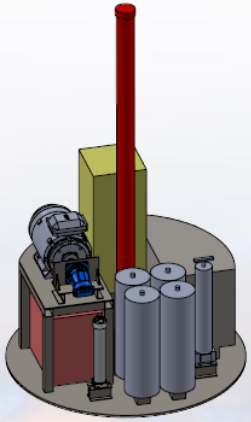
RM#2 River Turbine





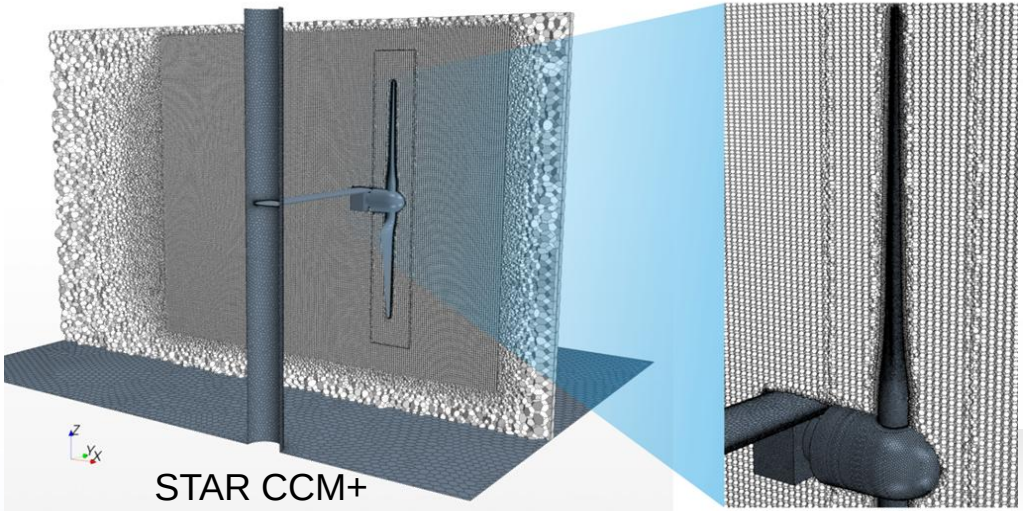
RM#1 Tidal Turbine

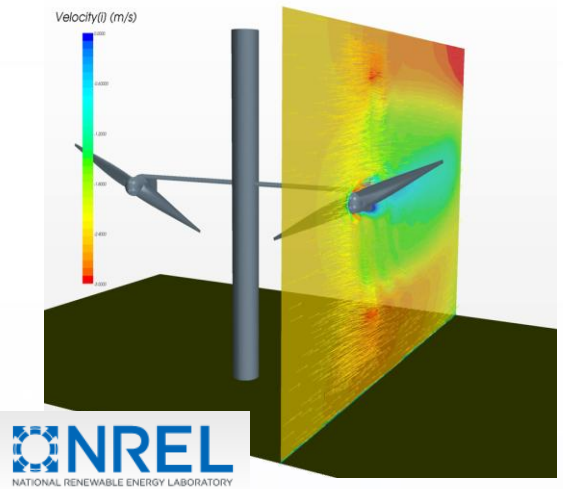


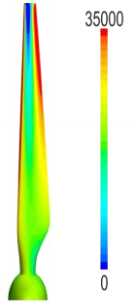


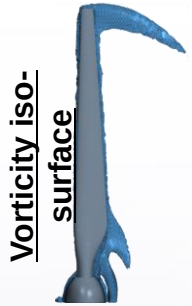
RM#3 WEC Point Absorber

Development and Application of Analysis Tools

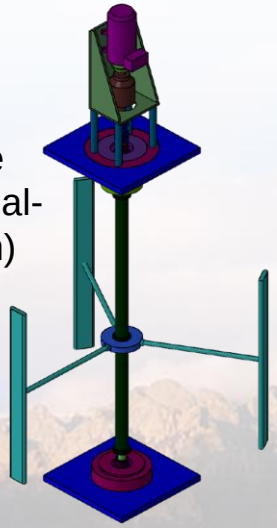


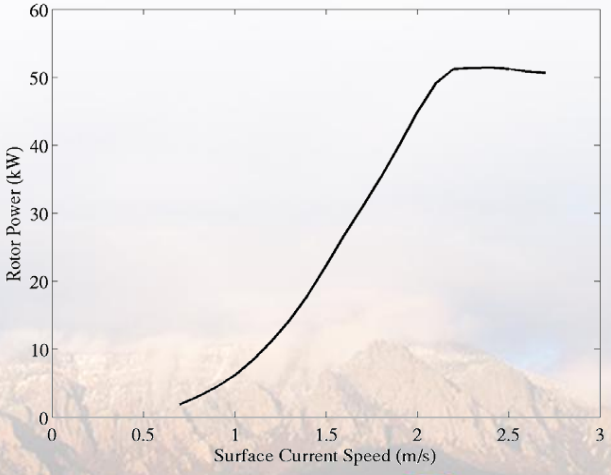






CACTUS (Code for the Analysis of Cross and axial-flow TUrbine Simulation)





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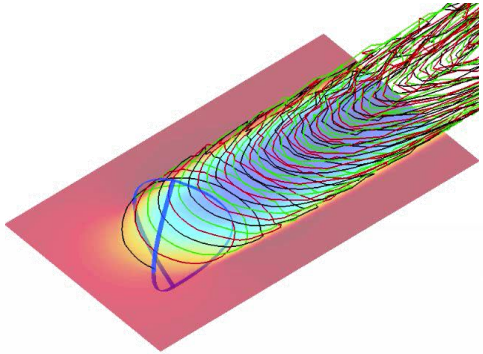
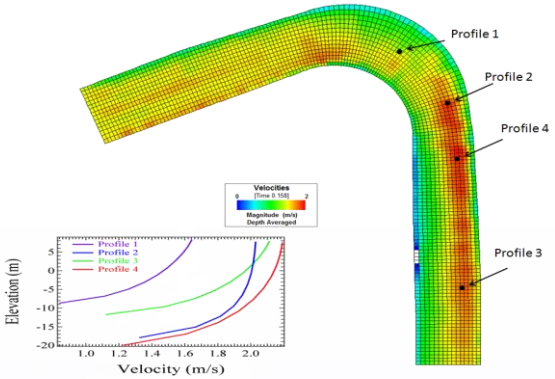
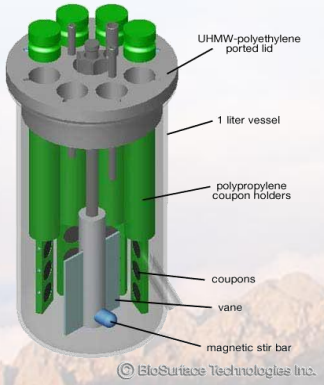
Research Tools and Testing

Code Development and Evaluation

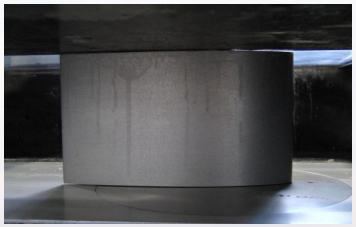


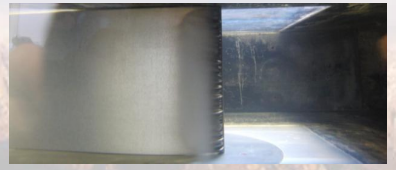


Materials and Coatings



Testing



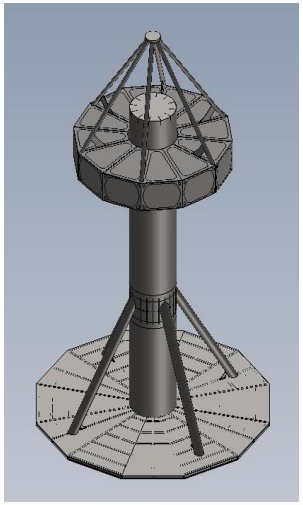


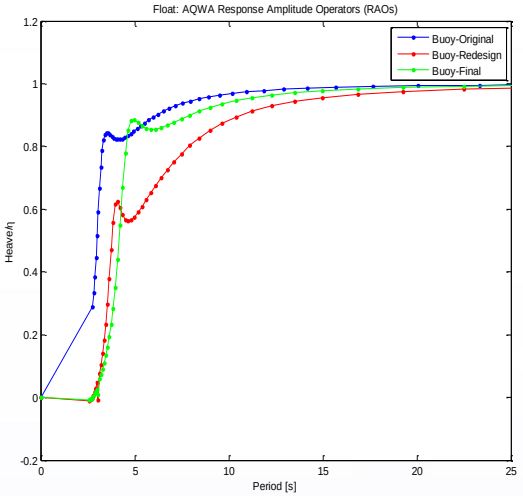
Sandia National Laboratories

Wave Device Modeling

Single Device

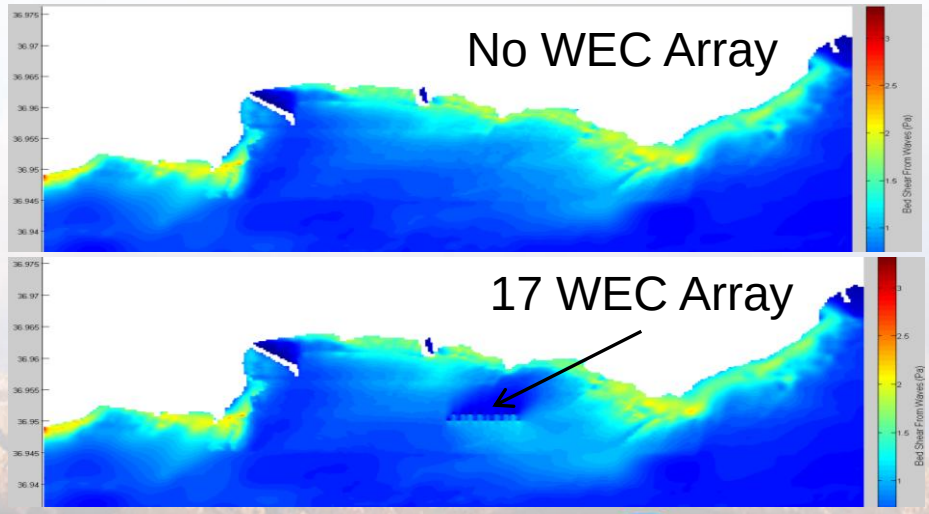
- Integrate Fluid-Structure interactions with performance modeling including PTO





Device Arrays

- Represent devices as reflection and/or transmission sink
- Integrated into SWAN/SNL-EFDC

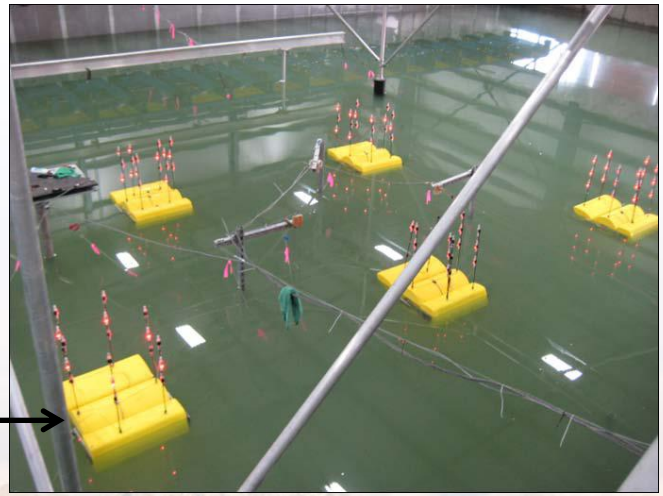


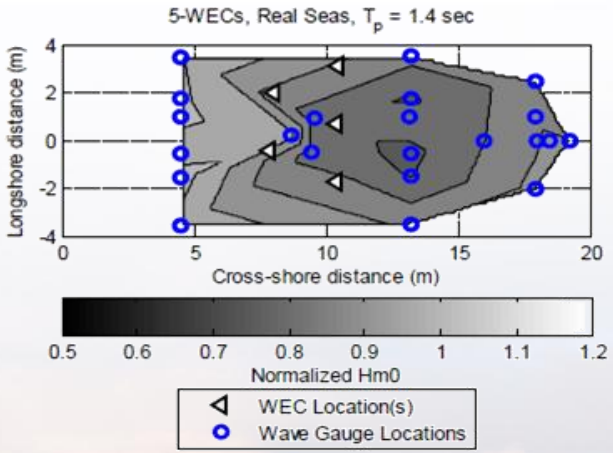
Sandia National Laboratories

WEC Array Testing for Model Development and Validation

- **Goal: In collaboration with OSU and Columbia Power, generate test data for WEC arrays to support code development and validation.**

- **Motivation: Once completed, this experimental test matrix will provide a basis for model validation and allow for a performance modeling tools for optimization WEC arrays**

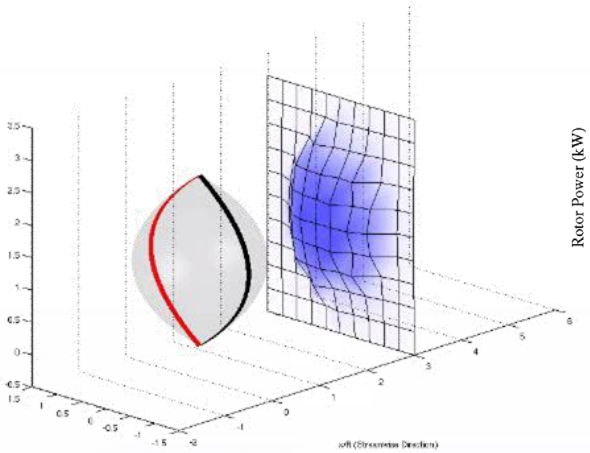


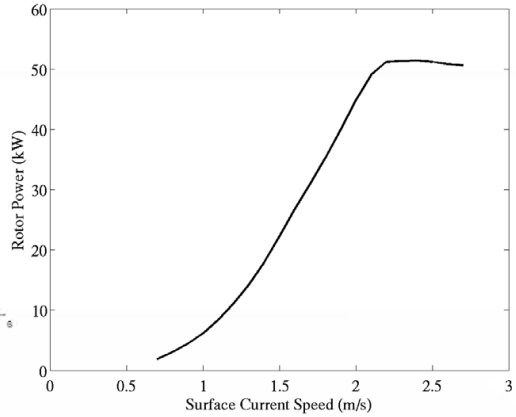


Sandia National Laboratories

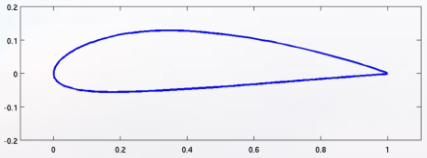
Single Turbine Modeling

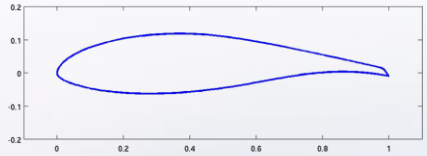
- **Single Device**
  - Development of CACTUS Code for both cross flow and axial flow turbine analysis

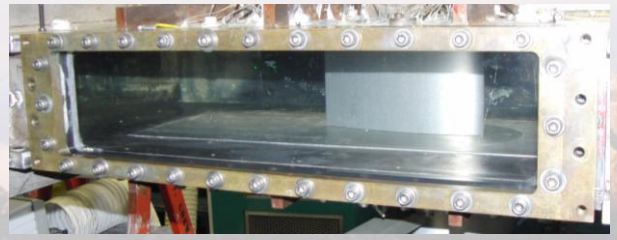


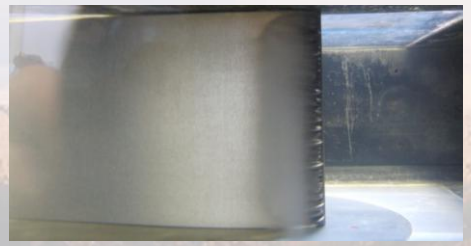


  - Design and test of high performance turbine blade (with Penn State ARL and UC Davis)



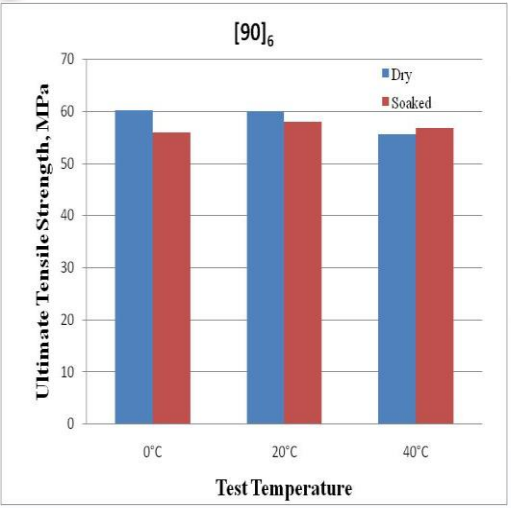


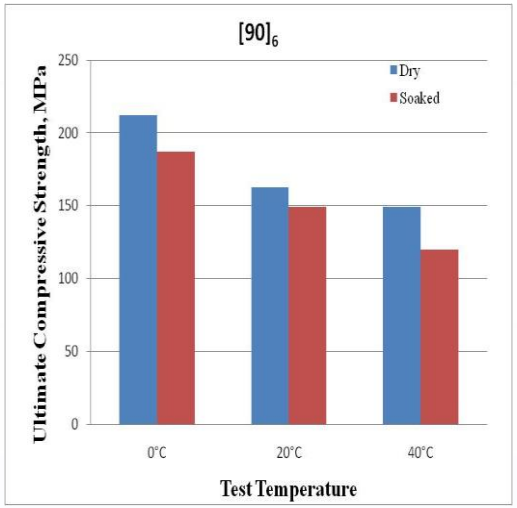




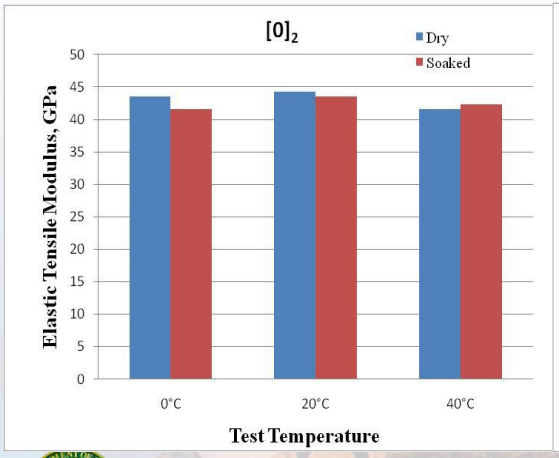
Sandia National Laboratories

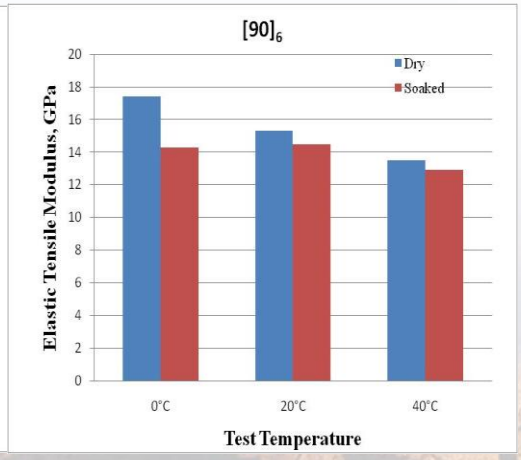
Materials and Coatings

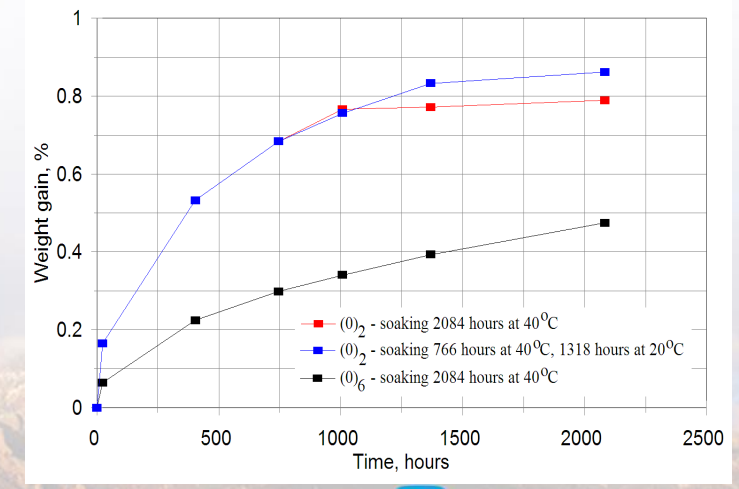




- **Collaboration with Montana State University**
  - Moisture Absorption
  - Mechanical Testing on salt water immersed composites
  - Fabrication

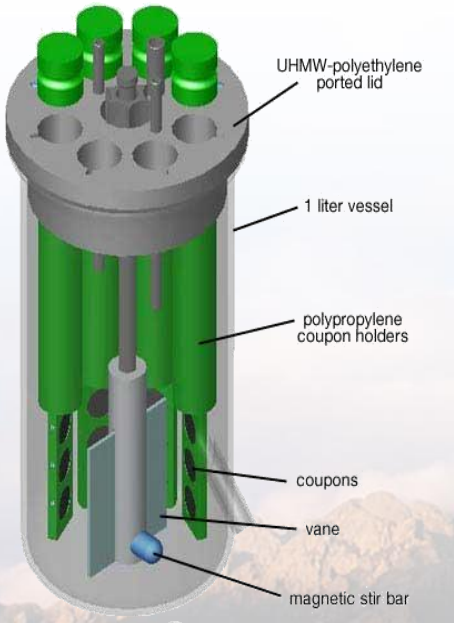






Materials and Coatings

- SNL
- Biofilm baseline measurements on commercial materials & coatings

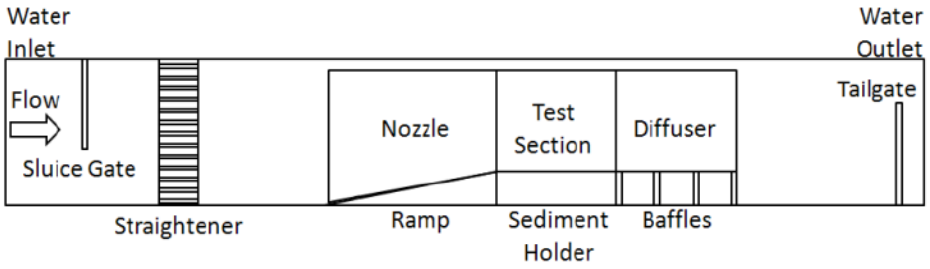


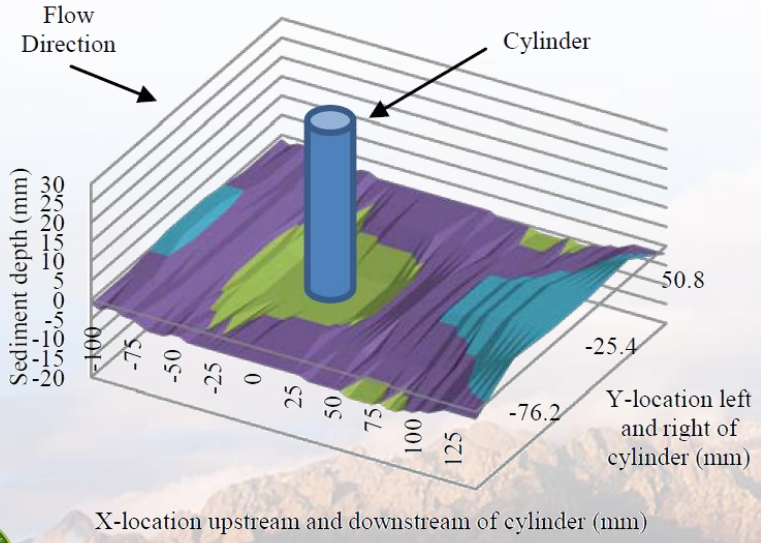
Test ID	Coating Source	Material	Significantly less fouling than control?	Fouling reduction (log CFU/cm^2)	Fouling Reduction (%)
EP2000	ePaint	SS	No	---	---
EP2000	ePaint	Al	No[1]	---	---
EP2000	ePaint	PVC	No	---	---
SN-1	ePaint	HDPE	No[2]	---[3]	---
SN-1	ePaint	SS	No[2]	---[3]	---
SN-1	ePaint	HR	No[2]	---[3]	---
SN-1	ePaint	PVC	No[2]	---[3]	---
SN-1	ePaint	Al	No[2]	---[3]	---
INT-757	Intersleek	PC	Yes	0.67	79
INT-757	Intersleek	SS	Yes	0.81	85
INT-757	Intersleek	HDPE	No	---	---
INT-757	Intersleek	HR[4]	No	---	---
INT-757	Intersleek	PVC	No	---	---
INT-757	Intersleek	Al	No	---	---
INT-970	Intersleek	PC	Yes	0.79	84
INT-970	Intersleek	SS	Yes	0.39	60
INT-970	Intersleek	HDPE	Yes	0.55	72
INT-970	Intersleek	HR[4]	No	---	---
INT-970	Intersleek	PVC	Yes	0.55	72
INT-970	Intersleek	Al	Yes	0.75	82
KNC 821B	S. Dirk	SS	No	---	---
KNC 821E	S. Dirk	SS	No	---	---
KNC 821F	S. Dirk	Al	No	---	---
KNC 821D	S. Dirk	Al	No	---	---
N/A	M. Hibbs	SS	No	---	---
N/A	M. Hibbs	HDPE	No	---	---
7-67-C	M. Hibbs	PVC	No	---	---
7-73-C	M. Hibbs	PVC	No	---	---
7-73-B	M. Hibbs	PVC	Yes	0.37	57
7-74-N	M. Hibbs	SS	No	---	---
7-73-K	M. Hibbs	SS	No	---	---
7-67-D	M. Hibbs	Al	No	---	---
1228B	Corning	Composite	No	---	---
1229A	Corning	Composite	No	---	---
1230A	Corning	Composite	No	---	---
1230B	Corning	Composite	No	---	---

1 More growth on coated coupon, assumed to be because the coating shielded the cells from the antimicrobial properties of Al.
2 Active ingredient thought to have leached into the reactor solution, thus impacting biofilm growth on controls as well.
3 Approximately 2.8 log CFU cm^{-2} more than EP2000 samples.

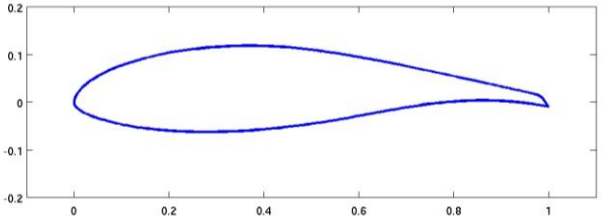
Turbine Testing

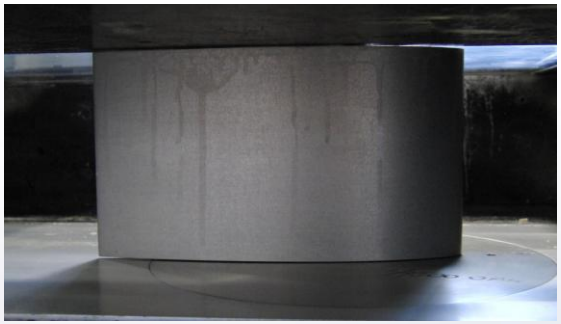
Bucknell University: Model testing for foundation performance and scour

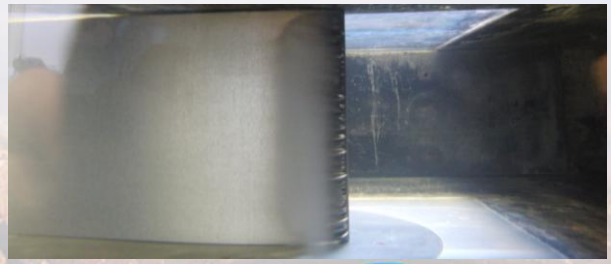




Penn State ARL: Model testing for blade and turbine performance



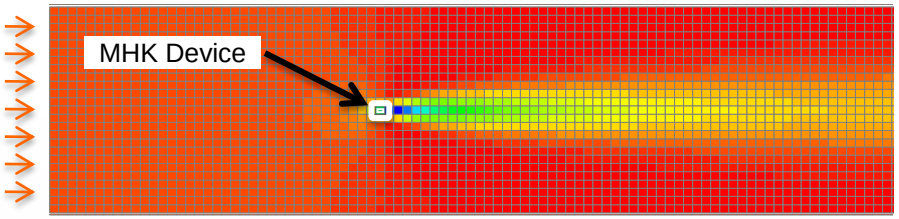




Market Acceleration: MHK-Friendly Tool Development

Progress

- Verification/validation of SNL-EFDC open-source code against scaled flume data
- Released code to public and completed two SNL-EFDC array optimization training courses
- Large river array optimization: maximize power production/minimize environmental effects



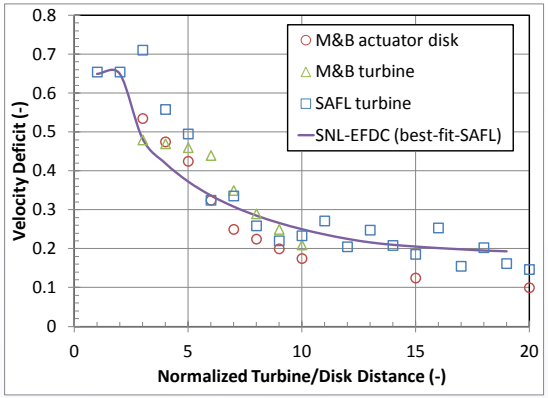
Treats MHK-turbine device as a momentum sink and source of turbulent kinetic energy and its dissipation rate

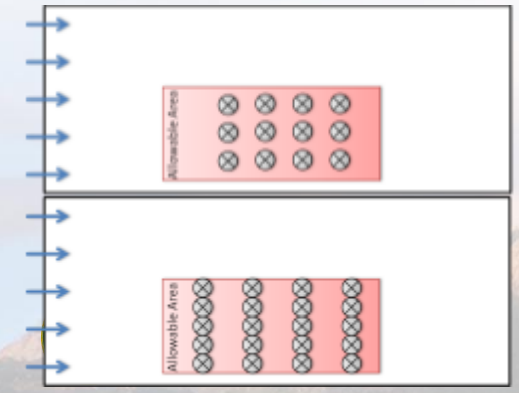
K-ε modifications

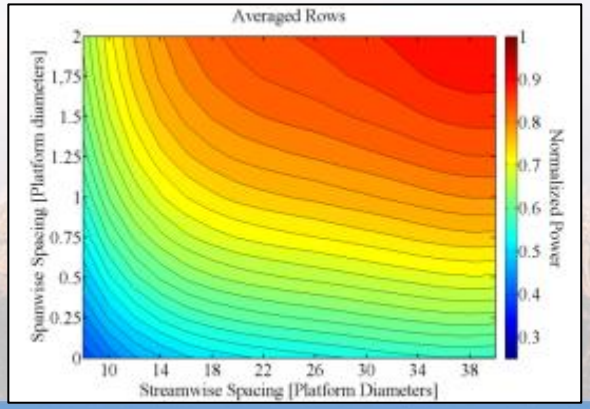
Empirical constants

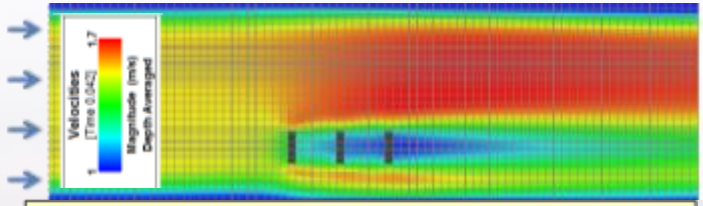
$$S_K = \frac{1}{2} C_T A_{MHK} \left(\beta_p \bar{U}^3 - \beta_d \bar{U} K \right)$$

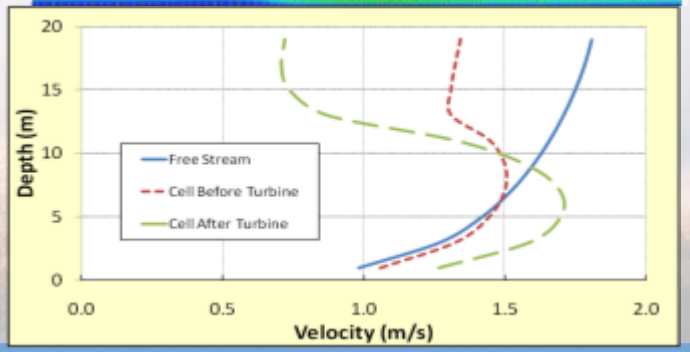
$$S_\varepsilon = C_{\varepsilon 4} \frac{\varepsilon}{K} S_K$$





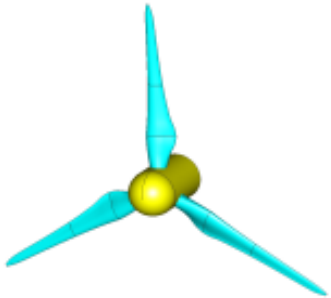


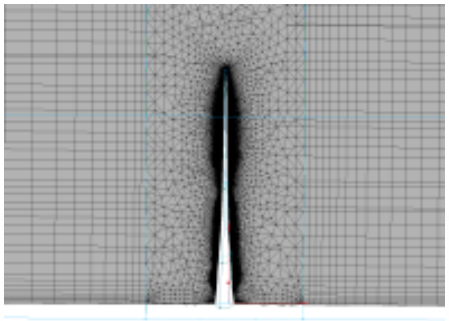


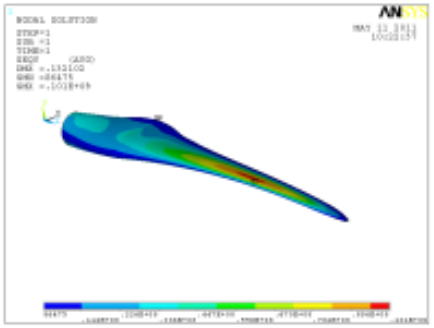


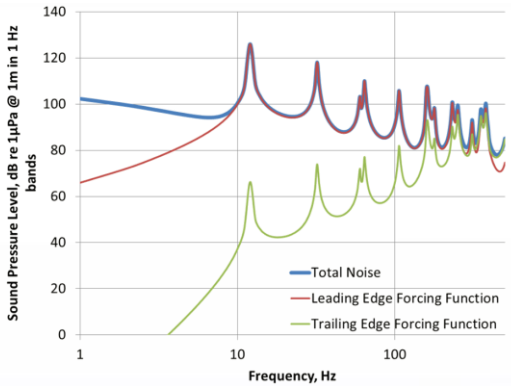
Additional Market Acceleration Projects

Acoustic Modeling: Turbine Blades

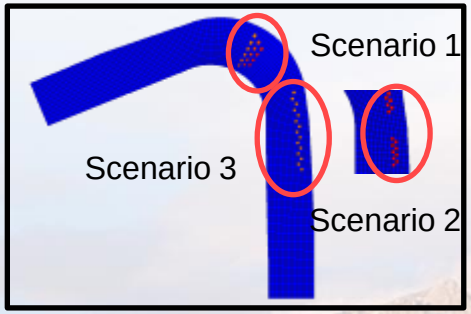


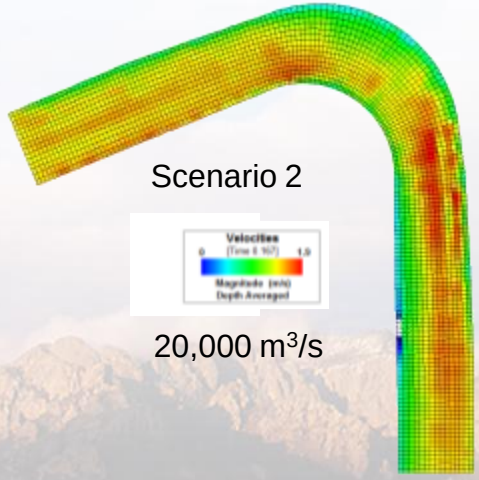


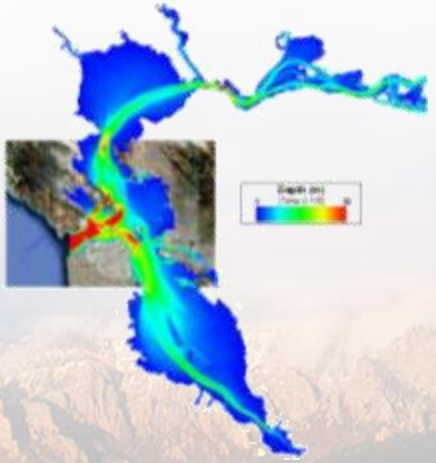


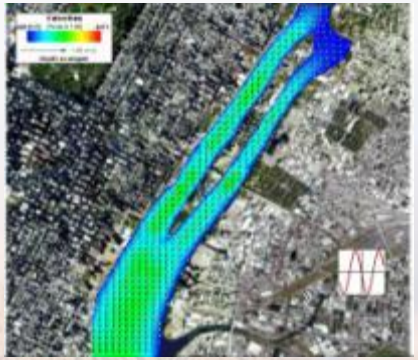


Large Scale Modeling: Optimizing Performance and Environmental Impact







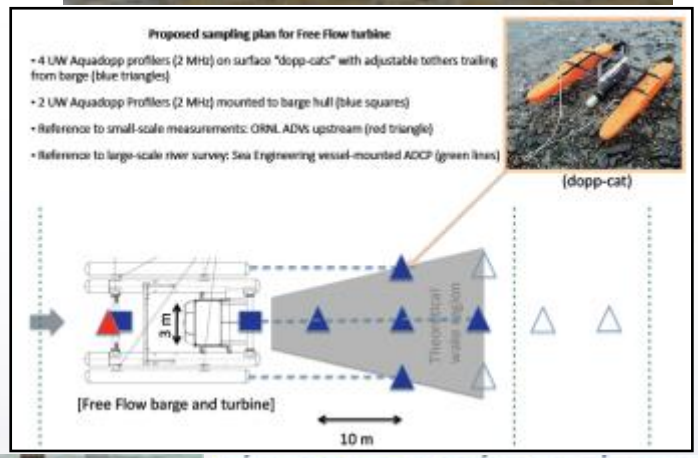


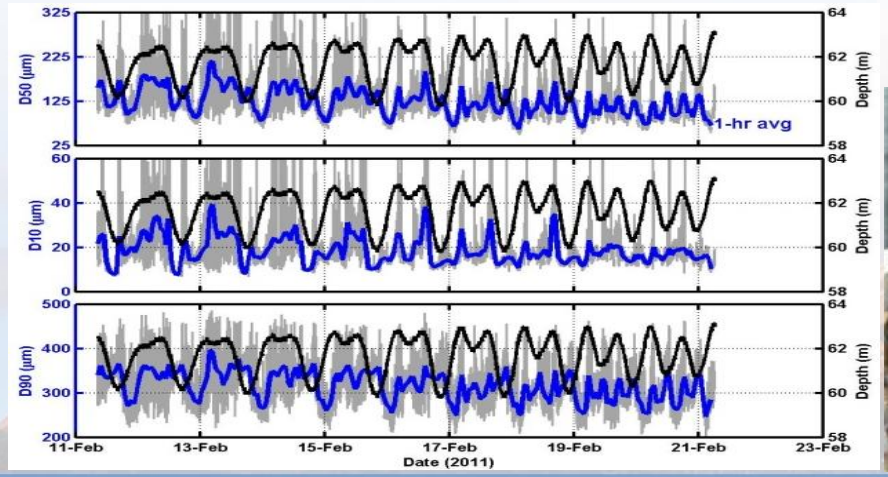
Sandia National Laboratories

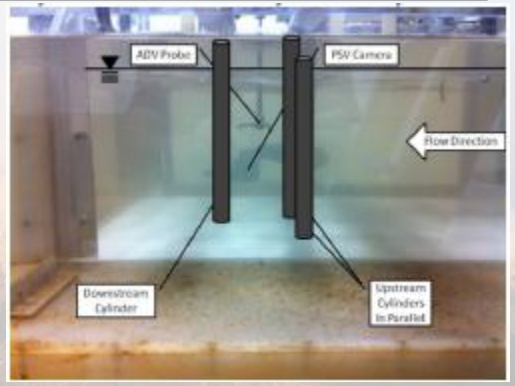
Market Acceleration: Field and Lab Testing

Major Accomplishments

- Completed data collection of suspended sediment in Admiralty Inlet, Puget Sound
  - Helped to close noise budget in Admiralty Inlet and develop relationship between SSC and tides
- Scaled lab tests (Bucknell): verified flow characteristics & completed initial measurements of scour around mock MHK-support (cylinder). Designed scaled support and turbine array experiments.
  - Provide scaled validation data sets
- Created test plan for field measurements around FFP demonstration turbine.
  - Will be first ever public data set of flow around MHK-turbine

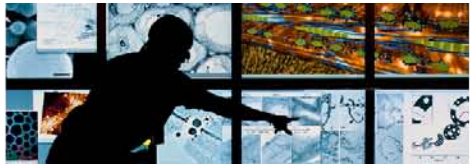






NREL
NATIONAL RENEWABLE ENERGY LABORATORY

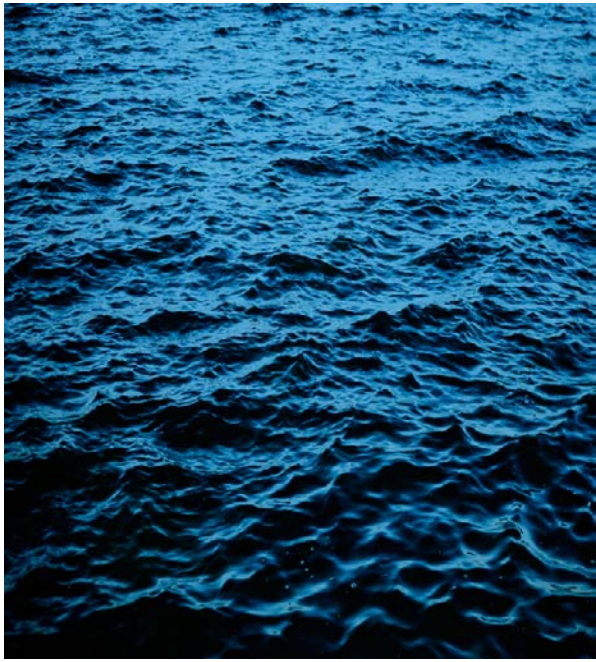
Marine and Hydrokinetic Activities at NREL

Albert LiVecchi
Program Integrator/Senior Project Leader
Wind and Water Power Program

Frederick Driscoll, Ph.D.
Senior Engineer
Offshore Wind and Ocean Energy Systems

January 12, 2012



Outline

Introduction

- Wind Evolution
- R&D Priorities
- Integrated Approach

Computer Aided Engineering Tools

- Economic Analysis
- Wave
- Current

Testing

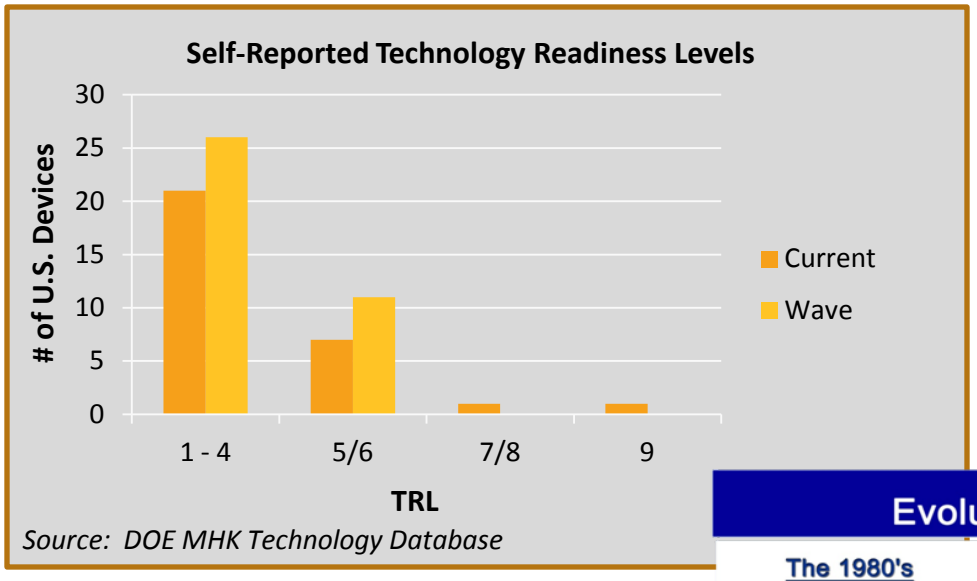
- Instrumentation/DAQ
- Protocols
- Laboratory

Analysis and Assessment

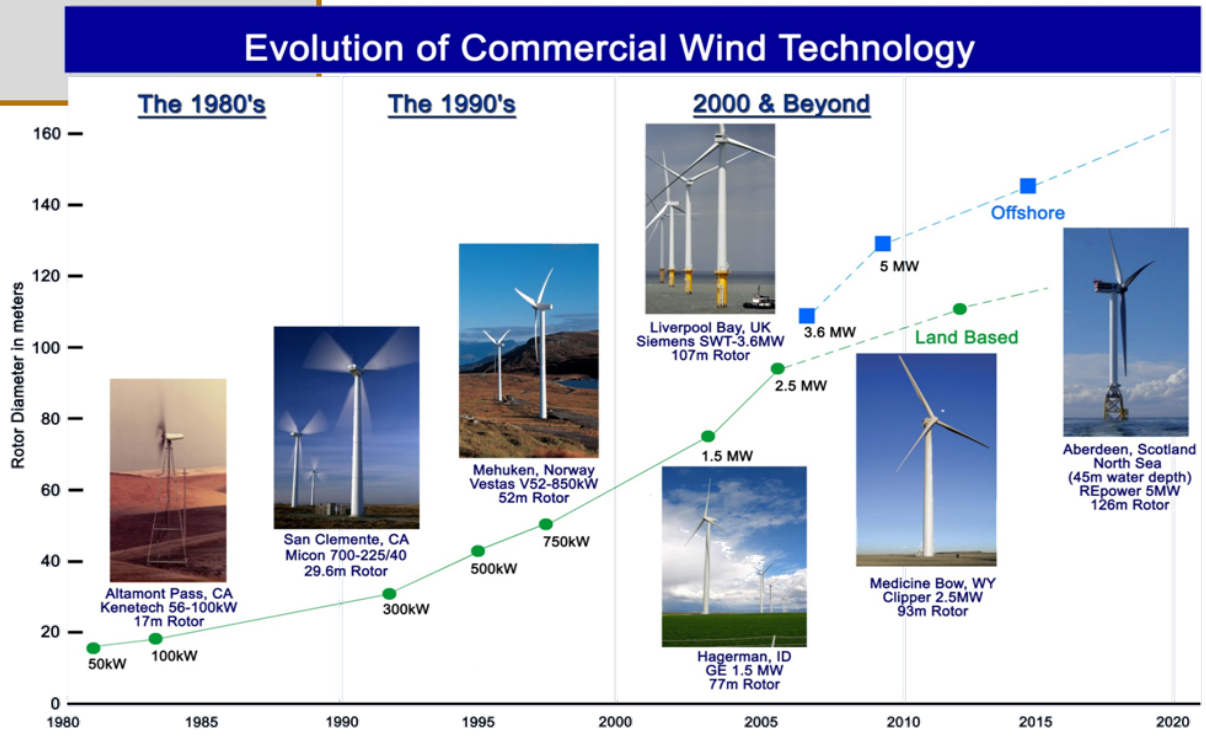
- Standards Development
- Resource Characterization
- Infrastructure Assessment

Questions?

The Challenge: To evolve MHK technologies faster!



Source: DOE MHK Technology Database



MHK Technology Advancement Priorities

1. **Cost Reduction and System Performance/Reliability**
   - Develop computer modeling tools to assist industry in device and system design and operation
   - Develop design and testing protocols
   - Support design and development of scale systems and components in order to reduce technology costs and improve performance and reliability

2. **System Deployment and Testing**
   - Facilitate the deployment and testing of full scale MHK prototypes and components
   - Generate data on performance, reliability and impacts
   - Validate models and identify areas for improvement

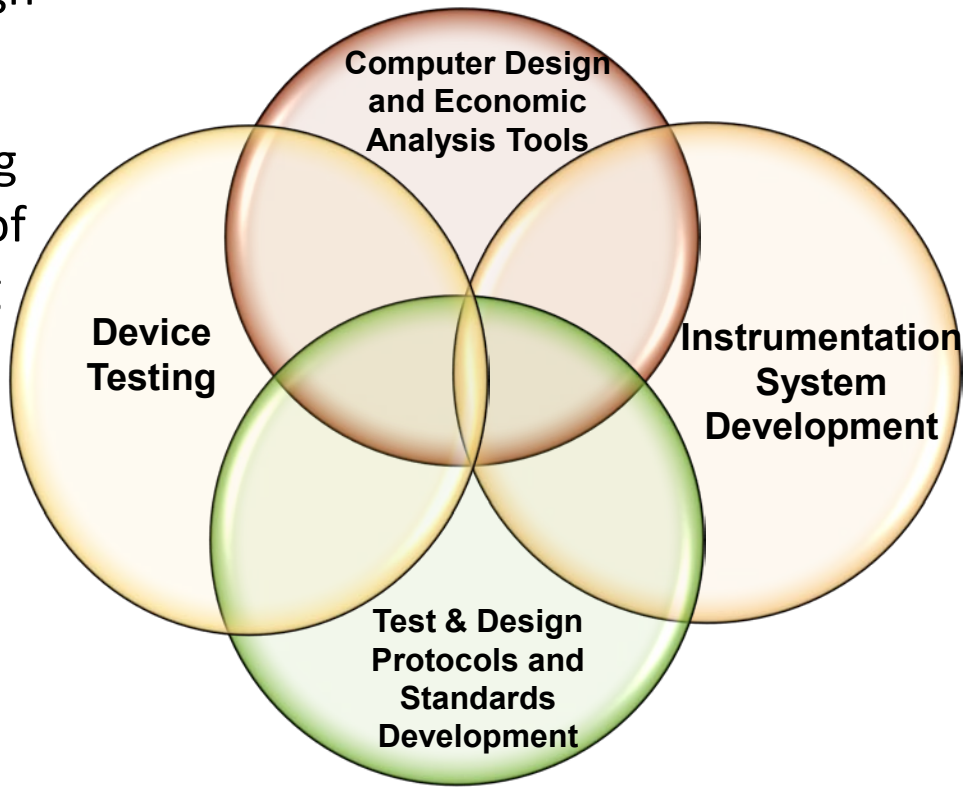
3. **Develop Evaluation and Performance Standards**
   - Characterize, evaluate and compare the wide variety of MHK technologies
   - Continue IEC/IEA standards development

4. **Resource Modeling and Characterization**
   - Determine the available, extractable, and cost-effective water resources in the US
   - Understand design environments

5. **Understand Environmental Effects**
   - Collect/disseminate data on environmental impacts to reduce deployment costs and environmental effects

Integrated Technical Approach

- Integrated approach provides industry with open source and validated design tools
- Develops instrumentation and testing protocols and standards for the use of industry and National Marine Testing Centers
- Supports demonstration projects by providing instrumentation design, software and hardware
- Subscale and full scale tests provide data for model improvement and technology characterization



Tools: Economic Analysis

Jobs and Economic Development Impacts (JEDI) Model:
http://www.nrel.gov/analysis/jedi/

- Easy-to-use model to analyze the magnitude of economic impacts that will likely result from developing MHK technologies
- Analyzes only specific deployment cases identified in the model. User inputted data required for analyzing other projects
- In the absence of historical cost data, where necessary engineering cost models were used to develop a set of reference cost data
- Partners – MRG & Associates, Re Vision Consulting

Regional Electricity Deployment System (ReEDS) Model:
http://www.nrel.gov/analysis/reeds/

- Deployment scenarios to generate energy supply curves

Computer Aided Design Tools: Wave Energy

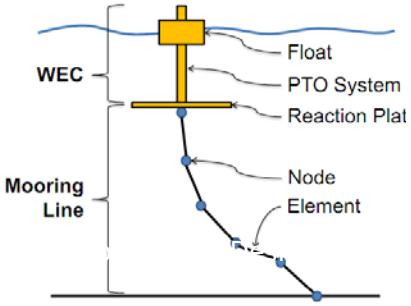
Objectives

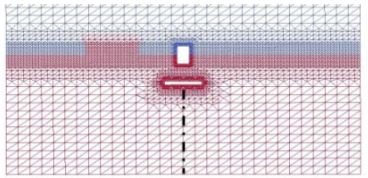
- Assess utility and limitations of commercial codes (e.g. OrcaFlex™, Star CCM+™, ANSYS AQWA™)
- Develop wave energy converter design tools for point absorber, attenuator, oscillating water column, and surge technologies – metocean, component, system (single device) and array
- Perform model to model verification and participate in laboratory and field testing to validate models
- Develop device survivability and reliability design methods
- Develop wave device/array optimization methods and control strategies

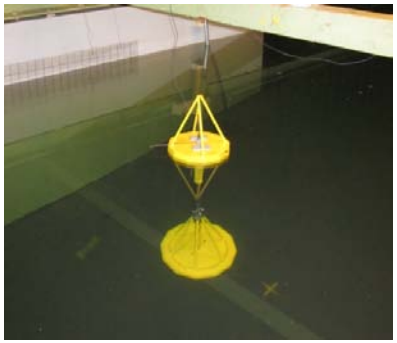
Approach

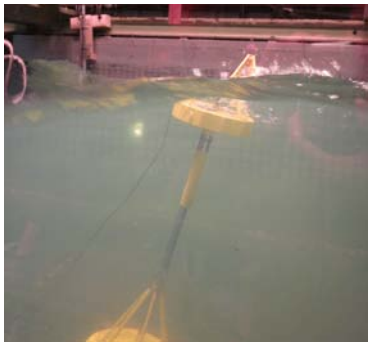
- Develop both first-order design tools and high fidelity analysis tools
- Validate codes with laboratory and field data
- Public domain source code, documentation and example application for several different modeling methods (e.g. parametric, boundary element, and CFD)
- Actively engage users to ensure utility

- Partners: MIT, Oregon State U., Sandia NL









Computer Aided Design Tools: Current Energy

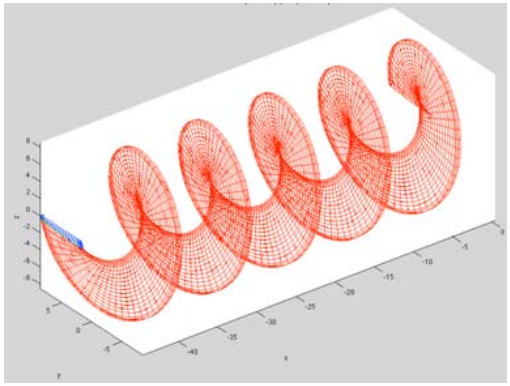
Objectives

- Develop modular computer aided engineering framework and tool set to support the design and analysis of wave and tidal systems – inflow, wake, component, system (single device), and to enable device and array design optimization (performance and loads)

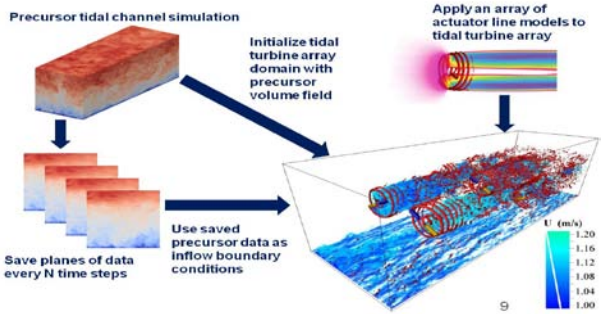
Approach

- Leverage experience in wind
- Adapt existing wind codes for MHK application (e.g. Harp_Opt, TurbSim, FAST)
- Utilize modular architecture and open source software to enable rapid development, ease of customization, and code sharing
- Utilize wind experimental expertise to develop protocols and instrumentation to validate tools

- Partners – Penn State U., U. Cincinnati, SNL, PNNL, ORNL



Axial Flow Turbine Wake Simulated with Vortex Method

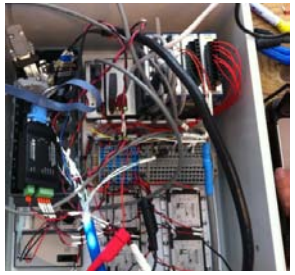


LES Simulation Of Tidal Array

Testing: Instrumentation

Objectives

- Develop a Modular Marine Integrated Measurement System (MMIMS) for laboratory and field data measurement
- Disseminate hardware layout/design and software source code
- Deploy system for in-water research, testing, and evaluation of MHK technologies

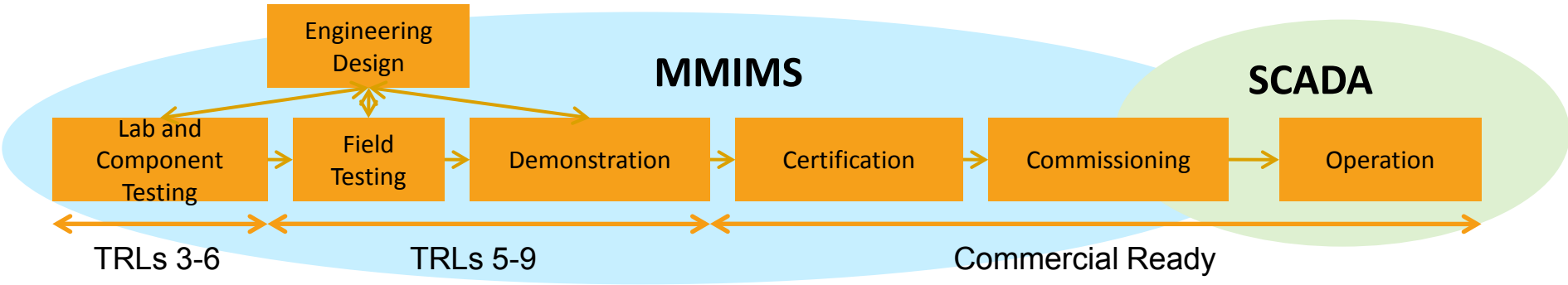



* Based on UW Design

Approach

- Leverage existing systems and know-how developed by the DOE wind and water power program
- Leverage internal marine specific operations and instrumentation experience
- Active integration of users to guide design and implementation (Instrumentation Working Group)
- Moored Turbulence Measurement Package Prototype

- Partners – NNMREC, NAVFAC, SNL, UNH, ORNL, PNNL, Cardinal Engineering, SNMREC, HINMREC, and others



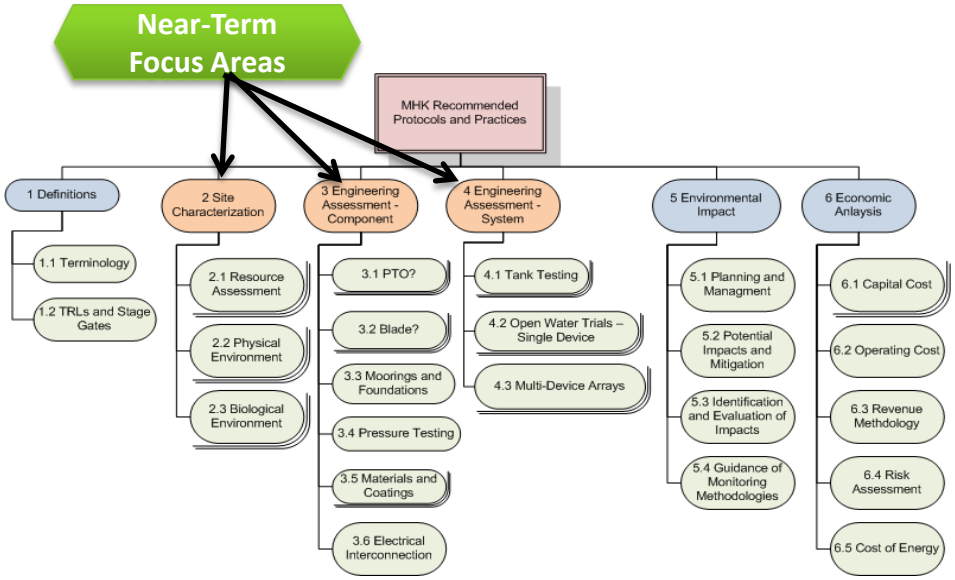
Testing: Protocols

Objectives

- Develop protocols for laboratory and open-ocean wave and water current component and systems testing that are relevant to and conforms with U.S. technology development and practices

Approach

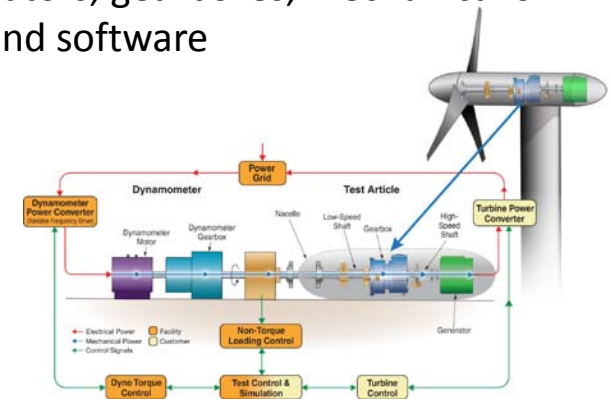
- Build upon protocols from wind, the marine industry, and other MHK efforts (e.g. EMEC, Equimar)
- Coordinate integrated Working Group of MHK experts from industry, national labs, National Marine Renewable Energy Centers, and academia
- Partners: OHMSETT, NNMREC, SNMREC, HINMREC, ORNL, PNNL, SNL, UHN, and others



Testing: Laboratory

Drive-train Testing

- Drive-train design validation: under 10 kW to 5 MW
- Test a variety of components and subsystems, including generators, gearboxes, mechanical or electro-dynamic brakes, power electronics, control systems, and software
- Highly Accelerated Life Testing (HALT)



Structural Testing

- Blades and other components
- Simulate operational performance from concept to production machine
- Typical component structural testing needed to validate models includes:
  - Property testing
  - Dynamic Characterization
  - Strength testing
  - Fatigue testing

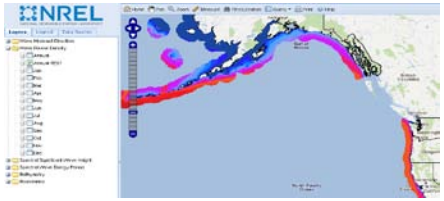
Analysis and Assessment

Standards Development: IEC TC 114 – Ocean Energy Systems

- **Goal:** Develop and implement standards that will facilitate accelerated MHK device development and ensure that they are effective, safe, and environmentally responsible

- Administer and facilitate U.S. efforts and participate in standards development (Technical Advisory Group, Working Groups, Project Teams, Shadow Committees)
- Provide technical experts to national and international teams
- Actively engage with international MHK community

Resource Characterization



- **Wave Resource** (EPRI Lead) - **http://maps.nrel.gov/mhk_atlas**
- **River Resource** (EPRI Lead) – expected release mid - 2012
- **OTEC Resource** (Lockheed Martin Lead) - expected release mid - 2012

U.S. Testing Infrastructure Assessment

- Wave and current related technologies
- Laboratory through full scale open ocean testing
- Partner – Sandia NL

Some MHK Publications: www.nrel.gov/publications

- "**1st Marine and Hydrokinetic Device Modeling Workshop: Final Report"** ; Li, Y.; NREL Report No. TP-5000-51421; DOE/GO-102011-3374.
- **"1st Advanced Marine Renewable Energy Instrumentation Experts Workshop Report"**, R. Driscoll, MP-5000-51584.
- **"A Large-Eddy Simulation Study of Wake Propagation and Power Production in an Array of Tidal-Current Turbines"** – Authors Matt Churchfield, Ye Li, and Pat Moriarty – presented at the 9th European Wave and Tidal Energy Conference, 2011, Southampton, England, September 4-9, 2011. NREL/CP-5000-51765.
- **"Development and Verification of a Computational Fluid Dynamics Model of a Horizontal-Axis Tidal Current Turbine"** Lawson, M.; Li, Y., Sale, D. – presented at the 30th International Conference on Ocean, Offshore, and Arctic Engineering, Rotterdam, The Netherlands, June 19-24, 2011. NREL/CP-5000-50981
- **"Structural Design of a Horizontal-Axis Tidal Current Composite Blade,"** Bir, G., Lawson, M., Li, Y - presented at the 30th International Conference on Ocean, Offshore, and Arctic Engineering (OMAE) in Rotterdam, Netherlands, June 19-24, 2011. NREL/CP-5000-50658
- **"A RANS Simulation of the Heave Response of a Two-Body Floating-Point Wave Absorber"** – Yu, Y. and Li, Y. – presented at the 21st International Offshore and Polar Engineering Conference, Maui, Hawaii, June 19-24, 2011. NREL/CP-5000-50980
- **"Developing an Instrumentation Package for In-Water Testing of Marine Hydrokinetic Energy Devices."** Nelson, E. [Proceedings] Oceans 2010, 20-23 September 2010, Seattle, Washington. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) NREL/CP-5000-50249
- **"Staging Rankine Cycles Using Ammonia for OTEC Power Production."** Bharathan, D. NREL/TP-5500-49121.
- **"Investigating the Influence of the Added Mass Effect to Marine Hydrokinetic Horizontal-Axis Turbines Using a General Dynamic Wake Wind Turbine Code."** Maniaci, D.; Li, Y. ; NREL/CP-5000-52306.
- **"Hydrodynamic Optimization Method and Design Code for Stall-Regulated Hydrokinetic Turbine Rotors."** Sale, D.; Jonkman, J.; Musial, W. NREL Report No. CP-500-45021.

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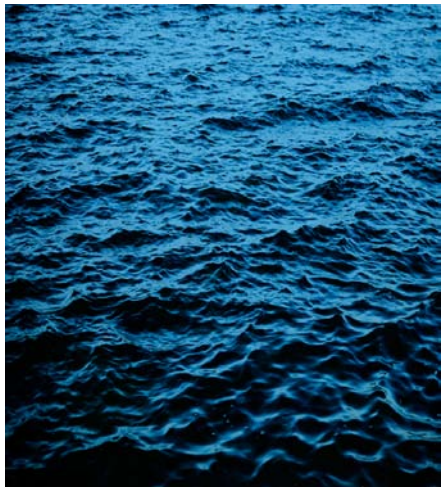
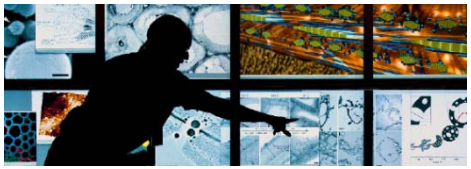


Questions?

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Getting Marine and Hydrokinetic Energy Devices in the Water: Contributions from the U.S. DOE National Laboratories*

Dr. Andrea Copping
Pacific Northwest National Laboratory

* with an emphasis on siting and permitting

In partnership with:

- Oak Ridge National Laboratory
- Sandia National Laboratories
- University of Washington- NNMREC
- Oregon State University – NNMREC
- Pacific Energy Ventures

Webinar: Marine Energy Technology Advancement Project
Coastal Energy States Alliance
January 12th 2012

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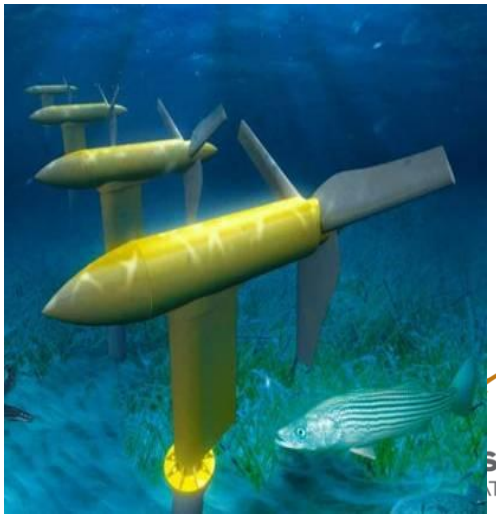
Today….

- What the MHK industry needs
- Key issues in siting and permitting
- PNNL (and partners') research and development
- Moving towards mitigation



Emerging MHK industry needs

- **Characterizing Resource**: Mapping optimal power densities
- **Technologies**: Reliable, efficient devices, anchors, foundations, etc.
- **Test Centers**: Ability to test technologies, standards
- **Financing**: Private, public, PPT, tax incentives
- **Policies**: renewables, etc.
- **Transmission**: investment, standards
- **Siting and Permitting**: regulatory pathway, environmental research to facilitate permitting

Emerging MHK industry needs

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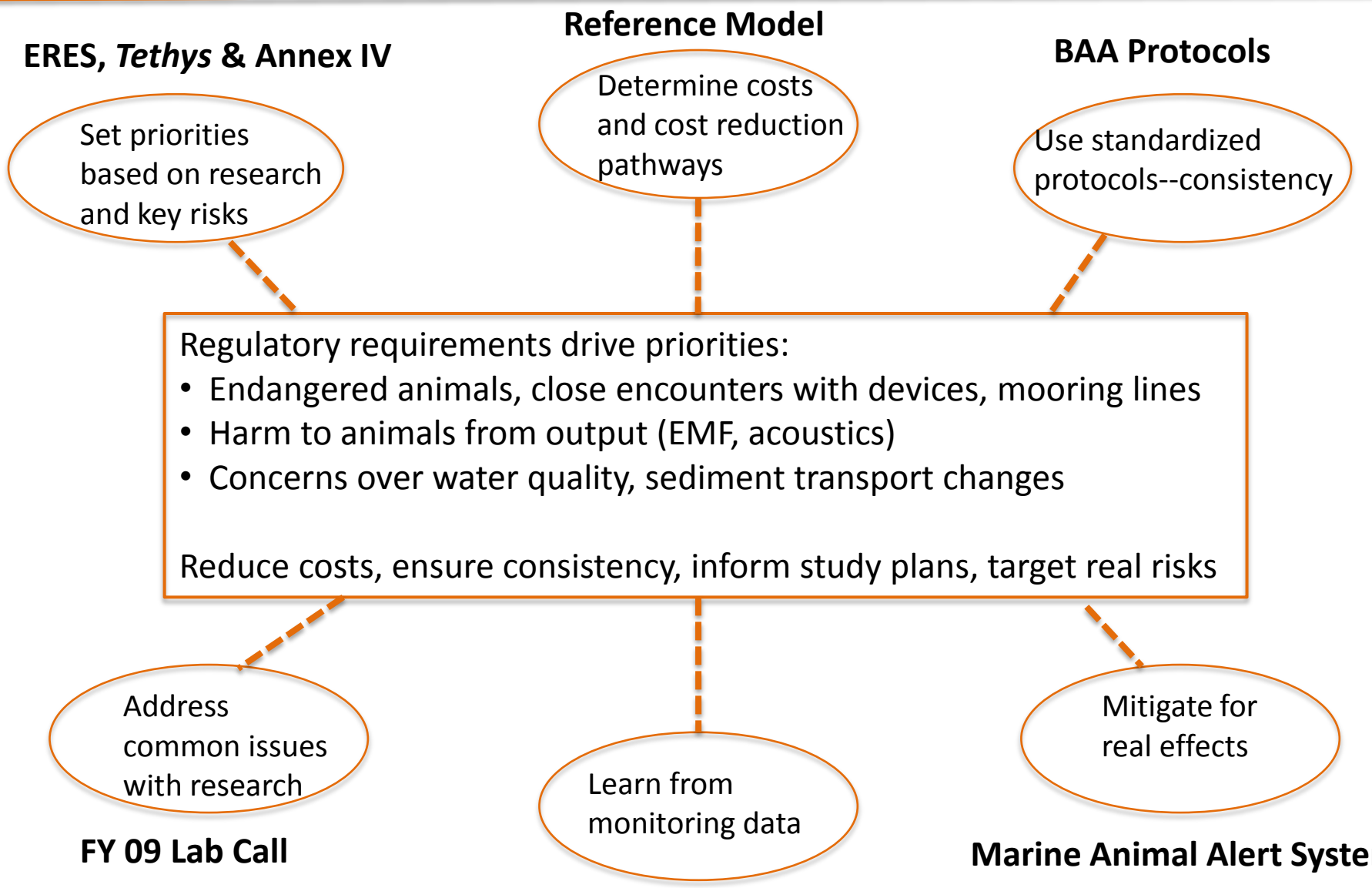
What environmental barriers do we need to overcome to get MHK devices in the water?



PNNL Research Team

Project	PNNL Staff and Partners	Focus/Area of Specialization
Risk-Based Approach to **Environmental Effects of MHK Energy** Development	• Andrea Copping • Jeffrey Ward • Scott Butner • Zhaoqing Yang/Taiping Wang • Irv Schultz, Dana Woodruff • Tom Carlson/Michele Halvorsen • Roy Kropp • Simon Geerlofs • Oak Ridge National Laboratory • Sandia National Laboratories • Univ WA/Oregon St Univ – NNMREC • Pacific Energy Ventures • Univ MA Dartmouth • Worley Parsons	• PI, risk assessment • PM • Knowledge Management System • Numerical modeling • EMF exposure • Acoustics exposure • Physical interaction • Stakeholder outreach, CMSP • EMF and acoustics • Hydrodynamic modeling • Tidal and wave interaction • Stakeholder engagement • Tidal modeling • Wave modeling
Annex IV – international data on environmental effects of MHK	• Andrea Copping • Scott Butner	• Collect and analyze MHK effects data from many countries, esp. EU. • Make data accessible
Reference Model – contribution of environmental studies/permitting to LCOE	• Andrea Copping • Simon Geerlofs	• Determine appropriate environmental studies to meet permitting needs. • Estimate costs of studies, to contribute to cost of energy from MHK development
Protocol framework for environmental monitoring of MHK projects	• Andrea Copping • Pacific Energy Ventures • Oregon State Univ • HT Harvey • NOAA Fisheries, SAIC	• Tidal effects case study • Stakeholder, management • Wave effects case study • Offshore wind case study • Marine animals, EMF, acoustics
Marine Animal Alert System	• Tom Carlson • Daniel Deng • Shari Matzner • Josh Meyers	Develop passive and active acoustic technology to detect, classify, localize marine animals at risk from MHK devices, beginning with marine mammals.
Acoustic effects of SnoPUD turbines on fish	• Tom Carlson • Michele Halvorsen • Univ WA NNMREC, SMRU	Measure effects of turbine noise on fish from proposed Puget Sound tidal turbines; surrogate measure for acoustic impacts on other animals
Puget Sound **Inflow Turbulence Characterization**	• Marshall Richmond • Vibhav Durgesh • Univ WA NNMREC	Inflow Characterization for MHK devices, field verification in Puget Sound
Predictive **Blade Strike Modeling**	• Marshall Richmond • Vibhav Durgesh	Predictive modeling distributions of strike/collision frequency, severity, and location for specific MHK designs

Classifying & Evaluating Environmental Effects of MHK Development

Limited information is available on the effects of MHK

=> uncertainty and delays in siting and permitting

Making information on potential environmental effects readily available and establishing which potential effects pose the greatest risk to the environment => streamline regulatory process

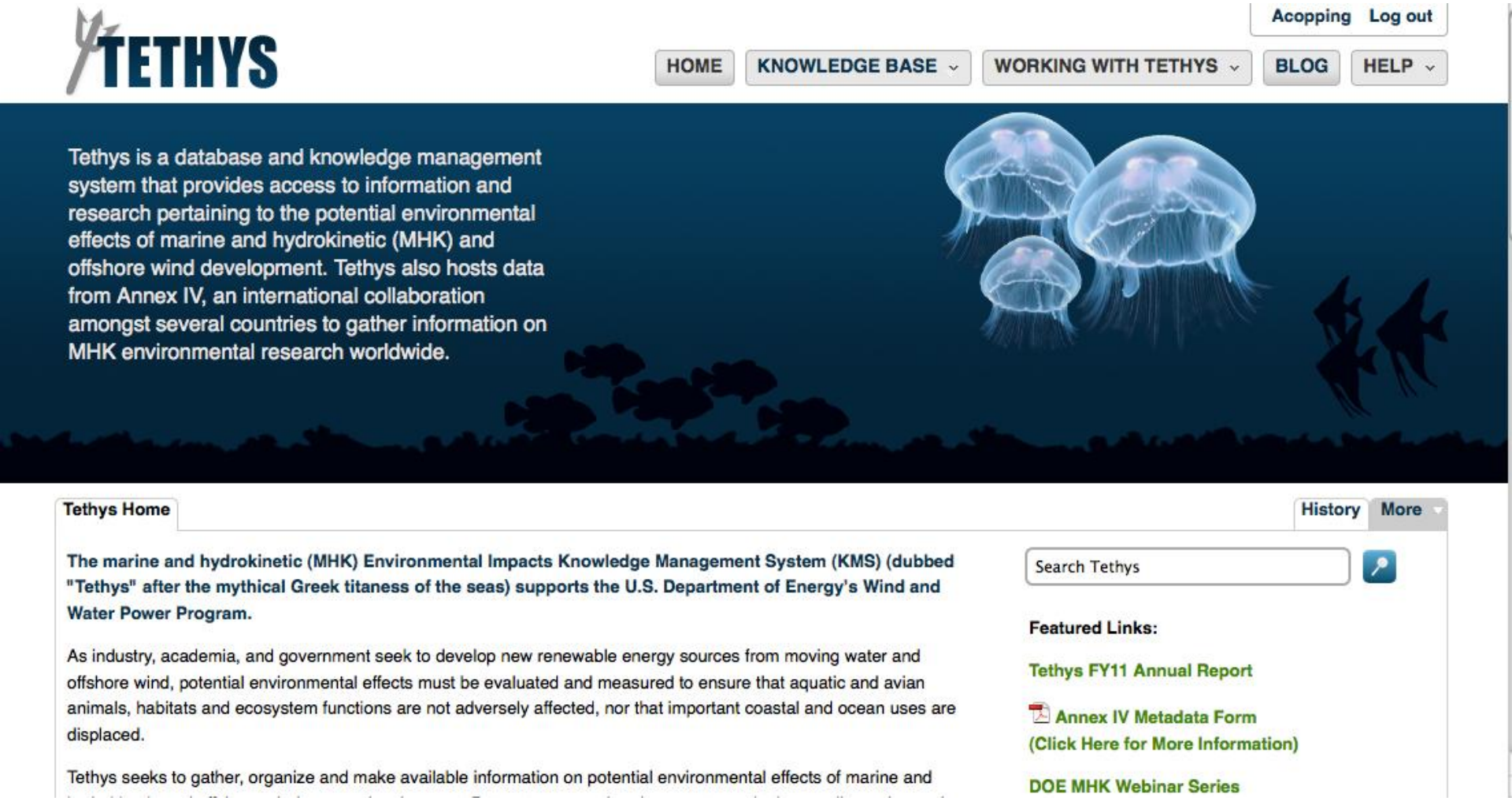
=> also supports research agenda to further reduce uncertainty and the cost of energy

PNNL has created:

=> a Knowledge Management System – *Tethys* to organize information and make it accessible: MHK, OSW and international info (Annex IV)

=> Risk-based priority ranking system – ERES to help set priorities for permitting attention

http://mhk.pnnl.gov/wiki/index.php/Tethys_Home



TETHYS

Acopping Log out

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Search Tethys

Annex IV Sites Main Page

History More

Information from MHK projects and research studies are contained on the **Browse Annex IV Knowledge Base** page. The location of each project can be viewed geographically on the map. Clicking on a location will provide site information and will connect to the appropriate metadata or research data form. From the map, you can also search for related documents and datasets within the Annex IV Knowledge Base, as well as throughout the **Browse Knowledge Base** Page.

Tethys Home » Annex IV Knowledge Base » Annex IV Sites Main Page

MAP • SPREADSHEET • TILES

8 Items

Search

Developer

Technology Type

Annex IV Metadata Form

1 ENVIRONMENTAL EFFECTS METADATA SURVEY FORM

Name of person filing the form (can opt to omit from on-line form) | Date submitted

Project name:

Project description:

Project Developer

Technology type

Resource (wave, tidal, wind)

Project scale (test site, prototype, array, commercial)

Installed capacity (MW)

Additional Description

Project Website

Location:

Ocean/Water body

Closest city

Country

Coordinates (please use Mercator)

Depth

Process status:

Current status of the project implementation and future developments.

Expected operation date (if project is under way please indicate the start date).

Licensing information (brief description):

Please provide a brief description listing the organizations involved, licenses needed and duration of consent process. One paragraph should suffice.

Key Environmental issues: *brief description on the most important environmental issues raised by the project (e.g. Sensitive species/habitats/areas that were of particular concern and/or received special protection) and how they were addressed.*

Baseline and project effects studies:				
General description				
Receptor	**Study description including question and/or objective** (several can be listed per receptor)	**Design and methods** (brief description)	**Results** (brief description)	**Status** (planned, underway, completed, with dates)
Physical environment				
Benthos				
Fish and fisheries				
Large vertebrates				
Birds				
Marine uses / users				
Other (can be named)				
Reports and papers	- When possible the files themselves can be made available in downloadable PDF format, alternatively links to the files or project website can be provided when available e.g. SeaGen. - Key papers on the areas addressed should be listed here			
Research projects	Past or on-going environmental research projects at the site			

Monitoring and adaptive management				
General description				
Receptor	**Monitoring program description including question and/or objective** (several can be listed per receptor)	**Design and methods** (brief description)	**Results** (brief description)	**Status** (planned, underway, completed, with dates)
Physical environment				
Benthos				
Fish and fisheries				
Large vertebrates				
Birds				
Marine uses/ users				
Other (can be named)				

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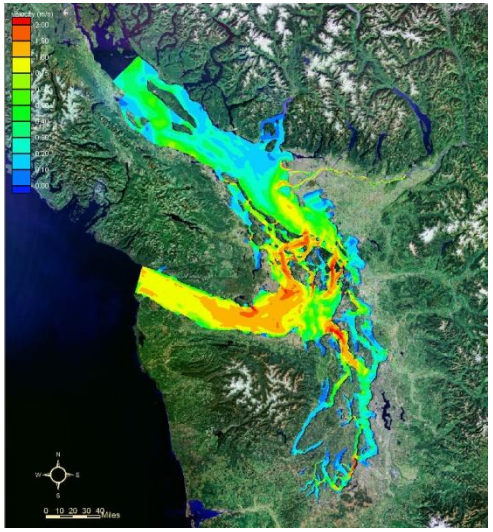
Removing energy, changing waterflows

- What are the effects of removing energy on the ecosystem?
- Computer models can simulate placement of turbines, WECs, long-term effects of changing flow of water, energy removal on:
  - Water quality
  - Sediment transport
  - Aquatic food web
- Same models: assessment of resource density, micro-siting
- Models can also experiment with array design, geometry



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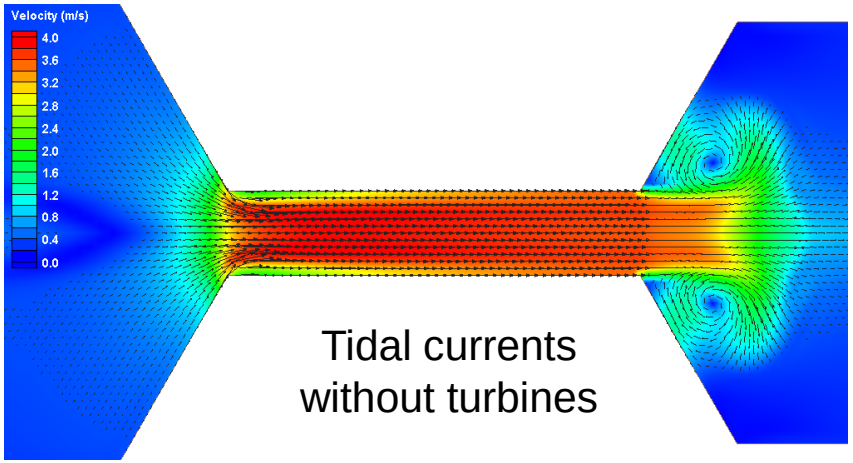
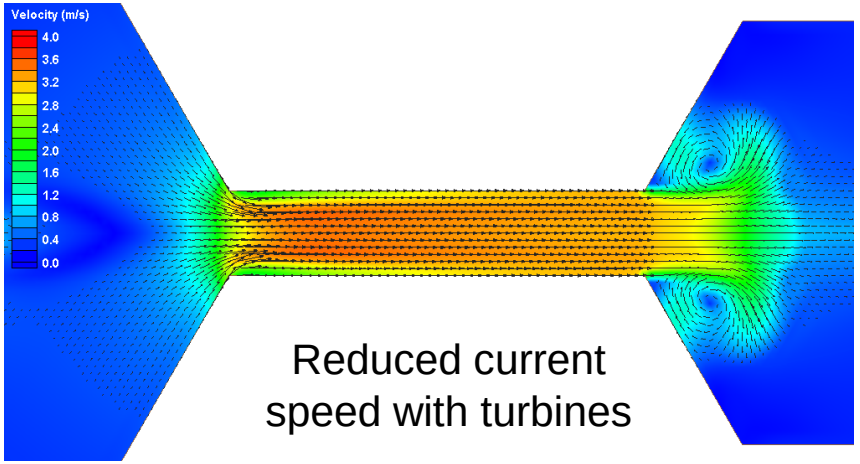
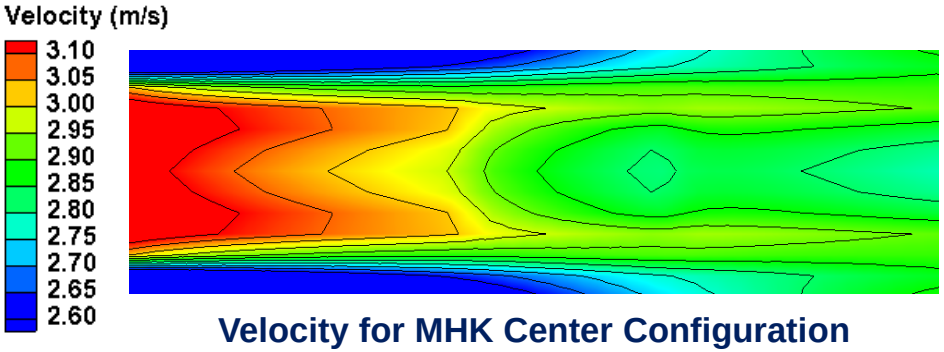
Outputs of tidal energy model: "idealized tidal waterbody"



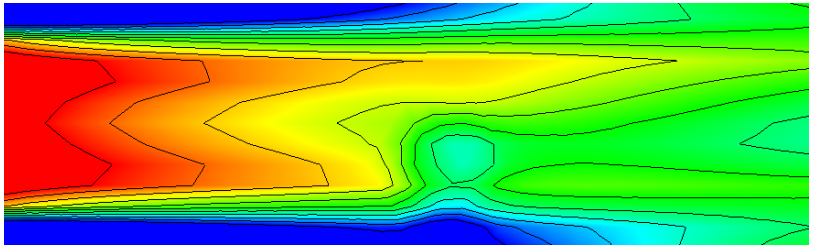
Tidal currents without turbines



Reduced current speed with turbines



Velocity for MHK Center Configuration



Velocity for MHK Side Configuration

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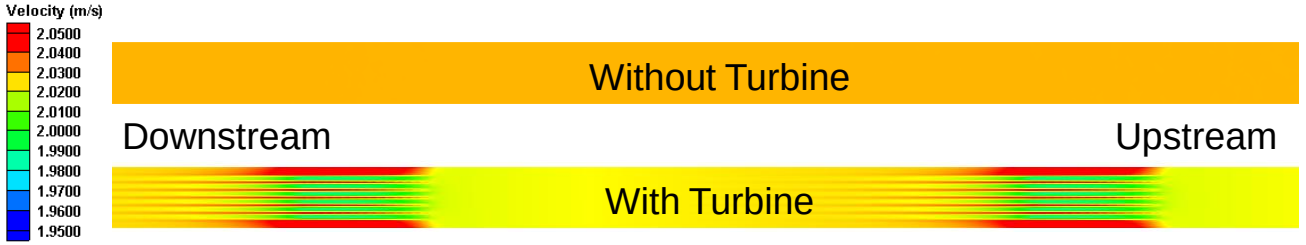
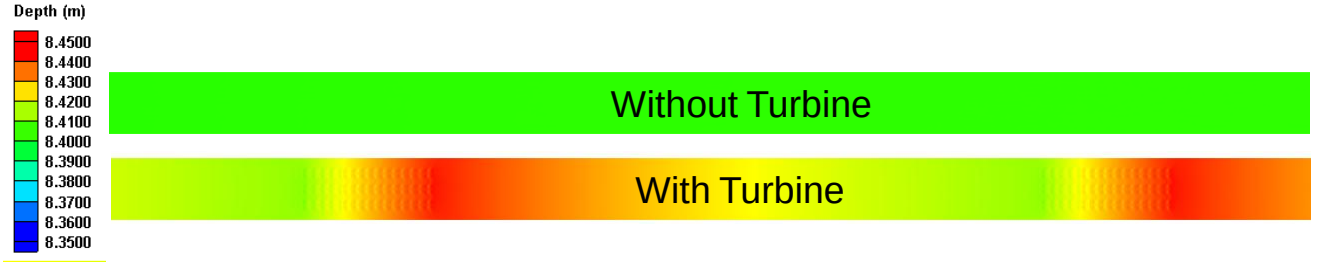
Effect of placement of 100s of turbines in a large river

Velocity (m/s)



Water Depth (m)



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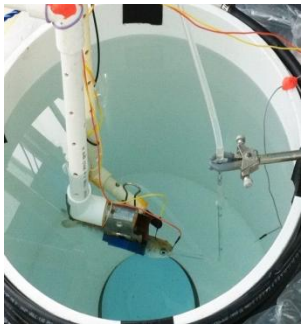
Effect of Stressors on Animals

Limited information on the potential effects of EMF or acoustics/noise:

=> significant regulatory uncertainty

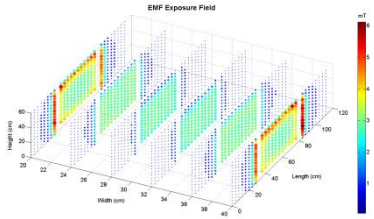
=> more information could help streamlining permitting

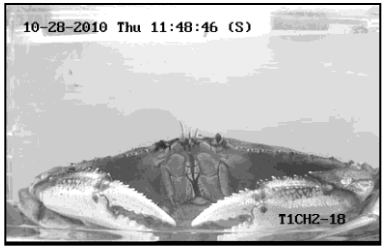
- Laboratory experiments: exposing animals to stressors: EMF & noise
- Sublethal effects: behavior, development
- Standardized methods and endpoints adapted for EMF and acoustics
- Upper bounding limits of EMF and acoustics evaluated, in a risk context to determine the potential for population-level effects
- If high levels show no effect => no further work
- If levels show effect => further experiments to determine effects of likely stressor levels

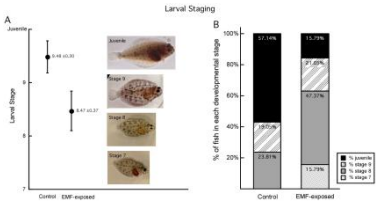


Accomplishments and Results: PNNL EMF Experiments

	Species Tested	Testing Endpoint	Result
	Juvenile Coho salmon	Decreased swimming as alarm- response behavior	Inconclusive @ 3mT
✓	Juvenile Coho salmon	Melatonin/cortisol production as indication of stress	Decreased melatonin levels at 3 and 0.13mT but NSS
✓	Rainbow trout eggs	Survival and development	SS delayed development @ 3mT for one exposure group; other exposure group NSS
✓	Atlantic halibut embryos	Growth and development	Decreased growth and development @ 3mT but NSS
	California halibut embryos	Growth and development	No difference between test and control exposures
	Adult Dungeness crab	EMF detection as change in antennular flicking rate	No difference between test and control exposures
✓	Adult Dungeness crab	Interference in food detection ability	Decreased flicking rate @ 3mT but NSS
	Adult Dungeness crab	Avoidance or attraction to EMF	No difference between test and control exposures







Next Steps:

Behavioral studies: are the animals attracted to cables?

- Halibut
- American lobster
- Elasmobranchs (sharks, skates)

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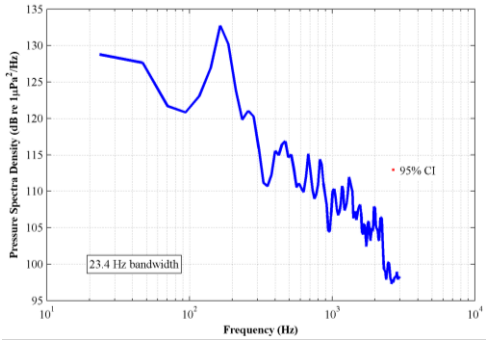
PNNL Acoustic Experiments

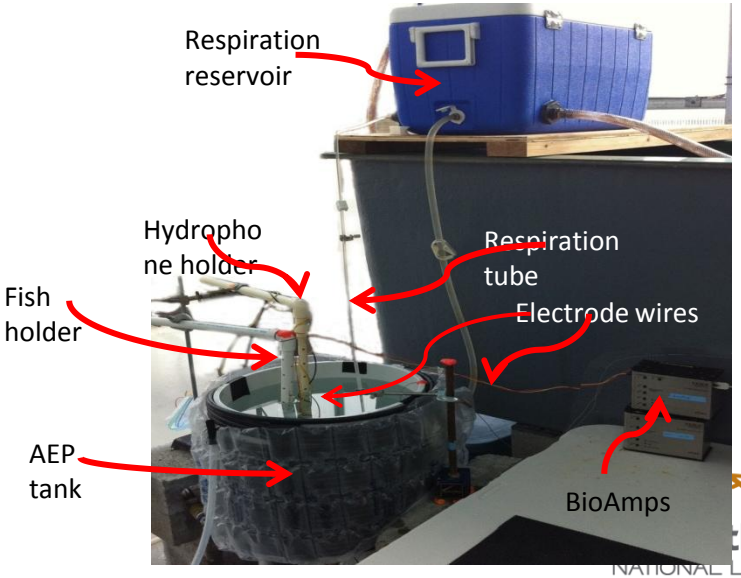
Species Tested	Testing Endpoint	Result
Juvenile Chinook salmon	Tissue damage	SS low levels of tissue damage observed @ 155-163dB. Low physiological cost to fish.
Juvenile Chinook salmon	Hearing loss	NSS difference between test and control exposures @ 155-163dB

Next steps:

- Testing different fish type
- Rockfish or elasmobranch



Recorded sound spectra for 6m OpenHydro tidal turbine



Experimental setup for Auditory Evoked Potential (AEP)

Moving towards Mitigation: Marine Animal Alert System

The Problem: Concerns over blade strike on endangered animals, notably whales, dolphins, diving birds, fish

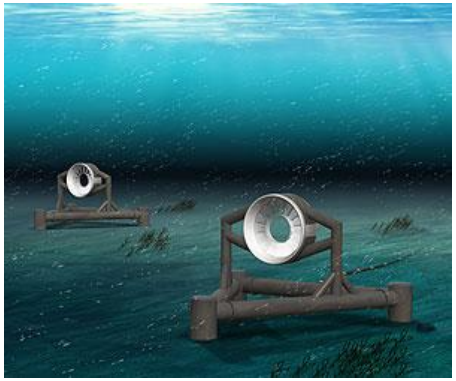
A Solution: Use active acoustics (active=sonar; passive= hydrophones) to pinpoint location and trajectory of animals; take action (example: shut down turbines)

PNNL Project:

- Improve ability to locate and range endangered killer whales from their calls
- Improved acoustic tools for determining locating swimming animals

Working with SnoPUD Tidal Project: addressing critical problems

- Planned deployment of two turbines in Puget Sound
- Endangered killer whale population – no take; other endangered species
- In partnership with Univ. Washington & SMRU
  - Develop sound profile for turbine;
  - Test effect on fish as surrogate for other animals
- In partnership with Sandia NL:
  - Develop estimate of severity of blade strike on killer whale
- In response to permitting requirements:
  - Evaluate highest risks for interaction
  - Contribute to estimate of risk including probability of encounter



Future PNNL Research to Support MHK

- Complete datasets and documents in Tethys for U.S. and international (Annex IV)
- Develop and apply risk assessment tools to determine highest environmental/regulatory risks
- Model effect of energy removal from waves
- Complete additional exposure experiments (EMF, noise)
- Test and apply mitigation measures, like MAAS
- Work with specific projects to provide support for siting and permitting

Thank you for your attention!

For more information, please contact:

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206.528.3049