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

WATER POWER PROGRAM

# WATER POWER FOR A CLEAN ENERGY FUTURE

April 2013

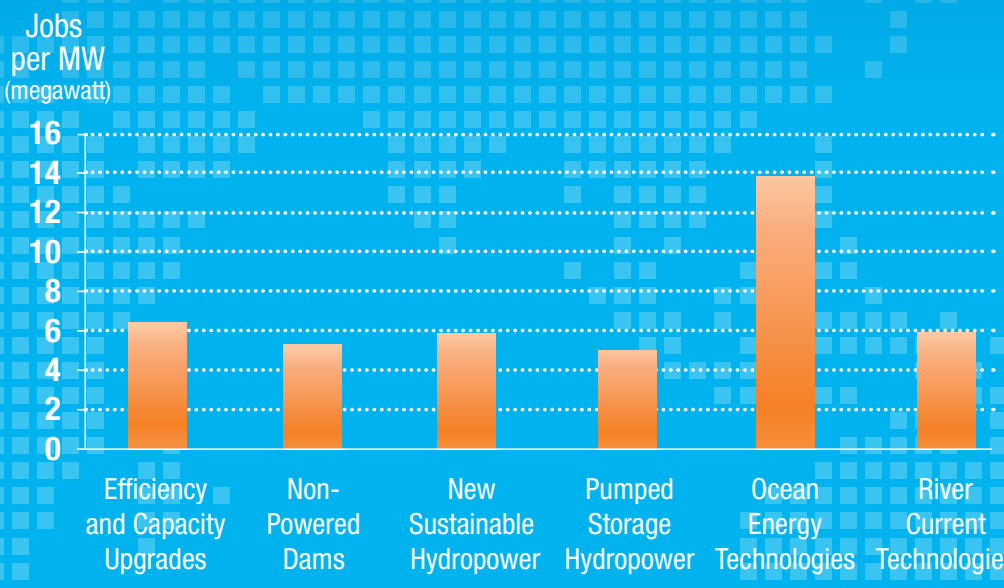
# Building a Clean Energy Economy

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 fellowships 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.

DOE is currently developing an aggressive strategy to support its vision of the nation obtaining 15% of its electricity needs from water power by 2030.

# Marine and Hydrokinetic Power

*The Future of American Clean Energy*

Marine and hydrokinetic (MHK) technologies generate energy from highly forecastable waves, currents, and ocean thermal resources. **With more than 50% of the American population living within 50 miles of American coastlines, a cost-effective MHK industry could provide a substantial amount of electricity for the nation.**

## Assessing Resource Potential

There is a vast amount of energy available in waves, tidal and river currents, and ocean thermal 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 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 thermal energy resources can be found on the following pages.*

## Reducing the Cost of Energy

DOE's Water Power Program is developing detailed cost models for six different MHK device designs using performance simulations and small-scale laboratory tests for validation. To build on these cost models and clearly identify cost reduction pathways, the Water Power Program is identifying research and development opportunities to reduce the levelized cost of energy for MHK devices, supporting a detailed techno-economic assessment of MHK technologies, and helping stakeholders identify research and development gaps to achieve cost-competitive energy rates by 2030.

## 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:** Environmental Information Database (next page)

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

## Program Highlights

### Wave Energy Conversion Device Testing

**Who:** Oscilla Power, Inc.

**Where:** Salt Lake City, Utah, and Puget Sound, Washington

**What:** Design and test a modifiable wave energy conversion prototype that has no moving parts.

**Impact:** Uses first-of-a-kind magnetic, adjustable alloys to convert kinetic energy into cost-competitive electrical energy.

### 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 and Northwest Energy Innovations

**Where:** Portland, Oregon

**What:** Design, install, and demonstrate 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 WET-NZ from Northwest Energy Innovations.

### Environmental Information Database

**Who:** Pacific Northwest National Laboratory

**Website:** *mhk.pnl.gov/wiki/index.php/Tethys_Home*

**What:** Develop a "smart," publicly accessible database of important research on the environmental impacts of MHK technologies.

**Impact:**
Identifies and organizes data on the potential environmental impacts of, and current monitoring efforts on, MHK development to facilitate the classification and evaluation of those impacts by regulators, MHK industry members, and other stakeholders.

TETHYS

## Investing in the Future

The Water Power Program is investing 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 will 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

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

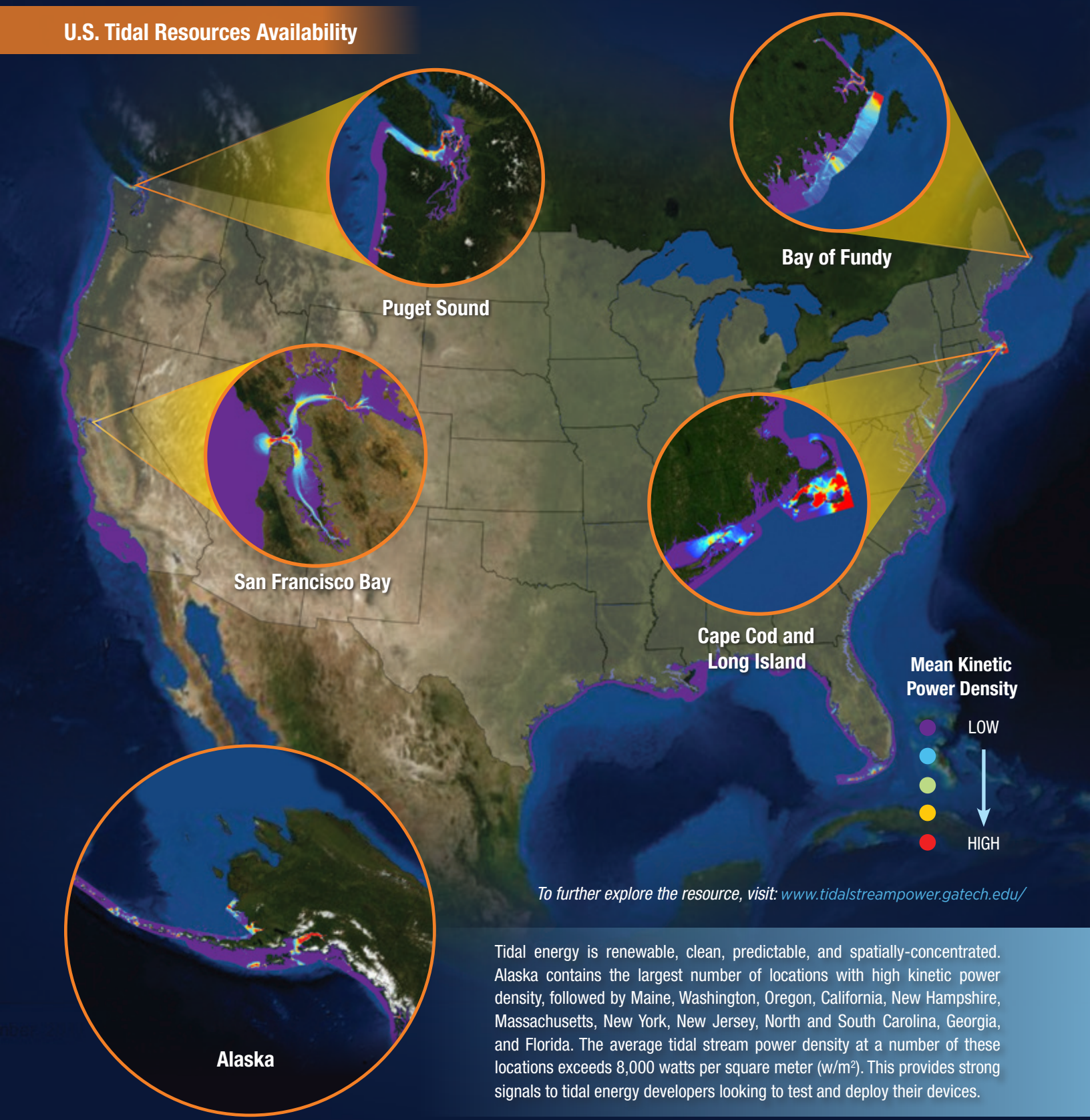
Managed by the University of Hawaii and focuses on ocean wave resources and technologies.

### 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**

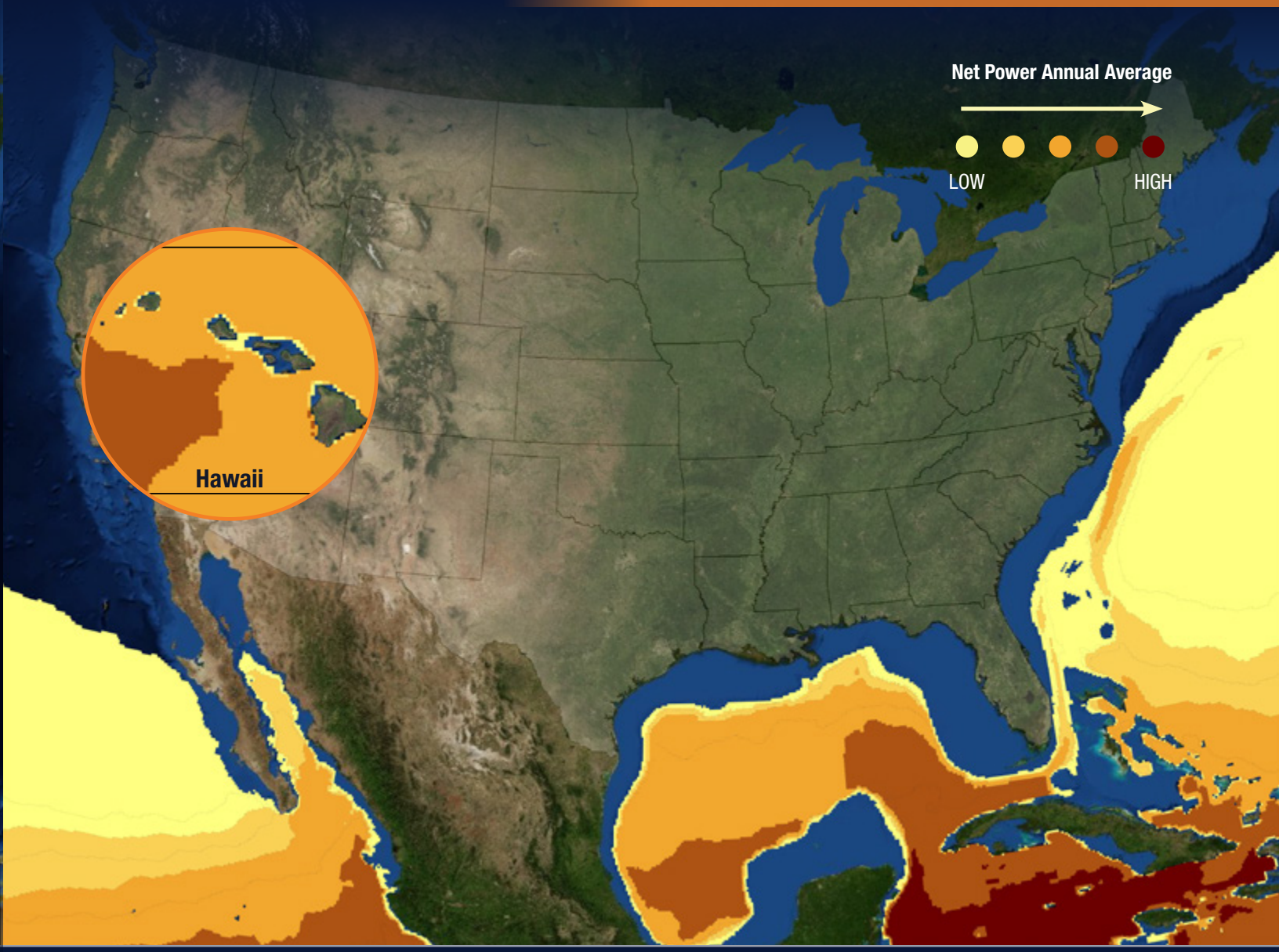
LOW

HIGH

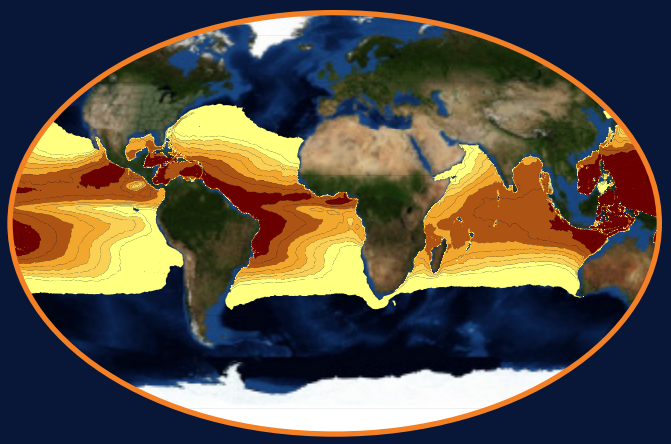
The nation has the potential for 120 terawatt-hours (TWh) per year from riverine hydrokinetic generation for the continental United States. Riverine, or "run-of-river," hydrokinetic energy is captured without the use of dams by harnessing the natural flow of a river or stream to power a turbine set at 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*

# U.S. Ocean Thermal Energy Conversion (OTEC) Resources




Within U.S. waters off the nation's coasts plus Puerto Rico, there is an estimated 576 terawatt-hours (TWh) per year of energy available of OTEC resource potential. The potential is concentrated in the following regions: 143 TWh per year located off of Hawaii, 53 TWh per year in the Gulf of Mexico, 342 TWh per year off of the East Coast, and 38 TWh per year off of Puerto Rico and the Virgin Islands. When expanded to include all U.S. exclusive economic zone waters, the cumulative potential is 4600 TWh per year.



*To further explore the resource, visit:*
*www.water.energy.gov/pdfs/1055457.pdf*

# Hydropower

*An American Tradition of Renewable Energy*


Hydropower provides about 7% of the nation's electricity and over 70% 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.** 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.

## Quantifying Hydropower's Value to the Grid

Conventional and pumped-storage hydropower can increase the flexibility and stability of the U.S. electric grid and support the integration of variable renewable resources like wind and solar. DOE's Water Power Program quantifies the benefits of effective and cost-competitive hydropower technologies and communicates those benefits to stakeholders. The Water Power Program is collaborating with Argonne National Laboratory to model the vast range of advanced pumped-storage hydropower capabilities with the aim of quantifying its full economic value. Studies like this one will help demonstrate the numerous and varied services hydropower can provide for today's modern electric grid.

## 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)

## Assessing Resource Potential

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. The Water Power Program's public Water Power GIS tool enables analyses of the nation's existing and potential hydropower resources at various geographic levels ranging from individual projects to congressional districts to the nation as a whole. The GIS tool also allows the Water Power Program to identify and focus on specific environmental issues and technologies with the largest potential for expanding clean, low impact hydropower generation.

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.

*A map showing the U.S. Non-Powered Dams resources can be found later in this document.*

[1] U.S. Energy Information Administration Net Generation by Energy Source: Total (All Sectors Including Pumped Storage), 2000-2010

## 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.

### Alden Fish Friendly Turbine

**Who:** An industry team that combines the manufacturing expertise of Voith Hydro with the research abilities of Alden Research Laboratory, led by EPRI.

**Where:** York, Pennsylvania and Holden, Massachusetts.

**What:** Provide for the safe passage of downstream-migrating fish through an operating turbine.

**Impact:** Will provide a more sustainable option for producing electricity at more than 1,000 estimated environmentally sensitive hydropower facilities and thousands of new developments.[2]

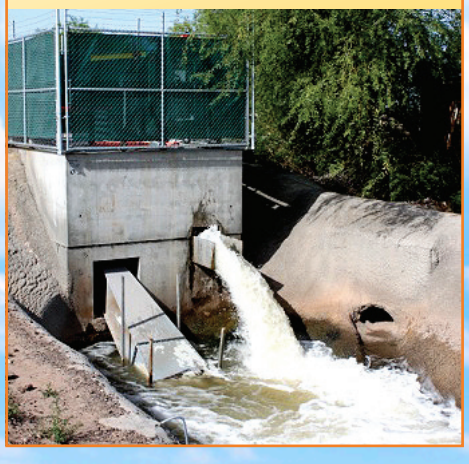
### New, Low-Head Hydropower

**Who:** Natel Energy

**Where:** Buckeye Water Conservation and Drainage District, Buckeye, Arizona.

**What:** Pilot project for testing the DOE-funded Schneider Linear Hydroengine, a new low-head turbine.

**Impact:** Enables the cost-effective generation of reliable, renewable electricity from thousands of existing low-head dams, miles of existing irrigation infrastructure, and the significant low-head potential in streams.



[2] "Fish Friendly" Hydropower Turbine Development and Deployment: Alden Turbine Preliminary Engineering and Model Testing. EPRI, Palo Alto, CA and U.S. Department of Energy,Washington, DC: 2011. 1019890

### 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:** Alden Fish Friendly Turbine (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.

# Working Together to Build Our Clean Energy Future

## Supporting a Developing Industry

In 2010, DOE's Water Power Program announced a solicitation for the acceleration of technological and commercial readiness of MHK technologies. 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. In 2010, DOE and the Department of Interior signed a memorandum of understanding to prioritize and facilitate the environmentally responsible deployment of commercial-scale offshore wind and MHK energy technologies on the Outer Continental Shelf. Also in 2010, DOE, the U.S. Army Corps of Engineers, and the Department of the Interior's Bureau of Reclamation signed a memorandum of understanding to increase U.S. hydropower generation at federal facilities in a sustainable manner and seek solutions to meet the integrated energy and water needs of future generations. Under this partnership, the three agencies completed assessments of hydropower resources, funded several research projects to develop and demonstrate new hydropower technologies, and produced a report examining the effects of climate change on water availability. Finally, in 2011, DOE and the Department of Commerce's National Atmospheric and Oceanic Administration signed a memorandum of understanding to advance collaborative efforts on the use of weather-dependent and oceanic renewable energy technologies.

### MHK Small Business Innovation Research Project

**Who:** FloDesign, Inc.

**Where:** Wilbraham, Massachusetts.

**What:** Advance the Mixer-Ejector Hydrokinetic Turbine to the prototype stage. This new type of shrouded hydrokinetic turbine incorporates proven aerospace propulsion and power technologies into an integrated, tightly coupled system delivering extremely high hydrodynamic efficiency levels.

**Impact:** Develops and demonstrates an advanced, high efficiency MHK device, which is critical to prove the economic viability of hydrokinetic turbines and deliver competitive costs of electricity.

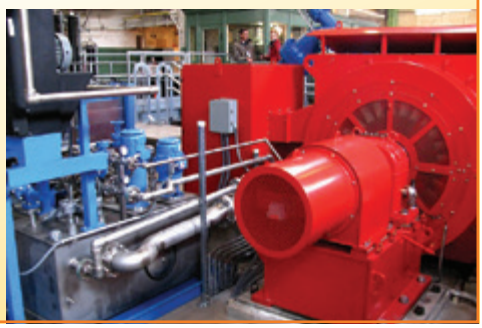
### American Recovery and Reinvestment Act: Boulder Canyon Hydroelectric Plant Modernization Project

**Who:** City of Boulder

**Where:** Boulder, Colorado

**What:** Increase renewable energy generation 30% 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.



# WATER POWER FAST FACTS

Hydropower and marine and hydrokinetic water power technologies can provide 15% of the nation's electricity needs 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.

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, offering a potential of 500 GW that could be captured by MHK technology deployment.

Hydropower provides about 7% of the nation's electricity overall, and more than 70% of its renewable electricity output annually.

DOE studies show that the maximum theoretical electric generation that could be produced from U.S. waves and tidal and river currents is approximately 1,540 TWh/yr--more than a third of the nation's annual electricity usage.

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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