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

WATER POWER PROGRAM

WATER POWER FOR A CLEAN ENERGY FUTURE

March 2014

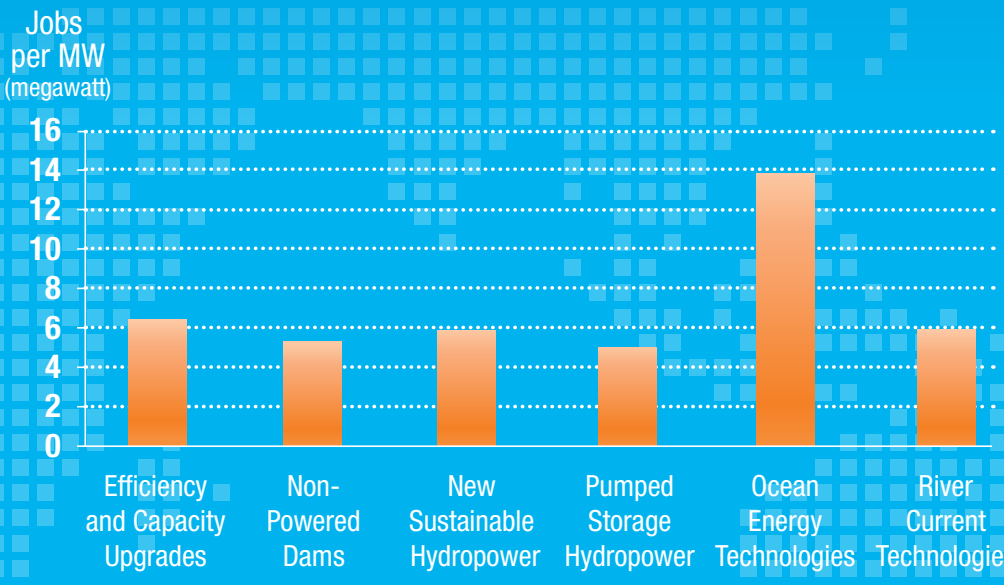
Building a Clean Energy Economy

Leading the world in clean energy is critical to strengthening the American economy. Targeted investments in clean energy research and development jumpstart private sector innovation critical to our long-term economic growth, energy security, and international competitiveness. The U.S. Department of Energy (DOE) Water Power Program (the Program) is strengthening the nation's global position by funding cutting-edge research to produce the next generation of hydropower and marine and hydrokinetic (MHK) technologies, and by accelerating the development of markets for those technologies.

Currently, the hydropower industry employs 200,000–300,000 workers in the United States, making it not only the longest-running, but also the largest renewable electricity production workforce in the nation. However, there has been a lack of consistent hydropower educational programs in the United States. In an effort to increase our nation's knowledge and skills in this area, the Program has sponsored new graduate research opportunities to train the next generation of hydropower specialists and engineers.

The newly emerging MHK industry holds tremendous potential for job growth as MHK technologies progress towards commercial readiness. The Program invests in fellowships that fund graduate-level training and sends U.S. researchers to advanced European research facilities to establish partnerships, boost innovation, and facilitate knowledge sharing. By capitalizing on water power's significant potential for sustainable growth, the United States can add thousands of clean energy jobs while building a sustainable, renewable energy future.

Water Power Jobs



The U.S. water power industry can create 1.4 million jobs (cumulative) by 2025*

** Job Creation Opportunities in Hydropower.* Navigant Consulting, September 20, 2009.

Department of Energy Water Power Program

Developing and Advancing a Renewable Energy Future

The Water Power Program (the Program) at the U.S. Department of Energy (DOE) is at the forefront of the nation's clean energy frontier. To help the United States meet its growing energy demand, the Program is pioneering research and development efforts in both marine & hydrokinetic (MHK) and hydropower technologies. These water power technology areas hold the promise of clean, affordable electricity that will move our nation towards energy independence.

Hydroelectric power, the largest source of renewable electricity in the United States, allows the nation to avoid 200 million metric tons of carbon emissions each year. Although only a small portion of dams produce electricity, new generation equipment can be added to existing infrastructure to access vast reserves of untapped hydropower capacity in the United States. DOE's Water Power Program leads the critical research and development efforts necessary to develop more efficient technologies that will drive sustainable growth and economic opportunity.

Additionally, DOE's Water Power Program invests in the new and innovative MHK industry. This nascent technology sector is an example of American ingenuity at its best, producing cutting-edge technologies that can contribute to our nation's energy independence. Through research, development, and demonstration efforts, the Program supports the emerging industry in its efforts to capture the energy from oceans and rivers for a new generation of environmentally sustainable and cost-effective electricity.

Marine and Hydrokinetic Power

The Future of American Clean Energy

Marine and hydrokinetic (MHK) technologies generate energy from highly forecastable waves and currents. With more than 50% of the American population living within 50 miles of American coastlines, we have vast potential to provide clean, renewable electricity to communities and cities across the United States using MHK technologies.

Assessing Resource Potential

There is a vast amount of energy available in waves, tidal and river currents, and ocean current resources. The Water Power Program supported collaboration between private research institutions and DOE's national laboratories to determine the location and magnitude of electricity generation from MHK resources. The Water Power Program has completed four assessments of U.S. MHK resources: wave, tidal, river hydrokinetic, and ocean currents. The resulting public databases and resource maps provide useful information for federal agencies, Congress, state and federal regulators, research institutions, and developers.

Maps showing U.S. tidal, wave, riverine hydrokinetic, and ocean resources can be found on the following pages.

Advancing Technology Readiness

Because MHK is a nascent industry with hundreds of developers and many potentially viable device types, there is currently no single technology leader. Therefore, the Program is leading the effort to prove functionality, evaluate technical and economic viability, and generate cost, performance, and reliability data for a variety of devices. By cost-sharing some of the initial financial risk for a range of technologies, the Program is evaluating device viability, thereby attracting the private sector financing necessary for commercialization.

See Program Highlights: Wave Energy Demonstration (next page)

Ensuring Environmental Responsibility

MHK technology advancement must preserve the integrity of the marine environment if it is to succeed. To that end, the Water Power Program is supporting a range of environmental studies to ensure that the energy generated from MHK is not only renewable, but also sustainable. These studies include research into the effects of energy removal in marine and freshwater systems, and the impact of devices and arrays on various physical and biological aspects of marine and freshwater systems. The end result of this research will be comprehensive models to guide future placement of MHK devices and arrays to ensure safe, sustainable deployment.

See Program Highlight: The Annex IV Project (next page)

Reducing the Cost of Energy

DOE's Water Power Program is developing detailed reference models for six different MHK device designs using performance simulations and small-scale laboratory tests for validation. To build on these reference models and clearly identify cost reduction pathways, the Water Power Program is identifying research and development opportunities to reduce the levelized cost of energy (LCOE) for MHK devices to achieve cost-competitive energy rates by 2030, and helping stakeholders to conduct LCOE and performance analysis for their devices.

DOE research is helping to address environmental barriers to deployment by demonstrating low risk of injury to fish for four types of hydrokinetic turbines.

Program Highlights

Tidal Energy Testing and Demonstration

Who: Ocean Renewable Power Company, LLC (ORPC)

Where: Cobscook Bay off Eastport and Lubec, Maine

What: Built, operated, and monitored a commercial-scale grid-connected TidGen™ device.

Impact: Bangor Hydro Electric company verified that electricity was flowing from ORPC's Cobscook Bay Tidal Project, marking the first time in U.S. history that such a project was connected to the electric power grid.

Wave Energy Demonstration

Who: Columbia Power Technologies

Where: Puget Sound, Washington and Corvallis, Oregon

What: Design, test, and demonstrate a wave energy converter prototype.

Impact: Improves upon previous prototype design, test, and deployment results to create an intermediate-scale prototype—the StingRAY—that uses direct drive technology for improved hydrodynamic performance.

Wave Energy Testing and Demonstration

Who: Northwest National Marine Renewable Energy Center (NNMREC) and Northwest Energy Innovations

Where: Newport, Oregon

What: Designed, installed, and demonstrated a mobile test unit to monitor efficiency and impacts of additional devices, including a multi-mode wave energy converter.

Impact: NNMREC's OceanSentinel obtains critical technical and cost performance data for a variety of technologies, including the multi-mode Azura device (previously called WET-NZ) from Northwest Energy Innovations.

The Annex IV Project

Who: Pacific Northwest National Laboratory, Bureau of Ocean Energy Management, National Oceanographic and Atmospheric Administration, Annex IV International Energy Agency's (IEA) Ocean Energy Systems (OES) Member Nations

Website: *mhk.pnnl.gov/wiki/index.php/About_Annex_IV*

What: The Annex IV initiative examines and documents research into the potential environmental effects of ocean energy devices with the goal of helping expand the use of sustainable, renewable energy sources

Impact: Developed through a partnership with IEA's OES Ocean Energy Systems initiative, the Tethys database and an accompanying Annex IV report identify research on potential environmental effects and monitoring methods for ocean power.

Investing in the Future

The Water Power Program has invested in three National Marine Renewable Energy Centers — centers of excellence and education undertaking research, development, demonstration and commercial applications of marine renewable energy technologies. These centers provide the necessary domestic expertise and infrastructure needed to facilitate comprehensive, standardized testing of MHK devices and to produce certified environmental performance data, ultimately providing the necessary level of confidence to enable the private financing of commercial generation plants.

OSU Oregon State University · University of Washington · HNEI Hawai'i Natural Energy Institute, University of Hawai'i at Mānoa · FAU Southeast National Marine Renewable Energy Center, College of Engineering and Computer Science, Florida Atlantic University

The Northwest National Marine Renewable Energy Center

Partnership between Oregon State University and the University of Washington that focuses on ocean wave and tidal energy and resources and technologies.

The Hawaii National Marine Renewable Energy Center

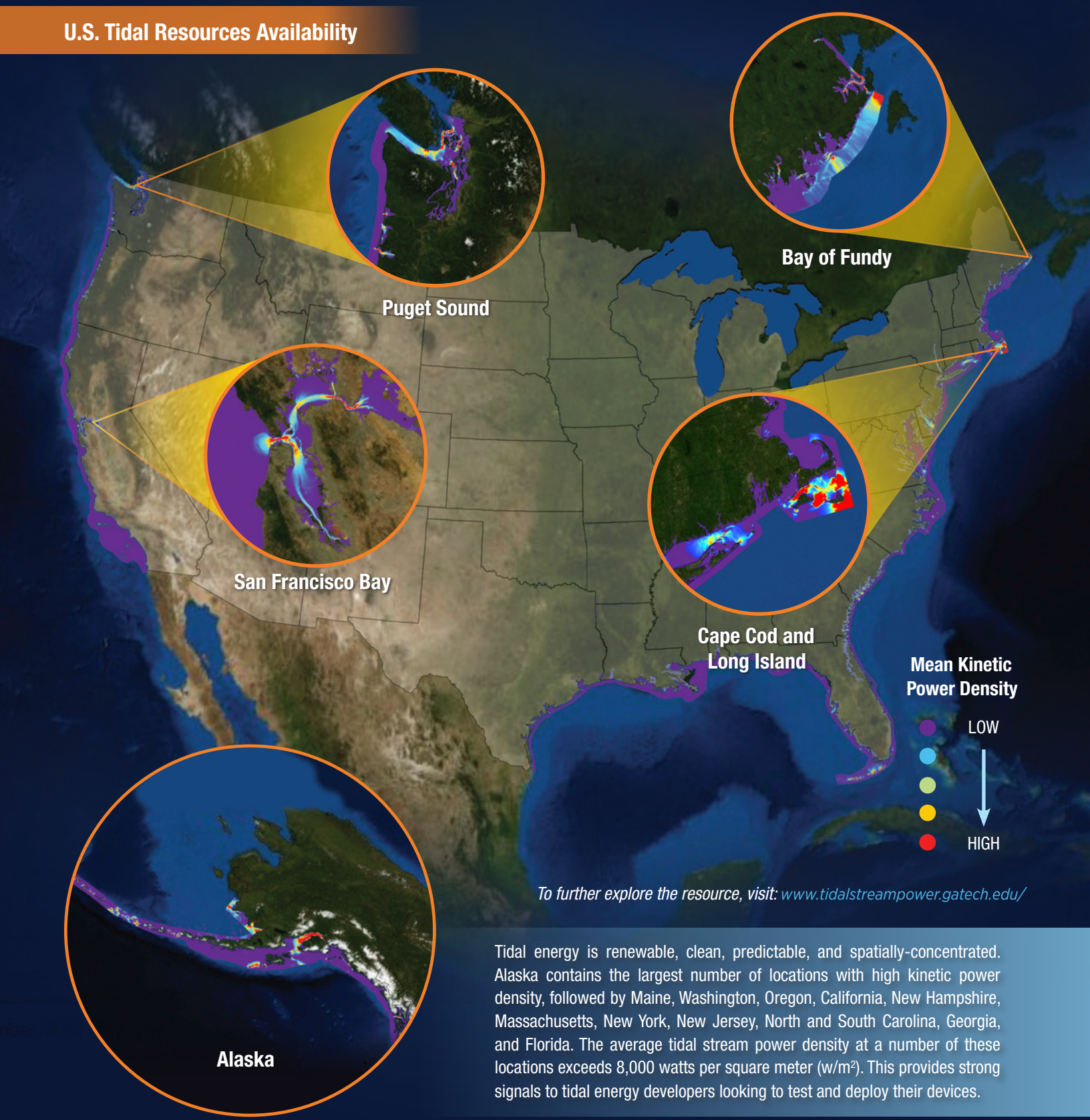
Managed by the University of Hawaii and focuses on ocean wave resources and technologies.

The Southeast National Marine Renewable Energy Center

Managed by Florida Atlantic University and focuses on ocean current resources and technologies.

U.S. WATER POWER RESOURCES

U.S. Tidal Resources Availability



To further explore the resource, visit: www.tidalstreampower.gatech.edu/

Tidal energy is renewable, clean, predictable, and spatially-concentrated. Alaska contains the largest number of locations with high kinetic power density, followed by Maine, Washington, Oregon, California, New Hampshire, Massachusetts, New York, New Jersey, North and South Carolina, Georgia, and Florida. The average tidal stream power density at a number of these locations exceeds 8,000 watts per square meter (w/m^2). This provides strong signals to tidal energy developers looking to test and deploy their devices.

U.S. Wave Resource Availablility

The total available U.S. wave energy resource is estimated at 2,640 TWh/yr. Given the limits of device arrays, approximately 1,170 TWh/yr of the total resource is theoretically recoverable: 250 TWh/yr for the West Coast, 160 TWh/yr for the East Coast, 60 TWh/yr for the Gulf of Mexico, 620 TWh/yr for Alaska, 80 TWh/yr for Hawaii, and 20 TWh/yr for Puerto Rico. At these levels, the nation's wave energy resource has the potential to power over 100 million homes each year.

To further explore the resource, visit: maps.nrel.gov/mhk_atlas

Continental U.S. Riverine Hydrokinetic Resources

Technically Recoverable Resource

LOW

HIGH

The nation has the potential for 120 terawatt-hours (TWh) per year from riverine hydrokinetic generation for the continental United States. Riverine, or "run-of-river," hydrokinetic energy is captured without the use of dams by harnessing the natural flow of a river or stream to power a turbine set at a lower elevation. 80% of the potential 120 TWh comes from four hydrologic regions: the lower Mississippi (48%), Alaska (17%), the Pacific Northwest (9%), and the Ohio River (6%).

To further explore the resource, visit:
http://maps.nrel.gov/river_atlas

Assessment of Energy Production Potential from Ocean Currents in the United States

To further explore the resource, visit:
www.water.energy.gov/pdfs/energy_production_ocean_currents_us_0.pdf

This map shows the potential of the ocean current energy resource available for the United States. The kinetic energy flux, or theoretical resource potential, of the Gulf Stream is 200 TWh/year. The technical resource potential power available for extraction in the Florida Current region of the Gulf Stream is approximately 5.1 GW (corresponding to approximately 45 TWh/year of generation). Considering a larger region of the Gulf Stream—within 200 miles of the U.S. coastline from Florida to North Carolina—the technical resource potential is approximately 18.6 GW (or roughly 163 TWh/year of energy).

Mean Kinetic Power Density

0 - 100 w/m²	500 - 600 w/m²	1,000 - 1,100 w/m²	1,500 - 1,600 w/m²	2,000 - 2,100 w/m²	2,500 - 2,600 w/m²
100 - 200 w/m²	600 - 700 w/m²	1,100 - 1,200 w/m²	1,600 - 1,700 w/m²	2,100 - 2,200 w/m²	2,600 - 2,700 w/m²
200 - 300 w/m²	700 - 800 w/m²	1,200 - 1,300 w/m²	1,700 - 1,800 w/m²	2,200 - 2,300 w/m²	2,700 - 2,800 w/m²
300 - 400 w/m²	800 - 900 w/m²	1,300 - 1,400 w/m²	1,800 - 1,900 w/m²	2,300 - 2,400 w/m²	2,800 - 2,900 w/m²
400 - 500 w/m²	900 - 1,000 w/m²	1,400 - 1,500 w/m²	1,900 - 2,000 w/m²	2,400 - 2,500 w/m²	2,900 - 3,000 w/m²

Hydropower

An American Tradition of Renewable Energy

Hydropower provides about 7% of the nation's electricity and an average of 60% of renewable electricity output annually.[1] Water Power Program studies demonstrate that there is 12 GW of development potential at the country's 80,000-plus non-powered dams and more than 65 GW of new development potential. Pumped-storage hydropower is the only existing utility-scale storage technology that can support the integration of variable renewable resources, such as wind and solar.

Leveraging Our Existing Fleet

Hydropower has an installed generating capacity considerably greater than any other renewable electricity technology. Even so, there are tremendous amounts of untapped hydropower resources within the United States from existing hydropower facilities, non-powered dams, and potential new, sustainable hydropower sites. However, more than 50% of the nation's turbines are over 50 years old, and without investment in our existing infrastructure, the many ancillary services we've come to depend on hydropower for—reduced thermal plant cycling, load balancing, and integration of an ever-increasing suite of variable renewables—may be significantly reduced over time. DOE's Water Power Program quantifies the benefits of hydropower, including the vast range of pumped-storage hydropower capabilities, to demonstrate the numerous and varied services hydropower can provide for today's modern electric grid. Additionally, the Program is investing in new tools and technologies to help optimize, upgrade, and expand the use of our existing fleet.

Assessing Resource Potential

Even with an installed capacity of 78 GW, DOE studies find that more than double that amount of hydropower still exists untapped within existing hydropower facilities, canals and conduits, non-powered dams, and potential new, sustainable hydropower sites across the United States. Leveraging our existing water resource infrastructure in the form of canals, conduits and non-powered dams alone could yield more than 13 GW of lower-cost, lower impact new capacity. The majority resides in our nation's undeveloped stream-reaches, with more than 65 GW of potential to explore as clean, lasting, renewable source of energy.

In addition, the Water Power Program partnered with Oak Ridge National Laboratory to create the National Hydropower Asset Assessment Program, which gathers, organizes, validates, and integrates a wide array of data in U.S. hydropower production. These data include water availability, historic generation, facility configuration, and stream network. The National Hydropower Asset Assessment Program provides a strategic planning and decision-making tool to ascertain the current value of the nation's hydroelectric infrastructure and the amounts of energy that could feasibly be generated.

Maps showing the U.S. Non-Powered Dams resources and New Stream-reach Development opportunities can be found later in this document.

Advancing New Hydropower

DOE's Water Power Program is investing in innovative hydropower technologies including those powering existing infrastructure (see the map of U.S. Non-Powered Dams resources later in this document). These technologies tend to be modular in design, allowing for greater siting flexibility and lower installation costs. Potential environmental impacts also tend to be low as the devices are often deployed in man-made environments such as canals, pipes, or locks and dams.

See Program Highlight: New, Low-Head Hydropower (next page)

[1] U.S. Energy Information Administration Net Generation by Energy Source: Total, 2011-2013

Program Highlights

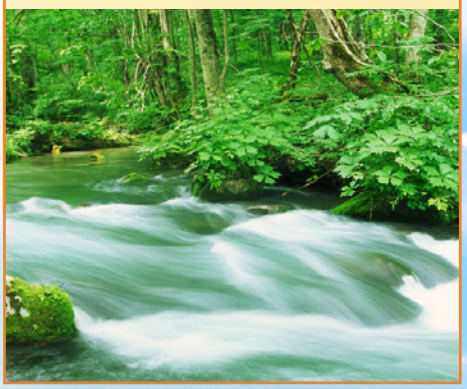
Water Use Optimization Toolset

Who: Argonne National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories

Where: Nationwide

What: Develop and demonstrate a hydropower optimization toolset to increase power generation and broaden alternative power integration opportunities from available water while enhancing environmental performance.

Impact: Provides a full range of integrated tools to increase energy generation, optimize ancillary services, and improve river health.



Sensor Fish

Who: Pacific Northwest National Laboratory

Where: Nationwide

What: The Sensor Fish is a small device deployed in turbines to measure changes in pressure, temperature, angular rate of change, and linear acceleration during passage. This development addresses the conern of potential injury or mortality of fish during passage through hydropower turbines.

Impact: The development and redesign of the Sensor Fish can improve the design of fish-friendly turbines, improving survival rate of fish populations and lessening the chance of injury.

New, Low-Head Hydropower

Who: Percheron Power

Where: Colorado and Washington

What: Percheron Power will install the nation's first Archimedes Hydrodynamic Screw (AHS) hydropower system for demonstration and evaluation.

Impact: This project supports development of new small hydropower projects by making previously marginal low-head sites viable and demonstrates to stakeholders that the AHS technology is simple, robust, economical, and does not negatively impact canal operations.

Investing in the Future

Building on hydropower's current contributions to the nation's energy supply through advanced technology development will allow non-powered dams, new environmentally-friendly technologies, pumped storage, and the existing hydropower fleet to generate more clean energy and facilitate the integration of variable renewables into the nation's electrical grid. This will cement hydropower's position as the sustainable and reliable base of the nation's renewable energy portfolio.

See Program Highlight: Sensor Fish (above)

U.S. WATER POWER RESOURCES

Top 600 U.S. Non-Powered Dams with Potential Capacity Greater than 1MW

To further explore the resource, visit: nhaap.ornl.gov/content/non-powered-dam-potential

The nation has over 50,000 non-powered dams with the potential to add about 12 GW of clean, renewable hydropower capacity. The 100 largest capacity facilities could provide 8 GW of power, the majority of which are locks and dams on the Ohio, Mississippi, Alabama, and Arkansas rivers operated by the U.S. Army Corps of Engineers. Power stations can likely be added to many of these dams without impacting critical habitats, parks or wilderness areas while powering millions of households and avoiding many more million metric tons of carbon dioxide emissions each year.

New Stream-reach Development (NSD) Potential by Subbasin

This map shows new-stream reach development (NSD) by subbasin for the United States. The estimated technical resource capacity for NSD is 85 GW with total undeveloped NSD generation estimated at 460 TWh/year. When protected lands—national parks, National Wild and Scenic Rivers, and Wilderness Areas— are excluded, the estimated capacity is more than 65 GW of potential with total undeveloped NSD generation estimated to be 346 TWh/year.

To further explore the resource, visit:
http://nhaap.ornl.gov/nsd

Working Together to Build Our Clean Energy Future

Supporting a Developing Industry

In 2013, DOE's Water Power Program announced a solicitation for 18 projects to help efficiently capture energy from waves, tides, and currents. Together, these projects will increase the power production and reliability of wave and tidal devices and help gather valuable data on how deployed devices interact with the surrounding environment. In 2010, twenty-seven cost-shared projects—the single largest investment in the MHK sector in U.S. history—were selected ranging from concept studies and component design to prototype development and in-water device testing.

Through the 2009 American Recovery and Reinvestment Act, the Water Power Program awarded seven projects totaling more than $30 million to revitalize the nation's existing hydropower fleet with more efficient technologies. In 2011, the Water Power Program released an advanced hydropower solicitation for the development and demonstration of small, innovative hydropower, environmental mitigation technologies, and support for the development of the nation's first pumped storage plant in more than 20 years.

DOE's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program has made over 20 advanced water power technology development awards. SBIR/STTR awards contribute to new, innovative technologies that can ultimately help lower the cost of energy. These awards also help remove barriers to commercialization by focusing their research and development efforts on specific industry needs, allowing MHK and conventional hydropower technologies to advance more rapidly.

Collaborating Across Government

The Water Power Program has taken a leading role in convening federal agencies to discuss ongoing MHK resource use and technology development. The U.S. Department of Interior awarded DOE, the Bureau of Ocean Energy Management (BOEM), and the National Oceanic and Atmospheric Association (NOAA) with its "2013 Partners in Conservation Award" for their Fiscal Year 2010 collaborative funding of environmental research to ensure the sustainability of ocean renewable energy technologies.

This honorary award recognizes public-private partnerships that promote conservation, protect natural and cultural resources, use innovative approaches for resource management, and engage youth and diverse communities in accomplishing the DOI's mission.

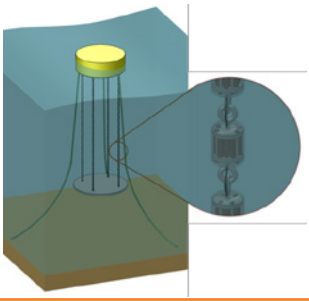
MHK Small Business Innovation Research Project

Who: Oscilla Power, Inc.

Where: Seattle, WA

What: Design and construct an ocean demonstration system, including magnetostrictive generators with full scale cores, buoy and mooring, to demonstrate functionality and initial reliability. This unique MHK technology utilizes magnetostrictive technology for a simple, no-moving-parts design.

Impact: Demonstrates an innovative, modular, and reconfigurable wave energy converter technology, critical to proving the economic viability of magnetostrictive MHK devices.



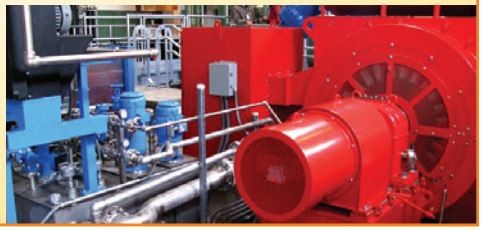
American Recovery and Reinvestment Act: Boulder Canyon Hydroelectric Plant Modernization Project

Who: City of Boulder

Where: Boulder, Colorado

What: Increase renewable energy generation 37% by installing a five megawatt turbine and generator.

Impact: Enables the cost-effective generation of reliable, renewable electricity while integrating project control equipment into Boulder's municipal waste system, and increases the safety and sustainability of the hydroelectric plant. In addition, the project has improved safety for personnel, equipment, and overall protection of the Boulder Creek environment.



WATER POWER FAST FACTS

Hydropower and MHK technologies have the potential to double water power's contribution to the nation's electricity supply by 2030.

The water power industry accounts for more than 300,000 jobs in the United States and has the potential to create thousands more by developing new water resources.

Hydroelectricity has been powering America for more than a century and still remains a reliable and dynamic energy resource today.

Hydropower provides about 7% of the nation's electricity overall, and an average of 60% of its renewable electricity output annually.

DOE studies show that the technical resource potential from U.S. waves, tidal, river, and ocean currents is estimated to be between 1,286 and 1,787 TWh/year.

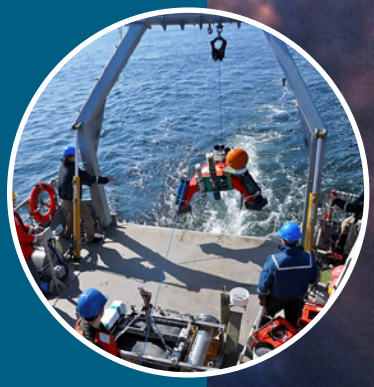
More than 50% of the American population lives within 50 miles of either coast, thus MHK resources could be developed close to load centers with short transmission distances.

By using hydropower, the United States avoids emitting more than 235 million tons of carbon dioxide pollution into the atmosphere each year.

Hydropower facilities provide a number of benefits in addition to producing electricity, such as flood control, irrigation, water supply, and a range of recreational opportunities.

The International Energy Agency estimates a global opportunity to install 748 GW of MHK technologies by 2050.

eere.energy.gov
water.energy.gov



U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
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