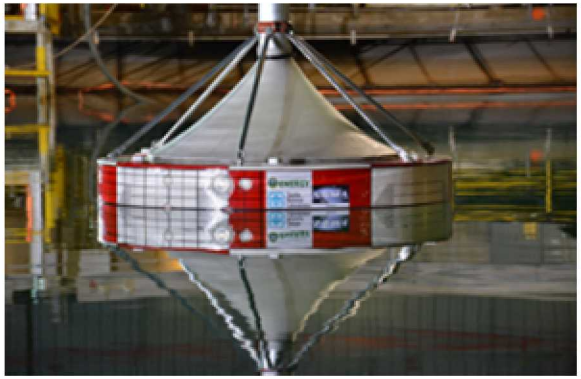
SAND2019-4804C



Marine Energy Technologies:
Technical Advancements and Cost Reduction Opportunities

Peter H. Kobos, Budi Gunawan, Jesse Roberts and Ryan Coe
Sandia National Laboratories

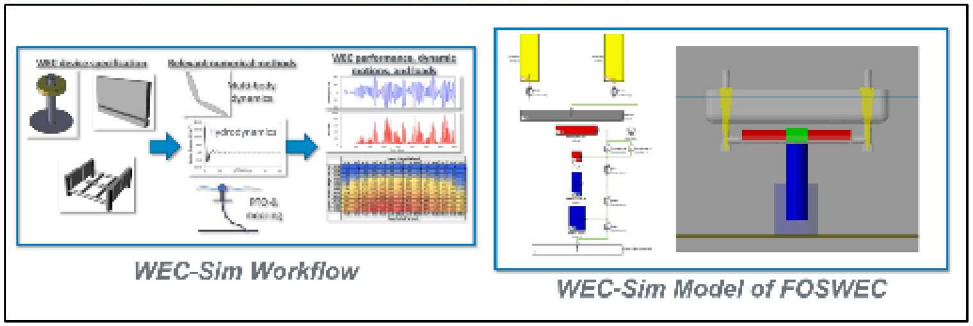
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline*

- Marine Hydrokinetics Technology (MHK)
- LCOE inputs for new technologies
- Wave Energy Prize
- Analysis on Permitting and Compliance Costs
- Structural Health Monitoring to reduce costs
- Concluding remarks

Water Power Technologies

The Water Power Technologies program conducts applied research to improve the performance and reliability of marine hydrokinetic (MHK) technologies while lowering the cost of energy.

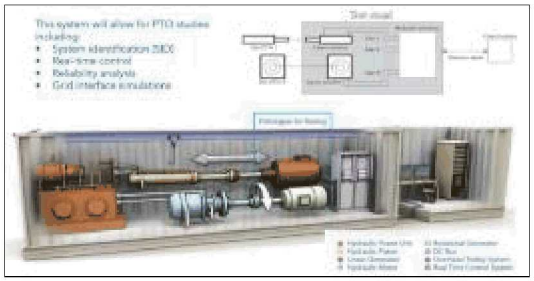


WEC-Sim Workflow

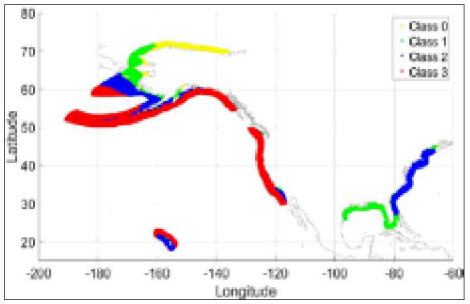
WEC-Sim Model of FOSWEC

Opportunities

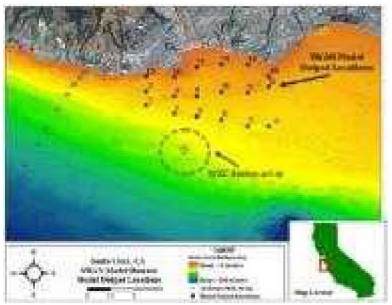
- Testing/collaboration at DOD Maneuvering And Sea Keeping (MASK) basin in Bethesda, MD.
- Developing new power take-off test stand.
- Several Staff members work with 5+ industry partners, 6+ universities – joint funding opportunities.
- Evolving device design standardization: Engaging with international standards committees & on industry technical projects.
  - Standard → Certification → Convince investors.
- Moving towards Blue Economy (Aquaculture, Desalination, Autonomous sensors, etc.)



Sandia Water Power Takeoff Laboratory (SWEPT)



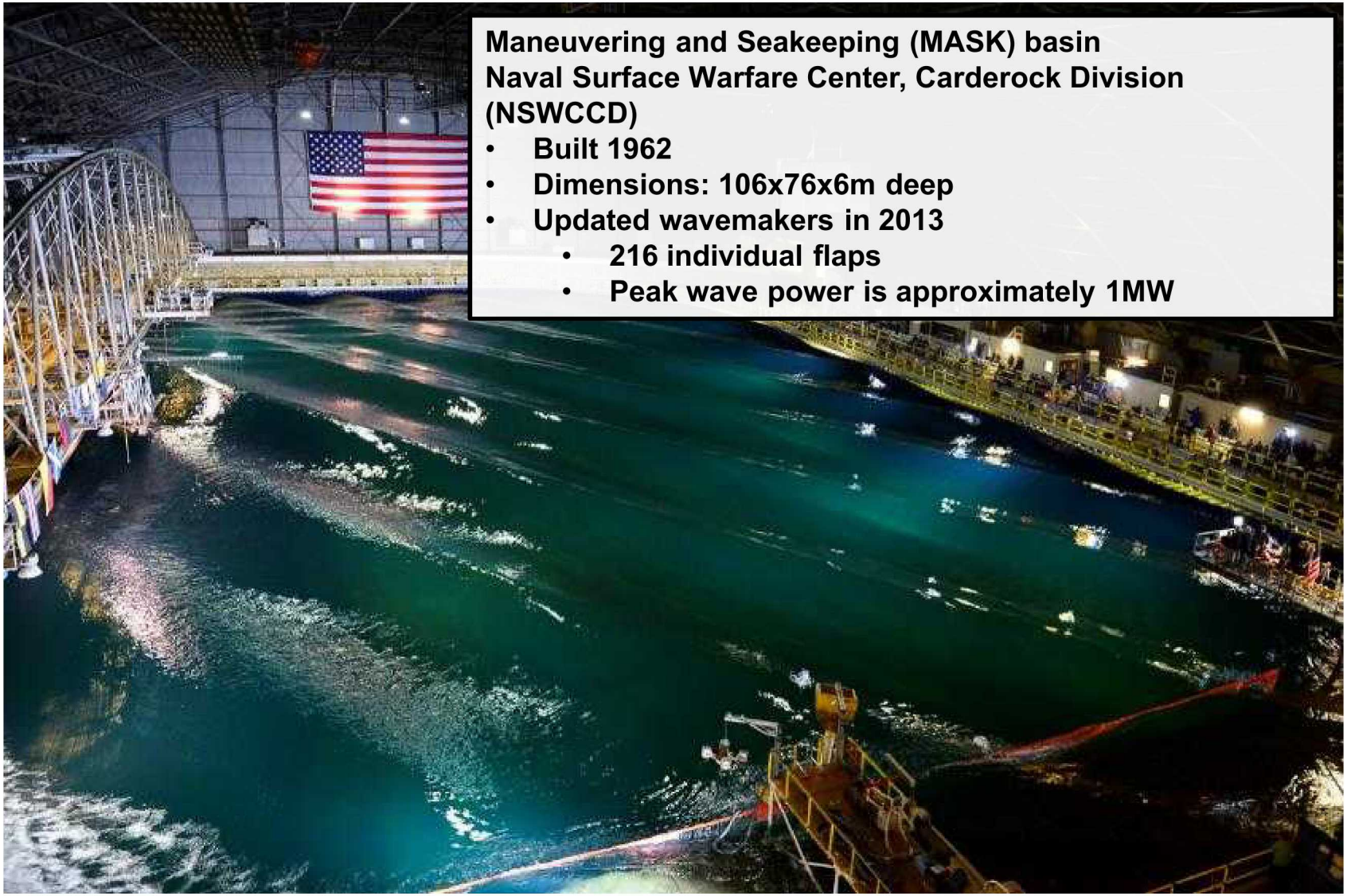
Resource Assessment



Potential Siting Assessments

Increasing Performance:

Test Wave Energy Converter Hardware & Controls



Maneuvering and Seakeeping (MASK) basin
Naval Surface Warfare Center, Carderock Division (NSWCCD)

- **Built 1962**
- **Dimensions: 106x76x6m deep**
- **Updated wavemakers in 2013**
  - **216 individual flaps**
  - **Peak wave power is approximately 1MW**

LCOE Formula: Approaches to Lower the Costs

- *Does the Traditional LCOE approach capture all the value and unique aspects for Water Power or other Renewables?*
- *Do new technologies have enough data to develop LCOE?*
- *Which aspects of the technology have the most potential to reduce LCOE?*

$$\text{LCOE} = \frac{(\text{FCR} \times \text{CapEx}) + \text{OpEx}}{\text{AEP}}$$

Focus on Materials Selection and Research + Best Practices to Reduce Costs

Focus on Component and General Device Design for Performance Increases

LCOE = Levelized Cost of Energy
AEP = Annual Energy Production
CapEx = Capital Expenditures[1]
OpEx = Operations and Maintenance Expenditures[2]

1 For Wave Energy Converters, this may include Development costs, Infrastructure, Mooring/Foundation, Device Structural Components, Power Take Off (PTO), Subsystem Integration, Installation, installation, and possibly profit and contingency costs. 2 This may include Marine Operations & Maintenance (O&M), Shore-side Operations & Maintenance (O&M), Post Installation, Environmental O&M, Replacement Parts, Consumables, and possibly Insurance.

U.S. Department of Energy: Wave Energy Prize

Goal: Drive innovation and evaluate technologies by targeting energy capture efficiency and representative cost metrics when full LCOE assumptions are not fully mature.

LCOE Challenge: Technology lifetime, O&M $, etc.

Methods: Evaluation Metrics, ACE & AAE

$$Average\ climate\ capture\ width\ divided\ by\ characteristic\ capital\ expenditure\ (\boldsymbol{ACE}) = \frac{ACCW}{CCE}$$

$$ACCW = Average\ Climate\ Capture\ Width\ (m)$$
$$CCE = Characteristic\ Capital\ Expenditure\ (\$M)$$

$$Annual\ absorbed\ energy\ (\boldsymbol{AAE}) = \frac{\sum_{j=1}^{7} 8766\ ACCW_j\ CP_j}{CCE}$$

Source: Dallman et al., 2018

ACE Metric: Comparing Reference Model Results to Wave Energy Prize Data

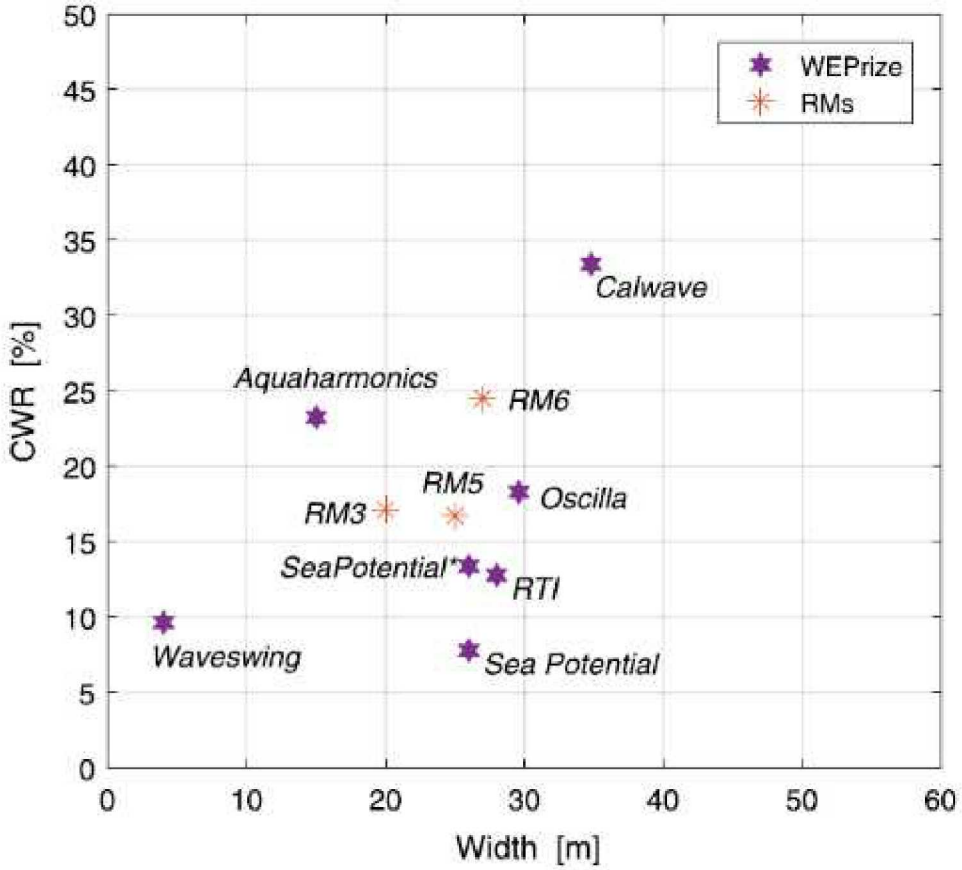
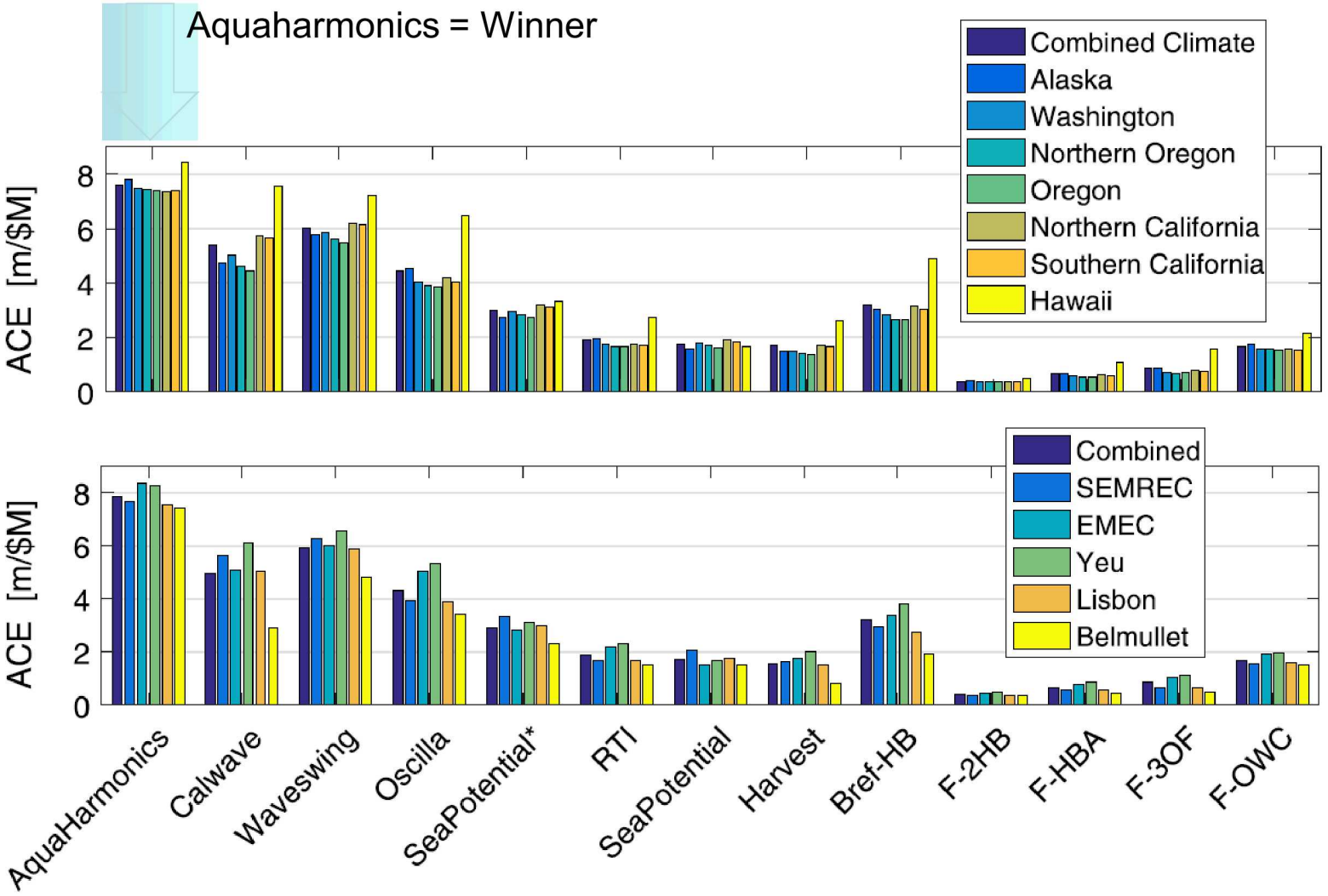


Fig. 3. Capture width ratio percentage plotted against device width for the top six WEPrize teams and the DOE WEC reference models (RM3: point absorber, RM5: oscillating surge WEC, RM6: oscillating water column). Note that Harvest is not shown for clarity because the device width is so large (see Table 3). SeaPotential* (with an asterisk) represents Sea Potential's results with all three PTOs included.

ACE metrics for WEPrize top 5 teams:

Wave climates, U.S. (above) and European (below)



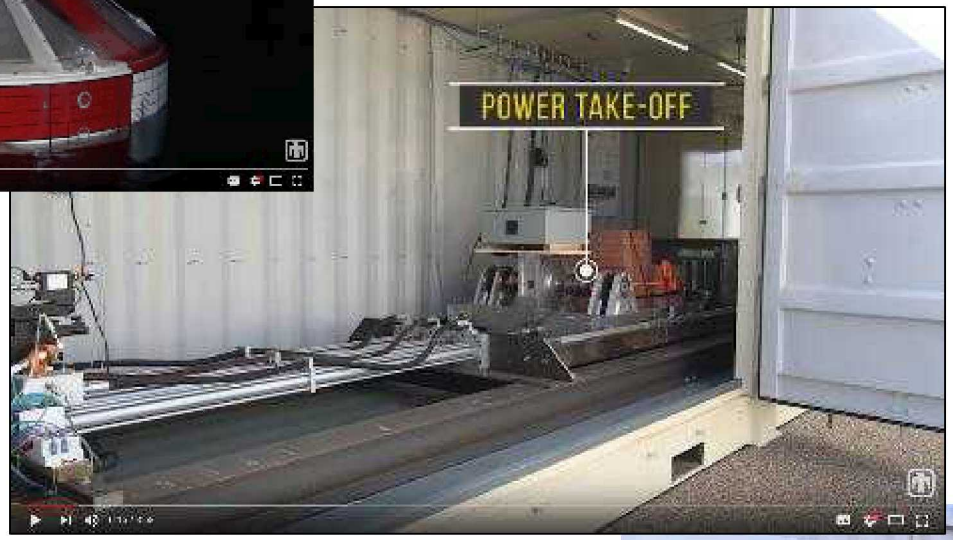
Source: Dallman et al., 2018

Sandia Wave Energy Power Takeoff (SWEPT) Lab:

Increasing Power Output through Advanced Dynamics & Controls R&D

Testing the Power Takeoff (PTO) Unit (the generator) within a WEC

PTO from lab to full-scale testing using simulated wave actions

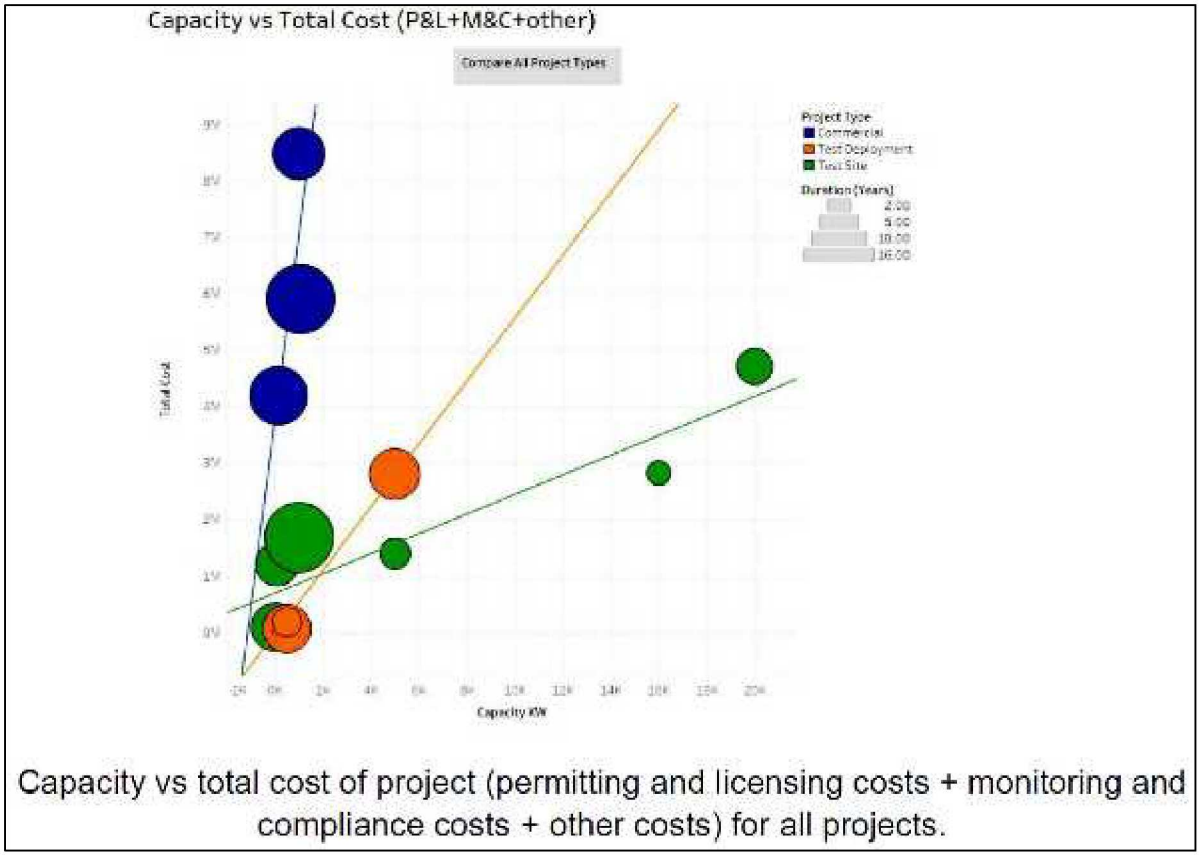


SWEPT is mobile – built in shipping containers

https://youtu.be/lQgPLUfttN8

Environmental Permitting and Compliance Costs

- **Goal:** Gathering cost data gathering for future deployments/tests feeding into O&M costs

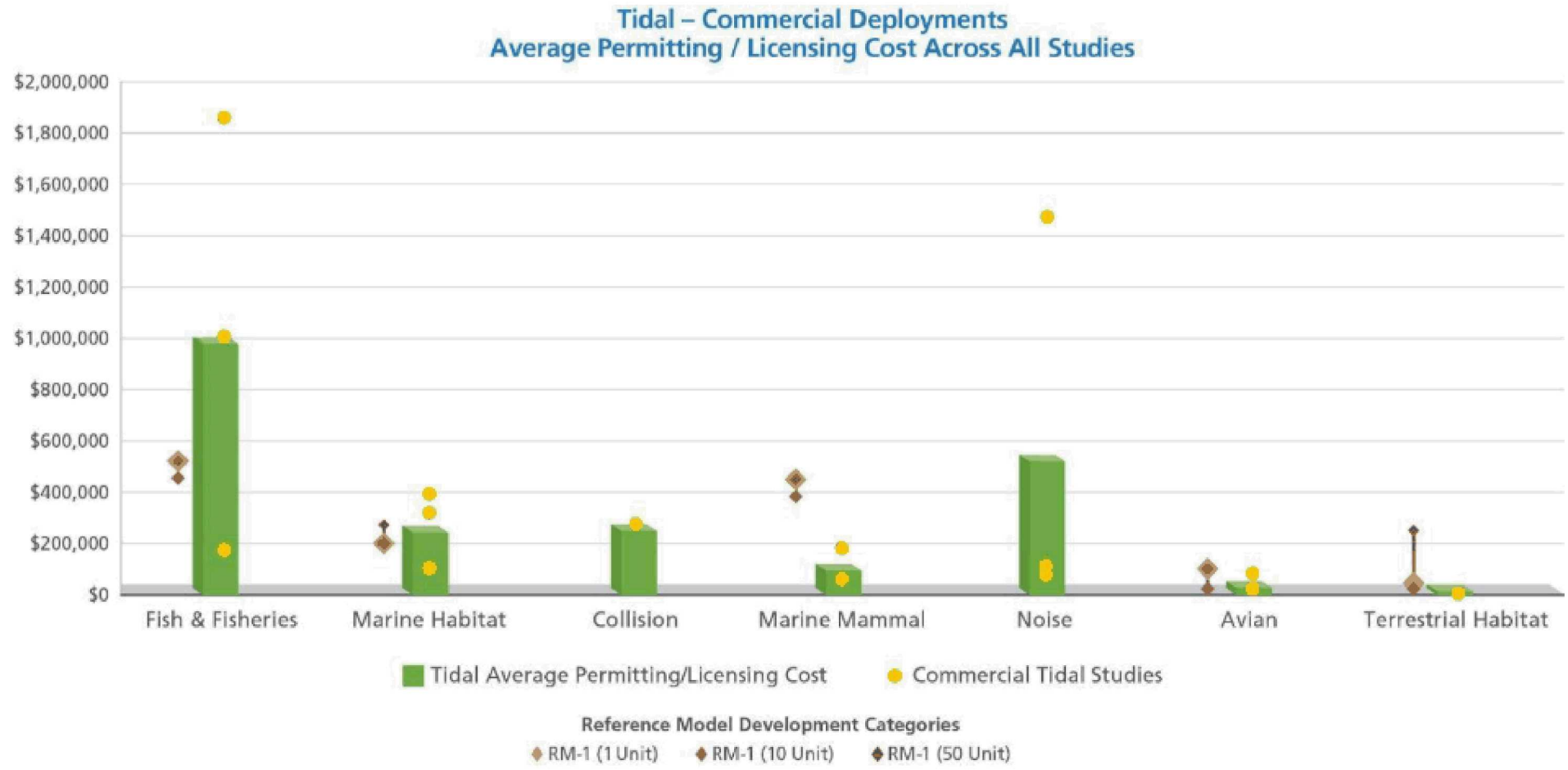


Capacity vs total cost of project (permitting and licensing costs + monitoring and compliance costs + other costs) for all projects.

Source: Peplinski et al., 2019

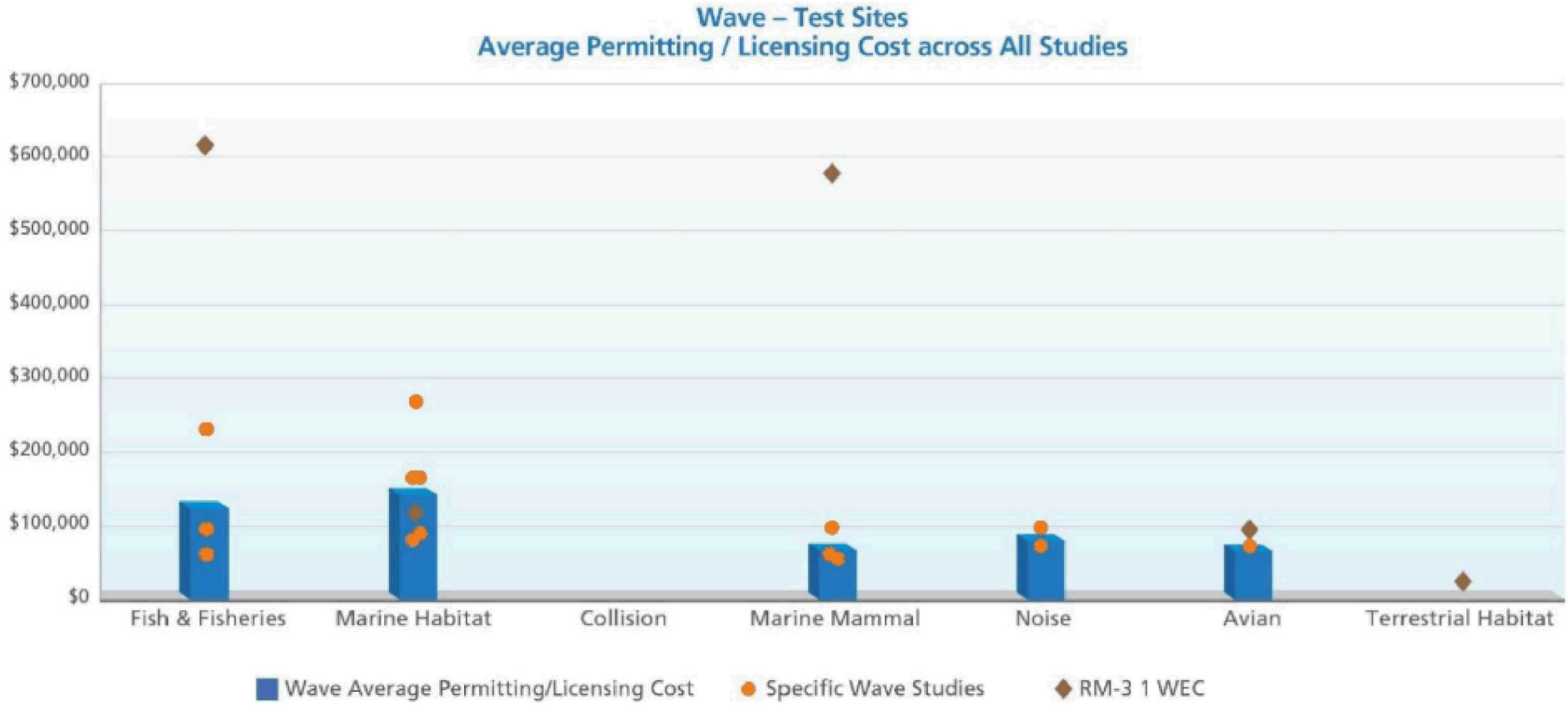
Environmental Permitting and Compliance Costs:

Tidal Power - Reference Model vs. Survey Data Insights



Source: Peplinski et al., 2019

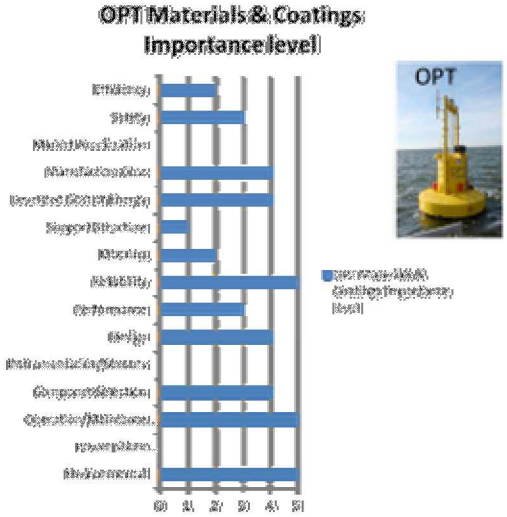
Environmental Permitting and Compliance Costs:
Wave Power - Reference Model vs. Survey Data Insights



Source: Peplinski et al., 2019

MHK Advanced Materials & Coatings

MHK Industrial Review

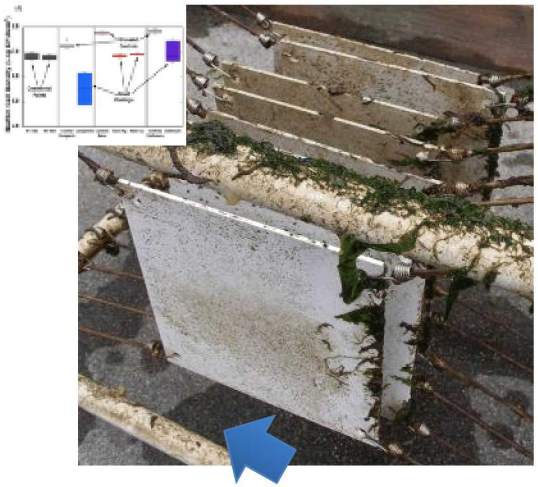


Water Power
Materials Science
& Engineering

PNNL Marine
Science
Laboratory

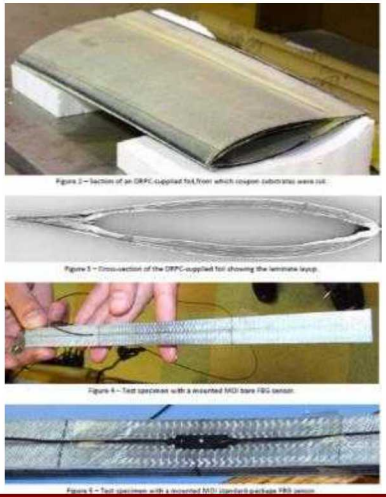
Pacific Northwest
NATIONAL LABORATORY

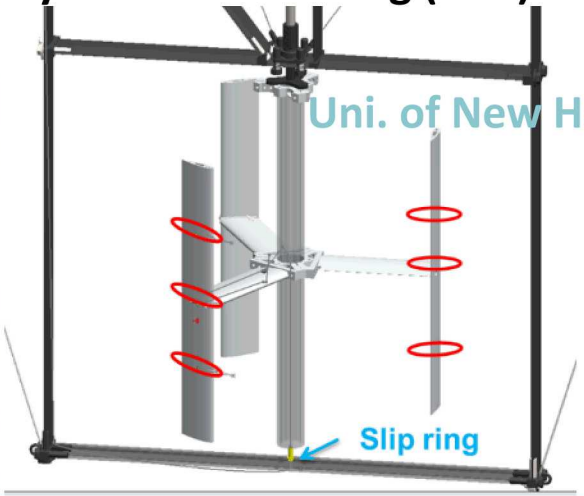
Protective Coatings



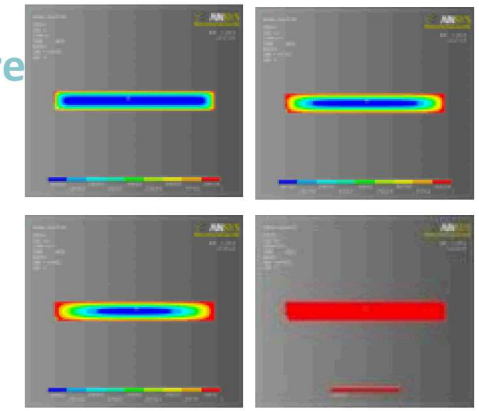
PNNL Open Water Testing

Materials Reliability: SHM Monitoring (FBG)

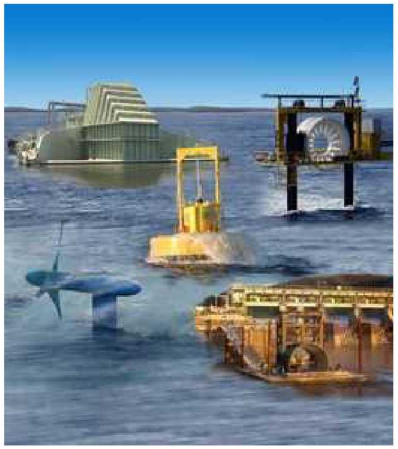




MHK Composite Performance



Addressing Barriers & Uncertainty in Using Composite Materials for Marine Hydrokinetic (MHK) Technology



MHK GPRA (Government Performance and Results Act) LCOE Goal: $0.27/kWH by 2030.

- Cost reduction for structural weight & construction costs ($/lb.)
- Composite cost is considered expensive and steel construction preferred (established vs. unknown)

Sandia National Laboratories · Montana State University · Pacific Northwest National Laboratory · NREL National Renewable Energy Laboratory · FAU Florida Atlantic University

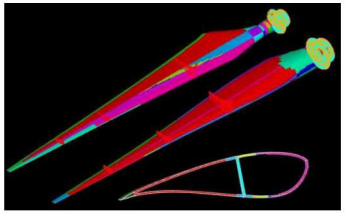
Multi-Laboratory Program Working to Meet Industry Research Needs

Sea Water Effects on Composite Performance

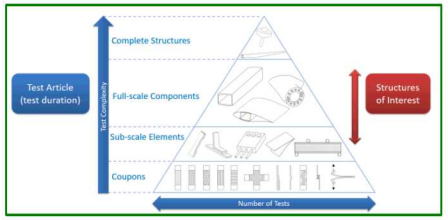
Biofouling & Environmental Effects on Composites

Corrosion of Metal – Carbon Fiber Composite Interconnects

Load/Environmental Effects on Subscale Elements & Joined Coupons



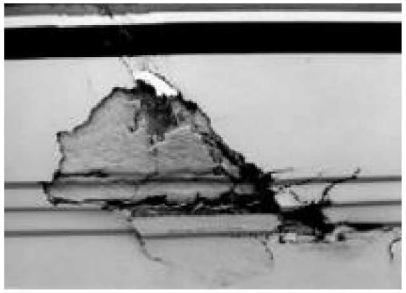
Load/Environmental Effects on Full Scale Subcomponent Testing



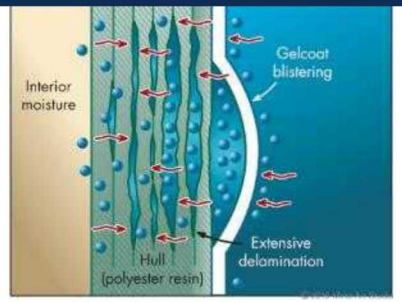
Materials Research

Engineering designs of MHK devices have difficult, although not unique, materials challenges

lightweight yet stiff



Strong & durable

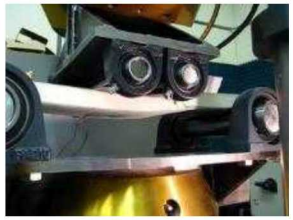


resist environmental degradation

inexpensive & easy to integrate into manufacturing

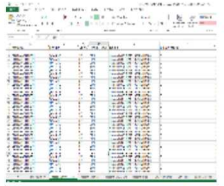
- Specialized applications require this level of materials application, knowledge and sophistication
- Challenges require broad experience to understand all of these challenges
- Our Technical Approach is to help bridge the technology gaps and knowledge that span across all four of these materials challenges through….

Coupons to Structural elements



Elements to Substructure

Testing to Dissemination (host database)



- **<u>Hosted Workshop to Identify Composite Related Barriers</u>** – What are the composite materials related manufacturing science and engineering barriers that increase the costs?

Concluding Remarks

→ LCOE

- Long term performance data coming
- O&M, unforeseen deployment costs coming into view
- Current opportunities to refine field data-driven LCOE

→ R&D Approaches and Topics

- Wave Energy Prize, Permitting & Compliance Cost Modeling, Materials Research
- Increasing technology performance & decreasing cost uncertainties

→ R&D efforts

- Increasing Performance and decreasing Capital & O&M costs
- LCOE being refined as technology moves from niche to larger markets

Acknowledgements

- The authors would like to thank the Department of Energy, office of Energy, Efficiency & Renewable Energy for supporting this research, as well as colleagues at Sandia National Laboratories including but not limited to Bernie Hernandez and Will Peplinski within the Water Power Technologies program, others at the National Renewable Energy Laboratory, other national laboratories and in the Marine Hydrokinetic research and industrial community.
- Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

THANK YOU

Select References

- Dallman, A., Jenne, D.S., Neary, V., Driscoll, F., Thresher, R. and B. Gunawan, 2018, Evaluation of performance metrics for the Wave Energy Prize converters tested at 1/20th scale, Renewable and Sustainable Energy Reviews, 98, pp. 79-91.
- Neary, V. S., Lawson, M., Previsic, M., Copping, A., Hallett, K.C., Labonte, A., Rieks, J. and D. Murray, 2014, Methodology for design and economic analysis of marine energy conversion (MEC) technologies, Tech Rep. SAND2014-9040, March.
- Neary, V., Kobos, P., Jenne, D.S. and Y-H Yu, 2016, Levelized Cost of Energy for Marine Energy Conversion (MEC) Technologies, EPRC6, Santa Fe, NM, September 8-9, 2016.
- Neary, V., 2017, Reducing Levelized Cost of Energy: A National Laboratory Perspective, National Hydropower Association Water Power Week, Washington, D.C., May 1−3.
- Peplinski, W., Roberts, J., S. Kramer and A. West, 2019, Marine and Hydrokinetic (MHK) Environmental Compliance Cost Assessment Project – Strategies Workshop, April 3, Washington, D.C.

Backup Slides

LCOE Formula (CapEx Categories)

- Development
- Infrastructure
- Mooring/Foundation
- Device Structural Components
- Power Take Off (PTO)
- Subsystem Integration & Profit Margin
- Installation
- Contingency

$$\mathrm{LCOE} = \frac{(\mathrm{FCR} \times \mathrm{CapEx}) + \mathrm{OpEx}}{\mathrm{AEP}}$$

LCOE Formula (OpEx Categories)

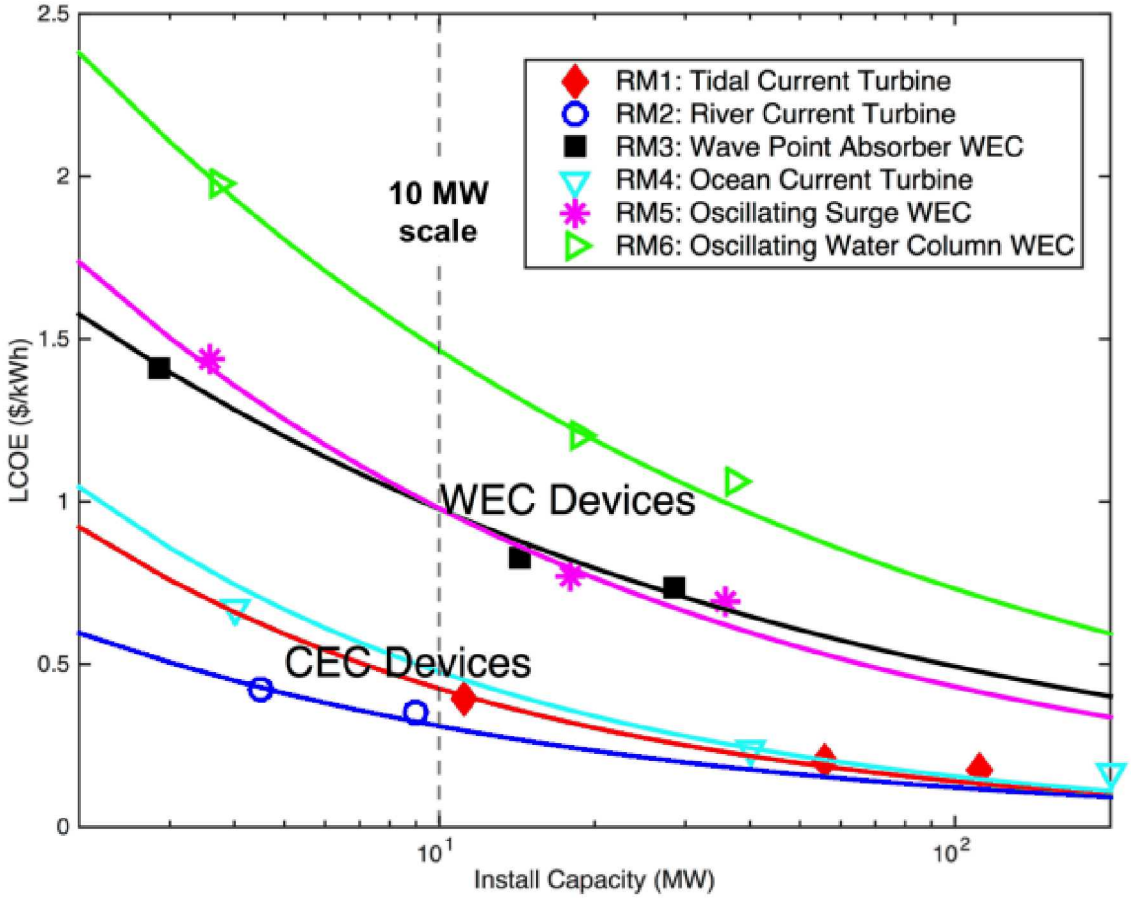
- Marine Operations & Maintenance (O&M)
- Shore-side Operations & Maintenance (O&M)
- Post Installation Environmental O&M
- Replacement Parts
- Consumables
- Insurance

$$\mathrm{LCOE} = \frac{(\mathrm{FCR} \times \mathrm{CapEx}) + \mathrm{OpEx}}{\mathrm{AEP}}$$

Reference Model Results/Estimates:

10 MW Installed Capacity

- Wave Energy Converters (WECs)
  - ≈ $0.98-1.53/kWh
  - At 10 MW structural mass is the largest contributor to LCOE.
- Current Energy Converters (CECs)
  - ≈ $0.31-0.45/kWh
  - Varying resource conditions impact installation, permitting, capacity factors, etc.



Technology Build out will help verify Cost reductions

Source: Neary et al., 2014, 2016, 2017

Device Performance Modeling: Reference Models

Developed 6 public domain designs to obtain baseline performance and Cost of Energy (COE) estimates

Incorporated:

- Power performance models
- Structural models
- Anchor and Mooring Design
- Economic Model
- PTO Design
- O&M / Installation
- Permitting & Environment

Project Impact:

- All reference models are public domain serving broader stakeh needs
- Process of obtaining COE facilitates knowledge / modeling tool gaps that the industry is facing thus allowing DOE to target their researc dollars effectively
- The creation of independent and experimentally verified COE acro multiple device architectures legitimizes the comparison

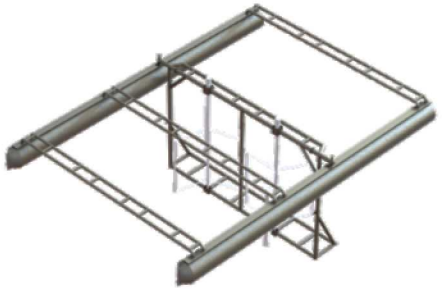
Information Dissemination:

- Project reports, Reference model designs
- Data from scaled model studies, COE model spreadsheets
- Release of RM5 and RM6 information

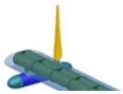
Tidal Turbine horizontal axis

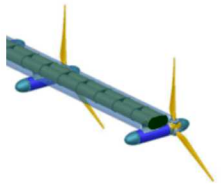
Point Absorber dual absorber

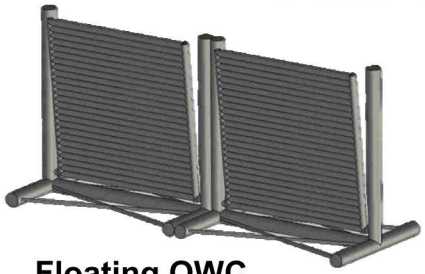
River Turbine vertical axis



Open Ocean Current horizontal axis

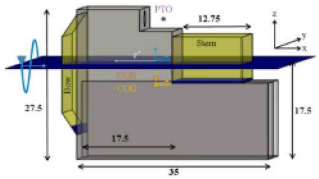






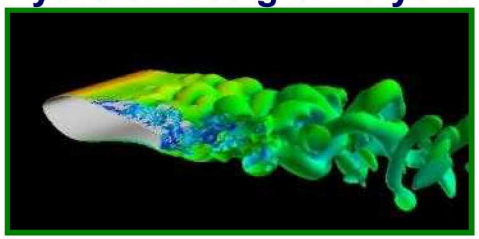
Floating OWC BBDB

Floating Surge Pitching Flaps

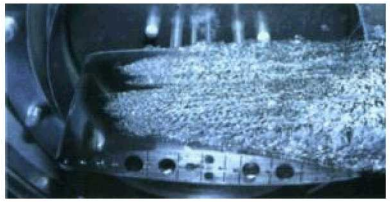


MHK Research Focus Areas at Sandia National Labs

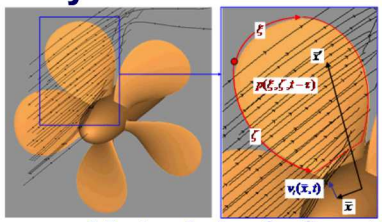
Hydrofoil Design/Analysis



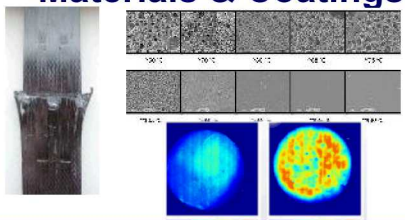
Cavitation



Hydro-Acoustics



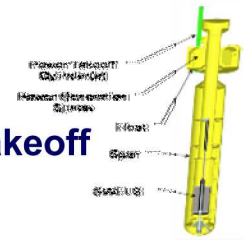
Materials & Coatings



Performance Modeling

Rotor Design & Testing

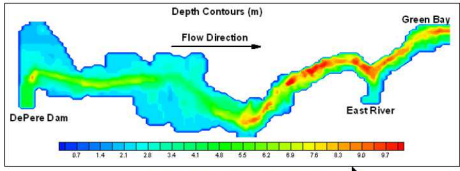
Power Takeoff Testing



Columbia Power 1/15th Scale Test (OSU)

Water Tunnel (PSU/ARL)

Coupled Device Array and Environmental Analysis



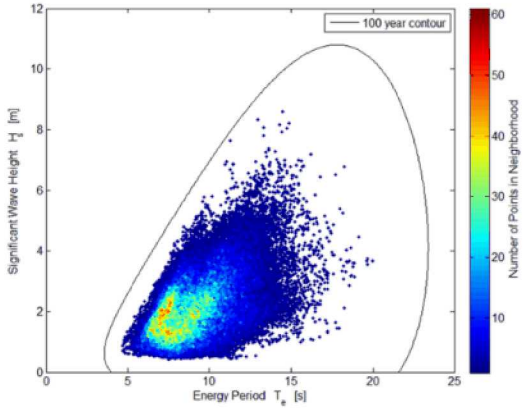
SNL EFDC

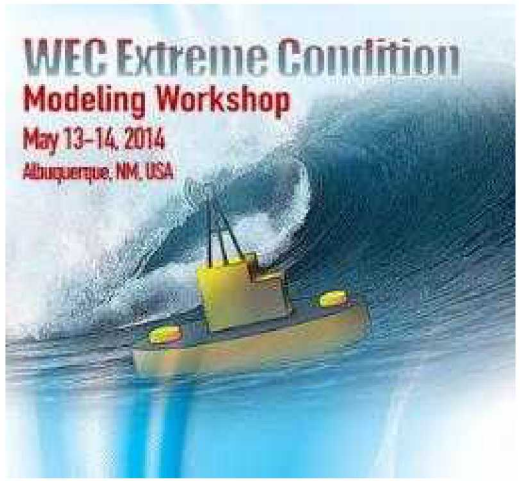
Technology Development Cycle

Components | Sub-systems | System Testing | Deployment

Device Performance Modeling

WECs must be designed to respond to ocean waves: Probabilistic methods for predicting extreme design loads → Improve best-practices for design response analysis of WECs





Images courtesy of Columbia Power