WEC-Sim

As the earth's climate continues to warm, severe weather and natural disasters such as hurricanes, wildfires, flooding, and other events are becoming the norm – devastating communities and neighborhoods. Several countries, including the United States, are exploring new ways to curb greenhouse gases, which contribute to an increasing average temperature. To meet the call of reaching net-zero carbon emissions by 2050 in the U.S., scientists and researchers are pursuing innovations to advance clean energy, such as ocean wave energy technologies, which harness the energy of ocean waves to generate electricity.

Sandia National Laboratories supports clean energy and emissions goals through its Wave Energy Converter SIMulator (WEC-Sim), an open-source software.

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Sandia National Laboratories

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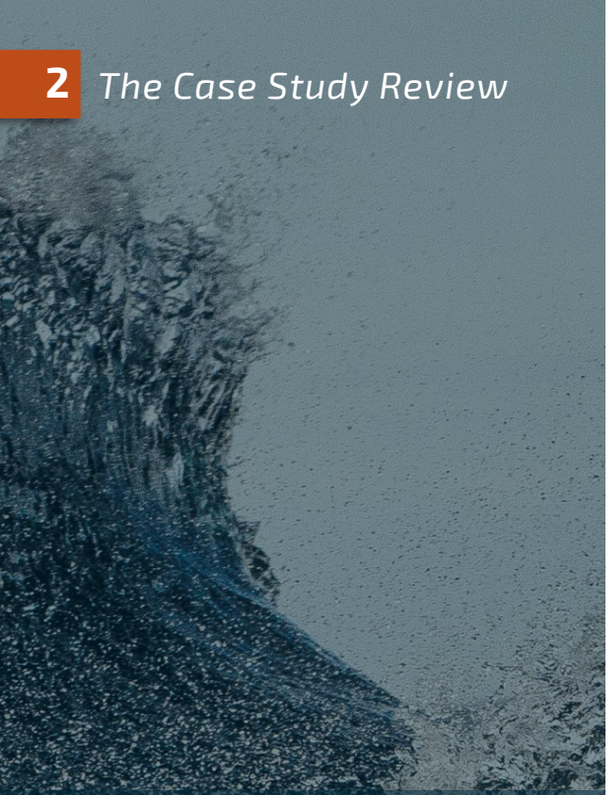
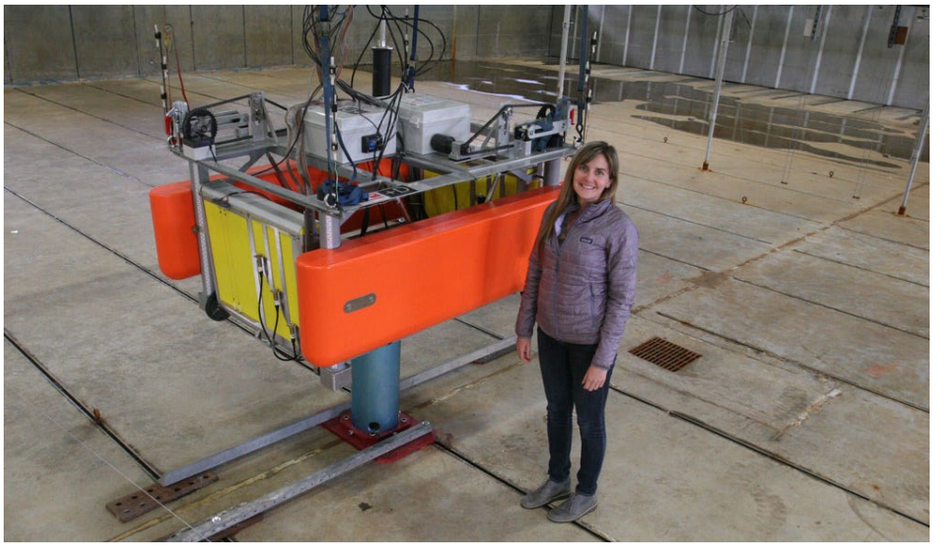


Harnessing the unrelenting power of the ocean is a clean, innovative, and sustainable way to curtail carbon pollution — benefitting American businesses and families, especially coastal communities hit hardest by the impacts of climate change. Diversifying and expanding our clean energy sources will usher in a new era of energy independence that makes the grid more resilient, curbs the climate crisis, and saves Americans money on their energy bills.[1]

- U.S. Secretary of Energy Jennifer M. Granholm

BACKGROUND

Ocean waves have the potential to produce large amounts of renewable energy. To capture this energy and convert it to carbon-free electricity, researchers can use wave energy converters (WEC). A WEC harnesses the waves' motion, which then generates electricity. WECs can be used on a large scale – as in generating utility-scale power, power for desalination, remote communities, ocean instrumentation, and more.



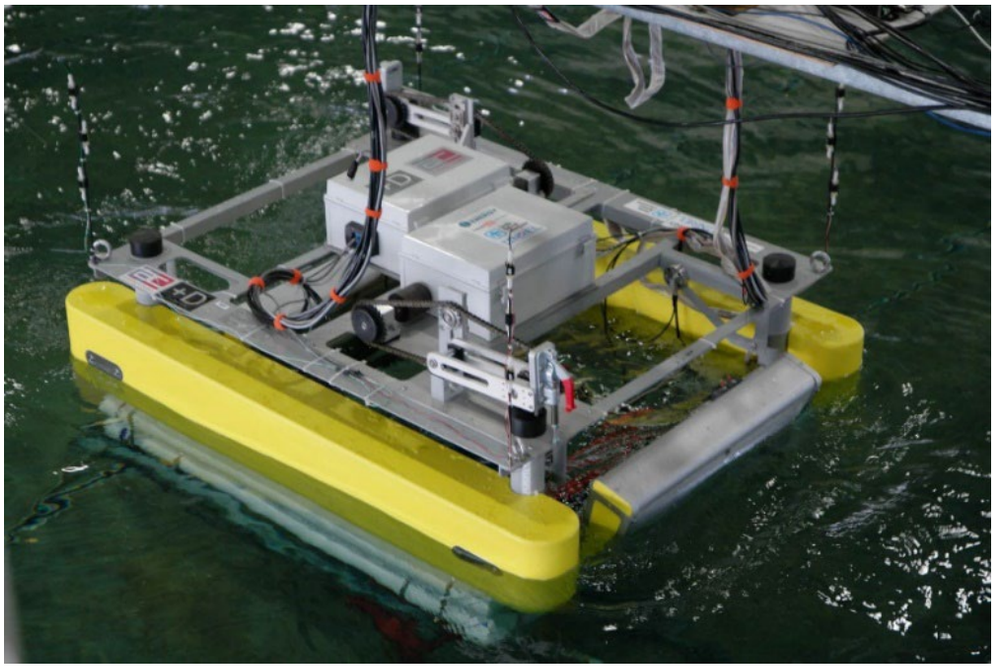
Kelley Ruehl, an Energy Water Systems Integration mechanical engineer at Sandia, next to a WEC. Photo credit: Bret Bosma, Oregon State University

Wave energy is a vast energetic resource, so designing a WEC that operates efficiently and cost-effectively in this harsh environment continues to be a challenge. Unlike other renewable energy options such as solar and wind, wave energy is in the early stages of development. Advancing wave energy is related to the Powering the Blue Economy initiative, which is described by the World Bank as "the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems."[2] WECs must be tested in realistic conditions at sea, which is more difficult to do than land-based testing. Numerous factors make the testing challenging, from the high cost of offshore testing to permitting challenges[3,4] to the corrosive nature of saltwater to biofouling.

Energy generated from waves is difficult to capture because of the complexity of harnessing wave power.[5] While some WECs generate electricity and transmit it through undersea cables to shore, others pass the mechanical energy of the wave onto land before it's turned into electrical energy. Researchers are continually looking for ways to generate energy from waves that are cost-effective so that the technology can eventually be leveraged to help the U.S. reach its goal of 100% clean energy.

BACKGROUND (CONTINUED)

Researchers at Sandia, in collaboration with partners at the National Renewable Energy Laboratory (NREL), developed the Wave Energy Converter SIMulator (WEC-Sim) – an open-source software for modeling the performance of WECs in operational and extreme environments. The open-source software is used by universities, industry, and others to better understand how WECs might fare in the open sea as they work to convert the motion of waves into usable energy. The WEC-Sim software is used prior to physical testing to model WEC dynamics and performance. Physical testing data can be used for validating WEC-Sim models. This allows wave energy developers to assess how their device will respond to different wave conditions, and whether it will operate as anticipated. It's also used after testing to determine how WECs will perform at different sites. The experimental testing is often to validate the numerical model so that it can be used to estimate power in conditions that can't be easily tested, such as deployment sites.[4]



WEC-Sim Phase 1 testing at the Oregon State University Hinsdale Directional Wave Basin. Photo credit: NREL

TECHNOLOGY DEVELOPMENT

The WEC-Sim software is funded by the Department of Energy's Water Power Technologies Office (WPTO). Around 2008, WPTO selected Sandia to lead a team in the Reference Model Project, which focused on developing open-access marine hydrokinetic technology point designs as reference models to include criteria such as cost, performance, design, and analysis. This award led to the beginnings of Sandia's Water Power Technologies group, which built on the Labs' previous work with water- and land-based wind technologies.[4]

About the same time, Kelley Ruehl, then a student, gave a presentation on wave energy conversion at a conference Sandia researchers were attending. Following the presentation, Ruehl was offered a position at Sandia as an intern. By 2011, Ruehl became a staff member, and in 2013, the WEC-Sim project was underway. Ruehl, now a mechanical engineer at Sandia, continues to lead WEC-Sim development. The software was initially copyrighted and released as open source in 2014, with the latest version, 5.0, being released in 2022.

The WEC-Sim software is developed in MATLAB/SIMULINK (programming platforms) using the multi-body dynamics solver Simscape Multibody, a simulation environment commonly used for 3D mechanical systems. WEC-Sim can model devices with rigid and flexible 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.[5] The computer simulation models the forces on floating objects and calculates their dynamic behavior. Numerical simulations using WEC-Sim can reduce development time and lower costs, allowing developers to refine and optimize their floating concepts before deploying the device in the water for physical trials.

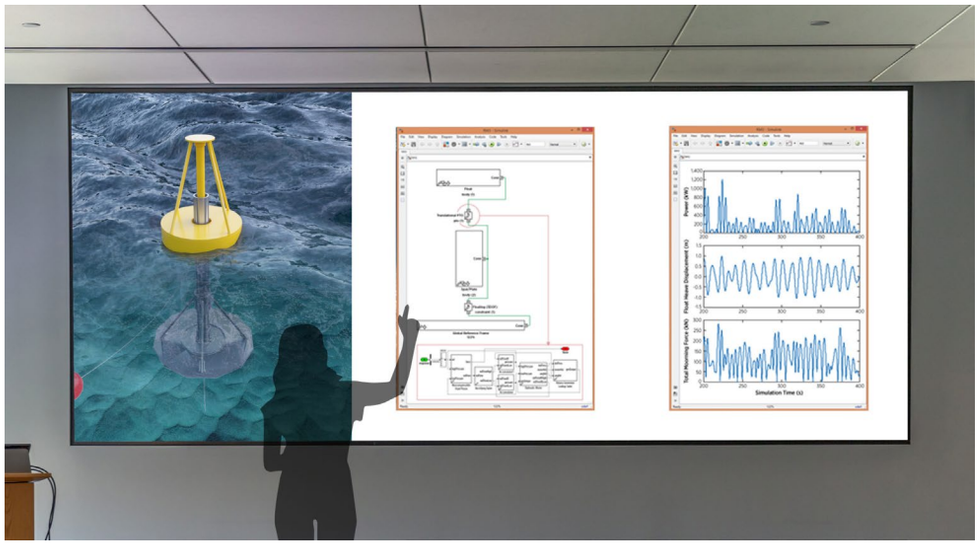
WEC-Sim is available on GitHub, and Sandia's WEC-Sim team works with developers from around the world on different concepts in wave energy conversion. Through the software, developers can use WEC-Sim to anticipate how their WECs will operate in different conditions in the ocean. Many users work with the software extensively and have contributed to enhancements.

The WPTO's Testing Expertise and Access for Marine Energy Research program (TEAMER) connects WEC developers with facilities and WEC-Sim expertise at both Sandia and NREL.[6] TEAMER also supports marine renewable energy testing and development projects by funding developers wanting to collaborate with top expertise and facilities.[7]

Through the program, companies can approach TEAMER and apply for funding for numerical support using the WEC-Sim software. After an application is awarded, the WEC-Sim team provides support through formalized partnerships on development of device simulations, online trainings, and/or formalized partnerships.[4] Numerous businesses and universities have used TEAMER to connect with WEC-Sim. For example, Ocean Motion Technologies used WEC-Sim to model and improve its engineering efforts.

RETURN ON INVESTMENT

As open-source software, WEC-Sim's return on investment is evident in the success it's had with TEAMER; its broad user base across academia, industry, and the national labs; and its potential to improve green/clean energy. In addition to its international recognition, WEC-Sim also is award-winning technology, having won an R&D 100 award in 2021 within the Software/Services category for cutting-edge innovation in lowering costs and reducing research and development cycle time in the growing field of ocean energy.[8]



2021 R&D 100 image: WEC-Sim allows users to simulate wave energy converter performance.

CRADAs

The TEAMER program has led to Cooperative Research and Development Agreements (CRADAs) between WEC developers and Sandia.[4] Through October 2022, there have been 14 separate WEC-Sim projects associated with the TEAMER program, for which 11 have provided funds-in to Sandia. The CRADAs have brought in approximately $700K in funds-in/anticipated funds-in. Many continue to be active today, and it is anticipated that, while the TEAMER program remains active, similar partnerships will continue to develop. The CRADAs generally last six-to-nine months during which the WEC-Sim team trains the developer's team on using the software. Sandia and NREL own the open-source software copyright, and the WEC-Sim team manages it as well as conducts online trainings, forums, and webinars for new partners.* Some companies have opted to modify the software to meet their needs.

** Note that TEAMER funds for CRADA projects are received directly from DOE.*

RETURN ON INVESTMENT (CONTINUED)

Other Partnerships

Other partners include Pacific Northwest National Laboratory, Oak Ridge National Laboratory (ORNL), and numerous universities. Sandia also maintains active partnerships with wave energy converter companies.

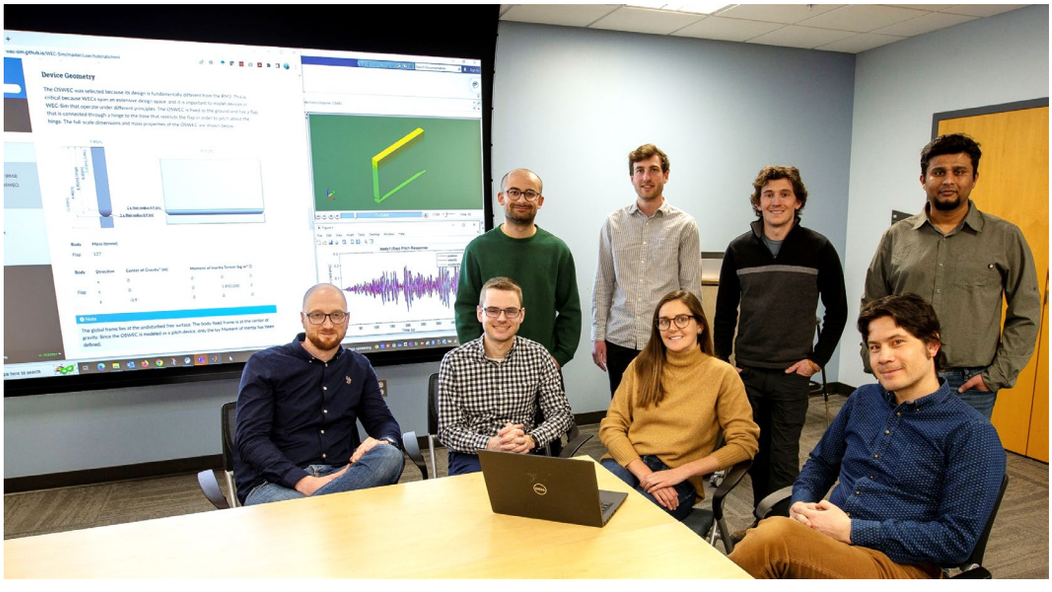
Open Source

Three different metrics are used for tracking use of the software: GitHub productivity, publications, and website analytics.

As of October 2022, WEC-Sim has a large international use-base and the number of users continues to increase annually. An indicator of its increasing use is the issue board on GitHub, which has received hundreds of inquiries. To date, the team has resolved more than 600 user questions regarding the software. Three hundred issues were closed from 2019 to 2021 alone. The issue board provides valuable feedback to Sandia and NREL developers through addressing real-time user issues and challenges (i.e., input into needed software revisions and new functions). Jorge Leon Quiroga, a postdoctoral appointee in the Water Power Technologies department at Sandia, says that the team is continuously improving the software. The more user-friendly the software is, the more people will use it, which is one step to making positive impacts in renewable energy.

Quiroga further explains that WEC-Sim is the main research tool numerous businesses and researchers are using in the early phases of WEC development. For example, the tool has been mentioned in scientific publications about WECs that rely on WEC-Sim for finding resolutions to problems. WEC-Sim has been referenced in publications 125 times since 2013, and more than half of those mentions took place from 2019 to 2021.[11] In addition, the WEC-Sim website has seen a 111% increase in worldwide traffic since FY18.

WEC-Sim has a large domestic and international user base, including companies Ocean Motion Technologies[12] and CalWave.[13]

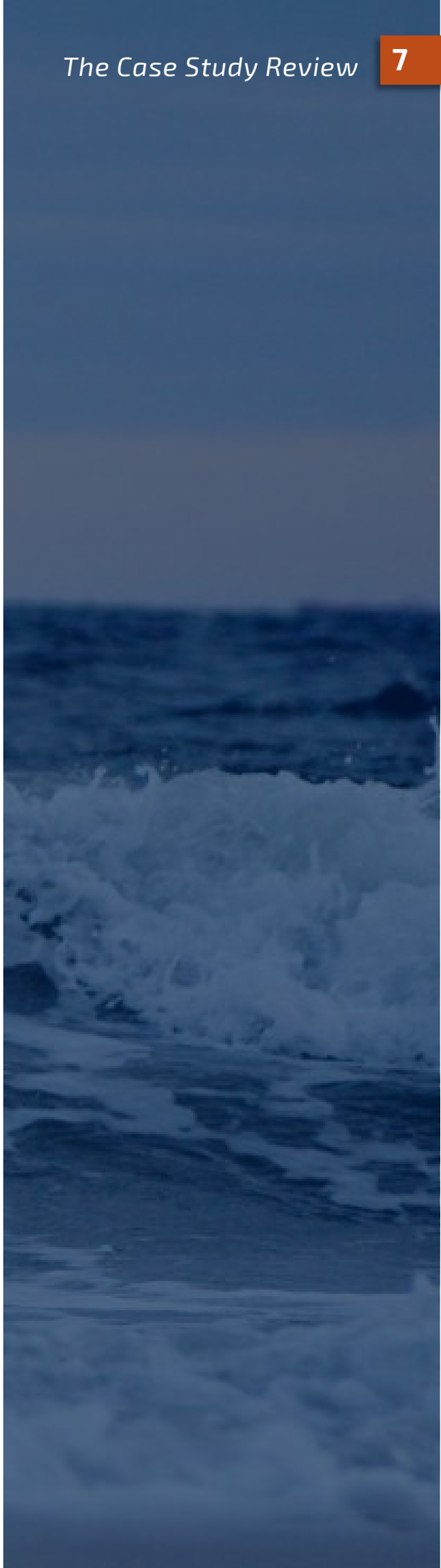


The WEC-Sim team. Left to right standing: Jorge Leon (Sandia), Jeffrey Grasberger (Sandia), Dominic Forbush (Sandia), Salman Husain (NREL); Left to right sitting: David Ogden (Velocity Global), Adam Keester (Sandia), Kelley Ruehl (Sandia), Nathan Tom (NREL). Photo by Taylor Mankle (NREL).

PUBLIC GOOD

Wave energy devices could one day power millions of U.S. homes, businesses, remote communities, and even military bases. Harnessing the motion produced by ocean waves to generate clean energy could eventually be applied for use in utility-scale power generation, powering energy-intensive desalination plants, and mechanical and electrical power applications. Using wave energy could also be part of the solution in easing severe weather caused by climate change by reducing greenhouse gases.

However, before new water-power technologies can successfully compete in the commercial clean-energy arena, developers must create dependable technology in wave energy conversion, which will in turn decrease the cost of powering communities. WEC-Sim is instrumental in advancing wave energy conversion technology so that it can potentially have a broad impact in the realm of affordable renewable energy alternatives. Sandia is committed to pursuing clean energy innovations in ocean wave energy technologies to advance the mission of reaching net-zero carbon emissions.



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4. Kelley Ruehl, mechanical/ocean engineer; subject matter expert, Sandia National Labs
5. https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2017/174561c.pdf
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10. https://www.energy.gov/articles/aquaharmonics-wins-energy-department-s-wave-energy-prize
11. Jorge Leon Quiroga, a postdoctoral appointee in Water Power Technologies at Sandia
12. https://www.oceanmotion.tech/partners.html
13. https://calwave.energy/partners/

WEC-SIM

WEC-Sim (Wave Energy Converter SIMulator) is an open-source software for simulating wave energy converters. The software is developed in MATLAB/SIMULINK using the multi-body dynamics solver Simscape Multibody.

> *"The overarching goal of my research has always been to support the advancement of renewable energy technologies for a sustainable future. It's really exciting to see the large-scale impact of the WEC-Sim open-source software. I'm constantly learning about new applications of the software, developed by users all over the world.*
>
> *- Kelley Ruehl, Sandia National Laboratories*

WEC-SIM capabilities include:

- *WEC-Sim has the ability to model devices that are comprised of bodies, joints, power take-off systems, and mooring systems.*
- *WEC-Sim can model both rigid bodies and flexible bodies with generalized body modes.*
- *Simulations are performed in the time-domain by solving the governing wave energy converter equations of motion in the 6 Cartesian degrees-of-freedom, plus any number of user-defined modes*

Return on Investment:

- *$700K in funds-in/anticipated funds-in from CRADAs associated with the TEAMER program*
- *Several partnerships, including with labs (PNNL, ORNL), universities, and wave energy converter companies*
- *Large international use-base as an open source software*
- *Referenced in publications 125 times since 2013 (as of November 2022)*
- *Clean energy with the potential for use in utility-scale power generation, powering energy-intensive desalination plants, and mechanical and electrical power applications*

U.S. DEPARTMENT OF ENERGY
Water Power Technologies Office

2010/2011
WEC-Sim development begins using WPTO funds

2015


WEC-Sim team wins the OMAE 2015 Hydraulic Modeling Competition during the 34th ASME International Conference on Ocean, Offshore, and Arctic Engineering (OMAE)

WEC-Sim phase 1 validation test complete

2016
WEC-Sim 2.0 released

WEC-Sim holds training course at University of Maine

2018
WEC-Sim 3.0 is released

WEC-Sim holds a training day at OMAE

2019
WEC-Sim 4.0 released

WECCOMP control competition

2021
Won an R&D 100 Award for Software/Services category for cutting-edge innovation in lowering costs and reducing R&D cycle time in the growing field of ocean energy

WEC-Sim lecture series at Oregon State University

2022
WEC-Sim 5.0 released

WEC-Sim training course at Autonomous University of Baja California

TEAMER
Testing & Expertise for Marine Energy

Partnerships from 2021-2022: TEAMER CRADAs with Rohrer Technologies, Inc.; Aquaharmonics; and HiSeas Energy

Partnerships from 2022-2023: TEAMER CRADAs with Triton Systems; Ocean Motion; Lancaster University; and University of Massachusetts, Dartmouth

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