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

CalWave
Open Water Demonstration

DE-EE0008097

CalWave Power Technologies

Marine and Hydrokinetics Program

October 10th 2019

Thomas Boerner M.Sc. M.Sc.

CalWave Power Technologies Inc.

Project Overview

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

Project Summary

Under FOA-1663, CalWave Power Technologies Inc (CalWave) uses advanced numerical simulations, hardware/tank testing, and ultimately **scaled open water demonstration** to increase the TRL level of an advanced WEC design while continuing to exceed DOE's target ACE threshold of 3 meters/M$. Budget Period 1 concluded in June 2019 with detailed design of the scaled demonstration unit and bench testing of the critical hardware components. Budget Period 2 entails the installation and operation of the demonstration unit in open water close to the Scripps Institution of Oceanography.

Project Objective & Impact

- Detailed design and fabrication planning of the scaled demonstration unit; risk management; installation, operation and maintenance planning;
- Validation of device performance and wave load management capabilities using advanced numerical simulations, wave tank testing, and hardware-in-the-loop component testing
- Manufacturing, open sea deployment, operation and decommissioning of the scaled demonstration unit
- Performance and load measurements for validating of high techno-economic performance of the full-scale device.
- Advance the TRL of CalWave's WEC design while continuing to exceed DOE's target ACE threshold of 3 meters/M$

Project Information

Project Principal Investigator(s)

Marcus Lehmann, Ph.D.
Thomas Boerner M.Sc. M.Sc.

WPTO Lead

Yana Shininger
Lauren Moraski
Martha Amador

Project Partners/Subs

Sandia National Laboratory
National Renewable Energy Laboratory
UC Berkeley & UC San Diego/Scripps
Czero, Evergreen Innovations
Glosten Associates
Delmar Systems

Project Duration

Project Start: **September** 2017
Project End: **February** 2021

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Alignment with the Program

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

Marine and Hydrokinetics (MHK) Program Strategic Approaches

Data Sharing and Analysis

Foundational and Crosscutting R&D	Technology-Specific Design and Validation	Reducing Barriers to Testing

Alignment with the MHK Program

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Foundational and Crosscutting R&D

- Drive innovation in components, controls, manufacturing, materials and systems with early-stage R&D specific to MHK applications
- Develop, improve, and validate numerical and experimental tools and methodologies needed to improve understanding of important fluid-structure interactions
- Improve MHK resource assessments and characterizations needed to optimize devices and arrays, and understand extreme conditions
- Collaboratively develop and apply quantitative metrics to identify and advance technologies with high ultimate techno-economic potential for their market applications

1. CalWave's Holistic Control approach:
Novel load management capabilities to directly control the energy input/wave loads exerted into the physical structure:

Absorber hydrodynamic tuning and load management

Being similar to pitch- and yaw control in wind energy, this novel approach has not been implemented in any deployed WEC so far. However, this allows a paradigm shift in designing and operating WEC devices.

2. Experimental system identification tests for multiple degrees of freedom:
Derivation of precise hydrodynamic models for simulation and control via experiments.

SNL staff attended wave tank testing campaigns. Results were used to **verify the system identification principles/approaches published by Sandia** prior using a floating point-absorber for an inherently different WEC architecture.

Alignment with the MHK Program

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Technology-Specific Design and Validation

- **Validate performance and reliability of systems by conducting in-water tests of industry-designed prototypes at multiple relevant scales**
- Improve methods for safe and cost-efficient installation, grid integration, operations, monitoring, maintenance, and decommissioning of MHK technologies
- **Support the development and adoption of international standards for device performance and insurance certification**
- Evaluate current and potential future needs for MHK-specific IO&M infrastructure (vessels, port facilities, etc.) and possible approaches to bridge gaps

1. WECs high performance numerical prediction and capability to survive extreme wave events was validated during **7 weeks of wave tank testing** at 1:25 scale (operational cases) and 1:30 scale (survival cases).

2. IEC-TS 62600-103 draft **standards** (wave tank assessment) guidelines **applied and critically evaluated.**

3. Final project objectives:
- Deployment and operation of a scaled device **in open ocean.**
- Device **performance validation**
- Validate novel **Holistic Control** approach including hydrodynamic tuning and absorber load management

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Project Budget

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1. Total Project Budget – Award Information		
DOE	Cost-share	Total
4,413 [$K]	1,104 [$K]	5,517 [$K]

2. Budget History			3. Total Actual Costs
FY17	FY18	FY19 (Q1 & Q2 Only)	FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
69 [$K]	1,586 [$K]	911 [$K]	2,566 [$K]

- No-Cost extension (< 4 month) caused slight delay in budget execution in BP1
- Project still expected to be completed within initial total budget

Management and Technical Approach

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CalWave *Project Management Plan as a designated task*:

- Product requirements & specifications;
- Tasks outcome thoroughly defined
- SOPO, specification catalogues, involved parties, interdependency between tasks

SMART techno-economic metrics for performance monitoring:

- e.g. LCOE, ACE, device load and power ratios, project timelines
- CalWave baseline defined at start
- Technical and commercial viability dictate *development targets*

CalWave Power Technologies

- Designated CalWave contact for each external partners
- Established workflow also *among* involved parties

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Management and Technical Approach

(Budget Period 1) Project Setup

- Six task groups with sub-tasks (WEC design and lab testing period)
- 11 Milestones passed including Milestone verification (external parties)
- 11 Deliverables submitted to MHK-DR including: Content models, design reports, tank testing setup, data, ..)

BP 1 Task Groups

1. Develop WEC System Design
2. Numerical Modeling, Controls Development, and Implementation
3. Subsystem Lab Testing and De-Risking
4. System Fabrication Plan
5. Preliminary IO&M and test planning
6. Open Water Site Permitting and Planning

- Quarterly DOE WPTO update calls & research reports (RPPRs)
- 7 RPPRs submitted → 7 x Green project health indicator
- Successful DOE Go/NoGo Review June 2019 → BP2 Go recommendation received

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WATER POWER TECHNOLOGIES OFFICE

Management and Technical Approach

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#1 Holistic (Controls) Co-Design Approach

- Concurrent design of device controls and all subsystems
- Load Management Control allows for cost efficient design and safe operation (Yaw and Pitch Control in Wind)
- *Hydrodynamic Tuning allows for efficient operation, device power rating & sizing*

WEC Geometry	WEC Kinematics	PTO Dynamics and Impedance	Shared PTO infrastructure and Power Electronics
Hull and PTO load management	*True* Multi-DOF Absorption	PTO Force Tracking	Load Balancing

#2 Key Technical Principles and Challenges

- Hydrodynamic models for advanced geometries and large device displacements
- Device kinematics for true multi-DOF devices influence WEC topology
- PTO dynamics require deep understanding of impedance matching in networks
- WEC Load Management principles as a novel field of research

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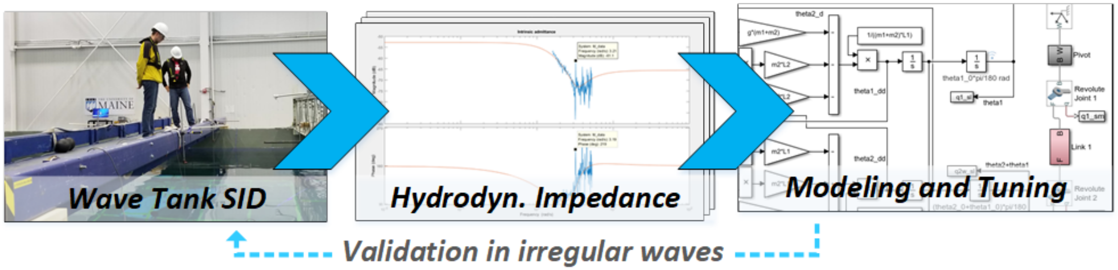
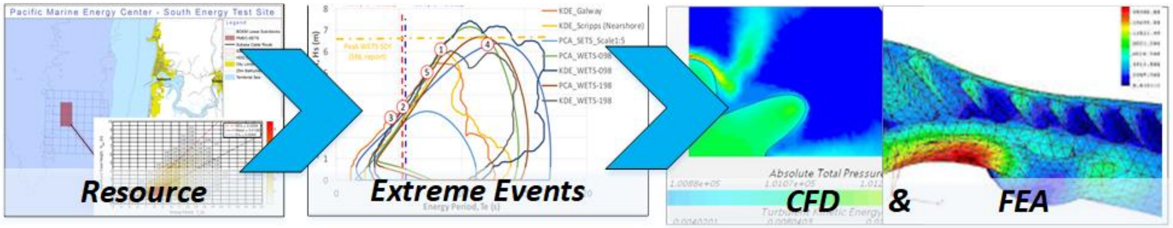
Management and Technical Approach

#3 Validation Efforts

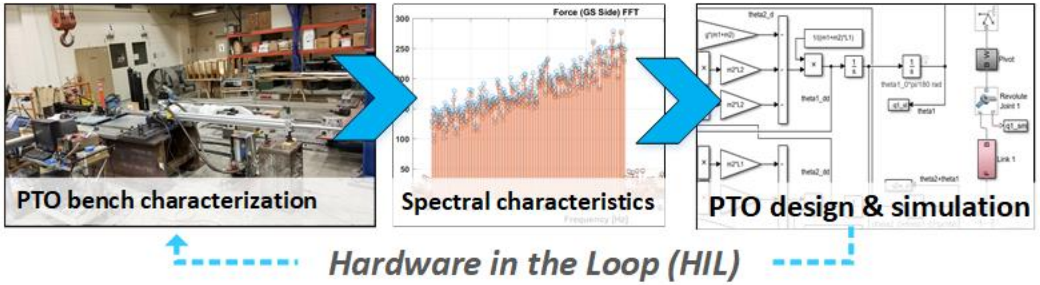
- Hydrodynamic Models



- Design Loads and Load Management Mechanisms



- PTO Dynamics and Impedance



#4 Third Party Review

- Sandia & IEC TAG members (Wave tank testing & PTO bench)
- NREL (Data post processing)
- DNV-GL (Design requirements and best practices)

Management and Technical Approach

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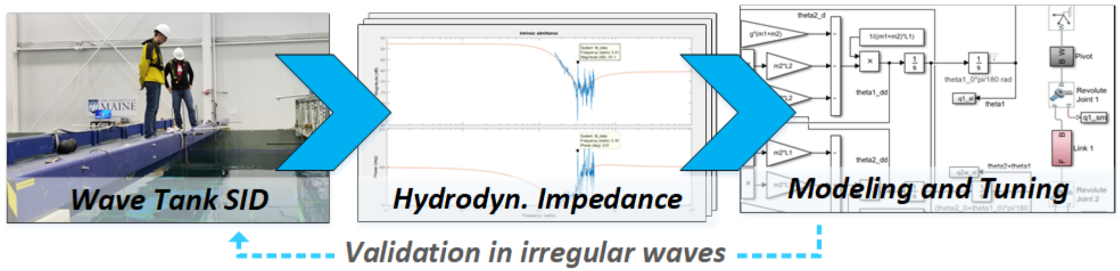

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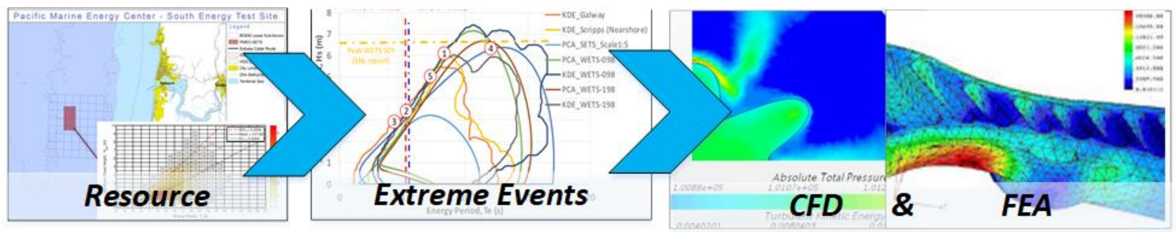

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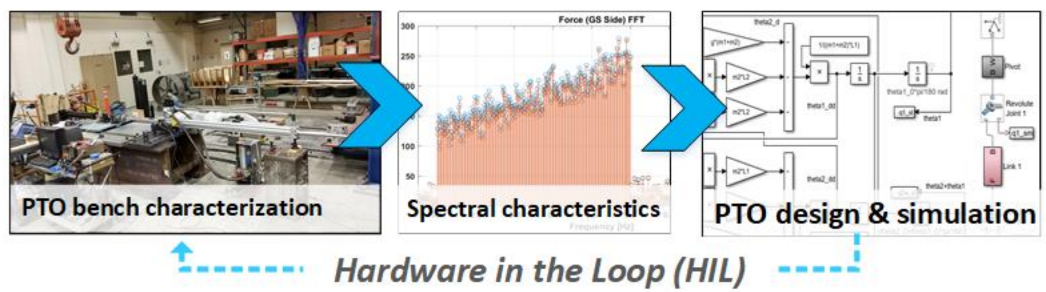

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Management and Technical Approach

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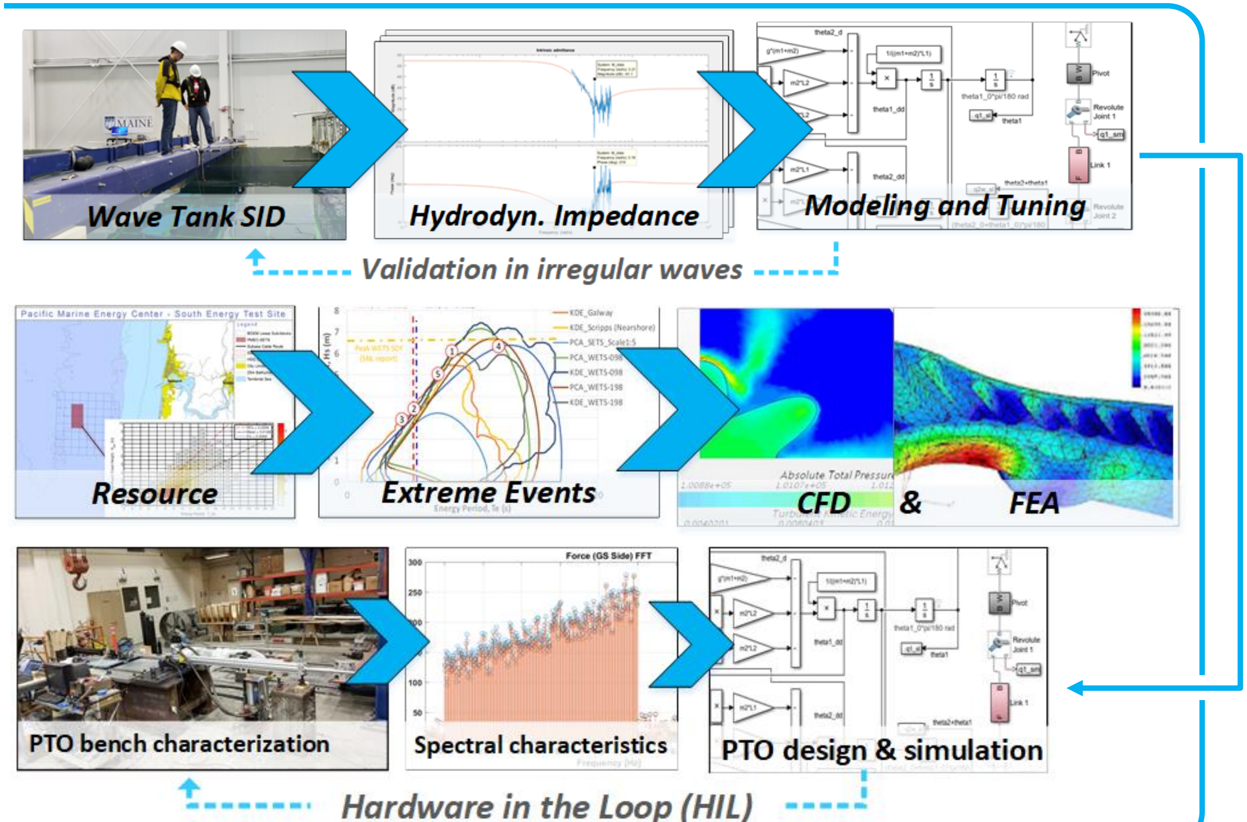

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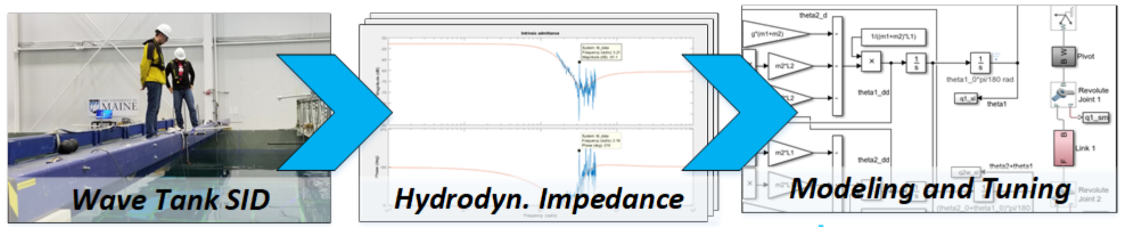
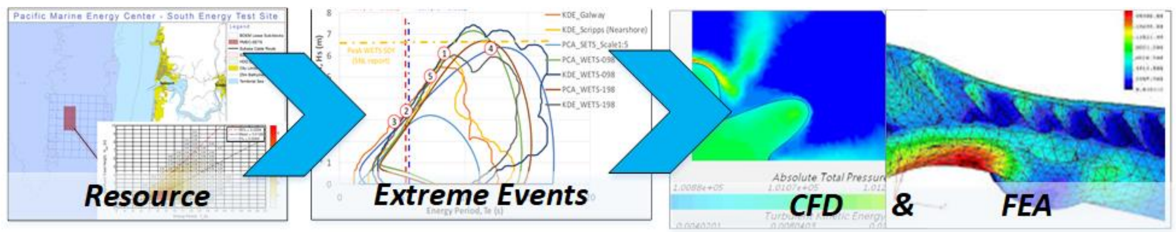
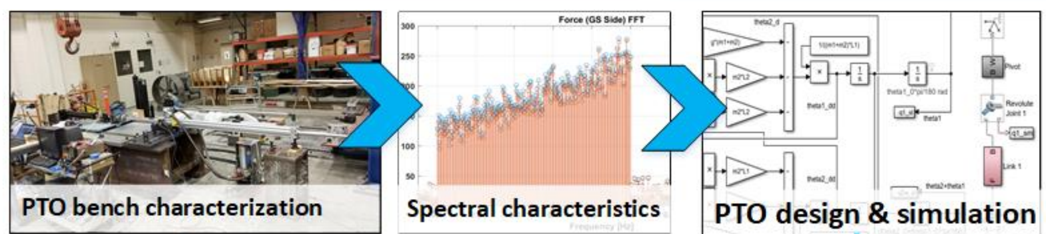


Validation in irregular waves

- Design Loads and Load Management Mechanisms



- PTO Dynamics and Impedance



Hardware in the Loop (HIL)

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End-User Engagement and Dissemination Strategy

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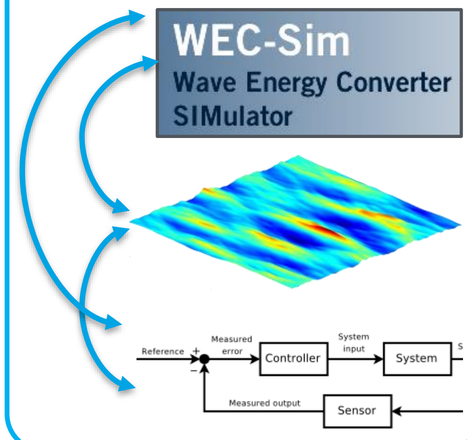
- Improvements and feedback to the WEC-Sim framework in collaboration with NREL and Evergreen Innovations (e.g. multi-DOF devices, numerical instabilities, Aqua-BEM integration, …)

- SNL: CFD modeling for extreme wave response: Coupling of CFD tools with other software environments (e.g. Simulink) to simulate staged failure modes of the device in extreme seas (presented at EWTEC 2019).

- Thorough documentation (>10 detailed reports) of a systematic device design on MHKDR for dissemination to the wider community.

- Demonstration device suitable for maritime markets (DOE's "Powering the Blue Economy"). Engagement with multiple potential customers from various industries. Customer discovery has updated and validated commercialization plan.

Advanced Research Community



Lessons learned for tech. developers

Customer and Users

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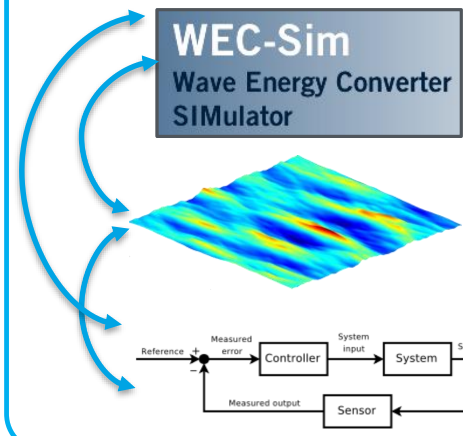

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MHK

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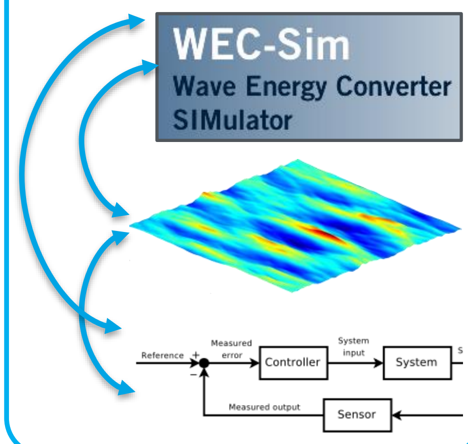

Lessons learned for tech. developers

Customer and Users

End-User Engagement and Dissemination Strategy

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- Raise awareness of MHK potential on state, local level and in the public domain.
- Ocean conservation awareness
- Promote importance of diverse renewable energies portfolio required for high targets of renewable energy grid penetration
- Engagement with California Energy Commission (EPIC)
- Scripps oceanographic/research community presentation
- Engaged with local congress affiliates

Global Climate Action Summit 2018

John Kerry learning about Wave Power

State Agencies

The Great Seal of the State of California

State of California Energy Commission

CITY OF BERKELEY

CITY OF OAKLAND

Public Domain

exploratorium

SOA

MBARI Monterey Bay Aquarium Research Institute

Technical Accomplishments

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Budget Period 1 Accomplishments (concluded June 2019):

Detailed design of scaled demonstration unit including all subsystems

- Absorber kinematics and hull design: Hydrodyn. and controls optimization
- PTO and conversion chain design: Physical and electric infrastructure
- Load management design: Physical mechanisms and actuation
- Mooring and anchor designed: Soil conditions and cost optimized

High techno-economic performance

Risk management, Installation, Maintenance and Operations planning

- 123 potential component/failure modes mitigation identified
- 110 potential activity failure modes and mitigation identified
- Over 31 high and mid risks removed or mitigated

De-risking project and technology

Sub-system lab testing & Hardware-in-the-loop

- PTO and conversion chain components thoroughly tested
- True to deployment scale setup
- Hardware-in-the-loop with validated hydrodynamic models
- 7 weeks of wave tank testing: SID, performance, and load management

Optimization and de-risking

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- PTO and conversion chain design: Physical and electric infrastructure
- Load management design: Physical mechanisms and actuation
- Mooring and anchor designed: Soil conditions and cost optimized

High techno-economic performance

Risk management, Installation, Maintenance and Operations planning

- 123 potential component/failure modes mitigation identified
- 110 potential activity failure modes and mitigation identified
- Over 31 high and mid risks removed or mitigated

De-risking project and technology

- PTO and conversion chain components thoroughly tested
- True to deployment scale setup
- Hardware-in-the-loop with validated hydrodynamic models
- 7 weeks of wave tank testing: SID, performance, and load management

Optimization and de-risking

Technical Accomplishments

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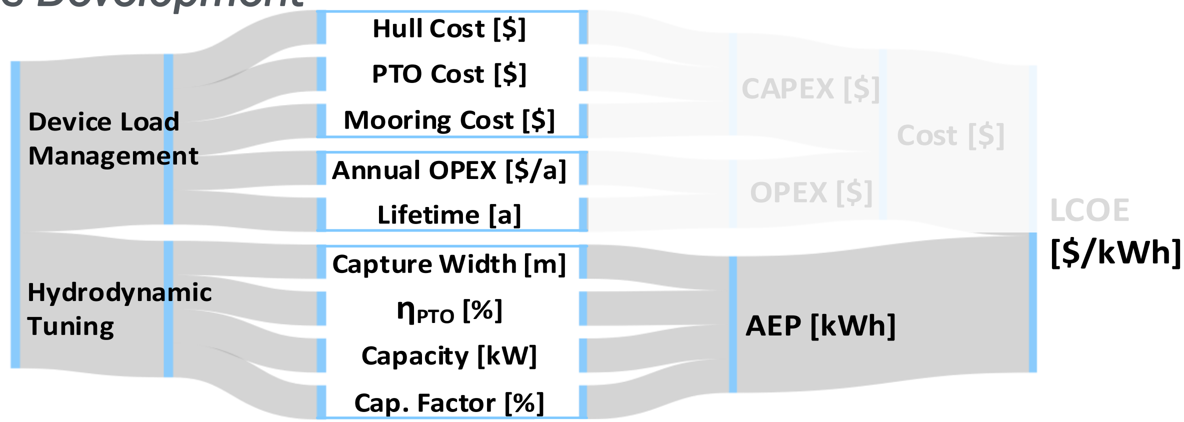
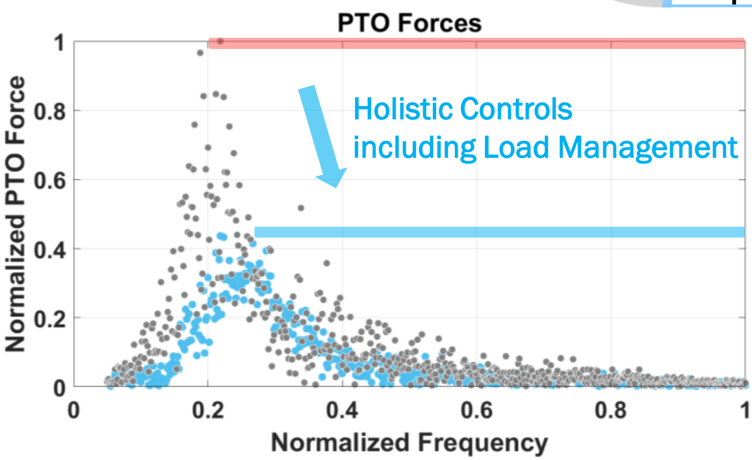
Holistic Controls Development

CalWave Power Technologies

Holistic Controls





CASE	CWR Improvement vs. WEP
IWS1	183.5%
IWS2	192.4%
IWS3	136.6%
IWS4	136.1%
IWS5	289.7%
IWS6	177.7%

→ **Load reduction** in extreme seas by average **factor of 2** (wave tank validated)

→ **Performance in absorption efficiency improved** by average **factor of 1.9** compared to Wave Energy Prize design (wave tank validated)

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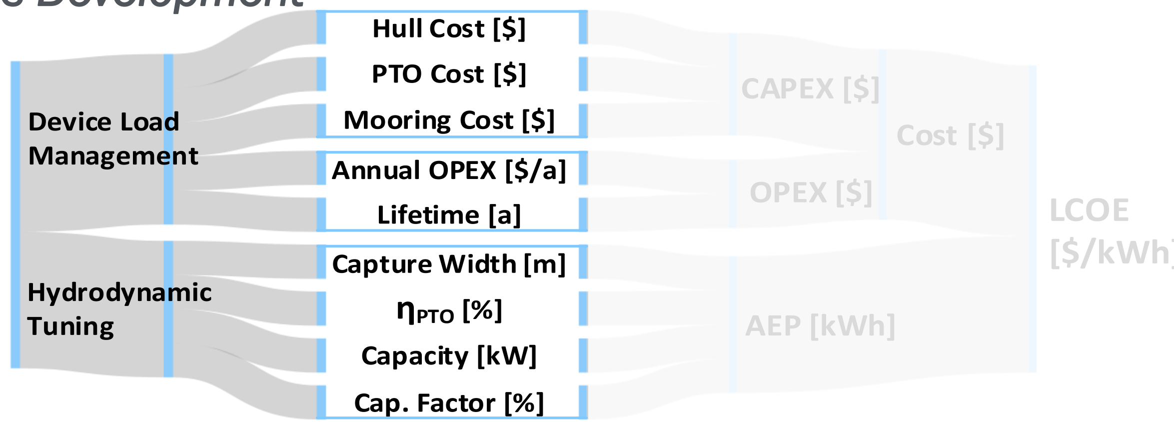

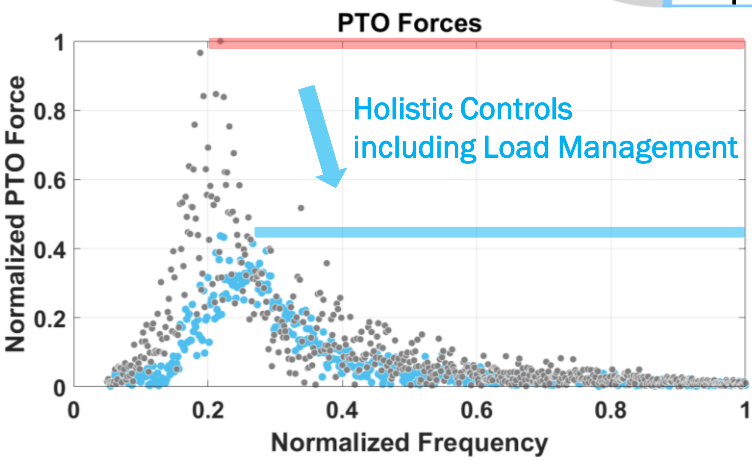

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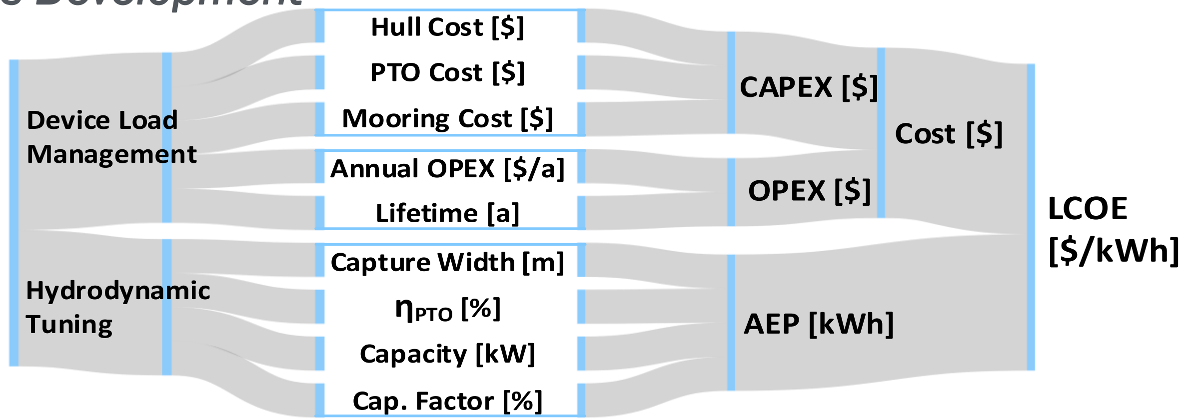

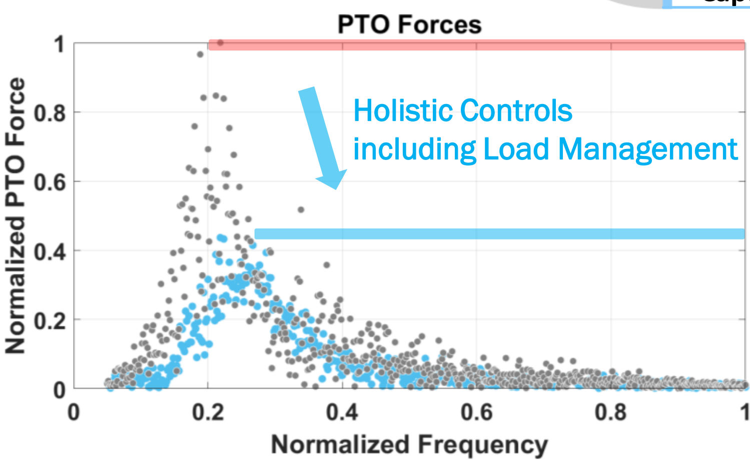

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Future Work

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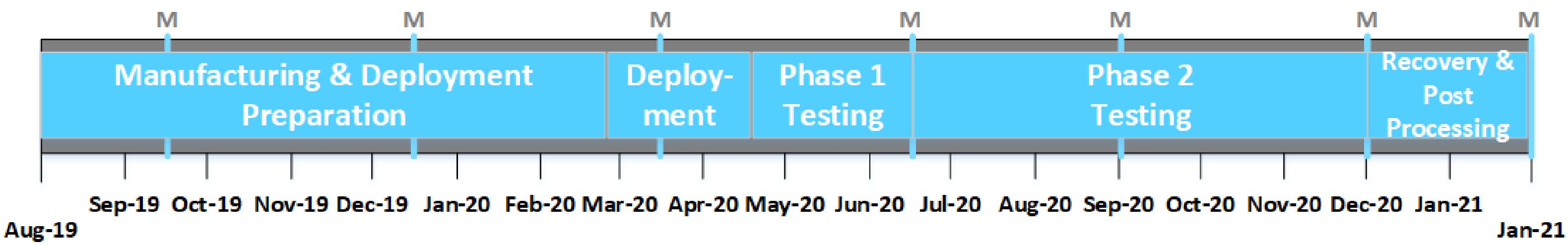
Budget Period 2 Setup

- 6 task groups with sub-tasks (device deployment and evaluation related)
- 6 upcoming Milestones: 2 operations/preparation related; 4 deployment related
- Device deployment Summer 2020
- Project concludes 2021: Decommissioning and deployment site remediation, Post-processing and data/report dissemination.
- Total BP2 budget remaining: $2,528,206



Project Outcome

- Validation of Holistic Controls impact: High device performance and load management capabilities
- Demonstrate survivability and effective load management in large sea states
- Validate numerical and lab device modeling tools

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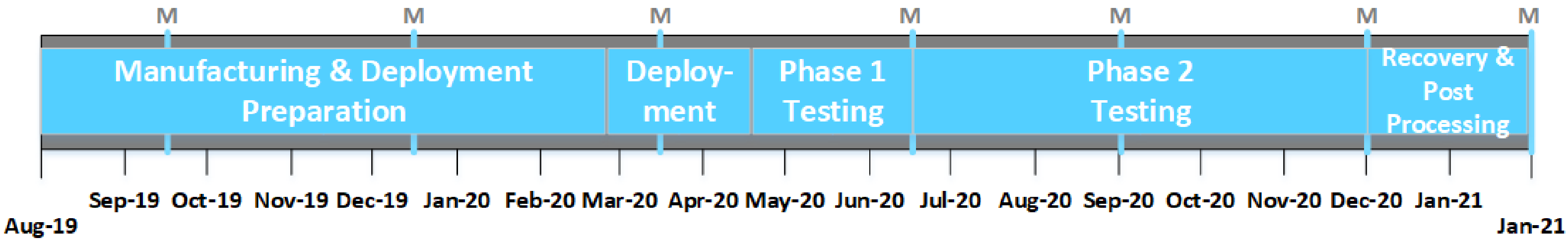

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