2015 Key Water Power Program and National Laboratory Accomplishments


U.S. DEPARTMENT OF
ENERGY

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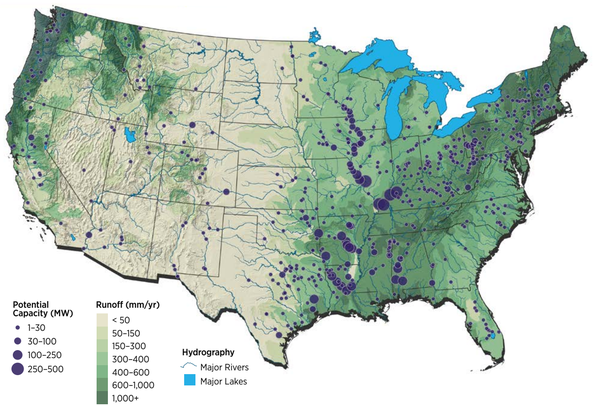
The U.S. Department of Energy (DOE) Water Power Program is committed to developing and deploying a portfolio of innovative technologies and market solutions for clean, domestic power generation from water resources across the United States.

By accelerating the development of markets for hydropower and marine and hydrokinetic (MHK) projects, the Water Power Program is striving to develop the next generation of water power tools and technologies, while jump-starting the private-sector innovation critical to the country's long-term economic growth, energy security, and international competitiveness.

Developing the technological and market-driven solutions necessary to lower deployment barriers and tap into new sources of clean, renewable energy from the nation's abundant water resources for electric power generation will help our country reduce emissions of greenhouse gases and other air pollutants, diversify its energy supply, and lower project expenses to provide cost-competitive electricity to key regions across the country.

U.S. Non-Powered Dams with Potential Capacity Greater than One Megawatt



HydroNEXT to Unlock 77 Gigawatts of Potential Clean Energy

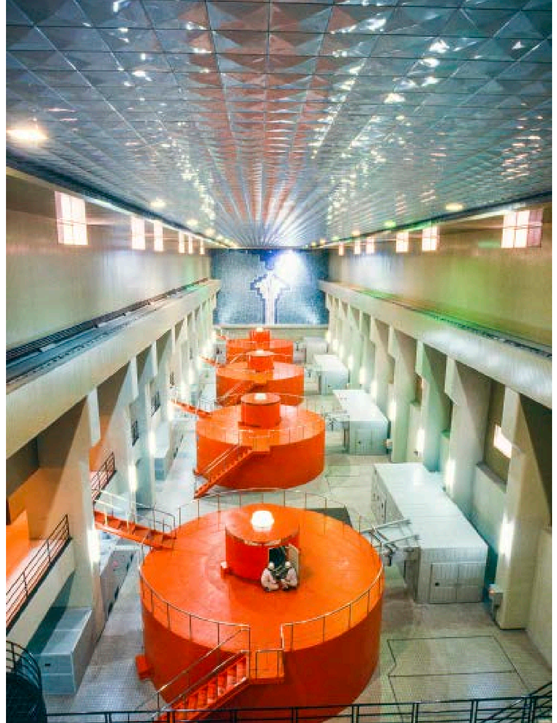
Similar to past initiatives that transformed energy potential into reality, the HydroNEXT initiative launched by DOE in 2015 intends to unlock the nearly 77 gigawatts (GW) of potential clean energy that exists within the undeveloped dams, rivers, and streams of the United States.

The objective of HydroNEXT is to lower the cost and environmental impacts of future hydropower generation by conducting leading-edge research, development, demonstration, and deployment of the innovative technologies that are necessary to generate cost-effective, clean renewable electricity from these resources.

The initiative focuses on three particular resource classes to increase the contribution of hydropower to the nation's energy mix: existing water infrastructure, undeveloped streams, and pumped-storage hydropower.

As part of its HydroNEXT efforts, DOE's Water Power Program released a funding opportunity in early 2015 that resulted in seven organizations selected to receive $6.5 million to advance the manufacturing and installation of low-environmental-impact hydropower technologies. The projects will address three technical areas: rapidly deployable civil works technologies, innovative methods and materials for hydropower construction, and powertrain components.

Continued innovation and advancements supported by HydroNEXT will assist in the development of hydropower technologies and manufacturing techniques that will help deliver more renewable energy to American homes and businesses than ever before.



DOE Collaboration Brings New Hydropower Online

Successful collaborations are essential to evolving an ambition into existence. Building on a memorandum of understanding that has helped spur increased interest in private hydropower development at federal facilities, DOE, the U.S. Department of the Interior, and U.S. Department of the Army for Civil Works announced a 5-year partnership extension in March 2015 to further advance hydropower development across the United States.

Through this continued collaboration and the partnerships with other stakeholders, the agencies will work to reduce hydropower costs by improving, developing, and evaluating new and existing technologies and environmental tools that will aid in the advancement of hydropower development nationwide, helping unleash the potential of this reliable, proven source of renewable energy.

Since the 2010 memorandum of understanding, 10 nonfederal projects, comprising 33 megawatts (MW) of capacity, have come online at Bureau of Reclamation facilities, with an additional 40 projects initiated and currently in development. For the U.S. Army Corps of Engineers, three nonfederal projects comprising 19.4 MW of capacity are now operational, with an additional 32 projects initiated and currently in some stage of development.

Wave Energy Prize Challenge Draws 92 Team Applicants

Doubling the energy capture capability of wave energy conversion (WEC) devices within 2 years is an ambitious goal that, if met, will reduce the cost of wave energy and unlock a resource that can provide electricity to millions of U.S. homes and businesses. In an effort to attract, motivate, and inspire the ingenuity, skills, and technical expertise necessary to achieve this, in April 2015, DOE launched the Wave Energy Prize, a design-build-test competition.

With a monetary prize, additional funding opportunities, and a chance to participate in two rounds of testing, the Wave Energy Prize registered 92 teams before narrowing the field down to 20 in August. These teams will build 1/50-scale models of their innovative designs and test the devices at one of five small-scale testing facilities across the country, prior to being narrowed to 10 finalists in March 2016. The final 10 will build larger 1/20-scale models of their devices, which will undergo tank testing at the nation's most advanced wave-making facility, the Naval Surface Warfare Center's Maneuvering and Seakeeping Basin in Carderock, Maryland.

WAVE ENERGY PRIZE
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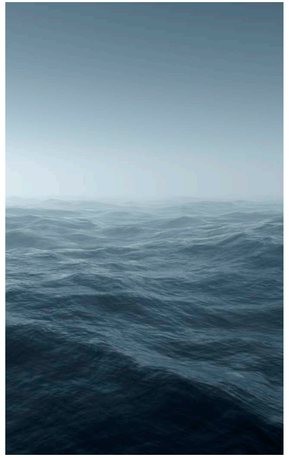
First Grid-Connected Wave Energy Conversion Device Launched in U.S. Waters

The MHK industry in the United States experienced a landmark moment in June 2015 when the Azura, a prototype WEC device developed by Northwest Energy Innovations with support from DOE and the U.S. Navy, was successfully launched and installed at the Navy's Wave Energy Test Site in Kaneohe Bay, on the island of Oahu, Hawaii, becoming the first grid-connected pilot project of its kind in U.S. waters.

Testing of this technology will provide U.S. researchers the opportunity to monitor and evaluate the long-term performance of the device while establishing lessons learned that will accelerate commercialization moving forward.

With abundant resources in coastal areas across the United States, MHK technologies hold the potential to help meet America's renewable energy needs. Supporting projects like the Azura furthers DOE's mission to research, test, and develop innovative technologies capable of generating renewable, environmentally responsible, and cost-effective electricity from clean energy resources, including water.



Ocean Energy Devices May Act as Artificial Reefs to Benefit Some Species

Questions about the anticipated effects that water and tidal energy converters (WECs and TECs) have on marine species are often raised during the permitting process and have the potential to delay projects until the impacts are fully understood. A better understanding of this technology's ecological effects on fish can help answer these questions and facilitate future project design and environmental permitting.

With a financial award from the Water Power Program, researchers from H.T. Harvey and Associates completed a study that evaluated potential interactions between WECs and TECs and fish and invertebrate communities in tropical, subtropical, and temperate western U.S. and Hawaiian coastal waters. This study analyzed scientific literature about surrogate marine structures (e.g., offshore aquaculture facilities, oil platforms, fish aggregating devices, and artificial reefs) and held discussions with resource managers and subject matter experts.

The study found that, depending on deployment location, WECs and TECs could act as small-scale artificial reefs or fish-aggregating devices and attract a larger number of fish, which may actually be beneficial to the growth and reproduction of some species. Additionally, the researchers found that negative impacts, such as increased predation on special status fish, are not likely.

Accelerating the Advancement of Marine and Hydrokinetic Technologies

Timely access to research data is critical to fostering innovation and advancing the industry. In an effort to improve future management of and access to MHK research data, DOE launched the Marine and Hydrokinetic Data Repository (MHKDR) in August 2015.

The MHKDR acts as the submission point for all research data collected using DOE Water Power Program funds. The MHKDR reduces duplication of effort and accelerates MHK innovation by enabling researchers to spend fewer resources finding the data they need, thus freeing up time, energy, and capital for analysis, innovation, and implementation.

The MHKDR will:

- Enable an easy data upload process to help with reporting requirements
- Provide a curation process to allow internal data experts to help evaluate the quality of the data
- Keep secure data secure (based on moratorium dates)
- Share secure data safely with DOE and partner laboratories
- Disseminate data to the public.

To learn more about the MHKDR database visit https://mhkdr.openei.org/about.

Marine and Hydrokinetic Data Repository
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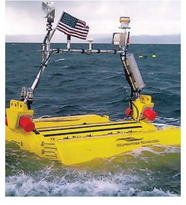
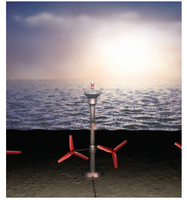




Research and Development

The Water Power Program's research and development (R&D) efforts focus on improving the performance, lowering the cost, and accelerating the deployment of cutting-edge technologies that generate renewable, environmentally responsible, and cost-effective electricity from the nation's water resources.

Technology Development – Hydropower

Significant opportunities exist to expand the development of the nation's hydropower resources through non-powered dams, water conveyance systems, pumped storage hydropower, and new site development. The Water Power Program supports this expansion through the development and deployment of new technologies and key components, as well as by identifying key opportunity areas through which hydropower generation can be enhanced.

Pumped Storage Hydropower Increases System Reliability

Efficient and reliable operation of the power system requires flexibility from participating resources. To understand the various grid services pumped storage hydropower (PSH) can provide and to assess the value of these services under a variety of circumstances, a project team, led by Argonne National Laboratory (ANL), studied the role and value of advanced PSH technologies.

The study demonstrated that PSH plants provide a variety of benefits to the power system. In addition to energy arbitrage and ancillary services (e.g., various system reserves), PSH provides a number of portfolio advantages that increase the reliability of power system operation and reduce overall electricity generation costs. These benefits include better and more efficient utilization of thermal generating units (i.e., fewer starts and stops, less ramping, and steadier operation at a higher efficiency point), fewer curtailments of excess variable generation, and deferred investments into new transmission lines and substations. The study also showed that the value of PSH capacity increases with the higher penetration of variable renewables in the system.

Performer: ANL
Principal Investigator: Vladimir Koritarov, koritarov@anl.gov

System-Wide Optimization Tool Demonstrates Unprecedented Benefits for Hydropower Production

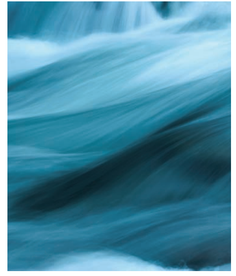
Supported by a DOE Advanced Hydropower Technology award presented through the Oak Ridge National Laboratory (ORNL), researchers at Vanderbilt University and David Lipscomb University, working closely with the Nashville District of the U.S. Army Corps of Engineers (USACE), completed a 4-year project to develop a highly successful modeling framework for improving hydropower generation while minimizing water quality impacts. The framework linked the operation of two of the main stem reservoirs on the Cumberland River (Cordell Hull and Old Hickory).

One of the many value-added benefits demonstrated by this system optimization tool showed that the two-reservoir-linked system enabled a 7.4% increase in hydropower revenue (approximately $19,500 per day during select key summer generation periods) while maintaining or improving water quality dissolved oxygen levels. As this highly flexible framework can be applied to larger systems, extrapolating the realized 7.4% hydropower revenue increase from two to four reservoirs on the main stem of the Cumberland River showed an approximate increase in revenue of over $35,000 per day for select summer pool operation periods.

Provision of a system-wide optimization tool will enable unprecedented advantages for hydropower production while simultaneously providing a system-wide, high-fidelity hydrodynamic and water quality system for improved prediction of water quality and environmental impacts. Such a system could also be designed for direct incorporation into the USACE's Corps Water Management System and provides an outstanding foundation to transfer to other regulated water bodies of interest.

Performer: ORNL

Principal Investigator: Boualem Hadjerioua, hadjeriouab@ornl.gov



Water Optimization Toolkit Increases Efficiency and Reduces Environmental Impacts of Hydropower Plants

As persistent drought conditions reduce water reservoirs to historic lows and the need to generate energy from clean renewable sources continues to grow, it becomes critical to use our nation's valuable hydro resources as efficiently as possible.

Under sponsorship from DOE, a multilaboratory team of experts from ANL, PNNL, and SNL has developed the Water Use Optimization Toolset (WUOT) to assist managers and planners in more efficiently operating hydropower plants. Applicable to a wide range of hydropower operations and environmental conditions, WUOT supplements and enhances currently available tools by integrating water forecasting, reservoir and power systems modeling, stream flow routing, environmental functionality analysis, and hydropower performance metrics. WUOT components are designed to operate individually or as an integrated suite. In addition, the toolset can address a continuum of time horizons—from long-term planning to real-time operations.

The objective of the WUOT project is to produce more energy and grid services from available water while enhancing environmental benefits from improved hydropower operations and planning. Analyses completed to date reveal ways in which the hydropower plant operations can be adjusted to increase energy output, reduce operating costs, and enhance the downstream environmental conditions, all without using additional water resources.

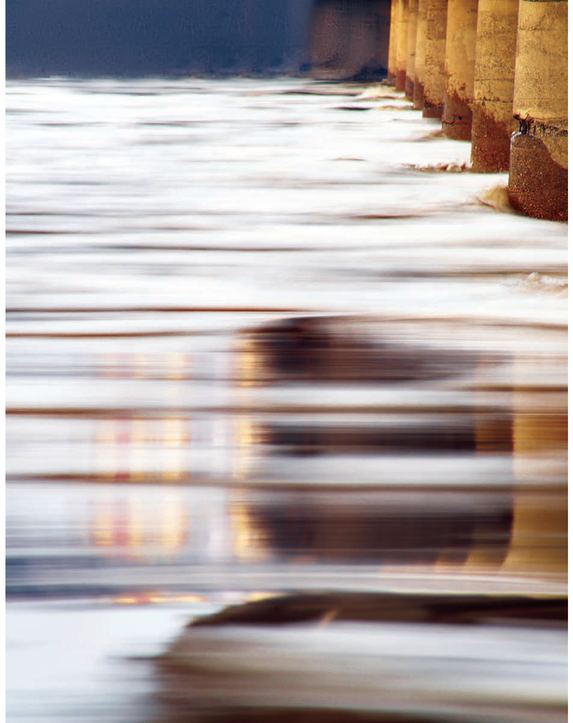
Performer: ANL
Principal Investigator: Matthew Mahalik, mahalik@anl.gov

New Model Helps Protect Water Quality Downstream of Hydropower Dams

Reliably meeting the constraints associated with all river activities while maintaining water quality is essential to ensuring future hydroelectric production from this vast resource. The various system-wide demands—irrigation, hydropower production, flood control, navigation, and fish passage—can require unique dam operations that may result in both voluntary and involuntary spill, thereby increasing tailrace levels of total dissolved gas (TDG) that can be fatal to fish. Appropriately managing TDG levels within the context of the systematic demands requires a predictive framework robust enough to capture the operationally related effects on TDG levels.

Researchers at ORNL, in conjunction with the IIHR-Hydroscience & Engineering center at the University of Iowa, have developed a model that predicts downstream TDG levels based on local saturation depth, spillway and powerhouse flow proportions, and entrainment effects. Integration and testing of the TDG module within RiverWare was led by the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems. Performance statistics indicated that the model predicts TDG levels with acceptable accuracy across most flow cases for all seven sites investigated. Testing and case comparisons made with RiverWare will serve as a basis from which improved operational decisions can be made. The successful implementation of a TDG minimization methodology used in conjunction with meeting the demands of any hydro system is considered to be a considerable improvement and step towards environmentally coupled hydro system modeling and planning tools.

Performer: ORNL
Principal Investigator: Boualem Hadjerioua, hadjeriouab@ornl.gov



Technology Development – Marine and Hydrokinetic

The Water Power Program supports the development of marine and hydrokinetic devices that capture energy from waves, tides, ocean currents, the natural flow of water in rivers, and marine thermal gradients, without building new dams or diversions. To meet its generation goals, the program supports the design, development, testing, and demonstration of technologies that can capture energy from waves, tides, and currents. Additionally, the program funds the creation of instrumentation, modeling, and simulation tools to enable real-condition testing of technologies.

Modular Ocean Instrumentation System Provides Data Critical to Future Designs

One of the elements crucial to improving future WEC designs is the ability to collect accurate and robust data from devices that are currently deployed in U.S. waters. In 2015, researchers at NREL developed and deployed a Modular Ocean Instrumentation System (MOIS) that will collect data critical to the future development and deployment of MHK devices. The new system is deployed on Northwest Energy Innovations' Azura, the nation's first third-party validated, grid-connected WEC.

Deployed offshore of the Marine Corps Base Hawaii in Oahu, the Azura converter will be collecting data with NREL's second-generation MOIS that is configured to measure the project's mooring line loads, motions, heading, position, float angle relative to the spar, and device depth. These measurements supplement the Azura's supervisory control and data acquisition system, which was also developed with NREL guidance.

The MOIS is part of ongoing work at NREL to develop a flexible, robust, next-generation instrumentation system to support the testing of MHK devices that are deployed in open water. Data collected by MOIS will provide device companies with the field measurements they need to better understand system operation and performance. The data will also support resource assessment and siting studies, as well as testing, evaluation, monitoring, demonstration, and eventual certification for a broad range of offshore renewable energy devices.

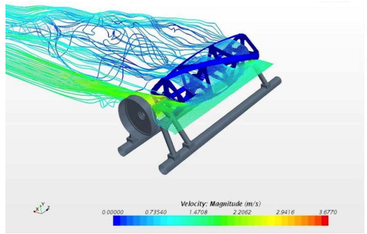
Performer: NREL
Principal Investigator: Eric Nelson, Eric.Nelson@nrel.gov

Sandia's High-Performance Computing Capability Addresses Challenging Tidal Turbine Performance Problem

High-performance computing at SNL played a key role in DOE's mission to advance the commercialization of tidal energy converters by identifying components in prototypes developed by the Ocean Renewable Power Company that were reducing power performance. Improving the system's power performance reduced the levelized cost of energy below the local "hurdle" price at which the company can compete with other regional generation sources without subsidies.

This study demonstrated the value of high-fidelity modeling and SNL's high-performance computing resources when resolving the complex three-dimensional (3D) flow effects on tidal turbine performance that are sometimes encountered with complex architectures. By identifying specific RivGen-prototype turbine generation unit components that were reducing power performance and quantifying the exact power reduction by these components, the Sandia/Ocean Renewable Power Company investigation provided a clear path for modifications to be made in the next design iteration of the RivGen turbine. Furthermore, this collaboration was able to deliver these impactful results in only 3 months.

Performer: SNL
Principal Investigator: Vince Neary, vsneary@sandia.gov



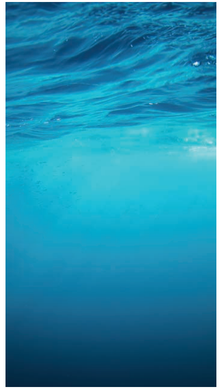
Triton Initiative Accelerates Commercialization of Marine Energy Devices

Supporting the development of environmental monitoring instruments can reduce two barriers that are currently delaying further deployment of marine energy devices: difficult permitting processes and high project costs.

The Triton Initiative, a new capability being developed at the Pacific Northwest National Laboratory's (PNNL's) Marine Sciences Laboratory in Sequim, Washington, will support DOE-funded projects in developing environmental technology that will be used to measure and monitor the potential environmental impacts associated with marine energy devices. The initiative will provide facilities and expertise to support development, testing, and validation of environmental monitoring technologies, and will complete a cost analysis to identify key areas where environmental monitoring costs can be reduced in both the near and long term.

In its first year the initiative has already provided testing support for three environmental monitoring instruments and plans are underway to collaborate with additional instrument developers in the coming year. Ultimately, activities performed as part of the Triton Initiative will facilitate the permitting process and reduce the overall cost of marine renewable energy.

Performer: PNNL
Principal Investigator: Genevra Harker-Klimes, genevra.harker@pnnl.gov



DOE-Sponsored Modeling Team Wins International Competition

To design systems that harness the power of waves to generate electricity, engineers must be able to predict how large floating devices will perform in a dynamic environment—that is, in the water among waves. To simulate the ocean environment and optimize the design of wave energy converters, the DOE Water Power Program funded a collaborative effort between NREL and SNL to develop the Wave Energy Converter Simulator (WEC-Sim). WEC-Sim's open-source platform models several types of WECs with increased simulation stability and speed.

In 2015, improvements and features were added to the WEC-Sim code that significantly improved its functionality and usability, and the NREL/SNL modeling team won the COER Hydrodynamic Modeling Competition held in conjunction with the International Conference on Ocean, Offshore and Arctic Engineering in St. John's, Newfoundland, Canada, May 31–June 5, 2015.

The competition challenged researchers to predict the dynamic motion of a floating body in an irregular wave field using computer-based modeling software. The NREL/SNL team won the competition with the smallest variance from the experimental results.

The success of the NREL and SNL modeling tools in the competition validates the viability and usability of open-source numerical simulation tools for the water power industry—tools that may help unlock the potential terawatts of power in U.S. wave resources.

Performers: NREL and SNL
Principal Investigators: Michael Lawson, Michael.Lawson@nrel.gov and Carlos Michelen, cmichel@sandia.gov

International Partnership to Accelerate Development of MHK Technologies

The DTOcean project, led by the European Commission, brings together 18 international partners from 11 countries to accelerate the development and commercialization of MHK energy systems by providing the industry with the design tools necessary to advance this market. As the only U.S. representative, SNL is developing tidal array modeling tools that will optimize the design of medium- to large-scale MHK arrays. When complete, these open-source tools will mitigate costs for developers and enable them to improve the power generation and reliability of MHK devices.

In 2015, SNL's work included:

- Co-developing the wave and tidal array modeling tools to determine the most efficient array spacing within a given deployment area
- Co-leading the design of the offshore electrical substation for ocean energy converter arrays from the shore side point of common coupling to the output of the ocean energy converter
- Supporting the moorings and foundation submodule that identifies component options based on array configurations and seabed conditions
- Providing guidance on multidisciplinary design optimization approaches to support the identification of the best ways for the software to communicate between modules to find a global optimal solution that considers levelized cost of energy, reliability, and environmental effects.

Performer: SNL

Principal Investigator: Jesse Roberts, jdrober@sandia.gov

Performer: ORNL

Principal Investigators: Rocio Uria-Martinez, uriamartiner@ornl.gov;

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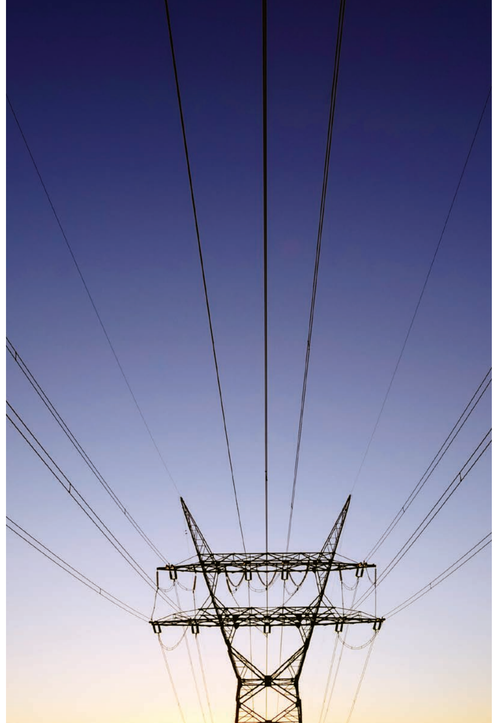
Resource Assessment and Characterization – Hydropower

The Water Power Program has released reports and maps that assess the total technically recoverable energy available in the nation's powered dams, non-powered dams, and untapped stream-reaches. These resource assessments are pivotal to understanding hydropower's potential for future electricity production. Hydropower already provides 6–8% of the nation's electricity, but more potential resides in our flowing waters to provide clean electricity to communities and cities across the United States.

The First Hydropower Market Report Quantifies the Current Size, Scope, and Variability of Our Nation's Hydropower Supplies.

Although hydropower has been providing the nation with clean reliable electricity generation for more than a century, there has never been a document that quantifies the hydropower fleet or analyzes the trends that influence the hydropower industry. The 2014 Hydropower Market Report, produced by ORNL, is the first report to quantify the current size, scope, and variability of the nation's hydropower supplies. Report highlights include the following:

- Hydropower currently provides approximately 7% of the U.S. electricity supply—enough to power more than 20 million homes
- The hydropower industry accounts for more than 55,000 U.S. jobs
- There were 331 projects in the development pipeline at the end of 2014
- The majority of new hydropower capacity will be provided by the development of nonpowered dams and new large-scale pumped storage hydropower projects
- Pumped storage hydropower facilities support the integration of other variable renewables into the grid.



First Multipurpose Reservoir Benefits Analysis

Federal hydropower dams in the United States support the grid with over 276,000 gigawatt-hours of clean, renewable electricity every year. Over 80% of these dams are multipurpose projects, congressionally authorized to provide flood control, irrigation, navigation, a water supply, and recreation. Each of these purposes has a significant and oftentimes quantifiable economic benefit.

Although multipurpose reservoirs account for billions of dollars in contributions to national economic development every year, no attempt has been made to evaluate their benefits on a national scale. In an ongoing effort conducted by ORNL, researchers have been conducting a benefits analysis focused on the three main federal hydropower owners: Tennessee Valley Authority, USACE, and U.S. Bureau of Reclamation. Together these three agencies own and operate 157 powered dams, accounting for almost half of the total installed hydropower capacity in the United States.

The analysis revealed that, as hydropower installed capacity at a reservoir increased, the benefit of hydropower is significant when only one or two additional purposes are present. For true multipurpose projects with four or five quantifiable uses, while a critical component, power generation does not contribute the largest national economic development benefit in most cases. Rather, recreation and irrigation provided the largest economic benefit for federal multipurpose reservoirs. The contributing factors towards these benefit distributions include recreation visitors and spending, and the value of irrigated crops.

Performer: ORNL

Principal Investigator: Boualem Hadjerioua, hadjeriouab@ornl.gov

Resource Assessment and Characterization – MHK

With more than 50% of the population living within 50 miles of coastlines, there is vast potential to provide clean, renewable electricity to communities and cities across the United States using MHK technologies. To understand the full potential for future electricity production that can be harnessed through our nation's water resources, the Water Power Program conducts resource assessments for waves, tidal streams, ocean currents, river currents, and ocean thermal gradients.

Providing for Local Electricity Needs with Hydrokinetic Energy in Irrigation Canals

Electricity generation from flowing water in irrigation/water supply canals has the potential to support local electricity needs with minimal regulatory or capital investment. Investigating how much excess energy is available for electricity generation, via enhanced/optimized hydrokinetic techniques, while still meeting the present needs of the water users, is critical for continued hydrokinetic site design and development.

SNL collaborated with the U.S. Bureau of Reclamation and the hydrokinetic energy developer, Instream Energy Systems, to perform field measurements near the Roza Hydro Power Plant in Yakima County, Washington, and to develop a predictive model with the ability to characterize the performance of a field-deployed turbine, determine the effects of hydrokinetic devices on local water-operations, and develop best practices for conducting canal-based hydrokinetic field studies.

An analysis conducted in 2015 indicated that the hydrokinetic turbine performed very well, with a maximum power coefficient comparable to that of medium-size wind turbines. In addition, the deployment impact of a single turbine to the canal's water depth is minimal, and is not expected to cause a disruption to canal operations. The results of this work and the associated best practice guidance for conducting canal-based hydrokinetic field studies will provide the foundation on which the canal-based hydrokinetic industry will grow.

Performer: SNL
Principal Investigator: Jesse Roberts, jdrober@sandia.gov

Catalogue Enables Developers to Choose Best Possible Test Site

To facilitate the technology advancement essential for the successful deployment of WECs, SNL released the second edition of the Characterization of U.S. Wave Energy Converter (WEC) Test Sites: A Catalogue of Met-Ocean Data. With five additional sites, the 2015 catalogue will open new pathways to commercialization by providing WEC developers with the critical wave statistics needed to determine the magnitude and quality of power resources at wave sites, as well as environmental loads required for WEC design.

The catalogue also enables WEC developers to compare wave resource characteristics among the different sites, allowing them to select locations that are the most suitable for their device and that best meet their testing needs and objectives.

Sites in the second edition of the Wave Energy Converter Test Site Catalogue include:

- Pacific Marine Energy Center's North Energy Test Site
- Kaneohe Bay Naval Wave Energy Test Site
- Humboldt Bay, California Site
- Jennette's Pier Wave Energy Converter Test Site
- USACE Field Research Facility
- Pacific Marine Energy Center's Lake Washington Test Site
- Pacific Marine Energy Center's South Energy Test Site
- CalWave Central Coast WEC Test Site (proposed).

Performer: SNL
Principal Investigator: Vincent Neary, vsneary@sandia.gov

Market Acceleration and Deployment – Hydropower

The Water Power Program's hydropower market acceleration and deployment efforts work to address environmental and regulatory barriers that prevent significant amounts of deployment, assess and quantify the value of hydropower to the nation's electric grid and its ability to integrate other variable renewable energy technologies, and develop a vibrant U.S. hydropower workforce and research community.

Fish-Friendly Hydropower Technologies Smooth Migration Paths

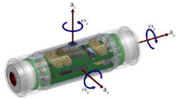
Although the nation's 2,500 hydropower dams provide inexpensive power to U.S. consumers and industries and play an important role in a variety of other functions (i.e., river navigation, flood control, recreation) dams present a considerable obstacle to migrating fish species.

To improve the biological performance of dams and hydro turbines, researchers at PNNL and ORNL developed specialized design and evaluation tools that will enable new turbine designs to meet power production goals and minimize effects on fish.

Based on biological data from field and lab studies, researchers developed a new version of the Sensor Fish, a small tubular device filled with sensors that analyzes the physical stresses fish experience. The latest rendition measures more forces, costs about 80% less, and can be used in more hydro structures than its predecessor. Data from the Sensor Fish, combined with computational modeling of turbine dynamics, inform the design of next-generation turbines.

Additional 2015 efforts in this field included the continued improvement of Version 2.0 of the Biological Design Tools software, which will be ready for licensing and use by industry by the end of 2015, furthering the development of small hydropower as a renewable, low-impact energy source for the future.

Performers: PNNL and ORNL
Principal Investigators: Mark Bevelhimer, bevelhimerms@ornl.gov; Brenda Pracheil, pracheilbm@ornl.gov, and Gary Johnson, Gary.Johnson@pnnl.gov



Tiny Injectable Transmitters Enable Researchers to Track Fish Migration Patterns

Even though they may be considered as less glamorous than other migrating fish, eels and lampreys play a pivotal role in the health of oceanic and riverine ecosystems. For both species, hydropower dams may impede migratory spawning routes. In an effort to enable the survival of these species, PNNL worked with the Army Corps of Engineers to create tracking systems to learn more about eel and lamprey migratory patterns that will inform the development of fish passage technology.

To develop a means of tagging and tracking juvenile lampreys and eels, PNNL is applying its expertise in acoustic transmitters and battery technology, creating tiny (less than 1.5 cm), injectable transmitters capable of tracking the fish in one, two, or three dimensions.

PNNL completed phase one of the project by successfully injecting the tags into juvenile lampreys and eels and has scheduled a pilot field trial for 2017. As the project progresses, PNNL researchers will gain a clear map of the fishes' migration, behavior around dams and structures, mortality rates, and additional data, which can be leveraged to boost the environmental performance of hydropower.

Performer: PNNL
Principal Investigator: Daniel Den, zhiqun.deng@pnnl.gov

New Fish Transport Systems Reduces Costs and Impacts

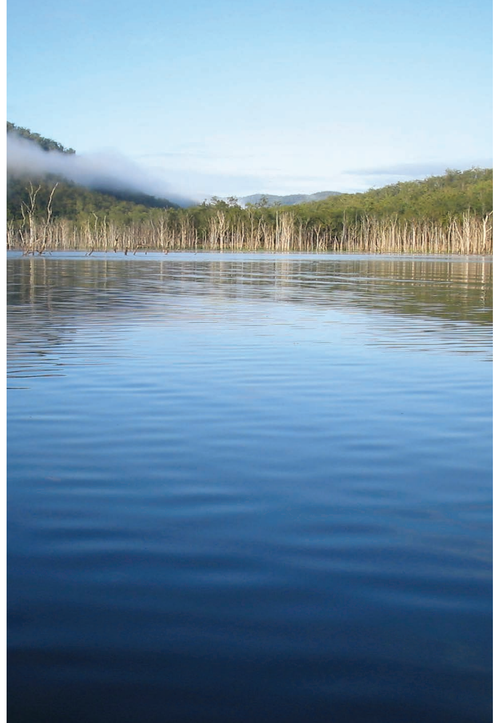
Each year millions of salmon and other fish species migrate hundreds of miles upstream to spawn. Along the way, more often than not, these migratory fish may encounter a dam or man-made structure that impedes their route.

Because current fish passage methods—ladders, fish lifts, and trap-and-haul programs—can be costly, the DOE Water Power Program is supporting the assessment of new technology intended to reduce the impact of hydropower on migrating fish.

In 2015, PNNL evaluated a new transport system—the Whoosh Fish Transport System developed by Whooshh Innovations, LLC—to gauge the technology's effectiveness. The system uses a flexible tube and a pressure system to guide fish over and around structures. Compared to techniques used today, it could transport fish more quickly and at less cost.

Using fall Chinook salmon, PNNL evaluated the Whooshh Fish Transport System against netting and the trap-and-haul technique. PNNL looked at adult survival, injury, reproductive readiness, physiological stress, and gamete survival, and found no significant differences between fish transported via the Whooshh system and other methods.

Performer: PNNL
Principal Investigator: Alison Colotelo, AlisonHA.Colotelo@pnnl.gov



New Pathways for Hydropower: Getting Hydro Built

New hydropower presents a substantial opportunity for increased electric generation, improvements in grid security and stability, and increased economic development. A new report published by ORNL in partnership with the Hydro Research Foundation in 2015 identifies the technological innovations and policy alternatives needed to decrease the expense and time required to build new hydropower facilities in the United States.

The report, *New Pathways for Hydropower: Getting Hydropower Built—What Does it Take?*, identifies 31 technological ideas, some of which address the need to nurture hydropower-specific innovation and education. Although the focus of the report is new small hydropower, many of the ideas are applicable to hydropower development in general, and once implemented, will reduce deployment cost and time through efficient design, manufacturing, permitting and licensing, installation commission, operation, and maintenance.

Performer: ORNL
Principal Investigator: Brennan Smith, smithbt@ornl.gov

DOE Hydro Fellowship Program Advances Educational Opportunities

Through targeted workforce development and training opportunities, the DOE Hydro Fellowship Program, in cooperation with the Hydro Research Foundation, supports the Obama Administration's goals of advancing education opportunities in the science, technology, math, and engineering fields. The program has funded 66 graduate students over the past 6 years at 31 separate universities to cultivate hydropower research at U.S. universities and target critical research areas needed to advance the hydropower industry across a number of diverse fields (civil, environmental, mechanical, materials, and electrical engineering). In 2015, the program funded 11 new fellowships to students at the following eight universities:

- Colorado School of Mines – 2
- Lehigh University – 1
- Northern Arizona University – 1
- Oregon State University – 2
- University of California Berkeley – 2
- University of Idaho – 1
- University of Massachusetts-Amherst – 1
- Washington State University – 1.

Market Acceleration and Deployment – Marine and Hydrokinetic

Though MHK energy is still in its infancy, the program is developing a robust portfolio of projects to accelerate wave, tidal and current project deployments and development of the MHK market in general. These projects include project siting activities, market assessments, environmental impact analyses, and research supporting technology commercialization.

First Fish Movement Simulator to Alleviate Ecological Concerns Relevant to Marine and Hydrokinetic Applications

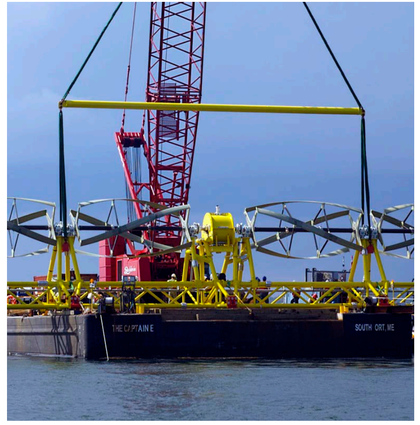
Individual-based models are important tools to assess the magnitude and ecological significance of the behavioral responses of fish to the presence and operation of MHK devices. The resulting behavioral simulations can be used to alleviate ecological concerns that are relevant to the permitting of MHK deployments and potentially facilitate a reduction of time and costs associated with these projects.

In collaboration with the University of Maine and USACE, researchers at ANL used hydroacoustic fish surveys and an ecohydraulic model, the Eulerian-Lagrangian-agent Method (ELAM), to analyze fish movements in the presence of a tidal turbine deployed in Cobscook Bay, Maine, by the Ocean Renewable Power Company.

Fish survey data and modelled flow fields will be integrated into the ELAM. Using this information, the ELAM will simulate fish movement trajectories that characterize fish behavior before, during, and after they encounter a turbine and the associated area of hydrodynamic effects.

Although the ELAM has been applied to dam operations and fish bypass designs in the past, this will be the model's first application designed specifically for MHK technology.

Performer: ANL
Principal Investigator: Mark Grippo, mgrippo@anl.gov



Open-Source Software Reduces Time and Costs Associated with MHK Project Permitting

The first MHK deployments in the United States have had to absorb unsustainable costs associated with permitting to get the first devices in the water. Consequently, there is an urgent industry need to reduce costs and time associated with meeting regulatory requirements. The crux of the problem is that regulations necessitate that a detailed understanding of the environmental effects of MHK deployments must come prior to deployment, requiring the use of numerical models to simulate the virtual design of MHK array layouts and the environmental response.

SNL is helping to overcome this technical challenge through the development of freely available, 'MHK-friendly' simulation tools that can accurately predict the changes to the physical environment associated with deploying arrays of MHK devices, fulfilling an industry-wide need. Thanks to a 10-year licensing agreement between SNL and software developer Deltares, the Delft-3D Software suite will be available to end users for the next 10 years.

The continued development and subsequent application of numerical tools like Delft-3D has matured and will continue to mature the nation's general knowledge regarding the interrelationship between the number, size, efficiency, and configuration of MHK arrays and the subsequent effects this may have on the marine environment. These tools facilitate the detailed analyses needed to guide the design and layout of MHK arrays to maximize power production and minimize environmental effects.

Performer: SNL

Principal Investigator: Chris Clayton Chartrand, cchart@sandia.gov

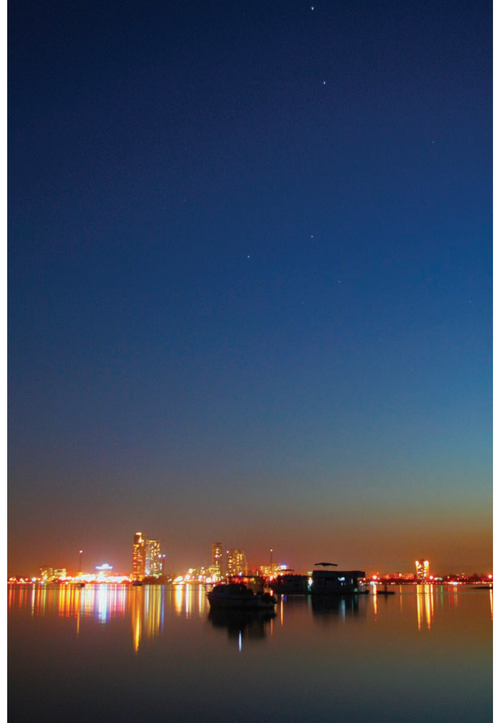
Thirteen Nations Address Environmental Effects of MHK Technologies

To further the responsible deployment of MHK technologies, it is critical for developers and researchers to share available information on its environmental effects. Led by PNNL, Annex IV brings together 13 nations to address the environmental effects of marine energy development.

Annex IV seeks to inform the MHK siting and permitting processes that will facilitate the development of this emerging industry. Through PNNL's Tethys database, Annex IV provides a common platform for collaborative work among marine energy researchers, regulators, developers, and stakeholders through a range of activities and products that include the broadcast and archiving of webinars, expert forums, and workshops focused on important scientific issues that are critical to the siting and permitting (consenting) of marine energy devices worldwide.

The signature output of Annex IV will be the State of the Science report, prepared by a team of international authors who are examining the most current knowledge. The report will be released in early 2016.

Performer: PNNL
Principal Investigator: Andrea Copping, Andrea.Copping@pnnl.gov

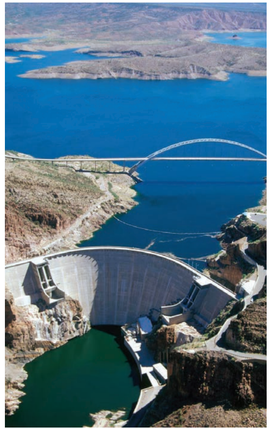


Study Evaluates Impacts of Acoustic Emissions from Hydrokinetic Turbines

The development of hydrokinetic energy technologies has raised concern over the potential impacts of underwater noise produced by hydrokinetic turbines on fish species likely to encounter these turbines. To address this concern, researchers at ORNL conducted experiments to evaluate fish response to sounds produced by MHK devices.

To assess the potential for behavioral impacts, redhorse (Moxostoma spp), freshwater drum (Aplondinotus grunniens), largemouth bass (Micropterus salmoides), and rainbow trout (Oncorhyncus mykiss) were exposed to varying intensities of hydrokinetic turbine recordings in a seminatural environment. Fish were evaluated for differences in mean location during noise exposure and control trials, trends in mean fish location were also evaluated during long duration exposure to recordings. Freshwater drum was the only species that showed avoidance behavior. Mixed results were observed for all species in long duration exposures. These outcomes highlight the need to establish minimum hearing thresholds for a wider range of fish species and characterize noise from differing hydrokinetic turbine designs and arrays.

Performer: ORNL
Principal Investigator: Mark Bevelhimer, bevelhimerms@ornl.gov



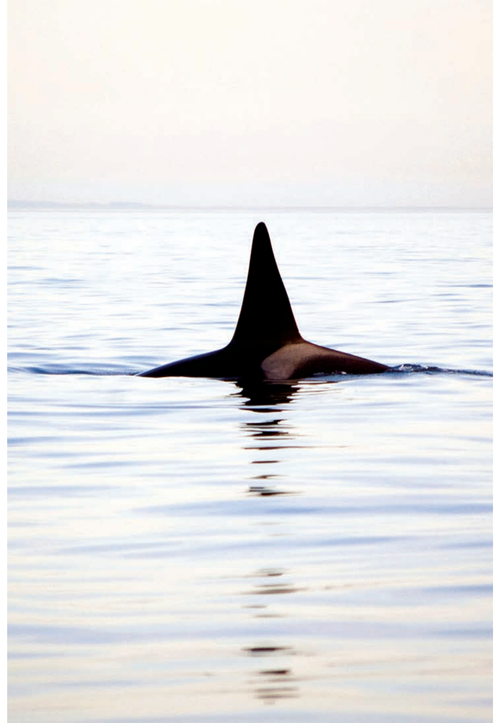
Assessing the Risk of Tidal Energy to Marine Mammals

Twice a day, every day, the tide comes in and the tide goes out. The constant ebb and flow presents an immense source of renewable energy. Although highly unlikely, the potential risk of marine mammals colliding with tidal turbines is one of the primary environmental concerns slowing tidal energy development in the United States.

Field measurement of marine mammal collisions is almost impossible to conduct; consequently, PNNL and SNL conducted a simulated analysis of the potential risks. The analysis provides the marine energy industry, researchers, regulators, and stakeholders with surrogate research in the absence of extensive field data.

Looking at turbine type—open center and two-bladed unducted—the study modeled potential strike scenarios for southern resident killer whales and harbor seals. The researchers considered the size of the mammal, strike location, angle, and skin/tissue structure when assessing the risk. For killer whales, the study found that the mammals face the possibility of lacerations, though such injuries were quite unlikely. Harbor seals, while extremely unlikely to get hit by turbine blades, face a greater risk of serious injury but are unlikely to be killed by a collision.

Performer: PNNL and SNL
Principal Investigators: Andrea Copping, andrea.copping@pnnl.gov and Rich Jepsen, rajepse@sandia.gov



Awards

	Award	Recipient	Sponsor
U.S. Department of Energy Wind and Water Power Technologies Office	Best Challenge Engagement Strategy for the Wave Energy Prize. As a result of their excellent outreach efforts, 92 teams registered for the competition.	Water Power Program Marine and Hydrokinetic Team	White House Office of Science and Technology
Argonne National Laboratory	2015 Technical Paper of the Year in the Market Trends and Strategies Category at HydroVision 2015: Operational Capabilities and Valuation of Benefits Provided by Advanced Pumped Storage Hydropower Technologies	Vladimir Koritarov, ANL; Ibrahim Krad, NREL; Charlton Clark, DOE	National Hydropower Association
National Renewable Energy Laboratory	First Place in the Hydrodynamic Modeling Competition held in conjunction with the International Conference on Ocean, Offshore and Arctic Engineering in St. John's, Newfoundland, Canada, May 31–June 5, 2015.	Michael Lawson, NREL; Carlos Michelen, SNL	Center for Ocean Energy Research (COER)
Oak Ridge National Laboratory	First Place Paper in the Water Management and Movement Category presented at HydroVision 2015: Development and Application of a Standardized Flow Measurement Uncertainty Analysis Framework to Various Low-Head Short-Converging Intake Types Across the United States Federal Hydropower Fleet	Kyutae Lee, Mark Christian, Brennan Smith	National Hydropower Association
	Third Place Paper in the Water Management and Flow Category presented at HydroVision 2015: High-Fidelity Reservoir Water Quality Model Emulation by Artificial Neural Network	Amelia Shaw, Heather Smith Sawyer, and Eugen LeBoeuf, Vanderbilt University; Mark McDonald, Lipscomb University	National Hydropower Association

	Award	Recipient	Sponsor
Oak Ridge National Laboratory	Second Place Paper in the Market Trends and Strategies Category presented at HydroVision 2015: Parametric Cost Modeling for National-Scale Hydropower Feasibility	Scott DeNeale, Patrick O'Connor, Dol Raj Chalise, Emma Centurion, Abigail Maloof, and Nicole Samu	National Hydropower Association
	Third Place Paper in the Environmental and Social Category presented at HydroVision 2015: Total Dissolved Gas Prediction and Implementation within Optimization Scheduling Model for the Mid-Columbia River System	Kevin Stewart, Adam Witt, Boualem Hadjerioua, Scott DeNeale, Abigail Maloof	National Hydropower Association
	Second Place Paper in the Equipment and Technology Category presented at HydroVision 2015: Economic Feasibility in the U.S. Markets for Modular Pumped Storage Hydro—Case Study Preliminary Results	Adam Witt, Boualem Hadjerioua, Rocio Uria-Martinez, Marisol Bonnet	National Hydropower Association
	First Place for Best Poster in the Post-Bachelor's/Post-Master's Category at the 3rd Annual ORNL Postdoc Research Symposium	Marisol Bonnet	Oak Ridge Postdoctoral Association
Sandia National Laboratories	First Place in the Hydrodynamic Modeling Competition held in conjunction with the International Conference on Ocean, Offshore and Arctic Engineering in St. John's, Newfoundland, Canada, May 31–June 5, 2015.	Michael Lawson, NREL; Carlos Michelen, SNL	COER

Publications

Water Power Program Publications

HydroNEXT Fact Sheet, *http://energy.gov/eere/water/downloads/hydronext-fact-sheet*

2014 Hydropower Market Report, *http://energy.gov/eere/water/downloads/2014-hydropower-market-report*

Hydropower Memorandum of Understanding and Action Plan, *http://energy.gov/eere/water/downloads/hydropower-memorandum-understanding*

Hydropower Projects, *http://energy.gov/eere/water/downloads/hydropower-projects*

Marine and Hydrokinetic (MHK) Databases and Systems, *http://energy.gov/sites/prod/files/2015/06/f22/pumped-storage-potential-hydropower-from-conduits-final.pdf*

Marine and Hydrokinetic Energy Projects, *http://energy.gov/eere/water/downloads/marine-and-hydrokinetic-energy-projects*

New Stream-Reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States

Pumped Storage and Potential Hydropower From Conduits, *http://energy.gov/sites/prod/files/2015/06/f22/pumped-storage-potential-hydropower-from-conduits-final.pdf*

Argonne National Laboratory

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Patents and Records of Invention

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	Wave Energy Conversion Devices With Actuated Geometry	ROI-15-58	2015
Sandia National Laboratories	Automatic Computation of Transfer Functions	9009640	2015
	Controller for a Wave Energy Converter	9140231	2015

Software Licenses and Deployment

	Title	Patent/ROI Number	Date
National Renewable Energy Laboratory	WEC.Sim v.1.1	Open Source	2015
	Simulator fOr Wind and Water Farm Applications	Open Source	2014
Sandia National Laboratories	WEC.Sim v.1.1	Open Source	11/26/19
	SNL-SWAN v.1.0	Open Source	7/22/19

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