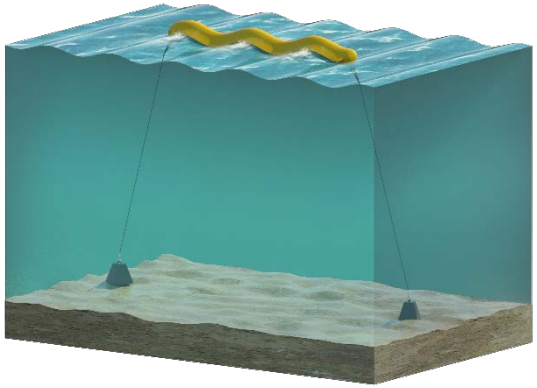
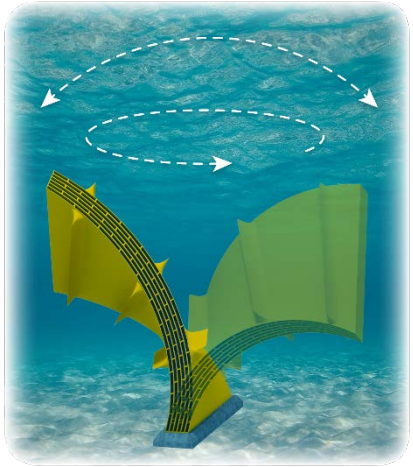
Flexible Material WEC Technology Techno-Economic Performance

2.2.1.407 / 34265





(Illustrations Various FlexWEC Concepts)

Marine and Hydrokinetics Program

9 October 2019

Jochem Weber

National Renewable Energy Laboratory

Project Overview

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

Project Summary

To investigate, innovate, assess, describe, and summarize the potential use of flexible materials with embedded distributed power (FMPDP) take-off systems for ocean wave energy conversion (WEC). To also disseminate results from the project to the renewable energy sector—showcasing the technology's potential for heightened techno-economic performance.

Project Objective & Impact

Primary Objectives: (1) System description, modeling, and investigation of FMDP-WEC concepts; (2) assessment of cost and performance drivers; (3) determination of techno-economic performance metrics; (4) assessment of achievability, remaining development costs, time, and risk to market; and (5) technical outreach to ensure impact and benefit for wider research, U.S. industry interest, and stakeholder satisfaction are understood and prioritized.

Impact: Renewable energy sector can benefit from this project as its results will identify whether another WEC technology and/or its subsystems show potential, promoting heightened techno-economic performance.

Project Information

Project Principal Investigator(s)

Jochem Weber, Chief Engineer, Ph.D.

WPTO Lead

Lauren Moraski

Project Partners/Subs

SBM Offshore—Information Source
Centrale Nantes—Scientific Advisory
Wave Venture—Scientific Advisory
Plymouth University—Scientific Advisory

Project Duration

Start Date: 1 July 2018
Project End Date: 31 March 2020

Alignment with the Program

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

Foundational and Crosscutting R&D

- **Driving innovation** in components, controls, manufacturing, materials and systems with early-stage R&D **specific to MHK applications.**
- **Developing, improving, and validating numerical and experimental tools** and methodologies needed to improve understanding of important fluid-structure interactions.

- Flexible materials with distributed power take-off systems embedded throughout (FMDP-WEC), appear to have many attractive characteristics: (1) broad-banded ocean wave energy absorption; (2) highly redundant multiplexed power take-off (PTO) systems; (3) near-continuous structural actuation and PTO control; (4) low cost and ease of material manufacture; and (5) simplified shipment and ocean deployment requirements.
- Development of new and novel numerical modeling schemes needed for modeling of flexible materials with distributed embedded PTO systems.
- Development of benchtop apparatus for empirical evaluation of flexible materials with distributed embedded PTO systems.

Project Budget

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Costed	Costed	Costed	Total Costed	Total Authorized
$0K	$0K	$51K	$51K	$426K

- FY19 Q3 and Q4 saw a noticeable increase in project expenditures as increased staff involvement and research are being conducted.
- Current expenditures are on pace with authorized budget.

Management and Technical Approach

Summarized Research Questions:

- What is the potential for those WECs with structures based upon flexible materials and whose power take-off systems are both embedded and distributed throughout that structure?
- Do FMDP-WECs represent a fundamental paradigm shift towards greater techno-economic feasibility for WEC development and commercialization?

Summarized Technical Approach:

- Research, distill, describe, and model those archetypical characteristics defining FMDP-WECs.
- Identify those cost-performance drivers predominantly associated with FMDP-WECs technologies.
- Assess the potential for FMDP-WECs to be game-changing, paradigm-shifting forms of WEC technology.
- Dissemination of results for review (e.g., journals, conferences, project website).

Summarized Management Approach:

- Regular counsel from external scientific advisors.
- Routine supervision via DOE meetings and updates.
- Inclusion of input from the Marine Energy Council.
- Incorporation of known industrial developer of FMDP-WEC technology.

Management and Technical Approach

Basic Project Schedule: Flexible Material WEC Technology Techno-Economic Performance

Q4 2018	Q1 2019	Q2 2019	Q3 2019	Q4 2019	Q1 2020	Q2 2020
• Project spool up.	• Interface with industry and scientific advisors regarding current state of the art and/or reference cases. • Investigation into theoretical and numerical modeling methods.	• New hire • Literature review and comprehension development for FMDP-WEC technologies. • Onset of numerical modeling efforts.	• Intern hire • Further FMDP-WEC technology research. • Identifying cost-performance drivers. • Implementation of structured assessment and innovation for FMDP-WEC technology awareness.	• New hire • Bench apparatus development to characterize flexible materials and PTOs. • Distillation of numerical modeling efforts.	• Preparation and development of project website for public dissemination of information. • Assessment of cost-performance drivers of FMDP-WEC archetype(s).	• Finalize project tasks and deliverables. • Look towards future and embarking upon those trajectories for continued FDMP-WEC research and development.
	• Internal Report: Description of FMDP-WEC reference cases.	• Internal Report: Description of theoretical and numerical modeling approach. • Webinar for industry input.	• Internal Report: Numerical model method.	• Internal Report: Numerical simulation results and model's effectiveness. • Internal Report: Cost and performance drivers.		• Internal Report: Describing life cycle of FDMP-WEC, application of FDMP-WEC technology, and opportunity for FDMP-WEC farms.

= Dominant Project Efforts = Major Milestones

Technical Approach

Research + Investigate

Understand + Describe

Model + Evaluate

Innovate to Know Full Potential

Assess Drivers of Cost + Performance

Management Approach

External Scientific Advisors: Centrale Nantes, Wave Venture, Plymouth University

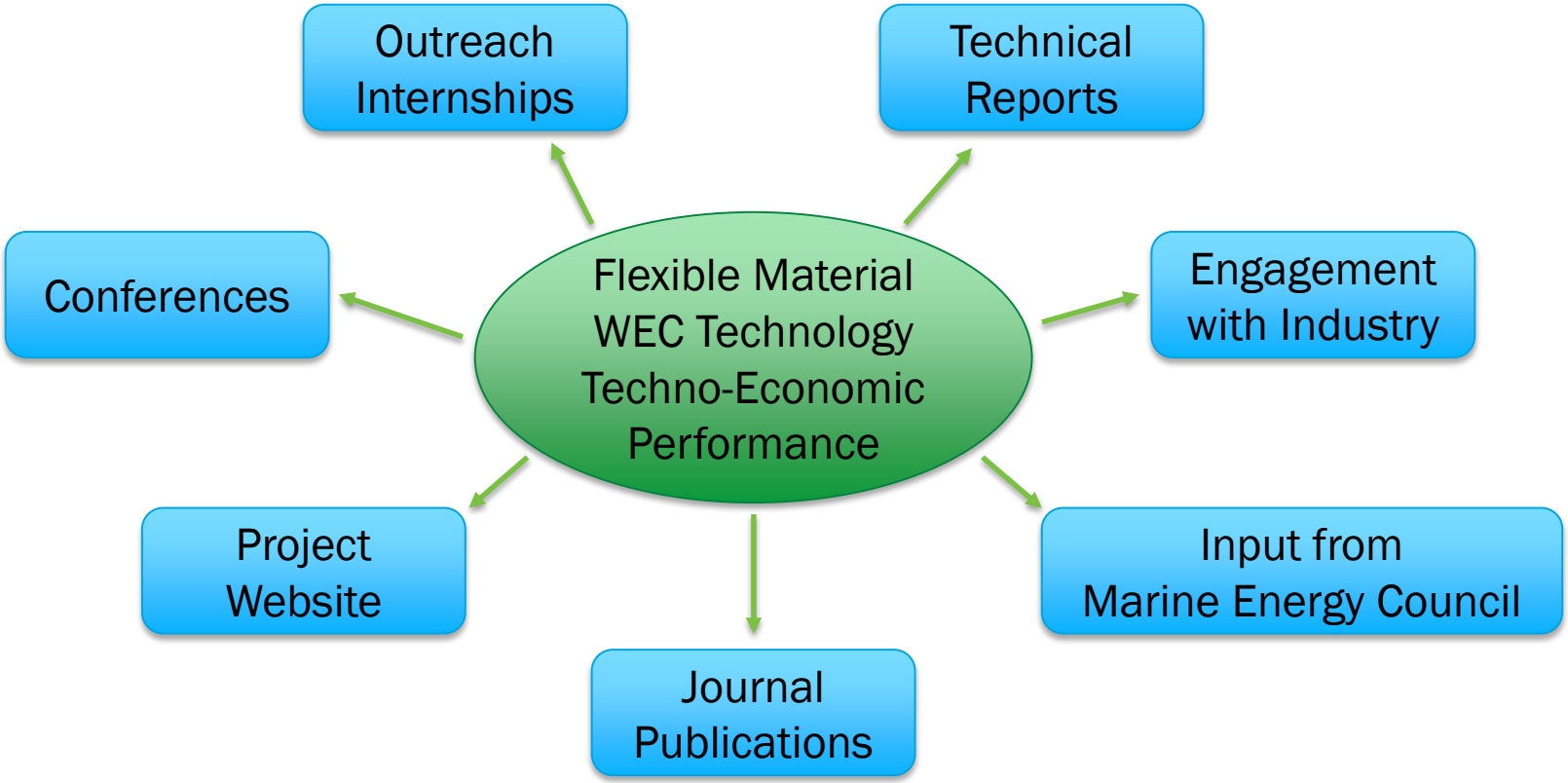
Regular Update Meetings with Department of Energy

Input from Marine Energy Council

Incorporating Industry, Known FMDP-WEC Developer SBM Offshore

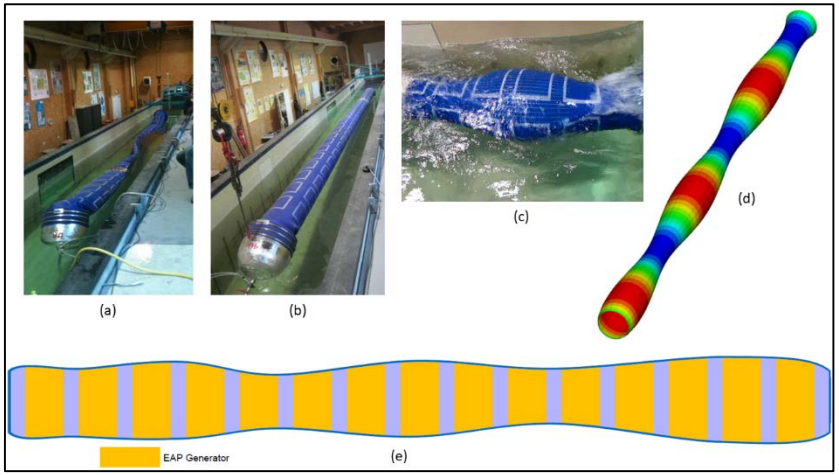
Inclusion of Technology Performance Level Assessments with Structured Innovation

End-User Engagement and Dissemination Strategy

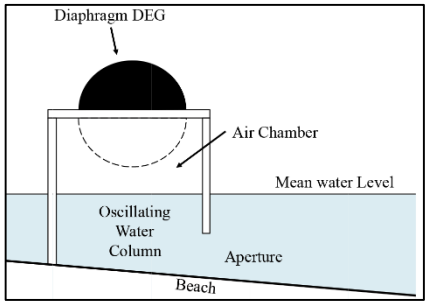


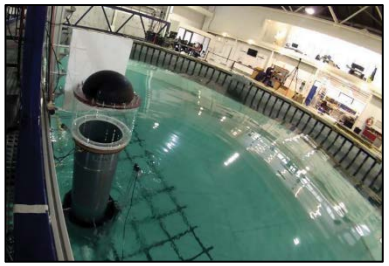
Technical Accomplishments

- Perform Thorough Literature Review
  - Identify and Research of FMDP-WEC Characteristics
    - Grasp Current State of the Art of FMDP-WEC Systems
      - SBM Offshore S3 Concept
      - Poly-OWC
    - Determine Key Subsystems
      - Elastic Polymers
      - Power Take-Off Systems
      - Power Electronics
      - Mooring Systems
  - Identify and Research Means of Manufacture
  - Identify and Research Maintenance and Repairs
  - Identify and Research Survival
  - Identify and Research Modeling Methods
  - Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy



SBM Offshore's S3 Concept; a FMDP-WEC whose radial expanding/contracting tube structure uses electro-active polymers to generate electricity from ocean waves.[1] (Images/Illustrations by SBM Offshore.)





Polymeric's Wave Energy Converter Concept; a FMDP-WEC whose bubble-like stretching diaphragm of dielectric elastomer generators bulges back and forth due to an oscillating water column.[2] (Images/Illustrations public domain via EU's CORDIS program.)

Technical Accomplishments (Cont.)

Perform Thorough Literature Review

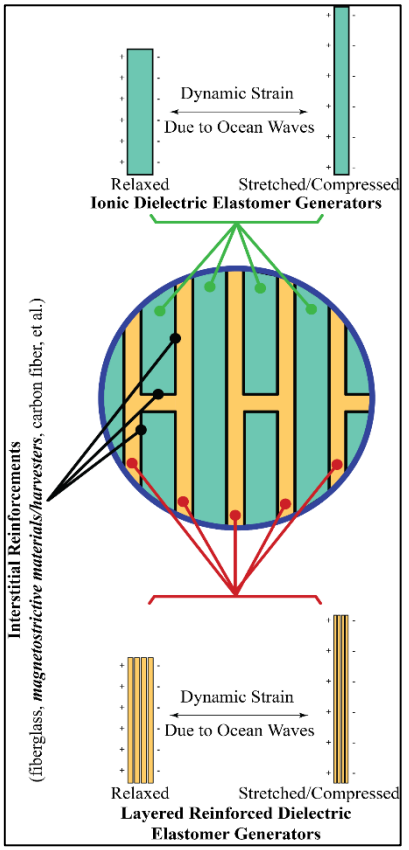
- Identify and Research of FMDP-WEC Characteristics
  - Grasp Current State of the Art of FMDP-WEC Systems
    - SBM Offshore S3 Concept
    - Poly-OWC
  - Determine Key Subsystems
    - Elastic Polymers
    - Power Take-Off Systems
    - Power Electronics
    - Mooring Systems
  - Identify and Research Means of Manufacture
  - Identify and Research Maintenance and Repairs
  - Identify and Research Survival
  - Identify and Research Modeling Methods
  - Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy

Dominant Flexible Materials Determined (Elastic Polymers)

Neoprene • Nitrile • Silicone • Polyurethane • Polyethylene

Power electronics capable of high voltage (>1kV) typically needed for pre-charging electro-active polymers of FMDP-WECs, buck-boost converters, fly back transformers, etc.

Special attention to **mooring system** attachment to FMDP-WECs should be carefully thought out; attachment from taut mooring cables to flexible materials could cause significant straining at the interface.



Most FMDP-WEC power take-off systems center upon the use of dielectric elastomer generators.

Technical Accomplishments (Cont.)

Perform Thorough Literature Review

- Identify and Research of FMDP-WEC Characteristics
  - Grasp Current State of the Art of FMDP-WEC Systems
    - SBM Offshore S3 Concept
    - Poly-OWC
  - Determine Key Subsystems
    - Elastic Polymers
    - Power Take-off Systems
    - Power Electronics
    - Mooring Systems
  - Identify and Research Means of Manufacture
  - Identify and Research Maintenance and Repairs
  - Identify and Research Survival
  - Identify and Research Modeling Methods
  - Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy

Major FMDP-WEC components could be produced using already existent synthetic rubber **manufacturing techniques**. The general means of FMDP-WECs manufacture, therefore, is straightforward and compact.

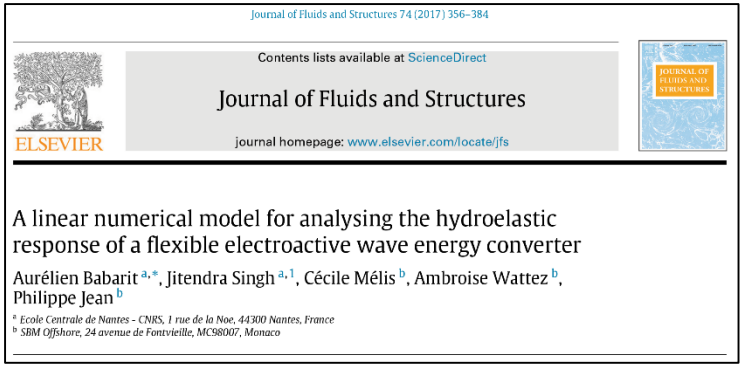
As with other elastomer-based technologies, FMDP-WECs need minimal **maintenance** as they have no gears, no electromechanical generators, no hydraulic lines/systems, etc.

Likewise for **repairs**, most malfunction can be fixed by gluing a replacement PTO or patch.

By there nature, FMDP-WECs are flexible enough to **survive** most large sea states. Indeed, for floating FMDP-WEC ballasted by air (e.g., SBM Offshore's S3 concept) they could simply breach their ballasts, scuttle themselves, and ride out a storm beneath the waves.

Technical Accomplishments (Cont.)

Perform Thorough Literature Review
- Identify and Research of FMDP-WEC Characteristics
  - Grasp Current State of the Art of FMDP-WEC Systems
    - SBM Offshore S3 Concept
    - Poly-OWC
  - Determine Key Subsystems
    - Elastic Polymers
    - Power Take-Off Systems
    - Power Electronics
    - Mooring Systems
- Identify and Research Means of Manufacture
- Identify and Research Maintenance and Repairs
- Identify and Research Survival and Recovery
- Identify and Research Modeling Methods
- Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy


Journal of Fluids and Structures 74 (2017) 356–384

Contents lists available at ScienceDirect

Journal of Fluids and Structures

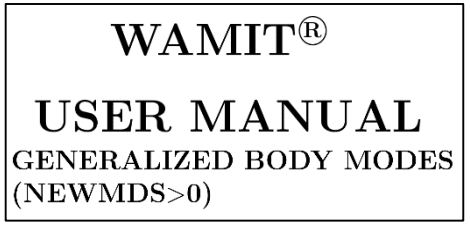
journal homepage: www.elsevier.com/locate/jfs

A linear numerical model for analysing the hydroelastic response of a flexible electroactive wave energy converter

Aurélien Babarit [a,*], Jitendra Singh [a,1], Cécile Mélis [b], Ambroise Wattez [b], Philippe Jean [b]

[a] Ecole Centrale de Nantes - CNRS, 1 rue de la Noe, 44300 Nantes, France
[b] SBM Offshore, 24 avenue de Fontvieille, MC98007, Monaco

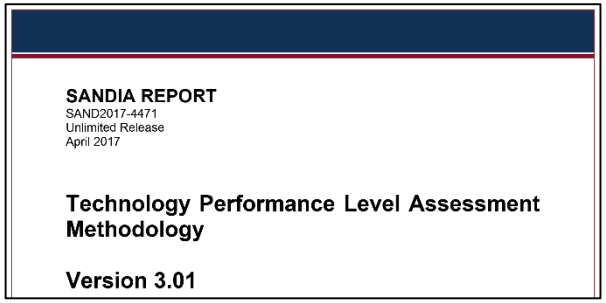
An effective source of information regarding the analysis of FMDP-WECs; Babarit's take on analytic models tubular FMDP-WECs.[3]


WAMIT®

USER MANUAL

GENERALIZED BODY MODES (NEWMDS>0)

A fruitful software tool to analyze ocean wave interactions with FMDP-WECs, especially in the sense of generalized/flexible body modes of motion.[4]


SANDIA REPORT
SAND2017-4471
Unlimited Release
April 2017

Technology Performance Level Assessment Methodology

Version 3.01

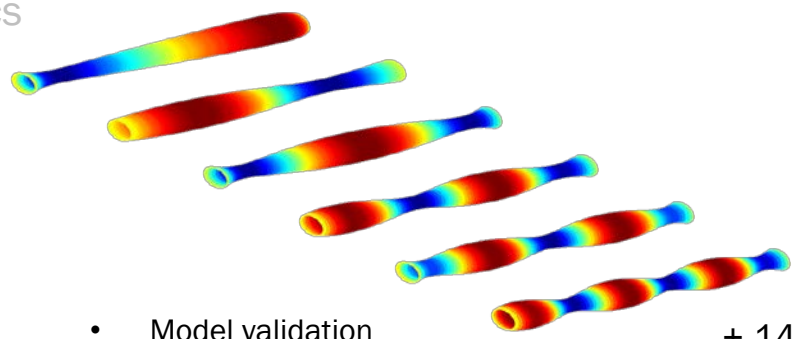
A means to assess the overall performance of FMDP-WECs; TPL Assessment Methodology.[5]

Technical Accomplishments (Cont.)

- Perform Thorough Literature Review
  - Identify and Research of FMDP-WEC Characteristics
    - Grasp Current State of the Art of FMDP-WEC Systems
      - SBM Offshore S3 Concept
      - Poly-OWC
    - Determine Key Sub-Systems
      - Elastic Polymers
      - Power Take-off Systems
      - Power Electronics
      - Mooring Systems
  - Identify and Research Means of Manufacture
  - Identify and Research Maintenance and Repairs
  - Identify and Research Survival and Recovery
  - Identify and Research Modeling Methods
  - Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy

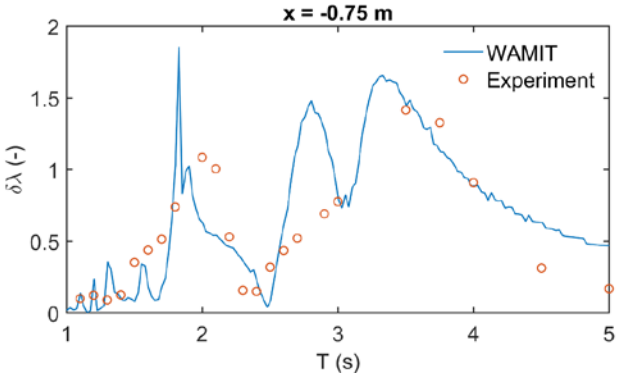
WAMIT Model

- 20 generalized body mode shapes



- Model validation

+ 14 higher order modes



WEC-Sim Model

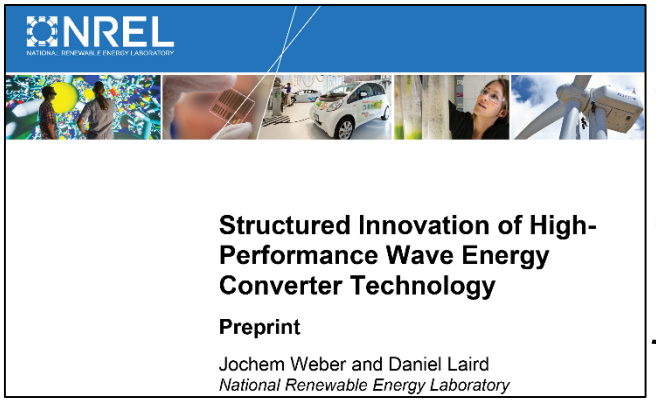
- Code changes have been validated with analytic solutions.
- The flexible tube model is still in development.

STAR-CCM+ Model

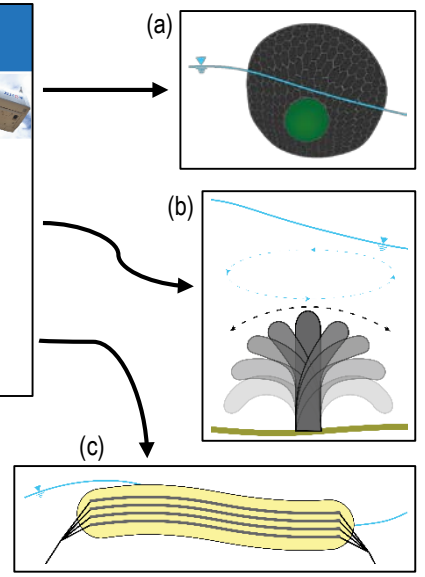
- The flexible tube model is still in development.

Technical Accomplishments (Cont.)

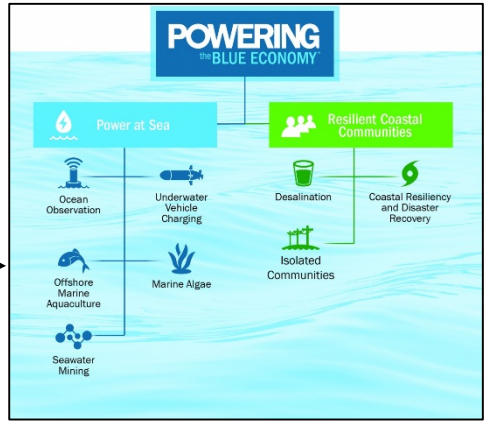
- Perform Thorough Literature Review
  - Identify and Research of
  - FMDP-WEC Characteristics
    - Grasp Current State of the Art of
    - FMDP-WEC Systems
      - SBM Offshore S3 Concept
      - Poly-OWC
    - Determine Key Subsystems
      - Elastic Polymers
      - Power Take-Off Systems
      - Power Electronics
      - Mooring Systems
  - Identify and Research Means of Manufacture
  - Identify and Research Maintenance and Repairs
  - Identify and Research Survival and Recovery
  - Identify and Research Modeling Methods
  - Identify and Research Appropriate Assessment Methods
- Implement Numerical Models
  - Analyze Results and Evaluate Effectiveness
- Structurally Innovate for Optimal FMDP-WEC Solutions
  - Expand FMDP-WEC Technology Towards Future Horizons
    - Powering The Blue Economy



To ensure full appreciation of optimal FMDP-WECs, structured innovation techniques are applied to FMDP-WEC archetypes thereby furthering their understanding and acknowledgment of additional potential.[6]



Examples of three FMDP-WECs (a, b, and c) stemming from structured innovation of FMDP-WEC archetypes. (Currently under provisional patent.)



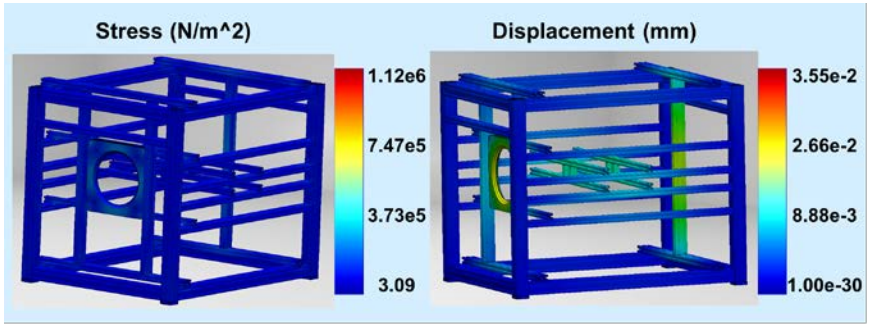
Through structured innovation and exploring opportunities for marine renewable energy in maritime markets (Powering the Blue Economy) a greater clarity regarding FMDP-WEC techno-economic potential and paradigm-shifting capacity can be obtained.[7]

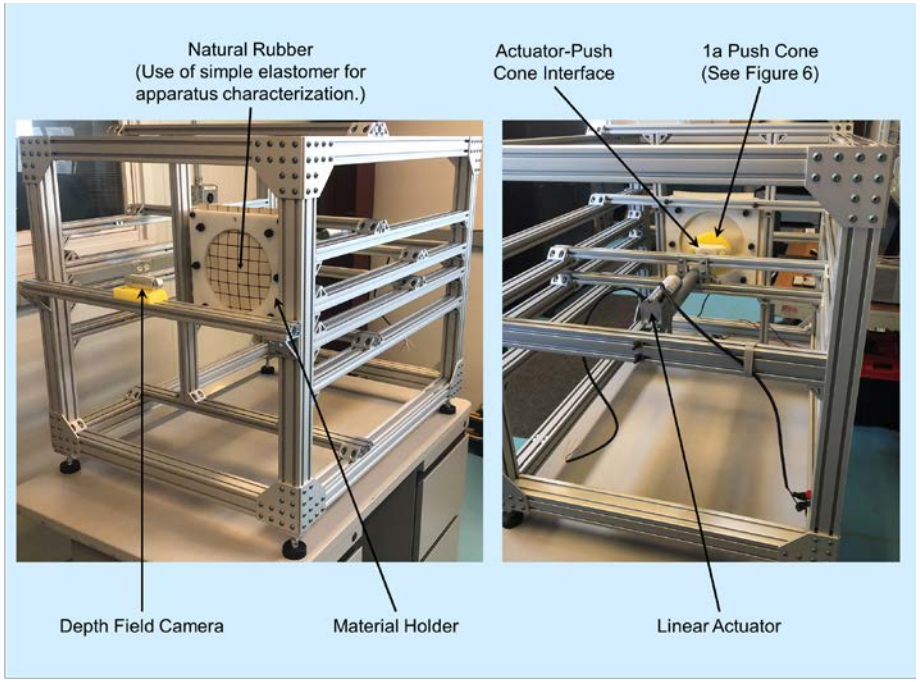
Progress Since Project Summary Submittal

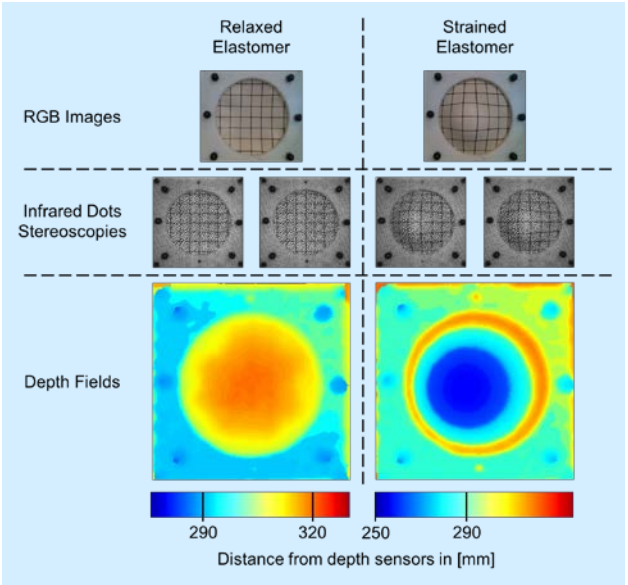
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

STEM Outreach for Development of Apparatus for Evaluation of FMDP-WEC Components

Science, Technology, Engineering, and Mathematics: Energy Efficiency & Renewable Energy Robotics Internship Program







Through collaboration with a EERE Robotics Intern, an apparatus was designed and developed for the evaluation of flexible materials and their corresponding stretchable PTO systems (e.g., dielectric elastomer generators). In this way, a means to better understand general FMDP-WEC characteristics can be leveraged for greater techno-economic FMDP-WEC performance analysis.

Future Work

- Further isolate and report upon major FMDP-WEC cost-performance drivers.
- Perform further numerical models of FMDP-WEC technology.
- Establish solid pathway towards the amalgamation of FMDP-WEC technology with Powering the Blue Economy. (Giving focus with a view towards FMDP-WEC technology powering navigation buoys, autonomous underwater vehicles, aquaculture, etc.)
- Shakedown/calibrate evaluation apparatus for FMDP-WEC elastomers and corresponding stretchable PTO systems.
- Develop project website.
- Prepare journal articles related to project approach and outcomes.

References

[1] SBM Offshore. 2016, “Wave Energy Converter Concept Development”, https://www.sbmoffshore.com/wp-content/uploads/2016/06/Technology-Wave-Energy-Converter-FINAL-LOW-RESOLUTION.pdf

[2] Polymeric & CORDIS. 2017, “POLYWEC (New mechanisms and concepts for exploiting electroactive Polymers for Wave Energy Conversion.)”, https://cordis.europa.eu/project/rcn/105863/reporting/en

[3] Babarit, A. 2017, “A linear numerical model for analyzing the hydroelastic response of a flexible electroactive wave energy converter”, Journal of Fluids and Structures; Vol. 74, Pgs. 356-384.

[4] WAMIT. 2017, “WAMIT User Manual Version 7.3”, http://www.wamit.com/manualupdate/v73_manual.pdf

[5] Bull, B. & et al. 2017, “Technology Performance Level Assessment Methodology”, Sandia Report, Sandia National Laboratory; SAND2017-4471.

[6] Weber, J. 2018, “Structured Innovation of High-Performance Wave Energy Converter Technology”, NREL Report, National Renewable Energy Laboratory; NREL/CP-5000-64744

[7] U.S. Department of Energy. 2019, “Powering the Blue Economy”, https://www.energy.gov/eere/water/powering-blue-economy-exploring-opportunities-marine-renewable-energy-maritime-markets