# Powering the Blue Economy: Foundational Research & Development

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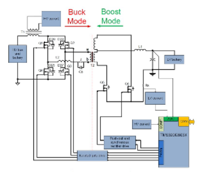
## Background

With increased use of the oceans for transportation, extraction of food, fibre, and minerals, recreation and tourism, and other blue economy industries, there is a need for additional power at sea. In the face of climate change, the increased power must come from renewable sources; often marine energy is the most energy-dense power source available. But we have little experience with adapting wave and tidal devices from large scale grid power to the specialized and small devices needed to power blue economy applications, nor the engineering solutions to support codesign of emerging marine industries. As directed by the U.S. Department of Energy (DOE), two DOE national laboratories have developed foundational research and development projects to replace conventional power or batteries at sea (ocean observation platforms), emerging industry power needs (offshore aquaculture operations), as well as examining common challenges for using marine power (efficient power systems, minimizing interference, optimizing materials and manufacturing).

## Efficient Power Systems (PNNL)



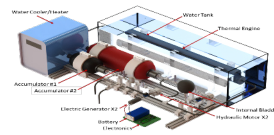

Systems Block Diagram

3-phase AC supply

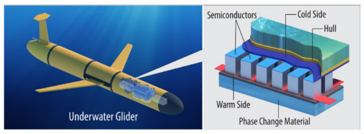

Battery storage simulator

**Challenge**: The intermittency and highly-variable output of marine energy makes using standard power systems less efficient than other types of renewables.
**Solution:** Power electronics and other components can be redesigned for tidal energy, using a programmable power supply and monitoring system to mimic electrical power of a tidal generator. This system supplies electricity to electronics designed to convert power into an efficient form for battery charging. Providing realistic power output without the need for a full scale generator.
**Results:** Power emulation has been demonstrated for the three-phase output of a small-scale vertical-axis tidal turbine in a closed-loop hardware-in-the-loop implementation.

## Power from Ocean Thermal Gradients (PNNL & NREL)



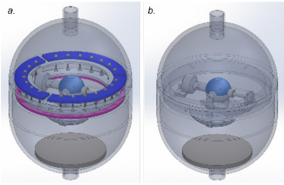
Laboratory version of PCM-based thermal gradient system




Concept of autonomous underwater vehicle with integrated TEG-PCM

**Challenge:** Increasing the efficiency of ocean thermal gradients to extend the life of autonomous underwater profilers.
**Solution:** The most efficient phase-change materials (PCM) can be chosen to drive a buoyancy engine, integrate a thermo-electric generator (TEG) with PCM, and redesign thermal-electrical-mechanical power handling.
**Results**: Hexadecane with carbon nanotubes has proven to be the most efficient phase-change material. TEG-PCM system can supply 0.32-1.28Wh per 1000 m depth dive (4-40% of the energy requirements for commercial UUVs). Electrical and mechanical systems were modeled and built at bench-scale, ready to be tested under ocean conditions, mounted in a pressure case.

## Characterizing Interference (PNNL)

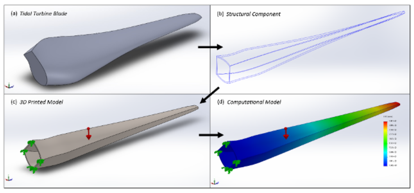



Pendulum generator mounted in buoy

Test of deployed WEC and wave measurement buoy

**Challenge:** Marine energy generators can power ocean observation systems but must not interfere with data collection, acoustically, electrically, or through motion. Here we look at motion interference for wave measurements.
**Solution:** A six-degrees of freedom pendulum-driven generator wave energy converter (WEC) was mounted on a small ocean observing buoy, and the motion of the buoy examined with waves in the field.
**Results:** Operation of WECs the same size as an observation buoy resulted in interference. Tradeoffs exist between WEC size, buoy size, and the amount of power that can be delivered while avoiding interference.

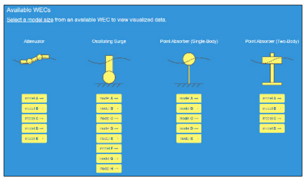
## 3D Printing of Tidal Blades (PNNL & NREL)

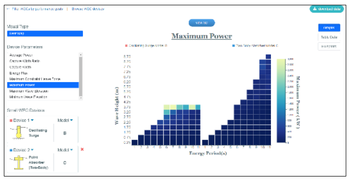


Modeling for 3D printing of tidal turbine blades

**Challenge:** Choosing the appropriate materials and additive manufacturing methods for low cost, robust tidal turbine blades and turbines for small applications.
**Solution:** The feasibility of 3D printing can be determined for tidal turbine blades and small tidal turbines, using additive manufacturing techniques for both polymer and metallic materials.
**Results:** Material samples were exposed to seawater for several months. Some of them retained their strength while others lost up to half. The robust materials are being used to print blades and small cross flow turbines for ocean testing.

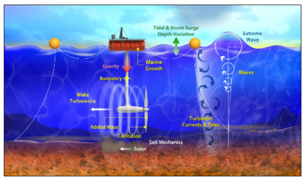
## Small WEC Modeling (NREL)

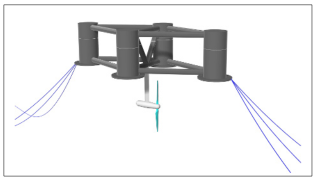





**Challenge:** Wave energy converters (WECs) come in many shapes and sizes. Choosing a WEC for a particular site can be difficult and time consuming for device developers.
**Solution:** A web application can be built using representative data for coastal regions and four different WEC archetypes (attenuator, oscillating surge, point absorbers, both single and multi-bodied), allowing device and project developers to compare different WEC performance for specific sites.
**Results:** An online, publicly available web application, the Small WEC Analysis tool was developed and released: https://apps.openei.org/swec/

## OpenFast (NREL)





**Challenge:** OpenFAST, a model developed for wind turbines, does not address the complexities of modeling underwater marine turbines.
**Solution:** The relevant hydrodynamics needed to model tidal turbines can be included, enabling the simulation of fixed and floating devices.
**Results:** New functionalities were added to model the effects of buoyancy, added mass, and inflow accelerations on underwater rotors. The addition of these capabilities included feature implementation in OpenFAST, as well as code verification and validation.

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