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

WATER POWER PROGRAM

WATER POWER FOR A CLEAN ENERGY FUTURE

March 2016

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.

Department of Energy Water Power Program

Developing and Advancing a Renewable Energy Future

The Water Power 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.

Resource Assessment and Characterization

Today's national resource assessments are at a low resolution, making industry decisions on technology development and deployment high risk. Higher resolution regional assessments for MHK will support resource classification schemes and provide more detailed information. These will reduce risk for investment opportunities in technology development and deployment.

Deployment

The process for permitting device deployments can be expensive and time consuming, leaving fewer resources for R&D and increasing project development costs. The lack of scientific information and high monitoring costs can drive environmental and regulatory expenses to 30%–50% of total early-stage MHK project cost. By assessing and addressing potential environmental impacts through scientific research, developing new instruments, and validating them with initial device demonstrations, this sector can avoid serious deployment barriers. National support for environmental monitoring can help reduce the monitoring cost burden for developers, allowing them to focus funds on technology development to approach cost competitiveness and facilitate more widespread deployments.

Technology Maturity

The MHK energy sector is currently represented by many diverse technology solutions. There are limited data available to identify low-cost, high-performance solutions with high reliability. Investments are spread across all of the technology types rather than focused on the most promising opportunities. Many new players are taking interest in developing possible winning solutions in this sector, and a national effort could develop cost competitive and environmentally responsible solutions. This would establish the United States as a global leader for domestic and international markets.

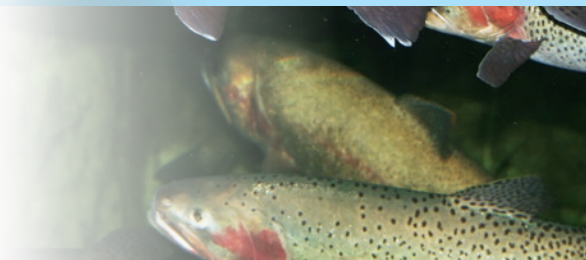
Demonstration

Developers ready to test full-scale prototypes lack access to test facilities and permitted demonstration sites. This impedes the developer's ability to validate device performance in its intended resource; test and iterate installation, operation, and maintenance logistics; and monitor device-to-environment interactions. Access to world-class test facilities and other demonstration opportunities can help accelerate technology evolution while substantially reducing development and demonstration costs to the industry. Specifically, early-adopter markets may present demonstration opportunities.

Cost Reduction

Significant innovation is still needed to bring costs down by more than 50% to achieve cost competitiveness of MHK devices. Devices need to capture more energy and reduce both capital and operating costs. Innovation mechanisms and a large body of knowledge that draws from other scientific and industrial sectors are available today to accelerate the cost-reduction profile.

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: Igiugig, Alaska

What: Deployed and decommissioned a commercial scale grid-connected RivGen® turbine.

Impact: Provided power to Igiugig and displaced power that would otherwise be generated by high-cost diesel fuel. Connecting to the small community grid and decreasing the use of diesel fuel will help lower electricity costs for consumers, since all fuel must either be barged or flown in to the rural village.

Wave Energy Demonstration

Who: Northwest Energy Innovation (NWEI) and the U.S. Navy

Where: The Navy's Wave Energy Test Site in Kaneohe Bay off of Oahu, Hawaii

What: The Azura wave energy device advanced successfully from initial concept to grid-connected, open-sea pilot testing, becoming the nation's first grid-connected wave energy device to be independently tested by a third party—the University of Hawaii—in the open ocean.

Impact: The primary objectives of this upcoming test are to utilize the data collected to optimize energy capture, validate existing cost and performance models, and further refine the models.

Wave Energy Testing and Demonstration

Who: DOE, Ricardo, Inc., and the U.S. Naval Surface Warfare Center, Carderock Division

Website: *www.waveenergyprize.org*

What: Encourage the development of more efficient WEC devices that double the energy captured from ocean waves, which in turn will reduce the cost of wave energy.

Impact: Ninety-two eligible teams registered to compete for a prize purse totaling more than $2 million. Of the 17 qualified teams that tested 1/50th-scale devices at five wave testing facilities across the United States, nine teams were selected as finalists that will test a larger 1/20th-scale model device at the Navy's MASK Basin in summer 2016.

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 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.

The Northwest National Marine Renewable Energy Center

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

The Hawaii National Marine Renewable Energy Center

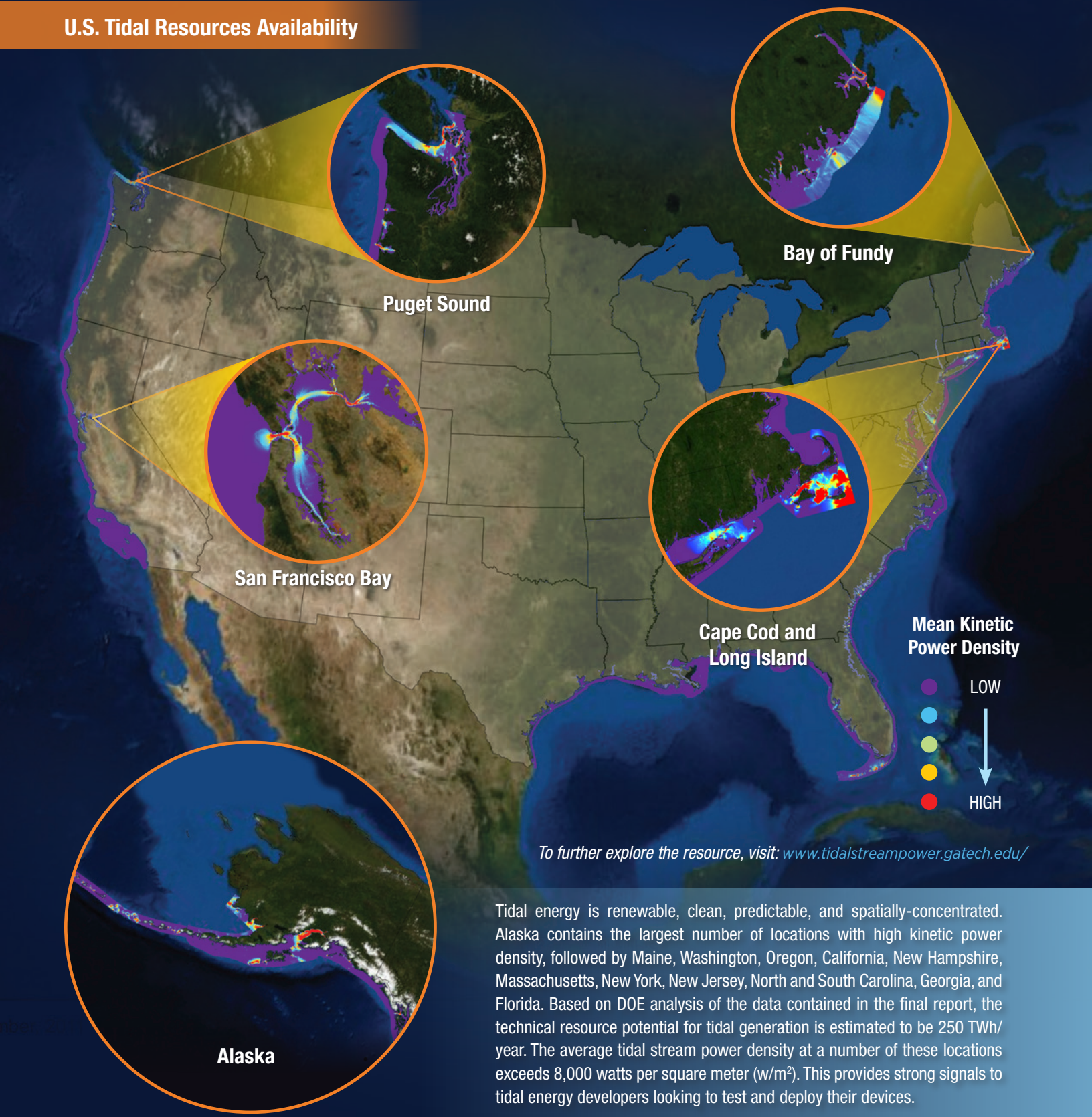
Managed by the University of Hawaii and focuses on ocean wave resources and technologies.

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. Based on DOE analysis of the data contained in the final report, the technical resource potential for tidal generation is estimated to be 250 TWh/year. 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. theoretical resource for waves 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. The theoretical resource potential for generation from riverine hydrokinetic resources in the continental U.S. is 1,381 TWh/year. 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

U.S. Ocean Current Resources

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

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).

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 untapped hydropower potential still exists 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 non-powered dams alone could yield more than 12 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.

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

Program Highlights

Small Hydropower

Who: Weisenberger Mills

Where: Kentucky

What: Install a permanent magnet generator controlled by a variable speed drive to utilize water flowing through the turbines more efficiently, which results in improved annual energy production.

Impact: This project demonstrates the ability to efficiently convert energy from low-head stream flows, often using existing infrastructure, with little to no environmental impact.

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.

Hydropower Market Report

Who: Energy Department, Oak Ridge National Laboratory

Where: Nationwide

What: This first-ever report quantifies the current size, scope, and variability of our nation's hydropower supplies. Hydropower currently provides approximately seven percent of the U.S. electricity supply --enough electricity to power more than 20 million homes.

Impact: This report models and analyzes the value of U.S. hydropower assets. The report also highlights how hydropower can be rapidly integrated with other renewable energy sources into the electric grid.sites viable and demonstrates to stakeholders that the AHS technology is simple, robust, economical, and does not negatively impact canal operations.

The Next Generation of Hydropower

The Energy Department is investing in the development of innovative technologies that dramatically change the way we think about hydropower by lowering cost, improving performance, and promoting environmental stewardship of hydropower development. This initiative, known as HydroNEXT, aims to increase the contribution of clean, renewable hydropower to the nation's energy mix: existing water infrastructure, undeveloped streams, and pumped-storage hydropower.

See Program Highlight: Small Hydropower (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. 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.

Wave, tidal, and hydropower offer great promise for clean energy but present technical and logistical challenges. Through DOE's Small Business Vouchers Pilot, small businesses can apply for assistance from DOE's national laboratories. The pilot aims to help small businesses bring next-generation clean energy technologies to the market faster by enabling them to access expertise and specialized equipment at the national labs.

DOE's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program has made more than 17 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 hydropower technologies to advance more rapidly.

Collaborating Across Government

The Water Power Program has taken a leading role in convening federal agencies to collaborate with the Energy Department. In 2015, the Department of the Interior, Department of the Army for Civil Works and DOE extended their partnership and commitment to advance low-impact, low-cost hydropower technologies for an additional five years. Additionally, the U.S. Department of Interior awarded DOE, the Bureau of Ocean Energy Management (BOEM), and the National Oceanic and Atmospheric Administration (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.

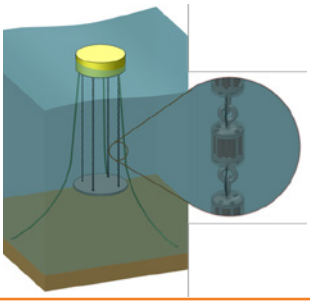
MHK Small Business Innovation Research Project

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.



Innovative Hydropower Technology Powers an Apple Data Center

Who: Natel Energy, Inc.

Where: Oregon

What: Make use of an existing, previously unpowered irrigation canal to generate reliable, renewable energy.

Impact: This project is producing electricity for Apple Inc. to lower its carbon footprint and help power one of its data centers. Small hydropower technologies like this one demonstrate the potential to tap into the vast opportunities that remain to contribute to the nation's renewable energy mix.

WATER POWER FAST FACTS

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.

Hydroelectricity, America's first renewable, has been powering the country for more than a century and still remains a reliable and dynamic energy resource today.

DOE studies show that the technical resource potential from U.S. waves, tidal, river, and ocean currents is estimated to be between 1,250 and 1,850 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.

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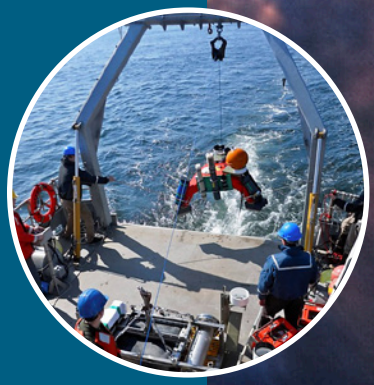

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