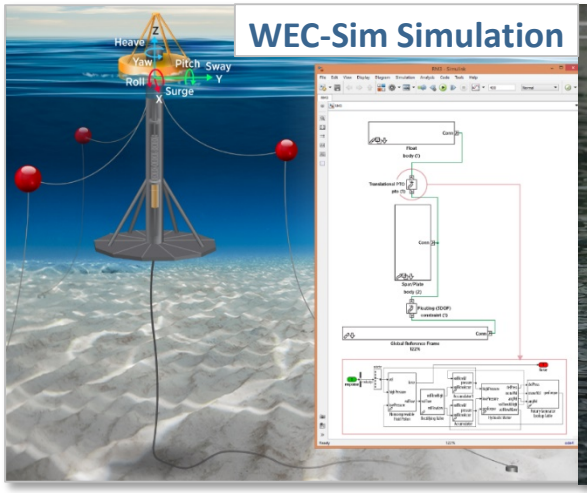
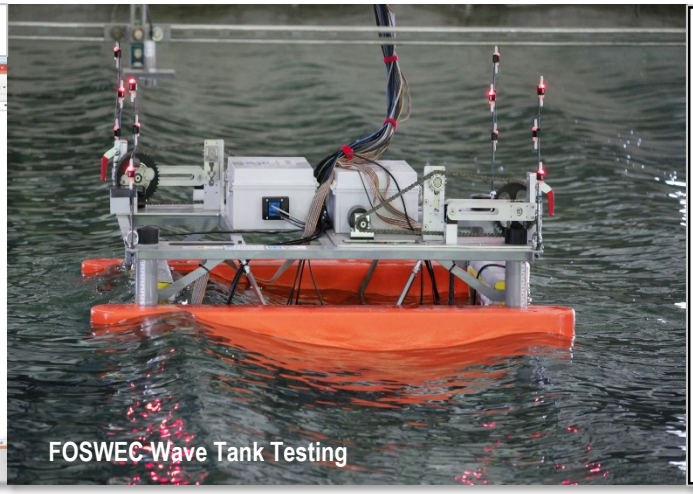
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





Wave Energy Converter Modeling

2.1.1.1.401

Marine and Hydrokinetics Program

October 8th, 2019

Principal Investigator:
Yi-Hsiang Yu (NREL)
Kelley Ruehl (Sandia)

Project Overview

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

Project Summary

This project supports the modeling capabilities to improve device performance and reduce cost for the wave energy industry, including

- Development, release, maintenance, and application of a suite of customizable open-source tools for wave energy converter (WEC) design and analysis and extreme condition modeling (ECM)
- Application of these tools for industry support
- Supports of international modeling verification and validation, standard development, and the WEC control competition

Project Objective & Impact

Objective: Support wave energy industry advancement by providing customizable, open-source modeling tools that can be used to analyze/optimize WEC dynamics and power performance and to predict loading on WECs under extreme wave environments.

Impact: This project provides the WEC community with a series of verified and validated modeling tools and methods that are customizable to meet user needs. By helping reduce WEC design uncertainty, enhance understanding of device power performance, and improve survivability in extreme conditions, the project aims to accelerate the pace of technology development while reducing risk.

Project Information

Project Principal Investigator(s)

NREL: Yi-Hsiang Yu, Yi-Hsiang.Yu@nrel.gov
Sandia: Kelley Ruehl, Kelley.Ruehl@sandia.gov

WPTO Lead

William McShane, william.mcshane@ee.doe.gov

Project Partners/Subs

Project Duration

- Project Start Date: FY12
- Project End Date: Ongoing

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

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

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

- The WEC Modeling project tasks include the development, release, maintenance, and application of Wave Energy Converter SIMulator (WEC- Sim) and WEC Design Response Toolbox (WDRT) for WEC design and analysis and for extreme condition modeling.
- This project includes a domestic industry support task, as well as international collaboration efforts.
- Both codes can be used to design and analyze systems for utility-scale power generation and blue economy applications.

Project Budget

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

Budget History (Multi-Lab Project)

Lab	FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016 – March 2019)	
Lab	Costed	Costed	Costed	Total Costed	Total Authorized
NREL	$955K	$602K	$169K	$1,726K	$1,880K
Sandia	$1,092K	$385K	$92K	$1,569K	$1,759K
TOTAL	$2,047K	$987K	$261K	$3,295K	$3,639K

Project Spending

- 90% of current project budget has been expended.
- The budget was split ~50/50 between NREL and Sandia.
- These costs include the expense of numerical model development, high-performance computational fluid dynamics (CFD) simulation models, hosting workshops and training classes and industry-support projects (FOAs).

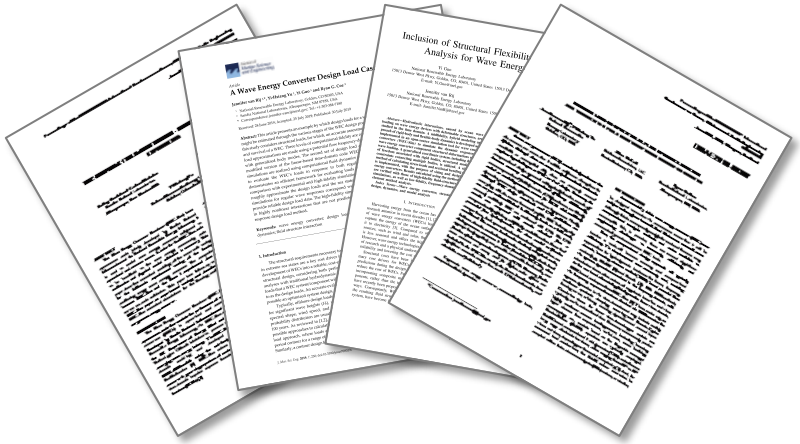
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

End-User Engagement and Dissemination Strategy

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

- The intended audience for the open source codes: Wave energy community, including industry developers & researchers from universities and other laboratories.
- The team publicizes the models and their use via the following channels:
  - Publicly available source code on GitHub (dissemination is tracked through Google Analytics of code users and GitHub issues/pull requests):
    a. WEC-Sim: http://wec-sim.github.io/WEC-Sim
    b. WDRT: http://wec-sim.github.io/WDRT
  - Support of international collaboration to demonstrate and improve the reliability and capability of WEC-Sim and WRDT and expand the user base



- Online documentation, training courses, webinars and issues forum that fields Q&As, bugs, and feature requests
- Journal/conference publications and press releases from NREL, Sandia, and DOE

Management and Technical Approach

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

Management Approach

Multi-lab project partners, members, and key capabilities:

NREL and Sandia (50:50 partnership) have developed and maintained open source code since the release of WEC-Sim and WDRT in FY14.

Project schedule and key milestones (FY17–FY19 Q2):

FY	Q1	Q2	Q3	Q4
FY17	*Host WEC-Sim code development webinar, online survey, and draft educational outreach white paper*	Tag release of WDRT, submit WDRT conference paper, attend IEA OES Task 10 meeting	Host WEC-Sim training course and establish organization to support educational outreach	*Host WEC-Sim training course and 3-4 advanced features webinars*
FY18	Submit WEC design load cases journal manuscript, develop WEC-Sim WaveStar WECCCOMP model	Submit FOSWEC validation journal manuscript, and draft WEC design load case report	Submit updated educational outreach plan, and attend IEC TC114 meeting	*Host WEC-Sim/WDRT training course*, and final WEC design load case report
FY19	Evaluation of numerical submissions to WECCCOMP Phase 1	Submit conference paper on IEA OES Task 10, WEC modeling verification and validation	Tag new release of WEC-Sim/WDRT	*Publish and present joint Sandia/NREL paper on WEC-Sim at OMAE 2019*

Management and Technical Approach (Cont.)

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

Technical Approach

Develop a set of verified and validated open-source tools that are customizable to meet users' needs and can be used to analyze WEC power performance and predict the extreme loading.

Model Development and Maintenance:

- **WEC-Sim:** Continue the development and maintenance of the open-source tool and improving model reliability, accuracy, and capabilities.
- **Validation wave tank testing:** Generate an open-access data set for model validation and upload it to MHKDR for data dissemination
- **ECM and WDRT:** Continue maintaining the toolbox and complete the design load case analysis and the development of the ECM framework.
- **Training courses and webinars:** Host training courses and webinars that demonstrate the latest developments and engage the community to improve model development efforts

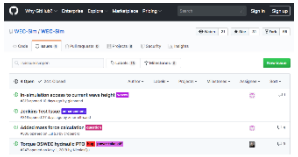
Industry Support:

Work with industry patterners under a FOA project to evaluate the design load and durability of their WECs and put the developed ECM methodology into practice.

Support of International Collaboration: To demonstrate and improve the reliability and capability of WEC-Sim and WRDT and expand the user base.

Progress is measured by tracking

Google Analytics



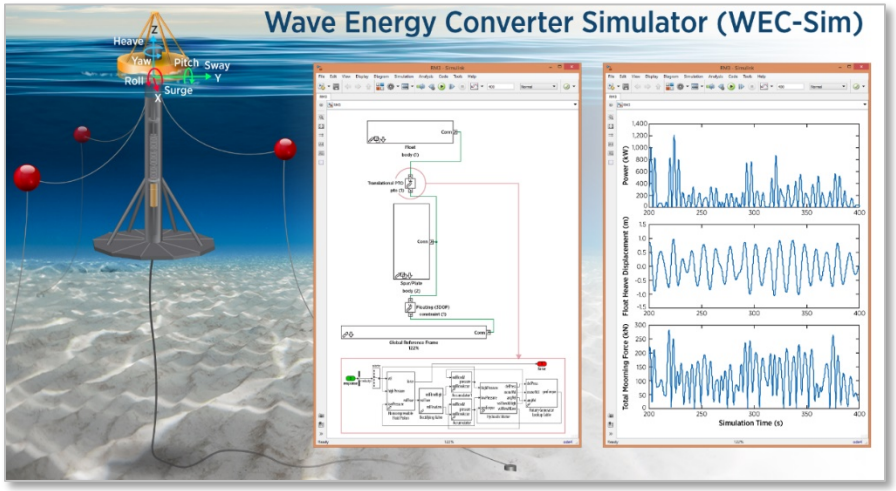
GitHub issues/pull requests

Technical Accomplishments

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

WEC-Sim:

- WEC-Sim is an open-source code for simulating WECs. The code is developed in MATLAB/SIMULINK using the multi-body dynamics solver Simscape Multibody.
- WEC-Sim has the ability to model devices that are comprised of rigid bodies, joints, power take-off systems, and mooring systems.
- Simulations are performed in the time-domain by solving the governing equations of motion in 6 degrees-of-freedom.
- First released in 2014; 4 four new version released since 2017 (v2.1 & 2.2 in FY17, v3 in FY18 and v3.1 in FY19)



- WEC-Sim has a large domestic and international user-base; logos from some of the users are provided on the right.

Technical Accomplishments

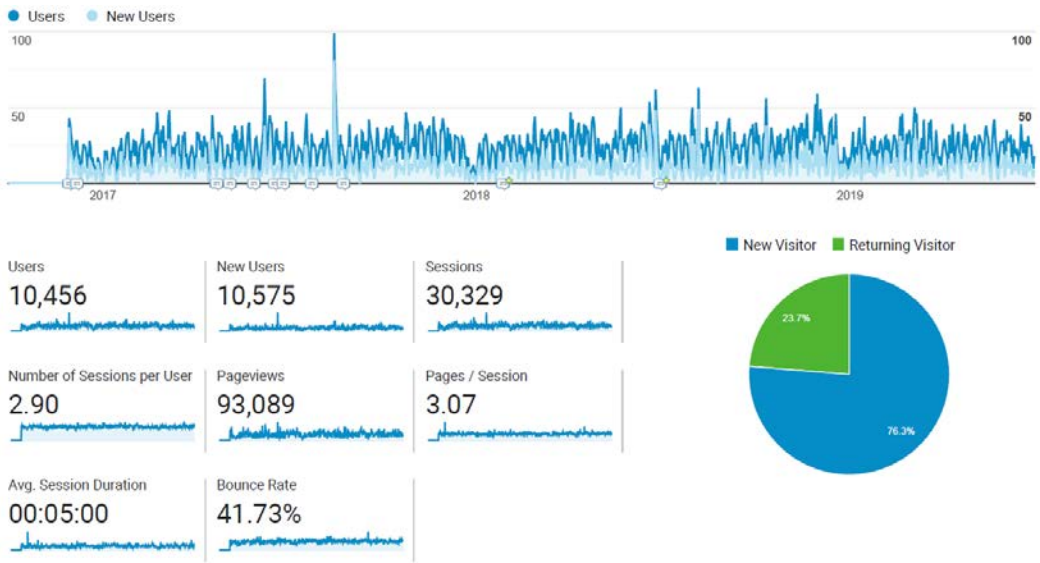
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

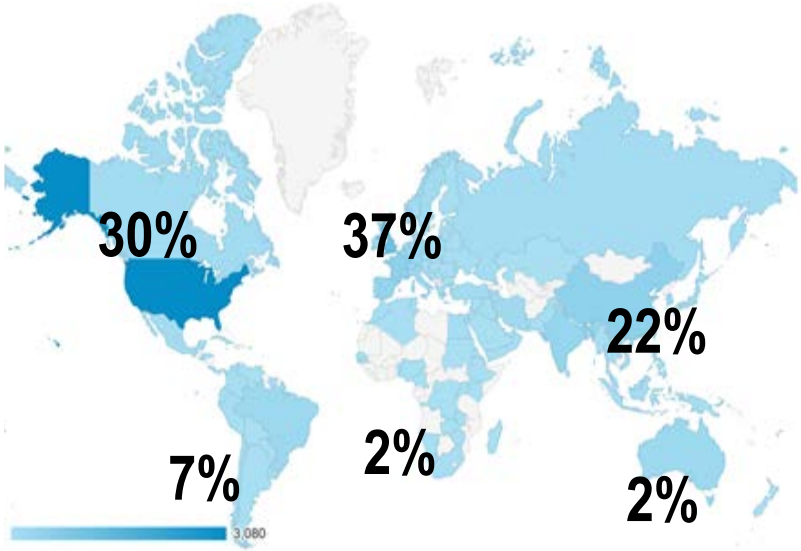
WEC-Sim (Cont.):

- The WEC-Sim repository has **~910 pageviews** and **~140 unique visits** biweekly. The WEC-Sim code has **51+ merged pull requests (contributions from outside collaborators)**, and **230+ closed issues** since its 2014 release on GitHub.
- **20+ news articles** and **26 publications by the WEC-Sim team** (**9 since 2017**)

  https://wec-sim.github.io/WEC-Sim/publications.html

- Tracked WEC-Sim **Google Analytics** from FY17 Q1–FY19 Q3 (10/1/2016 – 6/30/2019).





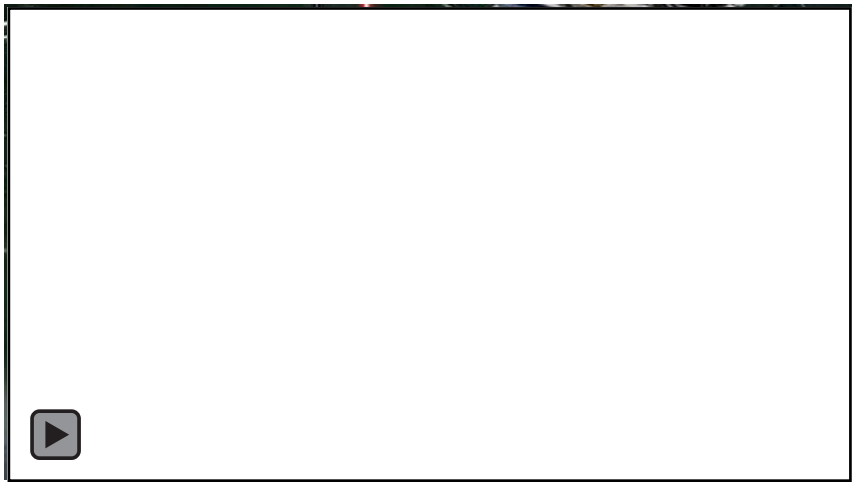
Technical Accomplishments (Cont.)

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

Validation wave tank testing:

Experimental Testing a Floating Oscillating Surge Wave Energy Converter (FOSWEC):

At Hinsdale Wave Research Laboratory (FY16)



Accomplishments Since Last Peer Review:

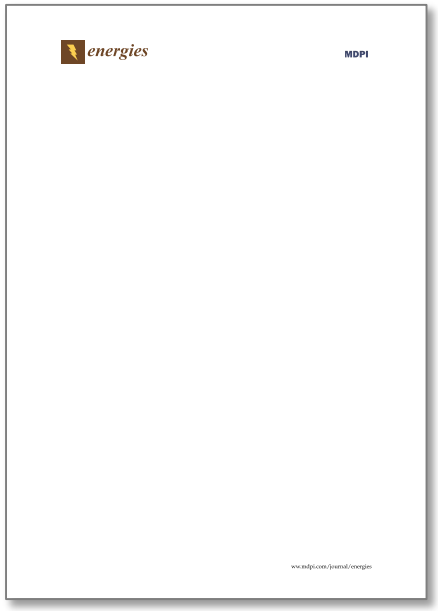
- The analysis of the testing has been completed and uploaded to Marine and Hydrokinetic Data Repository (MHKDR) (FY18).
- The results from the analysis and validation study using WEC-Sim are described in a journal manuscript submitted to *Ocean Engineering* (FY18 Q2 milestone).

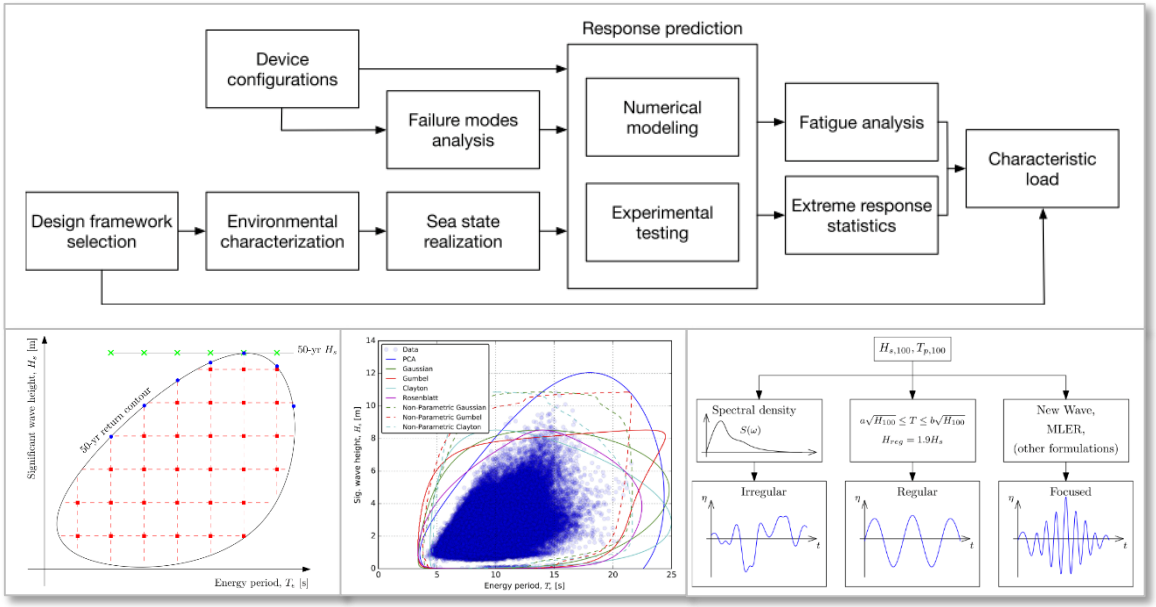
Technical Accomplishments (Cont.)

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

ECM and WDRT:

- Office of Naval Research (ONR)/DOE Water Power Roundtable Meeting:
  - Focused on ECM and survival analysis of WECs
  - With the intent that researchers working in these areas at ONR and DOE can maximize their application of existing knowledge (Jan. 4 and 5, 2017, in D.C.)
- WDRT Version update (FY17 Q2 milestone),
- 24+ publications (11 since 2017): https://wec-sim.github.io/WDRT/publications.html
  - Design practice and general WEC design workflow (published in *energies*, 2018)





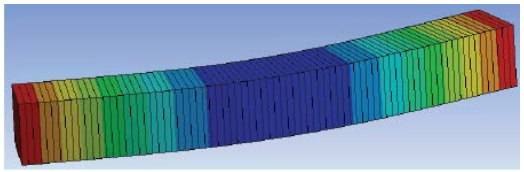
Technical Accomplishments (Cont.)

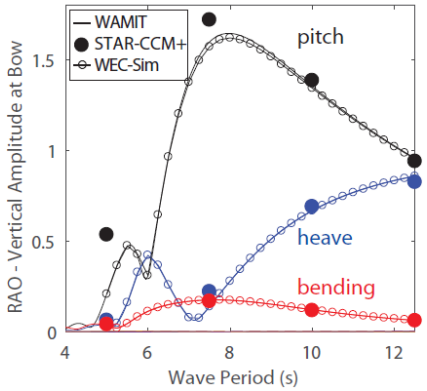
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

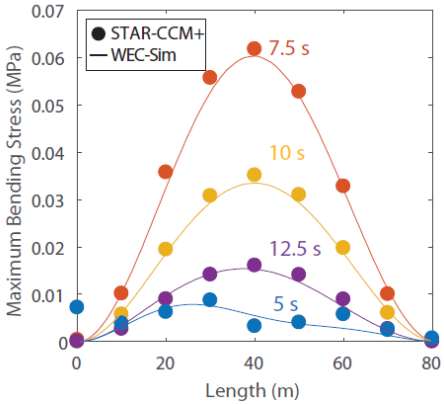
ECM and WDRT (Cont.):

- Development of a generalized mode method in WEC-Sim and applications for WEC structure loading and stress analysis (EWTEC2017 & OMAE2017). This method is now also used for modeling flexible WEC designs.

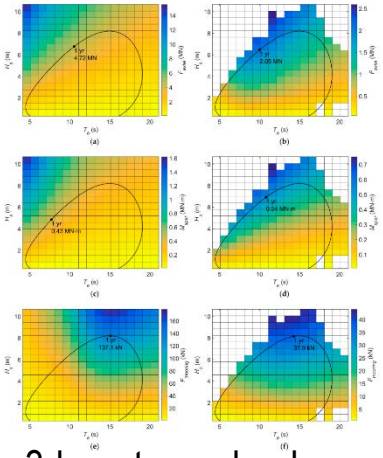
Floating Flexible Barge



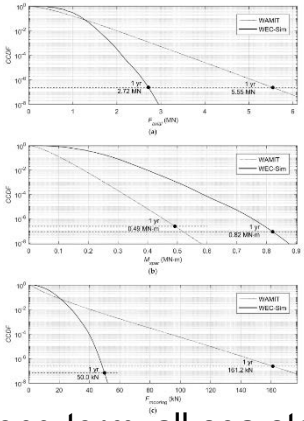




- Design load case analysis:
  a. An example of a computationally efficient framework was presented for evaluating the structural design loads of a WEC, from the conceptual design stages to the final design stages (**FY18 Q1 milestone**).
  b. Presented at OMAE 2018; published in *Journal of Ocean Engineering and Marine Energy, 2019*



3-hr extreme loads



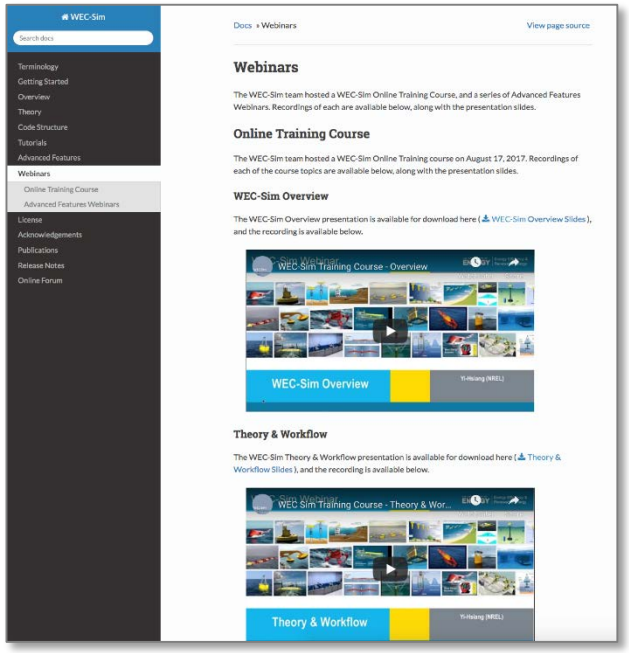
Long-term, all-sea-state extreme loads

Technical Accomplishments (Cont.)

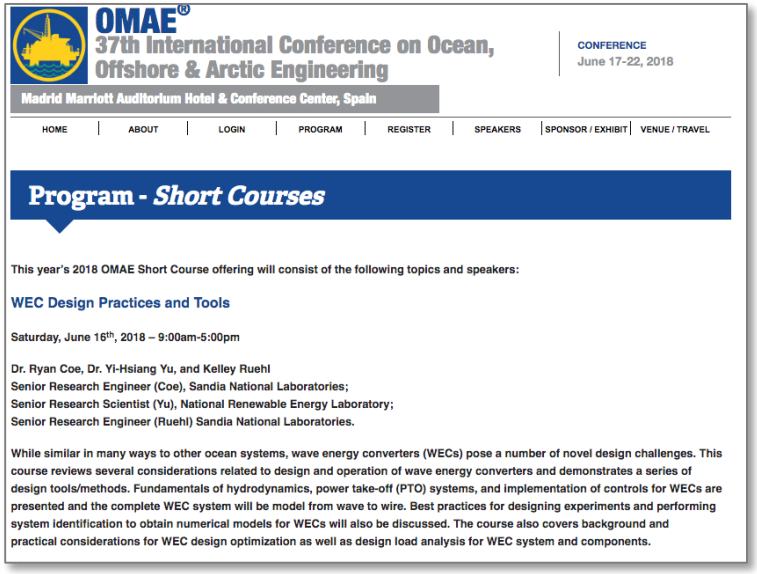
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Training courses and webinars (6+ training courses/webinars since 2017):

- Series of advanced features webinars (FY17 Q3 & Q4 milestones):



- Workshop & Short Course
  - METS (May 1, 2017)
  - OMAE (June 16, 2018)



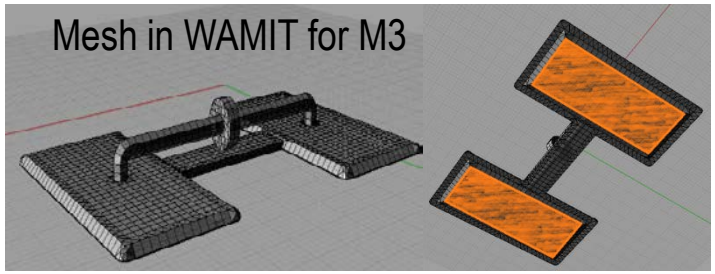
- An online survey was developed to understand who is using the WEC-Sim code and determine the best approach to future development and maintenance of the code, and a webinar was held to discuss the potential path forward for WEC-Sim development and maintenance (FY17 Q1 & Q3 milestones).

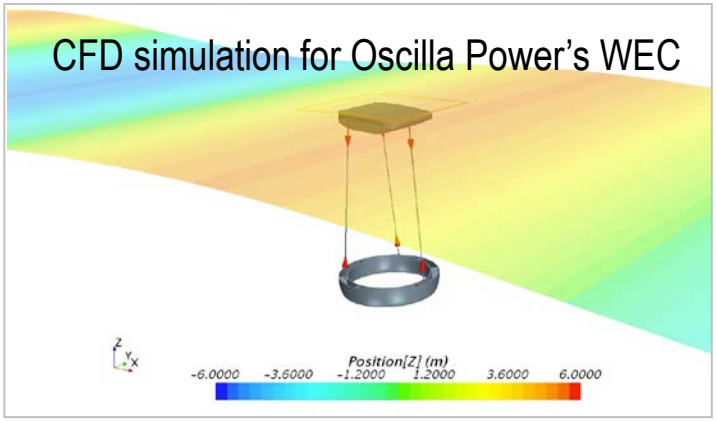
Technical Accomplishments (Cont.)

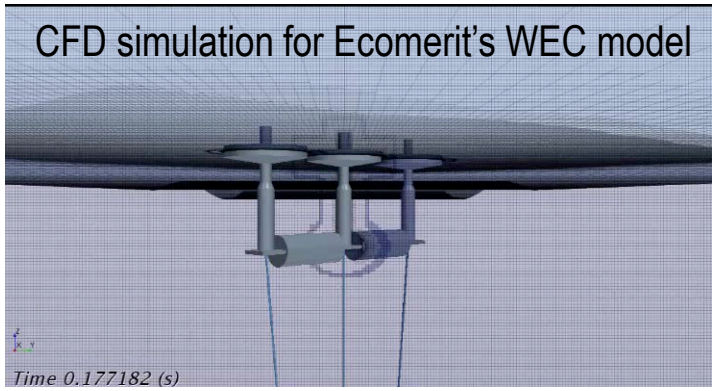
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Industry FOA supports:

- M3:
  - Analyzed the M3 Apex prototype
  - Focused on the influence of the flexible bag motion on potential sediment transport/scouring phenomena
- Oscilla Power:
  - Used the developed WDRT and the ECM modeling approach
  - Carried out a design survival analysis with a focus on the WEC power takeoff and mooring system loadings
  - *Journal of Ocean Engineering and Marine Energy,* EWTEC2017 & EWTEC2019
- Ecomerit:
  - Performed CFD simulations for a 1:35-scale Centipod mode tested at Carderock
  - Evaluate the device's extreme loads
  - OMAE 2019







Technical Accomplishments (Cont.)

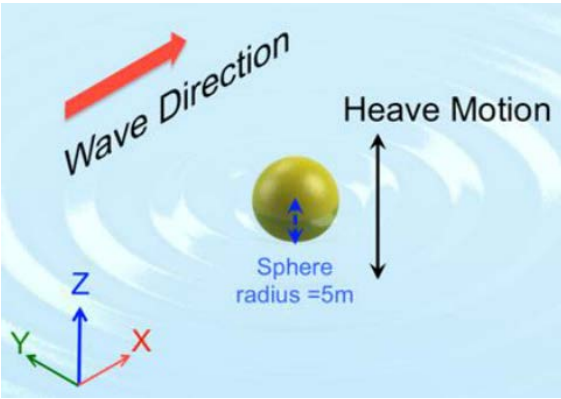
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Support of International Collaboration:

– IEA OES Task 10 (WEC modeling verification & validation):

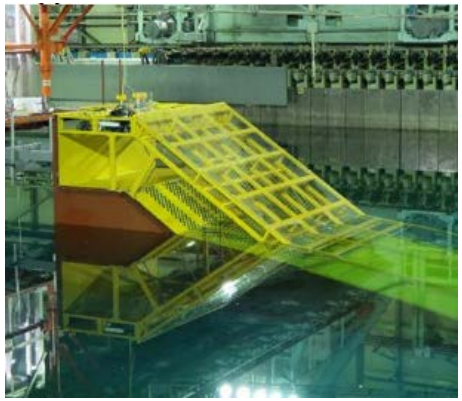
- The goals are to assess the accuracy of, and establish confidence in, the use of numerical WEC models, to determine a range of validity of existing computational modelling tools, to identify uncertainty related to simulation methodologies.

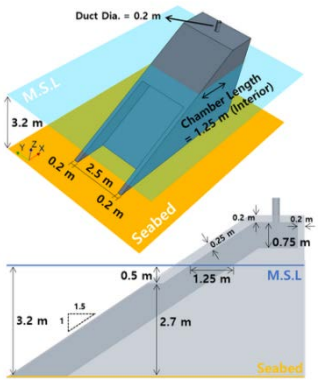
Phase I: Heaving sphere



Phase II: Model scale test article at Carderock wave basin

Phase III: Oscillating water column, test data from the KRISO ocean basin testing





- Results from the first two phases have been presented at EWTEC2019 and the 3rd International Conference on Renewable Energies Offshore (**FY19 Q2 milestone**).

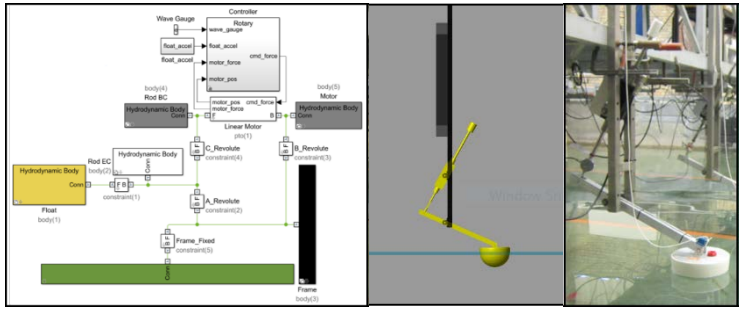
Technical Accomplishments (Cont.)

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

Support of International Collaboration:

- WEC Control Competition (WECCCOMP):
  - Responsible for evaluating the WECCOMP numerical submissions
  - Developed and validated a WEC- Sim model of the Wavestar device for WECCCOMP (EWTEC2017), which was used as a "platform" to for the contestant to develop and evaluate the their control model (**FY18 Q1 milestone**)
  - The validation study was published and presented at OMAE2018, and the evaluation of the numerical submissions was presented at OMA2019 (**FY19 Q1 milestone**).

WEC-Sim model and model scale Wavestar device



Award ceremony (numerical submissions) at OMAE2019

WEC3 COMP

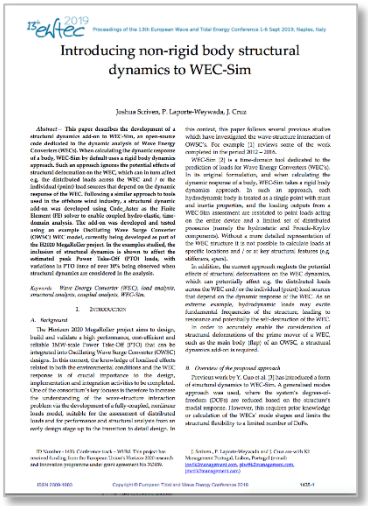
COER Centre for Ocean Energy Research

Maynooth University National University of Ireland Maynooth

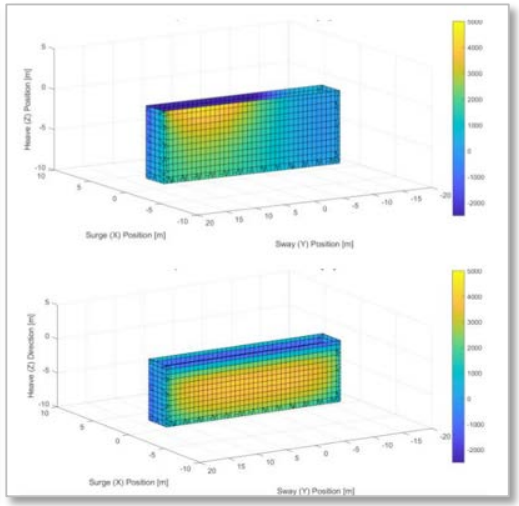
AALBORG UNIVERSITY DENMARK

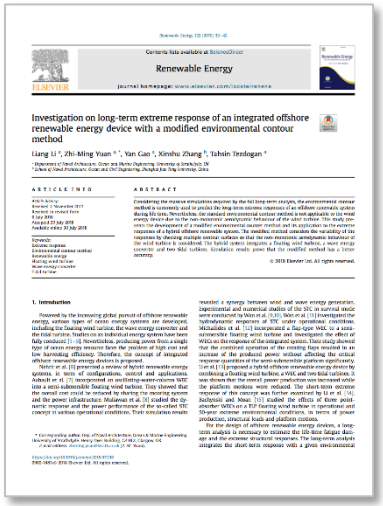
Review on WEC-Sim applications

- Beneficial for understanding WEC modeling needs and future WEC-Sim developments, and the outcome will be documented in a summary article.
- **40+ publications/studies** (**since 2017**) were presented by external researchers (excluding those from the WEC-Sim team members).
- The use includes hydrodynamics modelling, design optimization, structure loading analysis, PTO loading analysis, WEC control and other applications.
- Many of the studies involved additional code development or coupling of WEC-Sim to other models.
- Two examples are listed below:

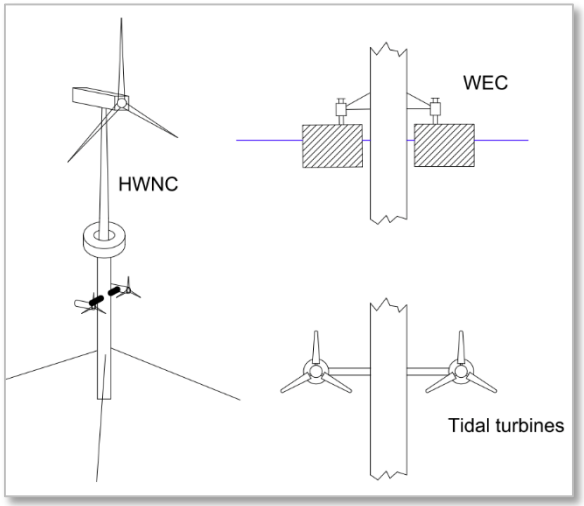

Introducing non-rigid body structural dynamics to WEC-Sim

Joshua Scriven, P. Laporte-Weywada, J. Cruz




Renewable Energy

Investigation on long-term extreme response of an integrated offshore renewable energy device with a modified environmental contour method



Future Work

Continue WEC-Sim and WDRT basic development maintenance and support of ongoing international efforts.

Upcoming key milestones and targets in FY19 include:

- Update/release new version of WEC-Sim/WDRT, including fixing bugs, updating model documents, and making improvements to the model. WEC-Sim v4.0 will be officially released in August 2019.
- Publish journal article that describes the collaborative IEA OES task 10 model verification and validation efforts. It will be submitted to the special edition of *Journal of Marine Science and Engineering* at the end of summer 2019.
- Start the third phase of IEA OES Task 10 in July 2019, which will be continued in FY20, with a focus on modeling an oscillating water column.