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

WIND AND WATER POWER TECHNOLOGIES OFFICE

U.S. Department of Energy Wind and Water Power Technologies Office Funding in the United States:

# MARINE AND HYDROKINETIC ENERGY PROJECTS

Fiscal Years 2008 - 2014

# Marine and Hydrokinetic Research and Development

## Introduction

### Wind and Water Power Technologies Office

The Wind and Water Power Technologies Office (WWPTO), within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE), supports the development, deployment, and commercialization of wind and water power technologies. WWPTO works with a variety of stakeholders to identify and support research and development (R&D) efforts that improve technology performance, lower costs, and—ultimately—deploy technologies that efficiently capture the abundant wind and water energy resources in the United States. WWPTO is one office that contains two distinct focus programs: wind and water. The Wind Program and the Water Power Program operate as integrated, but separate entities within WWPTO.

The Water Power Program is committed to developing and deploying a portfolio of innovative technologies for clean, domestic power generation to support of a clean energy future.

The Water Power Program provides R&D funding in two major areas:

1. Hydropower Projects
2. Marine and Hydrokinetic Projects

The breakdown of Water Power Program funding is presented in a pair of reports that showcase the projects funded in each of the abovementioned areas.

## Marine and Hydrokinetic Technology

The energy from waves, tides, ocean currents, the natural flow of water in rivers, and marine thermal gradients can be captured to generate new sources of clean and renewable electricity. Although the marine and hydrokinetic (MHK) industry is at a relatively early stage of development compared to other renewable energy technologies (such as wind and solar power), the rivers, coasts, and oceans of the United States represent significant potential as a renewable energy resource. The United States uses about 4,000 terawatt hours of electricity per year. DOE estimates that the maximum theoretical electric generation that could be produced from waves, tidal and riverine currents, and ocean thermal energy gradients in U.S. waters is more than 4,000 terawatt hours per year, more than half of the nation's total annual electricity usage. Although not all of this resource potential can realistically be developed, the nation's enormous MHK energy potential still represents major opportunities for new water power development in the United States.

Photo credit: Alison LaBonte

Verdant Power installs a testing device in the East River of New York City on August 29, 2012. Testing took 2 weeks and looked at new rotors and composite blades.

The Water Power Program helps industry develop and optimize MHK technologies that can harness this renewable, emissions-free resource to generate environmentally sustainable and cost-effective electricity. Through support for public, private, and nonprofit efforts, the Water Power Program promotes MHK technology development and testing in laboratory and open water settings, while gathering the operational, environmental, and market data needed to accelerate the responsible deployment and commercialization of MHK technologies. The Water Power Program works to assess the potential extractable energy from domestic water resources and to reduce the resources required for siting MHK power projects in order to assist industry and government in planning for the nation's energy future. In addition, the Water Power Program recognized a lack of standardized descriptions for the stages of technology development for the wide range of devices and systems within the emerging MHK industry. In FY 2010, the Water Power Program incorporated Technology Readiness Levels (TRLs) into the Funding Opportunity Announcement process to enable consistent and uniform discussions regarding MHK technologies.

From FY 2008 to FY 2014, the Water Power Program announced awards totaling about $120 million for 88 projects focused on MHK energy. Table 1 provides a brief description of these projects. There are two sources of funding for MHK projects covered in this report: competitive Funding Opportunity Announcements (FOAs), funded by Congressional Appropriations, and Congressionally Directed Projects (CDPs).

## Types of Funding Sources

WWPTO research and development (R&D) projects covered in this report are financed through two primary sources of funding: Congressional Appropriations and Congressionally Directed Projects (CDPs). Congressional Appropriations determine the operating budgets for each EERE office. WWPTO-funded R&D projects are typically awarded to recipients as grants through competitive Funding Opportunity Announcements (FOAs) that are dedicated to specific topic areas. CDPs are also funded by Congress, but are outside of the annual federal budget process. Frequently, there is a cost-share requirement for recipients of both competitive FOA grants and CDPs.

WWPTO also funds research projects at DOE's national laboratories through the laboratories' annual operating plans. This funding is not detailed in this report. However, a national laboratory may be a lead or a partner on a competitively awarded project covered in this report. In these cases, the national laboratory is identified as the lead or partner in the appropriate project descriptions.

The Small Business Innovation Research (SBIR) program, in DOE's Office of Science and the Advanced Research Projects Agency-Energy (ARPA-E), provides competitive awards-based funding for domestic small businesses engaging in R&D of innovative technology. SBIR and ARPA-E have funded MHK R&D projects; however, these projects are not covered in this report.

### Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **ABB, Inc.** | Advanced Direct-Drive Generator for Improved Availability of Oscillating Wave Surge Converter (OWSC) Power Generation Systems | $1,995,255 | FY13 MHK System Performance Advancement FOA | North Carolina |
| **Project Description** | | | | |
| ABB, Inc., in collaboration with Resolute Marine Engineering and Texas A&M University, will build a compact direct-drive generator and demonstrate its viability in Resolute Marine Energy's SurgeWEC™ wave energy device. When complete, this design will allow replacement of Resolute's existing hydraulic power take-off—the drivetrain and generator assembly that converts mechanical energy into electricity—with an electrical power take-off, resulting in increased operation time. The goal is to produce a generator 50% smaller than a traditional direct-drive generator. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Atargis Energy Corporation** | Cycloidal Wave Energy Converter | $400,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Colorado |
| **Project Description** | | | | |
| Atargis Energy has designed, constructed, and tested a 1:10 scale model of its Cycloidal Wave Energy Converter (CyCWEC) at the Texas A&M Offshore Technology Research Center. The CycWEC is designed to address storm survival and energy costs—two issues that hamper many wave energy converters currently under development. The DOE-supported work demonstrates on a kilowatt scale the world's first fully submerged wave energy converter system capable of cancelling deep ocean waves using hydrofoil lift. Laboratory tests and simulations have achieved 99% wave cancellation. System modeling indicates greater than 70% overall wave-to-electric power conversion efficiency and levelized cost of energy below $0.14 per kilowatt hour are attainable. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Bayer MaterialScience, LLC** | River Devices to Recover Energy with Advanced Materials (River DREAM) | $240,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Pennsylvania |
| **Project Description** | | | | |
| Bayer MaterialScience developed a new concept for hydroelectric energy generation from low-head water resources. Bayer has estimated 21,000 megawatts of existing low-head water resources in the United States, but these resources presently lack a technology to effectively harvest energy. The Bayer concept is low profile and largely non-invasive and is expected to leave rivers usable, aesthetically pleasing, and ecologically viable. The successful completion of the project resulted in the creation of a model able to fully define the operating parameters and performance capabilities of a generator based on the Galloping Hydroelectric Energy Extraction Device design. The resulting information will be used in the next phase of product development and to create an integrated laboratory-scale generator to confirm model predictions. The successful development of this new concept could help advance the MHK industry toward capturing low-head water resources in the United States. | | | | |

[a] DOE Funding Amounts identified in this table reflect the total DOE funding planned for award to each project for the total period of project performance that may span multiple years. DOE Funding Amounts shown in this table may be subject to change.

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **California Polytechnic State University** | California Wave Energy Test Center (CalWave) | $750,000 | FY13 Wave Testing Infrastructure Development FOA | California |
| **Project Description** | | | | |
| CalWave is investigating and characterizing one very good wave energy site in California that has already had some of the most extensive evaluation and permitting efforts to date for MHK projects in the United States. This site meets the annual average wave power density requirement of greater than 30 kilowatts per meter and the depth requirement of 50 meters. Spanning such a long stretch of coastline, however, it experiences a wide range of testing climates. By applying a common analysis and uniform selection criteria to a Californian site, DOE will obtain the best possible understanding of what CalWave may be able to offer that would not be available at the existing and planned test sites off the coast of Newport, Oregon. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Columbia Power Technologies, Inc.** | Benchmark Modeling of the Near-Field and Far-Field Wave Effects of Wave Energy Arrays | $598,154 | FY09 Advanced Water Power FOA | Virginia, Oregon |
| **Project Description** | | | | |
| Columbia Power Technologies and Oregon State University (OSU), through an industry-led partnership, performed benchmarking experiments and numerical modeling on arrays of wave energy converters. The experimental observations helped fill a knowledge gap in the near-field effects of multiple floating wave energy converters and are critical for estimating the potential far-field environmental effects of wave energy arrays. The experiments have been performed at the Hinsdale Wave Research Laboratory at OSU by subjecting an array of newly developed "Smart Buoys" (lab-scale floating power converters) to conditions expected off the central Oregon coast. The resulting data are an important resource for testing models for wave/buoy interactions, buoy performance, and far-field effects on wave and current patterns due to the presence of arrays. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Columbia Power Technologies, Inc.** | SeaRAY Direct-Drive Wave Energy Buoy | $1,417,990 | FY09 Advanced Water Power FOA | Virginia, Washington |
| **Project Description** | | | | |
| Columbia Power Technologies and its project partners completed a year-long deployment of a 7-ton intermediate-scale wave energy converter (WEC) called the SeaRAY to demonstrate and validate the technology in preparation for a full-scale ocean demonstration. The WEC technology was designed to capture energy through a highly reliable rotary approach, absorbing up to twice the energy for a given surface area compared to existing technologies. Columbia Power Technologies used data produced during the deployment to optimize its WEC technology and increase its energy capture. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Columbia Power Technologies, Inc.** | StingRAY Direct-Drive Wave Energy Buoy | $1,500,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Virginia, Washington |
| **Project Description** | | | | |
| Columbia Power Technologies is designing a small-scale wave energy converter called the StingRAY, which has directionally dependent device weathervanes to face into oncoming waves using a single mooring line. The design uses fore and aft floats that move independently and are attached to separate drive shafts, each of which is connected to a direct-drive, permanent-magnet generator. The direct-drive design creates a maintenance advantage by removing the need for gearboxes or hydraulics. The asymmetrical fore and aft float geometry design allows for float hard-stop capabilities during extreme events and will decrease costs by $400,000 per unit. The levelized cost of electricity is projected to improve by 60% to $0.13 per kilowatt hour. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Columbia Power Technologies, Inc.** | Build and Test of a Novel, Commercial-Scale Wave Energy Direct-Drive Rotary Power Take-Off Under Realistic Open-Ocean Conditions | $3,000,000 | FY13 MHK System Performance Advancement FOA | Virginia |
| **Project Description** | | | | |
| Columbia Power Technologies will demonstrate the use of a novel, high-performance power take-off module—the drivetrain and generator assembly that converts mechanical energy into electricity—for its StingRAY wave energy converter. The new power take-off system will use a generator and other unique equipment to provide high-efficiency, low-maintenance energy conversion and storage. The project seeks to not only improve cost competitiveness, but also reduce maintenance costs in deployed wave energy devices. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Columbia Power Technologies, Inc.** | Wave Energy Converter Structural Optimization through Engineering and Experimental Analysis | $1,000,000 | FY13 MHK System Performance Advancement FOA | Virginia, Oregon |
| **Project Description** | | | | |
| Columbia Power Technologies will optimize, build, and test a composite hull for its StingRAY wave energy converter. The project seeks to reduce the weight of dynamic structures and introduce a cost-effective concrete ballast to maintain the desired hydrostatic characteristics of the StingRAY device. Columbia Power Technologies has partnered with the Energy Department's National Renewable Energy Laboratory to leverage structural testing capabilities proven in wind and tidal applications and develop new procedures for testing wave energy converter structural components. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Concepts ETI, Inc.** | Development and Demonstration of a Wave Energy Converter System | $1,195,456 | FY08 Advanced Water Power Projects FOA | Vermont, Hawaii |
| **Project Description** | | | | |
| Concepts ETI and Oceanlinx developed a robust, maintainable, and commercially viable nominal 600-kilowatt wave energy converter (WEC) system to be deployed as part of a $10-million program being undertaken by Oceanlinx. The project focused on the design and manufacture of a second-generation variable pitch turbine with improved efficiency and reliability to be deployed offshore for testing and grid-connection evaluation in Maui, Hawaii. The project aimed to improve overall power recovery efficiency by as much as 50%—using also a pneumatic energy-storage technique—compared to the current state-of-the-art WEC systems. The full-scale demonstration will serve to validate the technology design approach, energy recovery efficiency, reliability, and system economics. The successful operation of the system will serve as an important milestone in the commercialization pathway of ocean wave power recovery systems. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Dehlsen Associates, LLC** | Siting Study for a Hydrokinetic Energy Project Located Offshore Southeast Florida | $600,000 | FY09 Advanced Water Power FOA | California, Florida |
| **Project Description** | | | | |
| Dehlsen Associates developed a siting study protocol and survey methodology for collecting baseline geophysical and benthic habitat data that can be used by MHK project developers and regulators to make initial project siting decisions that avoid or minimize adverse impacts to sensitive marine benthic habitat on the outer continental shelf off the coast of southeast Florida. The approach will help facilitate the licensing process for hydrokinetic and other ocean renewable energy projects within the study area and will assist in clarifying the baseline environmental data requirements, as well as reduce the time, effort, and cost to site and permit future MHK facilities offshore of southeast Florida. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Dehlsen Associates, LLC** | Aquantis C-Plane Ocean Current Turbine Project | $3,900,000 | FY10 MHK Technology Readiness Advancement Initiative FOA, FY09 Advanced Water Power FOA | California, Florida, Pennsylvania, Maryland, Virginia |
| **Project Description** | | | | |
| Dehlsen Associates developed the Aquantis Current Plane (C-Plane™) technology, an ocean current turbine designed to extract the kinetic energy from ocean currents and intended to achieve continuous, reliable, and competitively priced baseload power generation at a high capacity factor. The project will involve: (1) experimental validation of analytical tools/design; (2) a levelized cost of electricity model; (3) certification approvals; (4) a drawing package; and (5) direct-drive development. Dehlsen is employing a systems integration effort to develop its commercial-scale C-Plane™ Multi-Megawatt device. The successful completion of the project is expected to reduce risk in the following areas: energy extraction, dynamic stability, structural optimization, moorings, and attachments. Dehlsen estimates the impact of the C-Plane™ could result in more than 10,000 megawatts of clean, renewable, baseload energy extracted from the Gulf Steam. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Dehlsen Associates, LLC** | Advanced Controls for the Multi-Pod Centipod WEC Device | $500,000 | FY13 MHK System Performance Advancement FOA | California |
| **Project Description** | | | | |
| Dehlsen Associates will develop an advanced feed forward control algorithm for its multi-pod Centipod wave device. The multi-pod Centipod wave device reduces relative movement between the pods and the platform. The new software will help predict future wave conditions and provide control signals to adjust current system settings to make the Centipod's power output more responsive by maximizing energy capture, reducing loading, and increasing power plant durability. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Dresser-Rand** | HydroAir Power Take-Off System | $2,500,000 | FY13 MHK System Performance Advancement FOA | New York |
| **Project Description** | | | | |
| Dresser-Rand will design, build, and test a scaled-up version of a high power density, bidirectional radial HydroAir turbine. The use of a radial design (versus axial) is expected to reduce the turbine size and therefore cost. The HydroAir turbine is a crosscutting component that can supply any oscillating water column-type device with a power take-off. Dresser-Rand is teaming with Ocean Energy (OE), targeting integration of the HydroAir turbine into an OE Buoy. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Electric Power Research Institute** | Wave Energy Resource Assessment and GIS Database for the United States | $499,668 | FY08 Advanced Water Power Projects FOA | California |
| **Project Description** | | | | |
| The Electric Power Research Institute has performed an assessment of the total available and technically recoverable ocean wave energy resources for the United States. The final product includes a geospatial database, verified and validated by a third party, that displays power densities for specific spatial coordinates. The assessment estimates 1,170 terawatt hours per year is technically recoverable from wave energy resources. The expected users of this product include policymakers, wave energy project developers, wave energy device and technology developers, investors, and universities. The results have been validated and incorporated into the National Renewable Energy Laboratory geospatial renewable energy database. The analysis and development of the geospatial database is expected to accelerate investigation of the nation's wave energy resources. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Electric Power Research Institute** | A First Assessment of U.S. In-Stream Hydrokinetic Energy Resources since the 1986 NYU Study | $380,978 | FY09 Advanced Water Power FOA | California |
| **Project Description** | | | | |
| The Electric Power Research Institute conducted research to assess the total available and technically recoverable hydrokinetic energy from U.S. rivers. A comprehensive assessment of existing U.S. in-stream hydrokinetic resources did not previously exist and is of critical importance to accelerate the market for emerging hydrokinetic technologies. The project comprehensively assessed existing U.S. in-stream hydrokinetic resources and the achievable energy conversion rates possible by future hydrokinetic devices from that resource. The assessment estimates 101 terawatt hours per year, from approximately 20 gigawatts of installed capacity, is technically recoverable from hydrokinetic river energy resources. The final product includes a geospatial database, verified and validated by a third party, which displays power densities for specific spatial coordinates. The expected users of this product include policymakers, project developers, hydrokinetic energy device developers, investors, universities, nongovernmental organizations, environmental groups, DOE, the military, the U.S. Army Corps of Engineers, and the U.S. Geological Survey. The project is expected to accelerate investigation of the nation's in-stream hydrokinetic energy resources. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Electric Power Research Institute** | Assessment of the Environmental Effects of Hydrokinetic Turbines on Fish: Desktop and Laboratory Flume Studies | $597,408 | FY09 Advanced Water Power FOA | California |
| **Project Description** | | | | |
| The Electric Power Research Institute, in partnership with the U.S. Geological Survey Laboratory, is conducting desktop and flume studies to determine the potential for fish injury and mortality when encountering hydrokinetic turbines of various designs installed in tidal and river environments. Behavioral patterns are also being investigated to assess the potential for disruptions in the upstream and downstream movements of fish. A primary concern of regulatory agencies is how the operation of hydrokinetic turbines will impact local and migratory fish populations. The project aims to accurately and precisely determine the probability of blade strike and injury, as well as the behavior of fish as they encounter hydrokinetic turbines. The project will provide valuable data and information that can reduce costs and uncertainty for developers and resource and regulatory agencies. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Electric Power Research Institute** | Assessment of Potential Impact of the Magnetic Fields from Undersea Cable on Migratory Fish Behavior | $399,285 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | California |
| **Project Description** | | | | |
| Electric Power Research Institute will assess how electromagnetic fields generated by undersea electricity transmission may affect marine species. To simulate the conditions that would exist around a transmission cable connected to a hydrokinetic energy device, researchers will observe fish behavior around a high-voltage cable connecting the cities of San Francisco, California, and Pittsburg, California. The project will investigate whether the electromagnetic fields around the power cable alter the behavior or path of fish along a migratory corridor and find out whether the electromagnetic fields help guide migratory movements or create obstacles to migration. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Florida Atlantic University** | Southeast National Marine Renewable Energy Center | $5,189,375 | FY10 CDP, FY09 CDP, FY08 Advanced Water Power Projects FOA | Florida |
| **Project Description** | | | | |
| Florida Atlantic University is home to the Southeast National Marine Renewable Energy Center (SNMREC), a national open-ocean energy laboratory that advances research on the renewable energy resources of open-ocean current systems and ocean thermal energy conversion. SNMREC is building the capability, infrastructure, and strategic partnerships needed for testing hydrokinetic energy generation prototypes and related technologies in the open ocean. In the future, commercial-scale deployments of such systems, with the potential to provide significant baseload power, will depend critically on standardized testing procedures in the real-world operating environment. SNMREC works to identify, develop, and test open-ocean current systems to meet this need. SNMREC focuses on: (1) technology testing and resource monitoring; (2) research on technological approaches to detection and mitigation of potential underwater collisions through the use of acoustic and video monitoring, underwater observatory technology, scale-model testing, and other methods; (3) environmental monitoring, demonstration, and protocol enhancement; (4) development of an environmental assessment plan; and (5) education and public outreach. Research and development activities support multiscale field testing of prototype generating systems and bridge the gap between basic science and commercialization of innovative open-ocean current systems that can generate significant amounts of clean, renewable ocean power. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Florida Atlantic University** | Effects of EMF Emissions from Cables and Junction Boxes on Marine Species | $400,000 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Florida |
| **Project Description** | | | | |
| Florida Atlantic University will characterize the electromagnetic field (EMF) emissions at the Navy's South Florida Ocean Measurement Facility—an in-water test facility that consists of a number of bottom-mounted sensors for measuring and characterizing acoustic and electromagnetic signatures of submarines—as a representative location where MHK devices may be sited. This analysis will then be used to monitor and assess how EMFs affect the behavior of local marine species and sea-floor communities. The project will establish a database of field measurements, which will be used to assess the potential ecological impacts of EMFs on individual organisms, populations, and communities in the vicinity. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Free Flow Energy, Inc.** | Submersible Generator for Hydrokinetics | $160,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | New Hampshire |
| **Project Description** | | | | |
| Free Flow Energy designed a submersible generator as a separate critical subassembly optimized for MHK conditions and intended to couple with different turbine styles. For most existing large electromechanical assemblies found in manufacturing, industry, or renewable energy systems (such as wind), the generator is a separate and critical subassembly—not typically designed into the rotating turbine. Free Flow Energy designed and optimized a generator for use in a range of MHK systems and turbine styles that can be applied by MHK system designers into a complete system, including the turbine, ducting, and supporting structure. This project brought together experienced motor/generator design professionals with leading U.S. academic researchers in the field of motor/generator design and leading U.S. component suppliers to design a generator specifically for the application and acceleration of current and tidal energy. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Free Flow Power Corporation** | The Water-to-Wire Project | $1,384,503 | FY09 Advanced Water Power FOA | Louisiana |
| **Project Description** | | | | |
| The Free Flow Power (FFP) Water-to-Wire project evaluated and optimized the performance, environment, and cost factors of FFP hydrokinetic SmarTurbines™ through design analyses and Mississippi River deployments. Specific objectives included: (1) design, fabrication, and testing of a full-scale prototype turbine—endpoint: functional generating hardware; (2) in-river deployment and testing of the full-scale prototype turbine—endpoint: test data demonstrating performance, river environment, and resource potential; and (3) design and analyses for the commercial-scale infrastructure and sites—endpoint: refined cost and design for complete array systems to provide launch point for next-level deployments. The challenges included: (1) a lack of commercially operating hydrokinetic river systems in existence so uncertainty exists about the equipment performance in a relevant environment; (2) commercial cost of capital and operation and maintenance for practical systems; and (3) the generation from the available resource that is practically achievable. The project results provide a pathway and supporting data and demonstration results for FFP and all hydrokinetic developers to address the design and cost challenges associated with turbine siting, installation, and maintenance. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Georgia Tech Research Corporation** | Assessment of Energy Production Potential from Tidal Streams in the United States | $469,299 | FY08 Advanced Water Power Projects FOA | Georgia |
| **Project Description** | | | | |
| Georgia Tech Research Corporation has configured an advanced ocean circulation model for simulations of the tidal flows in multiple computation domains comprising the coast of the United States. The research program advances the state-of-the-art and market penetration in tidal energy resource assessment by modeling the entire U.S. coastline for tidal current variations, developing numerical simulation, and using spatial analysis tools for use in the critical site-selection process for energy converters. The completed assessment estimates 250 terawatt hours per year, from approximately 50 gigawatts of installed capacity, is technically recoverable from tidal current energy resources. The assessment has determined that more than 90% of the technically recoverable resource is in Alaska. The accuracy of the model results have been validated by DOE's Oak Ridge National Laboratory by comparing the model results with measurements for numerous locations. The data can be viewed at tidalstreampower.gatech.edu. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Georgia Tech Research Corporation** | Assessment of Energy Production Potential from Ocean Currents along the United States Coastline | $372,627 | FY09 Advanced Water Power FOA | Georgia |
| **Project Description** | | | | |
| Georgia Tech Research Corporation is developing a database on ocean current energy resource potential with participation from a group of experts in ocean circulation observations and modeling. Different sources of ocean current data will be synthesized, such as satellite observations, data assimilation models, in-situ measurements, and high-frequency radar. The research project will advance the state-of-the-art and market penetration in ocean current energy resource assessment via contributions on numerous topics, including the synthesis of multiple sources and modalities of ocean current data along the entire U.S. coastline and the development of spatial analysis tools and their use to facilitate the critical site-selection process for energy converters. The accuracy of the database will be validated by Oak Ridge National Laboratory by comparing the database with measurements for numerous locations. The velocity and power density probability distributions will be stored in a database, and several spatial analysis tools will be developed for the purpose of disseminating the data to the industry, as well as the general public. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Harris Miller Miller & Hanson** | Environmental Effects of Sediment Transport Alteration and Impacts of Protected Species: Edgartown Tidal Energy Project | $600,000 | FY09 Advanced Water Power FOA | Massachusetts |
| **Project Description** | | | | |
| Harris Miller Miller & Hanson (HMMH), along with Woods Hole Oceanographic Institution and the University of Massachusetts Dartmouth School of Marine Science and Technology, is conducting a feasibility study with the Town of Edgartown, Massachusetts, on a tidal energy project in the Muskeget Channel. The island towns of Edgartown (on Martha's Vineyard) and Nantucket recognize that they are vulnerable to power supply interruptions due to their position at the end of the power grid, as well as due to potential sea level rise and other consequences of climate change. HMMH is working with both towns and the marine science community to explore the potential for developing sustainable energy resources from the ocean. The objective of the feasibility study is to evaluate the potential environmental impacts associated with sediment transport alteration of two established tidal energy technologies, as well as to collect and analyze information on the occurrence and potential impacts of protected species in the project area. The research will generate information useful to the water power industry on the differences between the two tidal energy technologies' relationship to sediment transport alteration, as well as information of broader public interest on the existence of protected marine species in the project area that will be raised during the permitting process. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **H.T. Harvey & Associates** | Evaluating the Potential for MHK Devices to Become Artificial Reefs or Fish Aggregating Devices | $74,502 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | California |
| **Project Description** | | | | |
| H.T. Harvey & Associates will evaluate the potential for MHK devices to attract marine wildlife and fish. The goal of this research is to evaluate the nature, intensity, and frequency of potential interactions between MHK device surrogates and fish and invertebrate communities, helping to inform permitting and licensing policies. This study will analyze similar marine structures—such as offshore open-ocean fish farms, oil platforms, moored buoys, and artificial reefs built for recreational fisheries in tropical, subtropical, and temperate western U.S. and Hawaiian coastal waters. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Lockheed Martin Corporation** | Advanced Composite OTEC Cold Water Pipe Project | $1,195,758 | FY08 Advanced Water Power Projects FOA | California |
| **Project Description** | | | | |
| Lockheed Martin demonstrated an innovative cold water pipe fabrication and deployment approach that is lower in cost and risk than previous ocean thermal energy conversion (OTEC) designs. Commercialization of OTEC systems hinges on reducing the capital cost of key components, such as the heat exchangers, cold water pipe, and support platform for floating plants, to enable OTEC to be competitive with other renewable energy systems. Lockheed Martin used a novel design and materials to form an integrated structure that enables simultaneous in-situ fabrication and deployment of the cold water pipe, thereby reducing manufacturing costs and deployment cost and risk. The project also provides data and experience related to manufacturing methods, labor, and materials costs needed to validate cost projections for the full-scale production of its cold water pipe. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Lockheed Martin Corporation** | Ocean Thermal Extractable Energy Visualization | $375,000 | FY09 Advanced Water Power FOA | Virginia |
| **Project Description** | | | | |
| Lockheed Martin, in partnership with DOE's National Renewable Energy Laboratory, has developed a Geographic Information Systems (GIS)-based dataset and software tool—the Ocean Thermal Extractable Energy Visualization (OTEEV) tool. OTEEV is being used to provide a meaningful assessment of maximum practicably extractable energy from the global and domestic ocean thermal resource and identification of regions viable for ocean thermal energy conversion and Cold Seawater-Based Air Conditioning. The completed assessment estimates 576 terawatt hours per year is technically recoverable from ocean thermal resources in U.S. waters, and that much of the technically recoverable resource is in the Pacific Islands region. Through conferences and the publicly accessible Web-based GIS tool, the OTEEV team will disseminate the newly available knowledge and insights to policymakers, the energy industry, and the public. A multi-step technical methodology was developed using quality datasets that were synthesized from a wide array of sources to create a complete snapshot of the available energy resource. Using GIS technology, geospatial maps are being developed that include extractable energy, resource magnitude, thermal properties, and supporting information about data coverage and uncertainties. The OTEEV provides a current state-of-the-art resource assessment tool that is applicable to industry for development and commercialization, as well as research and policy agencies. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Lockheed Martin Corporation** | OTEC Life-Cycle Cost Analysis | $499,701 | FY09 Advanced Water Power FOA | Virginia |
| **Project Description** | | | | |
| Lockheed Martin is building on other ocean thermal energy conversion (OTEC) projects to conduct economic, cost, and life-cycle analyses of OTEC projects. The sizes and configurations of OTEC plants evaluated under this study are: 100 megawatt, 200 megawatt, and 400 megawatt net electrical power output plants where the electricity is cabled to shore via marine power cable, as well as open-ocean grazing 400 megawatt OTEC plants producing anhydrous ammonia as an energy carrier for shipment to selected ports. The project integrates data from previous work, multiple cost models, and projected technology and efficiency developments to extrapolate current and future capital, as well as operating and maintenance costs for these OTEC plant configurations. Utilizing DOE's defined approach, levelized cost of electricity (LCOE) is calculated for each OTEC plant configuration. LCOE provides a figure of merit that translates the life-cycle cost over the performance life of the plant into a single value. Utilizing the LCOE and projected build-out plans, energy supply curves are developed for Oahu, Hawaii, and the global OTEC resource. The financial analysis resulting from this project will provide decision makers in government and industry with a reliable means to assess the commercial viability of both nearshore OTEC cabled to local grid projects and grazing OTEC plant projects producing an energy carrier. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Lockheed Martin Corporation** | OTEC Pipe-Platform Sub-System Dynamic Interaction Validation | $599,965 | FY10 MHK Technology Readiness Advancement Initiative FOA | Virginia |
| **Project Description** | | | | |
| Lockheed Martin Mission System and Sensors, along with a team of leading industry experts, conducted a project that validated the ability to numerically model the dynamic interaction between a large cold water filled pipe and a floating ocean thermal energy conversion (OTEC) platform excited by meteorological and ocean weather conditions at a state-of-the-art ocean model basin. The OTEC cold water pipe is significantly larger than the marine risers that the conventional offshore industry has validated through scale model tests. The model was subjected to a properly scaled ocean environment simulated in a deep ocean model basin consisting of waves, swells, current, and wind. In parallel with the test program, numerical modeling was employed to predict the model performance based on the as-built model characteristics and the environmental conditions simulated in the model basin. The results of the numerical modeling were compared with the results obtained from the physical testing. Results were analyzed to develop best practices for numerical modeling inputs required to accurately predict OTEC scale pipe-platform interactions. These best practices were documented and distributed to become the standard by which future cold water pipe-platform analysis will be performed. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **M3 Wave Energy Systems, LLC** | Delos-Reyes Morrow Pressure Device (DMP): Simple, Scalable, and Submerged | $240,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Oregon |
| **Project Description** | | | | |
| M3 Wave Energy Systems conducted a 12-month project to explore the commercial viability of the submerged Delos-Reyes Morrow Pressure Device—a new method of converting ocean wave energy into electricity. The key result was a detailed levelized cost of energy model for a full-scale system. This project advanced the technology from concept definition/feasibility through analytical proof of concept and small-scale experimental testing. The Northwest National Marine Renewable Energy Center at Oregon State University provided M3 with an analysis of nearshore wave conditions and a detailed system response model. Pacific Energy Ventures and M3 worked with industry experts to estimate full-scale system and operating costs. This project created new tools and techniques for modeling and testing submerged nearshore devices. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Makai Ocean Engineering, Inc.** | Modeling the Physical and Biochemical Influence of Ocean Thermal Energy Conversion Plant Discharges into Their Adjacent Waters | $240,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Hawaii |
| **Project Description** | | | | |
| Makai Ocean Engineering has critically enhanced a numerical model to quantify the relationships between ocean thermal energy conversion (OTEC) discharge component design, OTEC performance, and environmental changes that may result from the OTEC discharge plume. This modeling capability will be essential for designing the discharge components to minimize OTEC's environmental impact and optimize cost, and for discussion with OTEC regulators and permitting agencies. Specifically, this work used collected oceanographic data to calibrate modeled ocean circulation, analyze the OTEC discharge plumes using these validated realistic ocean conditions, and provide biogeochemical model predictions in order to design OTEC plants to minimize environmental impacts and prevent algal blooms. The results of this project and model are relevant to both a 5 megawatt pilot-scale OTEC plant planned by Naval Facilities Engineering Command for Hawaii and the National Oceanic and Atmospheric Administration. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Missouri University of Science and Technology** | Remote Monitoring of the Structural Health of Hydrokinetic Composite Turbine Blades | $159,972 | FY10 MHK Technology Readiness Advancement Initiative FOA | Missouri |
| **Project Description** | | | | |
| Missouri University of Science and Technology developed a composite turbine blade for hydrokinetic energy systems that is capable of acquiring and transmitting its own structural health information. Developing technologies that allow hydrokinetic technologies to be remotely monitored and unattended for long periods of time is important for accelerating the deployment of these technologies, which operate in remote, harsh environments. These harsh conditions result in operation and maintenance costs expected to be 70%–95% of the total investment cost of the system. The project fabricated a prototype composite turbine blade, demonstrated underwater transmission of strain data, and developed a plan to advance the concept to a prototype demonstration phase. The results of developing a component to remotely monitor turbine blade structural health are: (1) the reduction of operation and maintenance costs; (2) the ability to alert monitors of the need for a replacement blade; (3) notification of a transient event causing damage; (4) accelerated deployment of hydrokinetic systems due to enhanced operational lifetime by operating at reduced capacity to reduce structural load; and (5) in the long-term, a benefit to consumers through savings on operation and maintenance costs that lower the cost of electricity. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Multnomah County, Oregon** | Bridge Hydro-Turbine Study | $150,000 | FY10 CDP | Oregon |
| **Project Description** | | | | |
| Multnomah County in Oregon conducted a feasibility study on attaching miniturbines to the face of bridge piers on the Willamette River in order to generate renewable and economically stable electricity. Since Multnomah County has limited geothermal, solar, and wind renewable energy, hydrokinetic resources on the Willamette River may be the most viable option for providing renewable and reliable electricity generation. Attaching miniturbines to seven county-owned piers could provide hydrokinetic electricity generation to the county or local grid without building a dam or diversion, while also providing some protection from shipping, fish, and wildlife. The feasibility study has determined whether generating electricity via these miniturbines attached to bridge piers is economically and logistically feasible; the optimal size, number, and placement of turbines and resultant electrical power generated; the compliance issues associated with the project; and whether the county, local utility, or third-party developer would be the best entity to undertake such a hydrokinetic energy production project. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Northwest Energy Innovations** | Azura Multi-Mode Wave Energy Converter Advancement Project | $1,818,519 | FY10 MHK Technology Readiness Advancement Initiative FOA | Oregon |
| **Project Description** | | | | |
| Northwest Energy Innovations, in partnership with industry leaders, has verified the ocean wavelength functionality of the Azura device (previously called WET-NZ) through wave tank testing and controlled open-sea deployment of a 1:2 scale device. The project built on previous testing in controlled nearshore wave environments by implementing a range of identified design improvements. Through the new round of wave tank testing and controlled sea deployment, this project gained energy-capture performance data for improved cost-of-electricity calculations and new understanding of the wave impedance matching ability of the Azura design. Azura is at an advanced stage of development and positioned for deployment of a full-scale pre-commercial prototype device. The Azura technology is positioned for implementation of a commercialization strategy in the United States. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Northwest Energy Innovations** | Azura Multi-Mode Technology Demonstration at the U.S. Navy's Wave Energy Test Site | $699,000 | FY12 In-Water Wave Energy Conversion Device Testing Support FOA | Hawaii |
| **Project Description** | | | | |
| Northwest Energy Innovations' Wave Energy Technology-New Zealand technology, which was recently renamed to Azura, will be deployed at the U.S. Navy's Wave Energy Test Site in Hawaii to conduct open-ocean grid-connected testing for a period of 12 months. The primary objectives of this project are to utilize data collected during the deployment to optimize energy capture, validate existing levelized cost of electricity and performance models, and further refine the models. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Oak Ridge National Laboratory** | Informing a Tidal Turbine Strike Probability Model through Characterization of Fish Behavioral Response | $150,000 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Tennessee |
| **Project Description** | | | | |
| Oak Ridge National Laboratory will quantify the distribution, behavioral response, and general patterns of fish movement around an operating tidal energy turbine. The research team will conduct an analysis of individual fish movements using previously unanalyzed sonar data collected at Verdant Power's Roosevelt Island Tidal Energy Project, located in the East River near Manhattan. This study will provide the industry with a complete analysis of fish interaction data at a full-size turbine that developers and regulators can use to estimate the likelihood of encounter and injury at tidal and riverine sites. The tools refined in this study will be widely applicable to other sites and conditions, and the results from this study will be used to refine estimates of potential effects, design mitigation to minimize impacts, and develop monitoring protocol. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Energy USA, LLC** | Optimization of Hull Shape and Structural Design for OE Buoy | $991,662 | FY13 MHK System Performance Advancement FOA | California |
| **Project Description** | | | | |
| Ocean Energy USA, LLC will develop and conduct wave-tank testing on a cost-effective hull design for its deep-water wave energy device. The OE Buoy aims to improve the power-to-weight ratio of the device through structural design optimization and accelerate the commercial deployment of this technology. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Engineering and Energy Systems International, Inc.** | The Potential Impacts of OTEC Intakes on Aquatic Organisms at an OTEC Site Currently Under Development | $594,961 | FY09 Advanced Water Power FOA | Hawaii |
| **Project Description** | | | | |
| Ocean Engineering and Energy Systems International and industry partners are conducting a project to evaluate the potential impacts of an ocean thermal energy conversion (OTEC) facility's intakes on the island of Kauai, Hawaii. Such work will be required for licensing of OTEC facilities under the OTEC Act of 1980 (administered by the National Oceanic and Atmospheric Administration). The site-specific data generated during the project will be valuable to the industry for designing OTEC facilities with minimal impact to aquatic organisms. Further, the data generated for this site should be readily transferable to other OTEC sites under development, thus facilitating the development and deployment of future OTEC facilities in an effective and environmentally responsible manner. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Power Technologies, Inc.** | PB150 PowerBuoy Project | $4,377,293 | FY10 MHK Technology Readiness Advancement Initiative FOA, FY08 CDP | Oregon |
| **Project Description** | | | | |
| Ocean Power Technologies leveraged Lockheed Martin's expertise in manufacturing, which can serve as a model for design improvements to the device structure and drivetrain components that will ultimately reduce the cost of building commercial production units. OPT also detailed operating characteristics over two years and gathered baseline environmental data off the coast of Oregon. These measurements included data on ambient acoustic levels and on electromagnetic fields at the site. The research generated will benefit future marine and hydrokinetic projects. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Power Technologies, Inc.** | 500kW Utility-Scale PowerBuoy Project | $3,900,000 | FY10 MHK Technology Readiness Advancement Initiative FOA, FY09 Advanced Water Power FOA | Oregon |
| **Project Description** | | | | |
| Ocean Power Technologies is building on its existing PowerBuoy technology to complete the major components for constructing a fully integrated design of the PB500 PowerBuoy. The components will be assembled to create a full-scale modular power take-off test bed device. The PB500 will have the ability to produce up to 500 kilowatts of power at a levelized cost of electricity that could compete with land-based fossil fuel generation systems in the global market for energy generation. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Power Technologies, Inc.** | Optimal PowerBuoy Structure Design for Maximized Power-to-Weight Ratio and Reduced Installed Capital Cost | $1,000,000 | FY13 MHK System Performance Advancement FOA | New Jersey |
| **Project Description** | | | | |
| Ocean Power Technologies will work on developing the float and spar—or cylindrical body—components of its PowerBuoy wave energy converter. These two components account for 50% of the device's mass, so improving materials, manufacturability, and durability of the float and spar could reduce the cost of energy and significantly improve the device's power-to-weight ratio. This work will make the PowerBuoy more reliable and marketable. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company Alaska, LLC** | Acoustic Monitoring of Beluga Whale Interactions with Cook Inlet Tidal Energy Project | $600,000 | FY09 Advanced Water Power FOA | Alaska |
| **Project Description** | | | | |
| Ocean Renewable Power Company Alaska is conducting a two-year study on the effects of tidal turbines on beluga whales in Cook Inlet, Alaska. Cook Inlet is home to some of the greatest tidal energy potential in the United States, as well as an endangered population of beluga whales. Successful permitting and operation of a tidal power project in Cook Inlet will require a rigorous biological assessment of the potential and realized effects of the tidal turbines on the Inlet beluga whales. This project will collect baseline data to characterize pre-deployment patterns of marine mammal distribution, relative abundance, and behavior in Ocean Renewable Power Company Alaska's proposed deployment areas near Fire Island and near East Foreland at the initial pilot project site. This project will attempt to adapt the use of passive hydroacoustic devices (previously utilized with Bowhead whales in the Beaufort Sea) to determine both relative abundance and location of beluga whale vocalizations within the proposed deployment areas. Hydroacoustic data collected during this effort will also be used to characterize the ambient acoustic environment of the proposed project sites pre-deployment, as required by project licensing. The project will compare this method with other passive hydrophone technologies and visual observation techniques performed simultaneously and recommend a best practice for future data collection based on the results. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company Alaska, LLC** | Abrasion Testing of Critical Components of Hydrokinetic Devices | $240,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Alaska |
| **Project Description** | | | | |
| Ocean Renewable Power Company (OPRC) Alaska worked with the University of Alaska Anchorage (UAA) to convert tidal and river currents into emission-free electricity. The project tested the performance of core ORPC Alaska device components in a laboratory setting that replicates environmental conditions encountered in Alaskan deployments. The project specifically focused on understanding wear caused by high-suspended sediment concentrations at tidal and river energy sites common in Alaska. One area of concern is the effect of sediments from the marine environment on device bearings and seals, as failures of these components could lead to both loss of efficiency and catastrophic system failures. The project performed laboratory testing of various combinations of bearings and seals to determine the relationships between bearing wear rates and seal failures due to suspended sediment abrasion. ORPC's proprietary turbine-generator unit was tested in Cobscook Bay, Maine, which is a lower-suspended sediment concentration environment. The UAA research will provide ORPC Alaska with an ability to test and adapt its technology to new and diverse conditions. The lessons learned will be applicable in future hydrokinetic projects worldwide. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company, LLC** | OCGen™ Module Mooring Project | $1,034,534 | FY09 Advanced Water Power FOA | Maine |
| **Project Description** | | | | |
| Ocean Renewable Power Company's OCGen™ Module Mooring Project is investigating the design of a standard mooring system for hydrokinetic devices that will be moored below the ocean's surface and above the sea floor in reversing tidal environments. Anchoring in fast water is not commonly performed, and standard anchoring systems for these conditions do not yet exist. The project includes hydrodynamic modeling of a buoyant OCGen™ module and subsequent development of a robust, effective, environmentally friendly anchoring system for the module. The project includes the analytical models for a design of a mooring system for an OCGen™ Power System; verification of these analytical models using scale model testing; design, construction, and deployment of an experimental version of the mooring system in the field; and monitoring of the performance and environmental effects of this deployed mooring system for a period of two months. The project enables Ocean Renewable Power Company to prove the technical and economic viability of a mooring system for fast water applications, and to move the OCGen™ Power System along the path from pre-commercial phase to an initial commercial production model that can be deployed in tidal streams to produce and deliver emissions-free, predictable, schedulable, and renewable electrical energy. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company, LLC** | TidGen™ Power System Commercialization Project | $10,000,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Maine |
| **Project Description** | | | | |
| Ocean Renewable Power Company (ORPC) conducted the TidGen™ Power System Commercialization Project in Cobscook Bay off Eastport and Lubec, Maine. Over three years and two phases, ORPC built, operated, and monitored a commercial-scale grid-connected TidGen™ device. ORPC's TidGen™ device was interconnected with the Bangor Hydro Electric Company distribution grid with a 20-year power purchase agreement. ORPC performed detailed testing and monitoring of the local environment, all system components, and all subsystems. The ORPC TidGen™ Power System Commercialization Project is an important step toward the accelerated distribution of a commercial tidal-current-based hydrokinetic system for reliable and cost-competitive delivery of utility-scale electricity with technology developed, manufactured, and deployed by a U.S. company in domestic waters. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company, LLC** | Advanced Energy Harvesting Control Schemes for Marine Renewable Energy Devices | $1,935,841 | FY13 MHK System Performance Advancement FOA | Maine |
| **Project Description** | | | | |
| Ocean Renewable Power Company will investigate, analyze, and model a control system for its grid-connected TidGen™ System that predicts tidal conditions based on measurements ahead of the device and uses them to adjust turbine settings for optimal performance. The improved control scheme could more efficiently harvest energy from highly turbulent water. The project has the potential to apply to a range of other tidal turbine devices. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Ocean Renewable Power Company, LLC** | Power Take-off System for Marine Renewable Devices | $3,000,000 | FY13 MHK System Performance Advancement FOA | Maine |
| **Project Description** | | | | |
| Ocean Renewable Power Company will develop and test components—including bearings, couplings, and a subsea electrical generator—for an advanced power take-off system, the drivetrain and generator assembly that converts mechanical energy into electricity, suitable for wave, tidal, and current energy devices. In addition, the company will conduct studies to measure the component and system performance benefits and identify how best to incorporate these components into its existing turbine technologies, which include tidal, riverine, and ocean current applications. This project seeks to develop a common set of components for wave, tidal, and current energy devices that will improve their power-to-weight ratio and availability. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Oregon State University** | Northwest National Marine Renewable Energy Center | $13,021,170 | FY10 CDP, FY09 CDP, FY08 Advanced Water Power Projects FOA | Oregon, Washington |
| **Project Description** | | | | |
| Oregon State University and the University of Washington have partnered to develop the Northwest National Marine Renewable Energy Center (NNMREC) with a full range of capabilities to support wave and tidal energy development for the United States. NNMREC activities are structured to facilitate device commercialization, inform regulatory and policy decisions, and close key gaps in understanding. NNMREC focuses on topic areas that address: (1) development of facilities to serve as an integrated, standardized test center for the United States and international developers of wave and tidal energy; (2) evaluation of potential environmental and ecosystem impacts; (3) device and array optimization for effective deployment of wave and tidal energy technologies; (4) improved forecasting of the wave energy resource; and (5) increased reliability and survivability of marine energy systems. The results of key NNMREC findings and research programs will be disseminated to all stakeholders and interested parties through workshops, conferences, publications, and an online portal. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Oregon State University** | The Pacific Marine Energy Center South Energy Test Site | $750,000 | FY13 Wave Testing Infrastructure Development FOA | Oregon |
| **Project Description** | | | | |
| The Northwest National Marine Renewable Energy Center (NNMREC), a collaboration between Oregon State University (OSU) and the University of Washington, was established by DOE's WWPTO to support wave and tidal energy development in the United States. In conjunction with other research and testing activities at OSU, NNMREC is developing the Pacific Marine Energy Center South Energy Test Site, a grid-connected test facility, to evaluate utility-scale wave energy conversion device performance, environmental interactions, and survivability. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Oregon State University** | Measuring Changes in Ambient Noise Levels from the Installation and Operation of a Wave Energy Converter in the Coastal Ocean | $149,613 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Oregon |
| **Project Description** | | | | |
| Oregon State University will measure changes in sound levels from the installation and operation of a wave energy converter in the coastal ocean, including comparison with other natural and manmade sources near the project site. This project will be used to develop a long-term "noise budget" for the area that will serve as a baseline for future assessments of noise impacts related to resource development in the region. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Oregon State University, Hatfield Marine Science Center** | Assessing Communities Near National Rocky Outcrops and an Adjacent Active WEC Site in the Pacific Northwest | $397,889 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Oregon |
| **Project Description** | | | | |
| Oregon State University will characterize fish communities near wave energy deployments in Oregon and compare them to adjacent natural reefs and quantify differences in fish attraction between an energy-producing wave device and a non-energy-producing analysis platform anchored in the same habitat. By understanding these impacts, device developers and regulators can potentially make decisions regarding device or mooring design to minimize interactions with fish. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Pacific Energy Ventures, LLC** | Siting Protocol for Marine and Hydrokinetic Energy Projects | $919,803 | FY08 Advanced Water Power Projects FOA | Oregon |
| **Project Description** | | | | |
| Pacific Energy Ventures (PEV) developed siting protocols that facilitate market penetration of the emerging MHK industry by increasing consistency, predictability, and efficiency in project siting. The multidisciplinary team engaged public and private sector stakeholders in an iterative, collaborative process to analyze and identify protocols for MHK siting. PEV captured the findings and results of this effort in a framework that explains and outlines permitting processes, synthesizes environmental information, and identifies key data gaps and options to address them (www.advancedh2opower.com/framework). The project findings have also been shared in formal reports, workshops, and conference presentations. In addition to providing clarity and guidance for project siting, the development of these protocols has helped foster collaboration and consensus-building among MHK stakeholders at large. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Pacific Energy Ventures, LLC** | Active Acoustic Deterrence of Migratory Whales | $593,846 | FY09 Advanced Water Power FOA | Oregon |
| **Project Description** | | | | |
| Pacific Energy Ventures is evaluating the effectiveness of an active acoustic deterrence system. Every year, more than 20,000 gray whales migrate from Baja, Mexico, to the Bering Sea off the coast of Alaska. Oregon State University's Marine Mammal Institute recently completed Phase I of an Oregon Wave Energy Trust (OWET) action plan to evaluate the impacts of wave energy development on gray whales. The study concluded that the migration paths of some gray whales occur at distances and depths similar to those proposed for offshore wave energy developments; thus, there is a possibility of collision, entanglement, or displacement for whales from wave energy structures. As part of the OWET-funded study, a group of acoustic and whale experts recommended the testing of a limited range acoustic deterrent system to discourage gray whales from entering wave energy parks. This project is testing the effectiveness of an acoustic pinger that emits a one-second-long pulse once every minute. Trained observers are tracking the whales' paths through the test area and will be able to determine the effectiveness of the deterrence system. The project is being conducted directly west of Yaquina Head near Newport, Oregon, where the Phase I baseline data was collected. The project site is in vicinity of the Northwest National Marine Renewable Energy Center's wave energy test site, and results are expected to provide West Coast wave energy developers with a mitigation measure to prevent gray whales from entering the project area or becoming entangled in mooring lines, if required. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Pacific Gas and Electric Company** | WaveConnect Wave Energy In-Water Testing and Development | $1,200,000 | FY08 Advanced Water Power Projects FOA | California |
| **Project Description** | | | | |
| The Pacific Gas and Electric Company (PG&E) WaveConnect project was intended to demonstrate the technical and economic viability of wave power in the open ocean adjacent to PG&E's service territory. WaveConnect was conceived as a multi-stage process leading to long-term megawatt-scale wave power production. The program was halted near the end of the first stage for the following reasons: (1) permitting issues were much more challenging than originally anticipated; and (2) the cost of developing a pilot project was much greater than the $15–$20 million originally estimated. Significant additional investment in design, testing, and demonstration will be needed to improve designs and reduce costs. PG&E estimated a cost of electricity that is not competitive with current or near-term renewable alternatives, such as wind or solar photovoltaics. As wave energy converter technologies mature and regulatory and permitting agencies grow more familiar with their environmental impacts, PG&E believes that wave power will merit further evaluation, demonstration, and deployment. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **PCCI, Inc.** | Marine and Hydrokinetic Renewable Energy Technologies: Potential Navigational Impacts and Mitigation Measures | $165,290 | FY08 Advanced Water Power Projects FOA | Virginia |
| **Project Description** | | | | |
| PCCI completed a technical manual to assist developers and regulators in obtaining the information needed for the permit application process relating to navigational impacts and mitigation measures. A key issue when siting renewable energy technologies in navigable waters is the impact of a proposed facility on traditional waterway uses. PCCI and its team coordinated with the U.S. Coast Guard to advance the industry's knowledge of potential navigational impacts and provide information to assist project developers to avoid or mitigate those impacts. The PCCI team also coordinated with two other project teams funded by DOE to develop a variety of tools and resources for use by stakeholders. The project and technical manual accelerate the deployment of MHK renewable energy installations by providing developers, regulators, and industry stakeholders with information and coordination guidance on navigational impacts, mitigation, and related permitting requirements. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Princeton Power Systems, Inc.** | Marine High-Voltage Power Conditioning and Transmission System with Integrated Energy Storage | $599,799 | FY10 MHK Technology Readiness Advancement Initiative FOA | New Jersey |
| **Project Description** | | | | |
| Princeton Power Systems demonstrated its Marine Power Conditioner with Storage, which combines three innovative technologies, including a high-voltage direct-current power terminal, ultra capacitor energy storage, and circuit architecture that allows for sophisticated sharing, control, and communications among three power terminals. Most MHK energy sources are variable and physically distant from load centers, requiring power conditioning systems that both buffer the power generation and transmit it to shore at high voltage. Previously available energy storage and transmission systems were expensive and poorly suited for these applications, and new technologies could provide substantial benefits. Tests have resulted in achieving a production cost under $0.50 per watt for a marine-rugged 500-kilowatt system. The results of this project have improved integration of wave/tidal power generators with load needs, leading to an increase in the number of wave/tidal power installations and, subsequently, a greater percentage of energy generated from non-polluting, renewable energy sources. In addition, the project helped to establish the United States as a global technological leader in advanced marine power conversion systems. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Principle Power, Inc.** | WindWaveFloat | $1,359,000 | FY09 Advanced Water Power FOA | California |
| **Project Description** | | | | |
| Principle Power conducted an engineering and cost study for the WindWaveFloat, an innovative wave energy concept with the potential to reduce the levelized cost of electricity and environmental impact of electricity generation. Most wave energy converters can only achieve a nameplate capacity of less than 1 megawatt due to physical limitations driven by metocean conditions. This leads to high structural costs and low power production, with mooring and installation encompassing 25%–40% of the device's capital cost. The project assessed a combination of a number of wave and wind energy power take-off mechanisms in an innovative floating support structure—the WindFloat—thus amortizing the mooring and installation costs over higher power output. The use of a floating support structure leads to a number of additional benefits, like reduced environmental impacts and more flexible siting in deep waters. The project consisted of engineering studies, numerical and physical models development, wave tank validation and testing, performance verification, cost/benefit analysis, and optimization studies to increase energy production. The Wind WaveFloat project will provide results in an integrated system with a combined power generation capacity of greater than 5 megawatts with reduced environmental impact, optimized use of space, and shared infrastructure that may result in the lowest levelized cost of electricity possible. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **RCT Systems, Inc. (formerly awarded to Wavebob, LLC)** | Advanced Machines for Marine Hydrokinetic Energy | $2,400,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Maryland |
| **Project Description** | | | | |
| Wavebob designed a switched reluctance machine (SRM) with electronic controls, and provided a utility grid interface by conducting a critical design review and producing manufacturing drawings. RCT Systems, who took over the project in 2011, designed, constructed, and analyzed novel concepts for an axial flux reluctance machine to capture energy from marine and hydrokinetic sources. RCT Systems performed detailed electromagnetic and mechanical analyses to validate the concept and compare it with Wavebob's rotary-based SRM design. The technical documentation and economic data generated during this project will advance the technology and provide an optimized design that can be manufactured for future demonstration projects, accelerating U.S. manufacturing entry into the hydrokinetic energy market. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **RE Vision Consulting, LLC** | Scenario-Based Assessment of Navigation and Environmental Effects of Wave and Tidal Technologies | $350,000 | FY08 Advanced Water Power Projects FOA | California |
| **Project Description** | | | | |
| RE Vision Consulting accelerated the adoption of MHK energy technologies by studying siting issues and developing materials to help the industry site projects more efficiently. One of the key issues that project proponents face as they engage stakeholders is that many conflicting uses and environmental issues are not well-understood. Much of this lack of understanding comes from a limited understanding of the technologies themselves and their life-cycle impacts. A scenario-based approach was used to provide a solid understanding of the impacts these technologies will have in respect to navigation and environmental effects. The final product consists of three reports: (1) a wave energy deployment scenario report, (2) a tidal deployment scenario report, and (3) an environmental assessment framework report. The frameworks and representative scenarios developed provide an objective and transparent tool for stakeholders, regulators, and developers to assist in the decision-making process for siting wave and tidal energy plants, and meet the goal of improving understanding between all stakeholders. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **RE Vision Consulting, LLC** | Assessment of Projected Life-Cycle Costs for Wave, Tidal, Ocean Current, and In-Stream Hydrokinetic Power in the United States Over Time | $374,991 | FY09 Advanced Water Power FOA | California |
| **Project Description** | | | | |
| RE Vision Consulting conducted an assessment of projected life-cycle costs for emerging MHK generation technologies with a final report delivered in September 2012. Unlike more mature renewable energy sectors, historical cost data available in this sector has been limited to a few pilot and demonstration projects worldwide. MHK technology represents its unique challenges in the evaluation of life-cycle cost profiles and relies heavily on predictive cost models and techno-economic assessments. Over the past six years, RE Vision Consulting has developed a suite of parametrically driven techno-economic models that were used in a wide range of siting and economic studies. The study addressed three major questions: (1) what is the present cost of MHK technologies, (2) how much energy can be extracted from these MHK resources at what cost, and (3) at which cost levels will the technology see significant deployment in the United States? To address these questions, RE Vision Consulting engaged in three sequential efforts: (1) establishment of present-day cost profiles for MHK technologies, (2) compilation of existing resource assessments to develop supply curves, and (3) development of deployment scenarios to evaluate how much present-day costs would need to be reduced to allow for significant technology deployment in the United States. The project's results support a more accurate understanding of the present and future life-cycle cost for emerging MHK generation technologies. This knowledge will serve the technology development process, help determine critical decisions on policy mechanisms that support the sector, and provide input to future capacity planning models. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Resolute Marine Energy, Inc.** | Wave Actuated Power Take-Off Device for Electricity Generation | $159,998 | FY10 MHK Technology Readiness Advancement Initiative FOA | Massachusetts |
| **Project Description** | | | | |
| Resolute Marine Energy developed a cost-effective power take-off system for the Surge Device, a wave energy converter already under development by the company. In addition, the project assessed the cost to manufacture power take-off systems at various scales, ranging from multi-kilowatt individual units for early-stage deployments in off-grid applications to sub-megawatt units for multi-megawatt, grid-connected arrays. The project developed a fully packaged embodiment of Resolute Marine Energy's power take-off concept at a 1-kilowatt scale to enable more realistic and comprehensive ocean testing of the Surge Device. The successful development of the power take-off concept will reduce the levelized cost of electricity when incorporated in the Surge Device and advance the integrated system's commercial readiness. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Resolute Marine Energy, Inc.** | Optimal Control of a Surge-Mode WEC in Random Waves | $1,075,227 | FY13 MHK System Performance Advancement FOA | Massachusetts |
| **Project Description** | | | | |
| Resolute Marine Energy developed feedback and forecasting control algorithms for a wave energy converter device. The algorithms factor in wave dynamics and local data, ultimately establishing a decision system sensitive to wave forecasts and measurement errors. The company estimates the control system in one of its full-scale SurgeWEC™ wave energy devices will produce improvements in capture efficiency, capacity, and energy cost. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Science Applications International Corporation** | International Standards Development for Marine and Hydrokinetic Renewable Energy | $593,000 | FY08 Advanced Water Power Projects FOA | California |
| **Project Description** | | | | |
| Science Applications International Corporation (SAIC) worked with a group of industry stakeholders to develop a set of relevant industry standards, as well as a consistent method and process for developing standards for the MHK renewable energy industry. The project used the well-established and proven International Electrotechnical Commission (IEC) development process as a foundation and included qualified U.S. industry technical experts to populate the standards development working groups. Standardization will enable marine renewable energy technologies to become marketable by providing a foundation for certification systems, promoting international trade of uniform high-quality products, and supporting transfer of expertise from traditional energy systems. SAIC convened multiple standards development working groups with participation by key U.S. industry technical experts; supported the international project teams; developed a report on existing IEC standards and processes; and disseminated a semi-annual newsletter to the marine renewable energy community to educate industry members and stakeholders about the processes, progress, and description of these standards. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Scientific Solutions, Inc.** | Underwater Active Acoustic Monitoring Network for Marine and Hydrokinetic Energy Projects | $600,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | New Hampshire |
| **Project Description** | | | | |
| Scientific Solutions (SSI) conducted a joint effort with Ocean Renewable Power Company (ORPC) to fully develop, integrate, test, and operate a full-scale active acoustic detection system for MHK technology and other offshore renewable energy projects. This system deployed and integrated with ORPC's TidGen™ tidal energy device in Cobscook Bay near Eastport and Lubec, Maine. MHK energy projects may not be viable without real-time monitoring of the surrounding underwater environment. There are unknown risks associated with harm to marine life and risks associated with floating debris interacting with moving parts. A viable solution for this problem is active acoustics or active sonar, which may provide detection of an underwater object. However, there were no sonar systems on the market that provided a comprehensive solution. SSI developed a technology used in the Swimmer Detection Sonar Network (SDSN) with a concept ideally suited for the MHK industry. The project combined SDSN with ORPC's advanced stage tidal turbine development and demonstration project. The successful completion of this project enabled the offshore renewable energy industry to conduct real-time monitoring of the surrounding underwater environment and reduce risks associated with marine life and floating debris. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Semprus Biosciences** | Environmentally Benign and Permanent Modifications to Prevent Biofouling on Marine and Hydrokinetic Devices | $160,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Massachusetts |
| **Project Description** | | | | |
| Semprus Biosciences developed environmentally benign and permanent modifications to prevent biofouling on MHK devices. Biofouling, including growth on external surfaces by bacteria, algae, barnacles, mussels, and other marine organisms, may accumulate quickly on MHK devices, causing mechanical wear and changes in performance. Biofouling on crucial components of hydrokinetic devices, such as rotors, generators, and turbines, imposes substantial mass and hydrodynamic loading with associated efficiency loss and maintenance costs. Most antifouling coatings leach toxic ingredients, such as copper and tributyltin, through an eroding process, but increasingly stringent regulation of biocides has led to interest in the development of non-biocidal technologies to control fouling. Semprus Biosciences' research team developed permanent modifications to prevent fouling from a broad spectrum of organisms on devices of all shapes, sizes, and materials for the life of the product. These modifications are expected to out-perform currently used nontoxic underwater coatings in biofouling resistance and be ready for the next stage of development with demonstration in MHK systems. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Shift Power Solutions, Inc.** | Protective, Modular Wave Power Generation System | $240,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | California |
| **Project Description** | | | | |
| Shift Power Solutions has developed a way to capture the energy from waves before they impact breakwaters, groynes, and other marine structures. Waves have high power densities. While this makes them good candidates for electrical energy conversion, their energy is often a destructive force that acts on natural and manmade coastal structures. Shift Power Solutions has developed a system to harvest wave energy that is scalable, modular, adaptable, and cost effective, and it also reduces degradation to coasts and marine installations. There are a wide variety of coastal situations in which this type of energy harvesting may be useful, but manufacturing location-specific components is expensive. Therefore, the project is focusing on development of a modular system to allow installations to be adapted for specific locations without the cost of tailored manufacturing. The benefits to the coastal communities are twofold: stabilization of the coastline and the local production of persistent renewable-based electricity. This project established the technical feasibility of the concept by analyzing, building, and testing a prototype capable of generating up to 1 kilowatt of electricity. If feasible, subsequent development may ultimately result in systems containing thousands of modules capable of generating megawatts of baseline power. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Snohomish County Public Utility District #1** | Puget Sound Tidal Energy In-Water Testing and Development Project | $1,200,000 | FY08 Advanced Water Power Projects FOA | Washington |
| **Project Description** | | | | |
| Snohomish County Public Utility District #1 (District) in Washington State conducted in-water testing of tidal flow technology with the Admiralty Inlet Pilot Tidal Project, a first step toward potential construction of a commercial-scale tidal turbine array. In this phase of the project, the District completed the engineering design and obtained construction approvals for a Puget Sound tidal pilot demonstration plant in the Admiralty Inlet region of the Sound. The project executed site studies necessary to support plant siting and design; complete plant design and construction planning; and conduct environmental studies and other activities required to complete all federal, state, and local permit applications for a pilot tidal plant. There is potential to generate clean, renewable, environmentally benign, and cost-effective electricity from tidal flows at selected sites in the Puget Sound, as well as at other U.S. sites. Successful tidal energy demonstration in the Sound is expected to facilitate technical advancement and commercial development of the tidal energy industry, providing benefits for both the region and the country. As the second-largest public utility in Washington, the District is well positioned to share key learning among other regional and national stakeholders. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Snohomish County Public Utility District #1** | Puget Sound Pilot Tidal Energy Project | $475,750 | FY09 CDP | Washington |
| **Project Description** | | | | |
| Snohomish County Public Utility District #1 (District), in partnership with the Northwest National Marine Renewable Energy Center (NNMREC) and Pacific Northwest National Laboratory (PNNL), has developed mitigation and monitoring plans with resource agency scientists that will serve as a roadmap for MHK proposal permitting for years to come. The primary focus is on development of near-turbine monitoring capabilities to observe aquatic species interactions in the immediate vicinity of turbine rotors and address concerns about the risk of post-installation blade strike. Additionally, equipment suitable for post-installation passive acoustic monitoring was tested, and the potential for cross-talk between different active acoustic instruments was evaluated. Overall, the project conducted: (1) near-field monitoring of blade strike and species-specific aggregation or avoidance; (2) passive acoustic monitoring; (3) current velocity monitoring; (4) component packaging; and (5) cost evaluation for each type of monitoring. Both the monitoring equipment purchased and the lessons learned through monitoring contributed to the District's Puget Sound Tidal Energy Demonstration Project and potential construction of a commercial-scale power plant. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Snohomish County Public Utility District #1** | Study of the Acoustic Effects of Hydrokinetic Tidal Turbines in Admiralty Inlet, Puget Sound | $522,550 | FY09 Advanced Water Power FOA | Washington |
| **Project Description** | | | | |
| Snohomish County Public Utility District #1 (District), and its partners determined the acoustic impacts of hydrokinetic turbines operating in Admiralty Inlet, Washington, which is the site selected for the District's Puget Sound Tidal Energy Demonstration Project where two OpenHydro Group Ltd. turbines will be installed off Admiralty Head. The pilot project provided both operational experience with the devices and the opportunity to monitor the site for any effects on the marine environment. To study acoustic impacts, this project employed complementary long-term measurements to characterize how aquatic species use Admiralty Inlet and deployed both in-water testing and laboratory studies to investigate how noise from a turbine could affect aquatic species. The study's results will provide regulatory agencies, tribes, and public stakeholders with continuous long-term monitoring of aquatic species within the project area and a new understanding of how species could be affected by the operation of the District's pilot project. In addition to assessing acoustic effects, the collected and interpreted information about aquatic species has helped to establish a baseline for assessing other possible project impacts—for example, interference with migration. As such, the methodologies developed under this project will be broadly applicable to hydrokinetic energy projects across the United States and worldwide. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Snohomish County Public Utility District #1** | Puget Sound Pilot Tidal Energy Project | $10,000,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Washington |
| **Project Description** | | | | |
| Snohomish County Public Utility District #1 (District) is building upon its efforts to study and develop the Puget Sound Tidal Energy Demonstration Project in the Admiralty Inlet, a site that has been identified as one of the largest tidal hydrokinetic resources in the United States. This phase of the project involves the deployment, operation, monitoring, and evaluation of two 6-meter diameter Open-Centre Turbines developed and manufactured by OpenHydro Group Ltd. with a capacity of 250 kilowatts each. While the turbines will be connected to the grid and produce a modest amount of energy, the primary purpose of the project is to gather data to advance the viability of commercial tidal energy generation from technical, economic, social, and environmental standpoints. The evaluation covers a three-year operational period and provides data that are critical to the responsible advancement of commercial-scale tidal energy in the United States. Successful tidal energy demonstration at Admiralty Inlet may enable significant commercial development of hydrokinetic energy elsewhere in Puget Sound and in other regions of the United States, resulting in important benefits for both the Northwest region and the country as a whole. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Sound & Sea Technology, Inc.** | Advanced Anchoring Technology | $239,899 | FY10 MHK Technology Readiness Advancement Initiative FOA | Washington |
| **Project Description** | | | | |
| Sound & Sea Technology worked on an alternative and novel solution for an anchor system. Anchoring and mooring systems for MHK energy systems constitute a portion of the overall cost of an installed MHK system. Improvements in anchoring can provide a significant reduction in the cost per installed kilowatt of MHK systems. Sound & Sea Technology's solution uses grouted pile anchor technology, which is commonly used in terrestrial construction projects. This project proved the new anchoring concept, improved the technology required to remotely attach MHK anchoring systems, and developed a quality control and certification procedure to validate deep underwater grouted pile anchor installations. Development of this technology will reduce the capital and installation costs of MHK systems by providing a more flexible anchoring technology suitable for varying water and sea bottom conditions. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Sunlight Photonics, Inc.** | Tidal Energy System for Onshore Power Generation | $399,990 | FY10 MHK Technology Readiness Advancement Initiative FOA | New Jersey |
| **Project Description** | | | | |
| Sunlight Photonics successfully demonstrated the proof of concept for a new, efficient, and robust Hydraulic Energy Transfer (HET) system that eliminates the primary technology problems of subsea electronics corrosion and high-ratio gear failure that has plagued MHK electric generation to date. The HET concept, originally proposed and published by Sunlight Photonics' partner, the National Aeronautics and Space Administration Jet Propulsion Laboratory (JPL), is an extension of work by JPL on ocean energy submersibles being tested for the U.S. Navy. A systems and cost analysis by JPL has shown that this hydraulic energy transfer system is more efficient and less costly than comparable conventional tidal energy systems. Building on this work, Sunlight Photonics, JPL, and other partners demonstrated a 15-kilowatt system and defined a clear path for scale-up and commercialization. The project model validated design predictions and system-level functionality. The critical subsystems have been integrated and tested at the Mechanical Engineering Department at Rutgers University, including immersion tank tests. The system is efficient, low-maintenance, and inexpensive, while also being applicable to tidal, current, river, and wave energy, as well as adaptable for offshore wind energy. In addition, the HET provided an attractive option for energy-storage issues found in smart grid development. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Turner Hunt Ocean Renewable, LLC** | Turner Hunt Ocean Renewable's (THOR's) Power Method for Hydrokinetic Devices | $400,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | Ohio |
| **Project Description** | | | | |
| Turner Hunt Ocean Renewable (THOR) demonstrated and tested a power control protocol method that maximizes, modulates, and controls the electrical power output from a hydrokinetic device. Other operational control methods were tested and evaluated using a fully functional scale model operating in THOR's unique open channel recirculating water flume. THOR's Power Method was previously shown to provide dramatic increases to the energy yield of the hydrokinetic device. This project implemented THOR's Power Method via a fully functional automatic control system resident in the scale model that was exposed to the full range of free stream current flow regimes expected to be encountered under actual conditions. THOR's Power Method for Hydrokinetic Devices tested and validated a power regulation scheme that can provide dramatic increases to the energy yield of hydrokinetic devices. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of California, Davis** | Active Flow Control on Bidirectional Rotors for Tidal MHK Applications | $158,336 | FY10 MHK Technology Readiness Advancement Initiative FOA | California |
| **Project Description** | | | | |
| The University of California, Davis has combined two existing technologies to develop an innovative, reliable, cost-effective rotor for tidal MHK applications. The project improves upon bidirectional rotor tidal turbines (BRTT) with the addition of microtabs to improve blade hydrodynamic and rotor performance while still permitting bidirectional rotor operation. Although BRTTs are already undergoing commercial development, there are some disadvantages to the design, such as efficiency losses. The University of California, Davis has optimized the rotor design to recapture some of the performance shortfalls of the BRTT, while also alleviating cyclic loads and extending turbine life. The successful development of an optimized BRTT rotor with microtabs will offer a new rotor technology that can: (1) reduce costs and improve reliability and yield; (2) offer a component technology that can be applied to all tidal current sites; (3) address load alleviation at any current-driven MHK site; and (4) provide a subcomponent technology that synergistically benefits parallel work in wind power. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Hawaii** | National Renewable Marine Energy Center in Hawaii | $7,999,647 | FY08 Advanced Water Power Projects FOA | Hawaii |
| **Project Description** | | | | |
| The University of Hawaii (UH) established the Hawaii National Marine Renewable Energy Center (HINMREC), led by the Hawaii Natural Energy Institute, to facilitate commercialization of wave energy converters (WEC) and accelerate development and testing of ocean thermal energy conversion (OTEC) technologies in Hawaii and elsewhere in the world. WEC and OTEC were selected since Hawaii has ample resources, significant expertise in these areas, and ongoing or planned commercialization and demonstration projects in the state. HINMREC is a collaborative effort between academia, industry, and government. HINMREC is structured to provide open access to its facilities and expertise, and broad dissemination of non-proprietary information through the Internet (http://hinmrec.hnei.hawaii.edu/), for all credible wave power system developers and other stakeholders. In addition to supporting tasks that address specific near-term needs of the industry partners, the UH faculty participants pursue independent research on critical technical issues related to resource assessment, device performance, and environmental impacts. HINMREC is collaborating closely with the U.S. Navy to implement a wave-energy-test-site (WETS) in Kaneohe Marine Corps Base Hawaii. The concept is to expand existing facilities to provide multiple-berthing for devices in the 100 kilowatt to 1,000 kilowatt range. WETS will allow for testing in water depths ranging from 30 meters to 70 meters. The vision for HINMREC consists of a fully operational WETS and continued offering of services required to evaluate WEC and OTEC designs. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Maine** | Maine Tidal Power Initiative | $1,951,500 | FY10 CDP, FY09 CDP | Maine |
| **Project Description** | | | | |
| The University of Maine has established the Maine Tidal Power Initiative to develop resource and environmental protocols while industry partners deploy a Tidal In-Stream Energy Conversion device. These protocols can then be used throughout the United States to evaluate tidal energy resources and better understand the potential impact of tidal energy development on the environment. The project includes: (1) a resource assessment; (2) development of the initial array design parameters using scale model tests; (3) baseline environmental studies and monitoring; (4) in-situ measurement and monitoring of TidGen developed by Ocean Renewable Power Company; and (5) a study of the human dimensions of this work. Site-specific work is focused on the Cobscook Bay/Western Passage area near Eastport, Maine, which is potentially the most viable commercial tidal energy site in the United States; it became the first grid-connected, commercial-scale tidal energy site in the country with Ocean Renewable Power Company's TidGen deployment in 2012. The protocols and methods developed at this site have been used to perform initial scoping reviews of smaller tidal sites in Taunton Bay, Castine, and Wiscasset, Maine. Upon successful completion, the project is expected to advance both research and education. The research component, linked with the testing of Ocean Renewable Power Company's TidGen in the Cobscook Bay/Western Passage site, will result in baseline resource and environmental data for the site, as well as the initial evaluation of the suitability of the approach for at least two other tidal development sites in Maine. The educational component involves graduate and undergraduate students at the University of Maine and the Maine Maritime Academy, providing training for a new generation of skilled workforce to support future ocean renewable energy industries. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Maine** | Interactions of Aquatic Animals with the ORPC OCGen® in Cobscook Bay, Maine. | $365,543 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Maine |
| **Project Description** | | | | |
| The University of Maine will use data on the interactions of fish with Ocean Renewable Power Company's TidGen tidal turbine to predict the probability of fish encountering MHK devices. Building on data gathered since 2010—which established baseline patterns of fish distribution at the turbine's location—this project will provide post-deployment data for comparison; improve techniques for distinguishing between fish species using undersea acoustic sensors; and implement a probability-of-encounter model. This work will aid assessment of possible effects of MHK devices on species or groups of species, and improve understanding of potential longer-term effects of a hydrokinetic device on local fish populations. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Massachusetts Dartmouth** | New England Marine Renewable Energy Center | $1,701,500 | FY10 CDP, FY09 CDP | Massachusetts |
| **Project Description** | | | | |
| The University of Massachusetts Dartmouth established the New England Marine Renewable Energy Center (NEMREC) in 2009 to promote the development of ocean energy—including wave, tidal, and offshore wind energy—through academic research; development of test sites; and stakeholder engagement with government, industry, academia, and the public. NEMREC has expanded its work to provide pre-permitted and closely monitored test sites in the National Offshore Renewable Energy Innovation Zone for marine renewable devices, maintain its University Research Consortium (URC), provide small grants for research at coalition universities, and initiate feasibility studies for ocean test sites. NEMREC's URC hosts an annual technical conference, as well as other technology-sharing activities. In addition, NEMREC will conduct public outreach via meetings with stakeholders, including governmental agencies, public interest groups, and the general public. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of New Hampshire** | Center for Ocean Renewable Energy (CORE) Infrastructure Enhancements | $750,000 | FY10 CDP | New Hampshire |
| **Project Description** | | | | |
| The University of New Hampshire is enhancing three principal components of the University's Center for Ocean Renewable Energy (CORE) research, development, and evaluation infrastructure, including Chase Ocean Engineering Laboratory (Chase Lab), the General Sullivan Bridge (GSB) tidal energy site, and the Offshore Wave and Wind (OWW) energy site, to serve the needs of ocean renewable developers. At the Chase Lab, upgrades were completed to the tank facility, ensuring that the wave/tow tank is improved to meet the required needs for model stage testing of ocean renewable energy devices. The water quality system has been improved to maintain water clarity for detailed visual and optical observations of turbine blade water interactions. Upgrades to the tow carriage can accommodate more and varied turbine designs and provide the measurement data required for engineering evaluation of the turbine. The wave-generating system is being carefully evaluated, and needed enhancements will be made. At the GSB site, a new testing platform has been designed and fabricated for deploying large-scale devices, complete with all the instrumentation needed to evaluate the tidal flow upstream and downstream of the device under test. Additional capabilities include measurement systems capable of evaluating in-situ loads on the mooring system, fluid flow measurements, and mechanical and electrical outputs of the device under test. At the OWW energy site, the environmental assessment buoy has been enhanced and upgraded to have wave measurement capability and a conductivity temperature depth for water property assessment deployed on the subsurface component of the buoy system. The above-surface structure has a weather station for measuring wind speed and direction and atmospheric temperature. The significant infrastructure upgrades to CORE's three sites are providing significant benefits to the ocean energy industry's research, development, and evaluation capabilities. | | | | |

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**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Washington** | Northwest National Marine Renewable Energy Center - Tidal Energy Research | $440,000 | FY10 CDP | Washington |
| **Project Description** | | | | |
| The University of Washington is advancing research and development of tidal in-stream energy conversion at the Northwest National Marine Renewable Energy Center (NNMREC). Numerical modeling and laboratory flume experiments of flow around turbines and in their wakes are performed. The numerical modeling allows the University of Washington to investigate optimization for energy extraction, as well as potential ecosystem effects. This includes tidal estuary and channel modeling. Comparison of the reduced-scale turbines in the flume improves the accuracy and dependability of numerical simulations and helps fill the gaps between the design and optimization stages of reduced-scale turbines and full-scale testing. Additionally, field work is conducted in Puget Sound, a very good controlled field site for studying tidal energy. The the University of Washington goal is to develop instrumentation methodology for field measurements that include tidal current velocity, ambient noise, biological activity, and water properties. Analysis and interpretation of the data are focused on quantification of natural variability in the tidal flow, as well as on forecasting of power generation potential. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **University of Washington** | Marine Mammal Behavioral Response to Tidal Turbine Sound | $399,572 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | Washington |
| **Project Description** | | | | |
| The University of Washington will characterize the behavioral responses of killer whales, harbor porpoises, and fin-footed marine mammals, such as seals, sea lions, and walruses, to the sounds produced by tidal turbines. This project will produce a description of the temporal and spatial variation in sound produced by a pair of tidal turbines deployed in Puget Sound, as well as demonstrate the effectiveness of wildlife observation techniques around marine renewable energy projects. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **US Synthetic Corporation** | The Development of Open, Water-Lubricated Polycrystalline Diamond Thrust Bearings for Use in MHK Energy Machines | $146,984 | FY10 MHK Technology Readiness Advancement Initiative FOA | Utah |
| **Project Description** | | | | |
| US Synthetic Corporation provided a new bearing technology to MHK machines to reduce operating costs, improve reliability, and reduce power loss. Polycrystalline Diamond (PCD) thrust bearings have been successfully used in oil and gas devices for many years. PCD advantages are the ability to operate in the open without seals using abrasive liquids (e.g., such as drilling fluid) as a lubricant. In addition, they can withstand the rigors of severe load variation and lubricant contamination. A hydrokinetic energy machine with water-lubricated PCD bearings would reduce maintenance costs and improve reliability over equivalent machines using conventional bearings. In addition, PCD bearings without lubricants other than the water itself reduce the danger of polluting a marine environment. This project used advanced analytical tools for the initial design of thrust bearings for use in a conceptual water turbine; built and tested the bearings in the US Synthetic bearing test facility; and compared the measured bearing performance with the design predictions. Finally, design protocols based on both experimental results and analytical models were developed, permitting the design of a thrust bearing for any desirable size and length of time. At the conclusion of this project, two sets of sample test bearings were supplied to qualified MHK developers free of charge. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Vantuna Research Group** | Impacts of Electromagnetic Fields Associated with Marine and Hydrokinetic Surrogate Technologies on Fish Movements | $69,935 | FY13 MHK Environmental Effects Assessment and Monitoring FOA | California |
| **Project Description** | | | | |
| Vantuna Research Group will conduct a review of existing literature related to the impacts of electromagnetic fields associated with technologies similar to MHK and evaluate potential effects on specific species or groups. The project will identify important knowledge gaps regarding the potential interaction of fish with MHK energy devices and make recommendations for future studies that will help address those gaps. | | | | |

*continued >*

**Table 1: FY 2008 – FY 2014 Marine and Hydrokinetic Project Descriptions[a]**

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Verdant Power, Inc.** | Improved Structure and Fabrication of Large, High-Power Kinetic Hydropower System (KHPS) Rotors | $1,120,830 | FY08 Advanced Water Power Projects FOA | New York |
| **Project Description** | | | | |
| Verdant Power has designed, developed, and deployed an improved blade structure and concomitant blade design for manufacture, fabrication, and testing. The improved design allows for larger, higher-power, and more cost-effective Kinetic Hydropower System (KHPS) rotors. Verdant Power has already proven the performance of the entire KHPS from water to wire at the Roosevelt Island Tidal Energy Project in New York City's East River. The most critical subsystem of the KHPS is the rotor itself and, while the current rotor is highly successful at a 5-meter diameter, broad commercialization requires rotors to capture energy from higher water velocities and deeper resources that can accommodate larger rotor diameters. The project supports scale-up of the rotor with improvements to handle the loads imposed by larger rotor sizes and higher water flow speeds while maintaining the present high performance of the rotor. This new design cycle requires a multidisciplinary collaboration of hydrodynamic and structural modeling, blade design and analysis, and design for manufacture and fabrication technique development. A 5-meter diameter prototype has been fabricated, undergone extensive strength and fatigue testing in laboratory conditions, and endured full-scale in-water hydrodynamic testing. The project has significantly contributed to advancing larger, more robust, and more cost-effective devices that will significantly hasten the commercial development of kinetic hydropower resources. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Verdant Power, Inc.** | Advancement of the Kinetic Hydropower System (KHPS) to DOE TRL 7/8 | $1,500,000 | FY10 MHK Technology Readiness Advancement Initiative FOA | New York |
| **Project Description** | | | | |
| Verdant Power aims to advance key components and deployment requirements of its Kinetic Hydropower System (KHPS) toward a DOE Technology Readiness Level of 7/8. Verdant Power will be conducting critical component testing and analysis to progressively validate longevity and reliability parameters for the KHPS and U.S. MHK devices overall, and will continue compliance work on approved operational environmental monitoring plans in anticipation of KHPS turbine installation. The project scope will include: evaluation of four Generation 5 KHPS turbine critical components (blades, seals, brake, and gearbox) for longevity and reliability; evaluation of components as part of a cost-effective operation and maintenance projection for MHK devices; and continued compliance work and implementation of instrumentation that builds the case for MHK devices as environmentally compatible. Beyond this project, Verdant's goal is to successfully deploy a KHPS system at the Roosevelt Island Tidal Energy Project site in New York. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Vortex Hydro Energy, LLC** | Advanced Integration of Power Take-Off in Vortex-Induced Vibration Aquatic Clean Energy (VIVACE) | $999,955 | FY10 MHK Technology Readiness Advancement Initiative FOA | Michigan |
| **Project Description** | | | | |
| Vortex Hydro Energy accelerated the development of the Vortex-Induced Vibration Aquatic Clean Energy (VIVACE) converter, which is a University of Michigan-patented MHK device designed for slow-moving currents. Unlike water turbines, VIVACE does not use propeller blades. Rather, river or ocean currents flow around cylinders, causing them to move up and down. The kinetic energy of the cylinder is then converted to electricity. In addition to being simpler in design and more cost effective than a water turbine, the VIVACE converter is a transformational technology designed for water currents as slow as 2 to 4 knots. The majority of river and ocean currents in the United States are slower than 3 knots, but conventional turbine technology targets rivers with water currents greater than 4 knots. The VIVACE converter thus taps into a new source of clean and renewable energy. The project focused on improving the energy conversion efficiency of the VIVACE converter in a laboratory setting and open-water testing of the improved system in the Saint Clair River at Port Huron, Michigan. | | | | |

| Project Recipient | Project Title | DOE Funding Amount | Funding Source | Project Location |
|---|---|---|---|---|
| **Whitestone Power and Communications (operated by the Whitestone Community Association)** | Whitestone Poncelet River In-Stream Energy Conversion (RISEC) Project | $142,050 | FY10 MHK Technology Readiness Advancement Initiative FOA | Alaska |

**Project Description**

Whitestone Power and Communications, in partnership with Hasz Consulting Company, conducted in-water testing and evaluation of the Whiteston Poncelet River In-Stream Energy Conversion (RISEC) technology, which is representative of what could be expected for a commercial-scale hydrokinetic power plan. The project used renewable river current hydrokinetic energy from the Tanana River in Alaska. The design successfully met the unique challenges presented by the Alaskan river environment, including high density of aquatic life, high debris and sediment loads, and severe weather. As developed, the concept proposes solutions to materials, transmission, and power generation obstacles encountered by traditional waterwheels, resulting in unprecedented efficiency, longevity, and cost effectiveness. This low-impact design provides a carbon-neutral and cost-effective solution with global potential to harness renewable marine resources for the production of electricity. Whitestone Power and Communications anticipates the proposed system being widely used in river applications throughout Alaska, the United States, and globally in shallow, swift water applications where large-diameter submersible turbines cannot be used. Whitestone Power and Communications also expects the design to significantly diminish the cost of electricity, which is potentially a significant challenge for remote and rural communities throughout Alaska.

# Marine and Hydrokinetic Funding Distribution

DOE funded 88 MHK projects through the Water Power Program from FY 2008 to FY 2014. These projects are categorized in the following sections by activity area, topic area, geographic region and division, state, recipient type, and funding source.

## Funding by Activity Area and Topic Area

The Water Power Program's R&D efforts between FY 2008 and FY 2014 fall under two activity areas: Technology Development and Market Acceleration and Deployment. The Water Power Program's Technology Development projects are aimed at reducing the technical barriers to MHK device development, improving device reliability and performance, and enhancing the understanding and evaluation of various technology types. The Water Power Program's Market Acceleration and Deployment projects are aimed at reducing the time and costs associated with siting water power projects; better quantifying the potential magnitude, costs, and benefits of water power generation; and identifying and addressing other barriers to deployment. When total DOE funding for MHK from FY 2008 to FY 2014 is categorized by activity area, Technology Development activities received nearly 90% of the funding, while Market Acceleration and Deployment activities received approximately 11%.

MHK renewable energy is an emerging industry actively working to research, develop, and demonstrate technology designs. To support the development and deployment of MHK devices, nearly 90% of WWPTO's MHK funding from FY 2008 to FY 2014 was directed toward technology development.

Within the Technology Development and Market Acceleration and Deployment activity areas, the Water Power Program funds particular topics in priority areas. The Technology Development activity area is mostly divided among Ocean/River/Tidal/Current Energy Systems, Testing Facilities, and Wave Energy Systems. Environmental Impacts and Siting projects represented the largest topic area funded under the Market Acceleration and Deployment activity area. Table 2 provides details on the MHK funding for each topic area within the Technology Development and Market Acceleration and Deployment activity areas.

Photo credit: Oregon State University

The Northwest National Marine Renewable Energy Center's first open-water testing platform, the Ocean Sentinel, was deployed August 17, 2012, and the first test at the new platform was held a week later by WWPTO-funded Northwest Energy Innovations.

**Table 2: FY 2008 – FY 2014 Marine and Hydrokinetic Funding Distribution by Topic Area**

| Topic Area | Total Funding | Percent of Total |
|---|---|---|
| **Technology Development Subtotal** | **$106,922,950** | 89.1% |
| Ocean/River/Tidal Current Energy Systems | $31,606,883 | 26.3% |
| Test Facility Support and Construction | $30,601,692 | 25.5% |
| Wave Energy Systems | $21,093,938 | 17.6% |
| Component Design and Development | $18,917,022 | 16.6% |
| Ocean Thermal Energy Conversion Systems | $2,035,723 | 1.7% |
| Technology Assessment | $1,467,692 | 1.2% |
| Instrumentation, Testing, and Evaluation | $1,200,000 | 1.0% |
| **Market Acceleration and Deployment Subtotal** | **$13,097,423** | **10.9%** |
| Environmental Impacts and Siting | $10,999,851 | 9.2% |
| Resource Assessments | $2,097,572 | 1.7% |
| **Total** | **$120,020,373** | **100%** |

## Funding by Geographic Region & Division

MHK projects were awarded in each of the nation's four geographic regions. Table 3 provides details on how the Water Power Program's funding was distributed within regions and divisions. The geographic regions and divisions used to present the distribution of WWPTO's funding are based on the U.S. Census Regions and Divisions.[1]

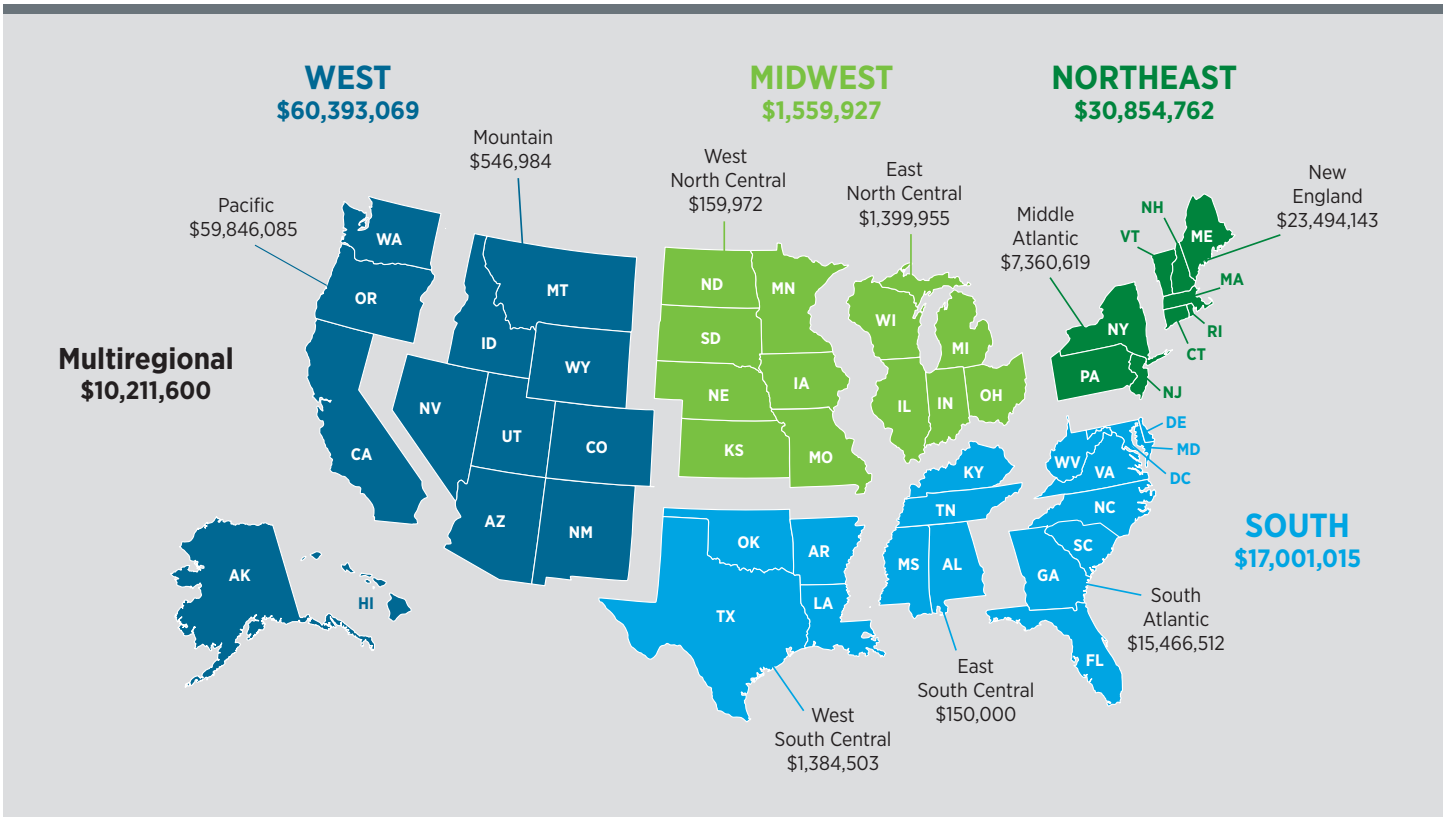
Seven projects spanned several regions and divisions and are thus categorized as multiregional.[b]

Exhibit 1 provides a map that shows how the Water Power Program's MHK project funding was distributed throughout the United States.

**Table 3: FY 2008 – FY 2014 Marine and Hydrokinetic Funding by Geographic Region & Division**

| Region | Region Total Funding | Division | Division Total Funding |
|---|---|---|---|
| West | $60,393,069 | Pacific | $59,846,085 |
| | | Mountain | $546,984 |
| South | $17,001,015 | South Atlantic | $15,466,512 |
| | | West South Central | $1,384,503 |
| | | East South Central | $150,000 |
| Northeast | $30,854,762 | New England | $23,494,143 |
| | | Middle Atlantic | $7,360,619 |
| Midwest | $1,559,927 | East North Central | $1,399,955 |
| | | West North Central | $159,972 |
| Multiregional[b] | $10,211,600 | National | $10,211,600 |
| | | **Total** | **$120,020,373** |

**Exhibit 1: FY 2008 – FY 2014 Marine and Hydrokinetic Funding by Geographic Region & Division**




[b] The multiregional category is not used in the U.S. Census Regions and Divisions. The multiregional category reflects WWPTO funding awarded to projects occurring across multiple divisions and regions.

## Funding by State

Projects in 24 states have received funding for MHK projects through the Water Power Program. Funding awarded to seven projects is disbursed across many states (including Vermont, which is not listed in Table 4) and is categorized as multistate.[c] Table 4 outlines funding by state.

Combined, Maine, Oregon, and Washington received nearly 40% of total funding for MHK projects. All three states had projects aimed at improving, testing, and demonstrating various MHK technologies that are nearing commercialization, and some of the strongest wave and tidal resource potential in the continental United States also resides off the coasts of these states.

**Table 4: FY 2008 – FY 2014 Marine and Hydrokinetic Funding Distribution by State**

| State | Total Funding |
|---|---|
| Alaska | $982,050 |
| California | $9,734,523 |
| Colorado | $400,000 |
| Florida | $5,589,375 |
| Georgia | $841,926 |
| Hawaii | $9,533,608 |
| Louisiana | $1,384,503 |
| Maine | $18,287,418 |
| Maryland | $2,400,000 |
| Massachusetts | $3,696,725 |
| Michigan | $999,955 |
| Missouri | $159,972 |
| New Hampshire | $1,510,000 |
| New Jersey | $1,999,789 |
| New York | $5,120,830 |
| North Carolina | $1,995,255 |
| Ohio | $400,000 |
| Oregon | $13,296,963 |
| Pennsylvania | $240,000 |
| Tennessee | $150,000 |
| Utah | $146,984 |
| Virginia | $4,639,956 |
| Washington | $13,277,771 |
| multi-state[c] | $23,232,770 |
| **Total** | **$120,020,373** |

[c] The multistate category reflects WWPTO funding awarded to projects occurring across multiple states.

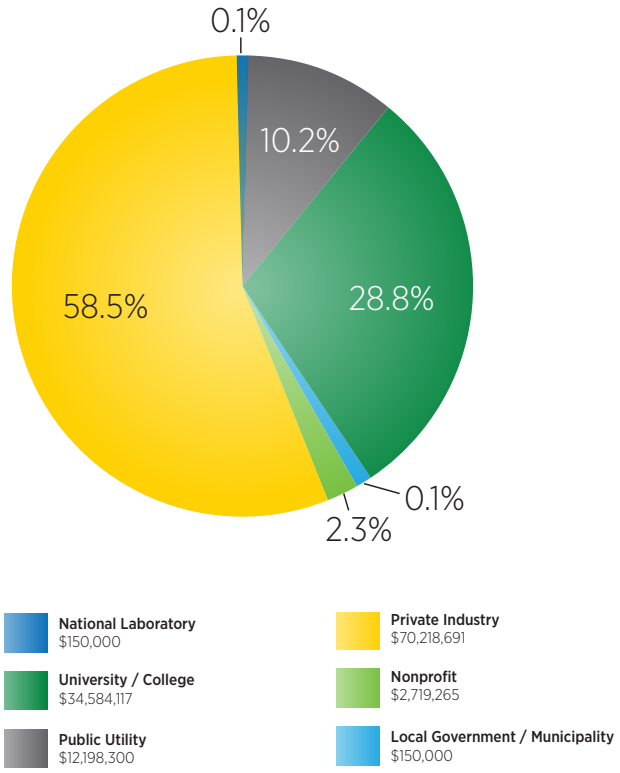
## Funding by Recipient Type

DOE funds a variety of recipient types, including private industry, nonprofit organizations, universities and community colleges, investor-owned utilities and public utilities, local and state governments, as well as DOE national laboratories, federal agencies, and interstate government agencies.

More than half of the total MHK funding from FY 2008 to FY 2014 was awarded to private industry, and nearly one-third went to universities or colleges. Combined, the three university-run National Marine Renewable Energy Centers in the Pacific Northwest, Hawaii, and Florida represented 85% of university funding and 22% of all MHK funding from FY 2008 to FY 2014.

The remaining funds were awarded to public utilities, nonprofit organizations, and local or municipal governments. Exhibit 2 provides these details by recipient type.

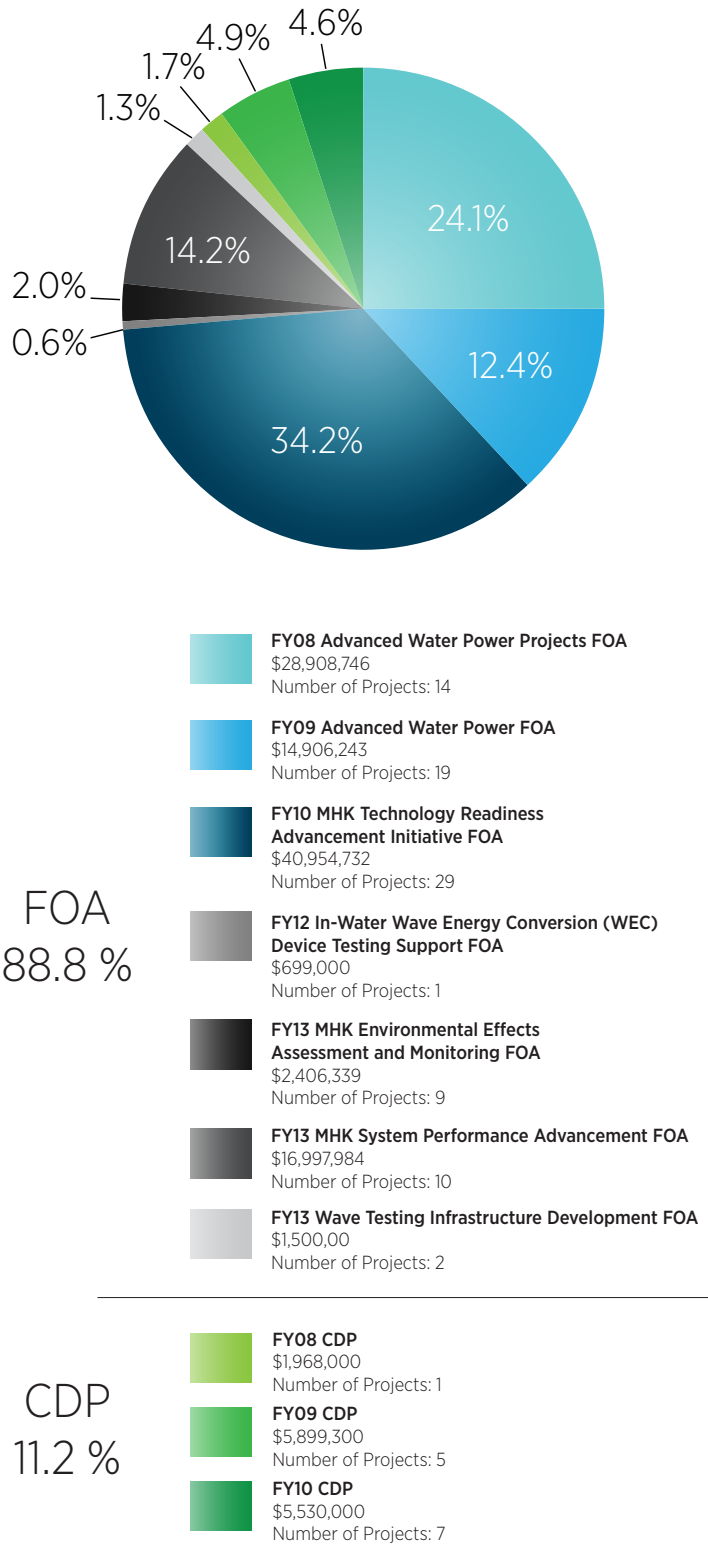
**Exhibit 2: FY 2008 – FY 2014 Marine and Hydrokinetic Funding Distribution by Recipient Type**




**Total Funding: $120,020,373**

Industry projects awarded to private-sector companies dominate the Water Power Program's MHK investment portfolio, representing more than 58%—or $70 million—of total funding.

**Exhibit 3: FY 2008 – FY 2014 Funding Sources for Marine and Hydrokinetic R&D Projects**




**Total Funding: $120,020,373**

## Funding Sources

From FY 2008 to FY 2014, the Water Power Program issued seven competitive FOAs focused on MHK. These FOAs provided about $120 million in announced awards for 84 unique MHK projects. An additional $13 million was awarded to 13 unique MHK projects through Congressionally Directed funds. Although the unique number of awards made by the Program is 88, some projects, where bodies of work overlapped significantly, were combined in Table 1 resulting in an operational total of 88 projects. Exhibit 3 provides details on the funding sources for the Water Power Program's 88 unique MHK projects.

# Accomplishments

The Water Power Program provided about $120 million in funding for MHK projects from FY 2008 to FY 2014, with numerous projects operating over multiple years. The Water Power Program has already realized significant returns on the federal investment to date and anticipates significant key accomplishments in the years to come.

A few of the Water Power Program's project accomplishments include the following:

- In 2013, **Dehlsen Associates, LLC** fabricated a basin-scale model of the Aquantis C-Plane ocean current device and completed a series of highly successful tow tank tests at the Naval Surface Warfare Center, Carderock Division's David Taylor Model Basin in Bethesda, Maryland. The tests demonstrated static and dynamic stability of the C-Plane in a variety of modes and validated numerical and modeling data, bringing the technology another step closer to commercialization. In 2012, Dehlsen Associates, LLC completed a study that identified regulatory requirements for avoiding sensitive benthic habitat off the coast of southeastern Florida to inform siting of ocean current technologies. Geophysical and benthic habitat surveys were conducted within areas selected by the Bureau of Ocean Energy Management to inform MHK siting development and to create ocean energy benthic survey methodologies.
- In 2013, **Verdant Power, Inc.** and Cornell University signed a Memorandum of Understanding with the intention of entering into a long-term relationship centered on research and other activities related to MHK technologies. Verdant Power's MHK project is the first commercially licensed tidal energy plant in the United States. On September 7, 2012, Verdant successfully completed an in-water dynamometry test, with the new rotor performing very well. This project in New York City builds upon an initial DOE investment in 2008 to improve Verdant Power's turbine blade design. It remains the only project in the world where an array of tidal energy turbines has successfully been deployed and operated.
- In 2012, the Water Power Program completed four assessments of U.S. MHK resources: wave, tidal, river hydrokinetic, and ocean thermal energy. These resource assessments are pivotal to understanding water power's potential for future electricity production. Based on various resource assessments, the theoretical resource potential for United States wave, tidal,

current, and riverine hydrokinetic resources is over 4,000 terawatt-hours per year (TWh/year) and the technical resource potential is estimated to be between 1,286 and 1,787 TWh/year. The wave assessment, completed by the **Electric Power Research Institute (EPRI)**, found that 1,170 TWh/year are recoverable, with the West Coast (including Alaska and Hawaii) containing high potential for wave energy development. The tidal assessment, completed by **Georgia Tech Research Corporation**, found that 249 TWh/year are recoverable, with locations with high kinetic power density scattered along both the Atlantic and Pacific coasts. The river hydrokinetic assessment, also completed by EPRI, found that 120 TWh/year are recoverable, with the Mississippi River containing nearly half of U.S. potential. The ocean thermal energy assessment, completed by **Lockheed Martin**, found that 576 TWh/year are recoverable in U.S. waters. Additionally, Georgia Tech Research Corporation updated an assessment of U.S. ocean current resources that finished in 2013. The ocean current assessment found that 200 TWh/year are recoverable. The maps of each completed resource assessment are available at: http://energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization.

- In the spring of 2012, **Harris Miller, Miller & Hanson, Inc. (HMMH)** completed a project aimed at providing siting information to the Edgartown Tidal Energy Project. HMMH developed a model to predict changes in hydrodynamics and sediment transport due to energy extraction by tidal devices in Muskeget Channel, Massachusetts, and used model results to assess potential changes to benthic habitat. The project also determined the occurrence of protected species in the area to inform monitoring efforts at the proposed project location. These data have been used specifically to inform the Edgartown Tidal Energy Project Draft License application, but the methodology could be used to help other tidal energy projects secure a license.
- In 2012, **Northwest Energy Innovations (NWEI)**, in partnership with industry leaders from New Zealand, verified the ocean wavelength functionality of the Azura device (previously called WET-NZ) through wave tank testing and a controlled open-sea deployment of its 1:2 scale device. Azura was deployed on August 22, 2012, at the Northwest National Marine Renewable Energy Center (NNMREC) off the coast of Oregon. As the first developer to test at NNMREC's offshore mobile ocean test berth, NWEI obtained six weeks of power performance data, as well as installation experience. Next, the device will be tested for one year at the U.S. Navy's Wave Energy Test Site on Kaneohe Bay in Oahu, Hawaii.
- In 2012, **Ocean Renewable Power Company (ORPC)** successfully deployed the first U.S. commercial tidal project in the United States using its TidGen™ Power System. Bangor Hydro Electric Company verified that electricity was flowing from ORPC's Cobscook Bay Tidal Project in Maine, marking the first time in U.S. history that such a project was connected to the electric power grid. Due to its success, ORPC was named Emerging Company of the Year in November 2012 by the New England Clean Energy Council. ORPC is currently developing the next generation of their TidGen device using lessons learned from this deployment.

*Photo credit: Northwest Energy Innovations*

Northwest Energy Innovations verified the ocean wavelength functionality of the Azura device (previously called WET-NZ) through wave tank testing and a controlled open-sea deployment of its 1:2 scale device.

- In September 2012, **Vortex Hydro Energy** tested the Vortex-Induced Vibration Aquatic Clean Energy (VIVACE) converter in Michigan's St. Clair River. The VIVACE converter is a novel device that generates power on a river bottom by creating vortices as the water flows through it, which makes the device bob up and down (vortexhydroenergy.com/technology/). The VIVACE converter is designed for water currents as slow as 2 knots to 4 knots—a flow range not targeted by conventional turbine technologies.

## End Notes

[1] Energy Information Administration, U.S. Census Regions and Divisions. June 14, 2000.
http://www.eia.gov/emeu/recs/census_map.html

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