

Hydropower

Setting a Course for Our Energy Future

- Improving turbine performance
- Providing safe fish passage
- Facilitating new hydropower generation
- Integrating with other renewables



U.S. Department of Energy
Energy Efficiency and Renewable Energy

Bringing our prosperous future where energy is clean, abundant, reliable, and affordable

*Wind and Hydropower
Technologies Program*



Wind & Hydropower Technologies Program — Harnessing America’s abundant natural resources for clean power generation.



Contents

- Hydropower Today 1
- Enhancing Generation and Environmental Performance 6
 - Large Turbine Field-Testing 9
 - Providing Safe Passage for Fish 9
 - Improving Mitigation Practices 11
 - From the Laboratories to the Hydropower Communities 12
- Hydropower Tomorrow 14
 - Developing the Next Generation of Hydropower 15
 - Integrating Wind and Hydropower Technologies 16
 - Optimizing Project Operations 17
- The Federal Wind and Hydropower Technologies Program 19
 - Mission and Goals 20

2003 Hydropower Research Highlights

- Alden Research Center completes prototype turbine tests at their facility in Holden, MA 9
- Laboratories form partnerships to develop and test new sensor arrays and computer models 10
- DOE hosts Workshop on Turbulence at Hydroelectric Power Plants in Atlanta 11
- New retrofit aeration system designed to increase the dissolved oxygen content of water discharged from the turbines of the Osage Project in Missouri 11
- Low head/low power resource assessments completed for conventional turbines, unconventional systems, and micro hydropower 15
- Wind and hydropower integration activities in 2003 aim to identify potential sites and partners 17

Cover photo: To harness undeveloped hydropower resources without using a dam as part of the system that produces electricity, researchers are developing technologies that extract energy from free flowing water sources like this stream in West Virginia.



HYDROPOWER TODAY

Water power — it can cut deep canyons, chisel majestic mountains, quench parched lands, and transport tons — and it can generate enough electricity to light up millions of homes and businesses around the world.

Hydropower, also known as hydroelectric power, is a reliable, domestic, emission-free resource that is renewable through the hydrologic cycle and harnesses the natural energy of flowing water to provide clean, fast, flexible electricity generation. Hydropower, one of our nation's most important renewable energy resources, has grown over the last century from 45 hydroelectric facilities in 1886 to more than 2,000 facilities in 50 states and Puerto Rico that contribute approximately 80,000 megawatts (MW) to our nation's electrical capacity. That represents about 10% of our country's electrical generating capability and provides more than 75% of the electricity generated from renewable sources.

Because hydropower generation begins the minute water starts to fall through the turbines, it is capable of rapid response to peak demands and emergency needs, contributing to the stability of our nation's electricity grid and energy security. Hydropower is also one of the most economic energy resources and is not subject to market fluctuations or embargos, which helps support our nation's energy independence — and it can provide that support for years to come. The average lifespan of a hydropower facility is 100 years. By upgrading and increasing the efficiencies and capacities of existing facilities, hydropower can continue to support our nation's growing energy needs.

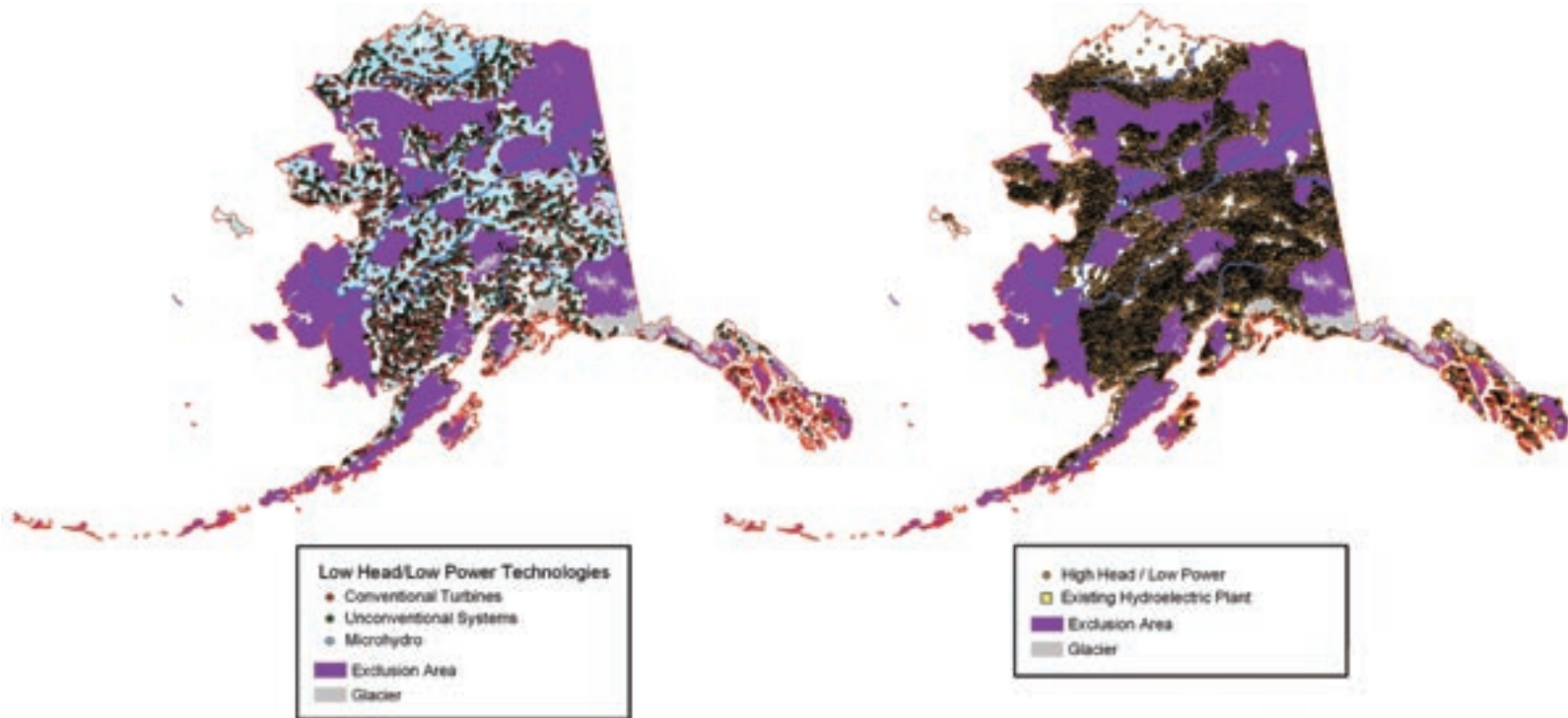
Hydropower also has more non-power benefits than any other generation sources, including water supply, flood control, navigation, irrigation, and recreation. In terms of recreation, hydropower projects in the United States provide the public with more than 47,000 miles of shoreline; 2,000 water access sites; 28,000 tent, trailer, and recreational vehicle sites for camping; 1,100 miles of trails; and 1,200 picnic areas.

While there are many advantages to hydroelectric production, the industry also faces unique environmental challenges. Potential environmental impacts include changes in aquatic and stream side habitats; alteration of landscapes through the formation of reservoirs; effects on water quality and quantity; interruption of migratory patterns for fish such as salmon, steelhead, American shad, and sturgeon; and injury or death to fish passing through the turbines. The challenge facing hydropower researchers today is how to take advantage of

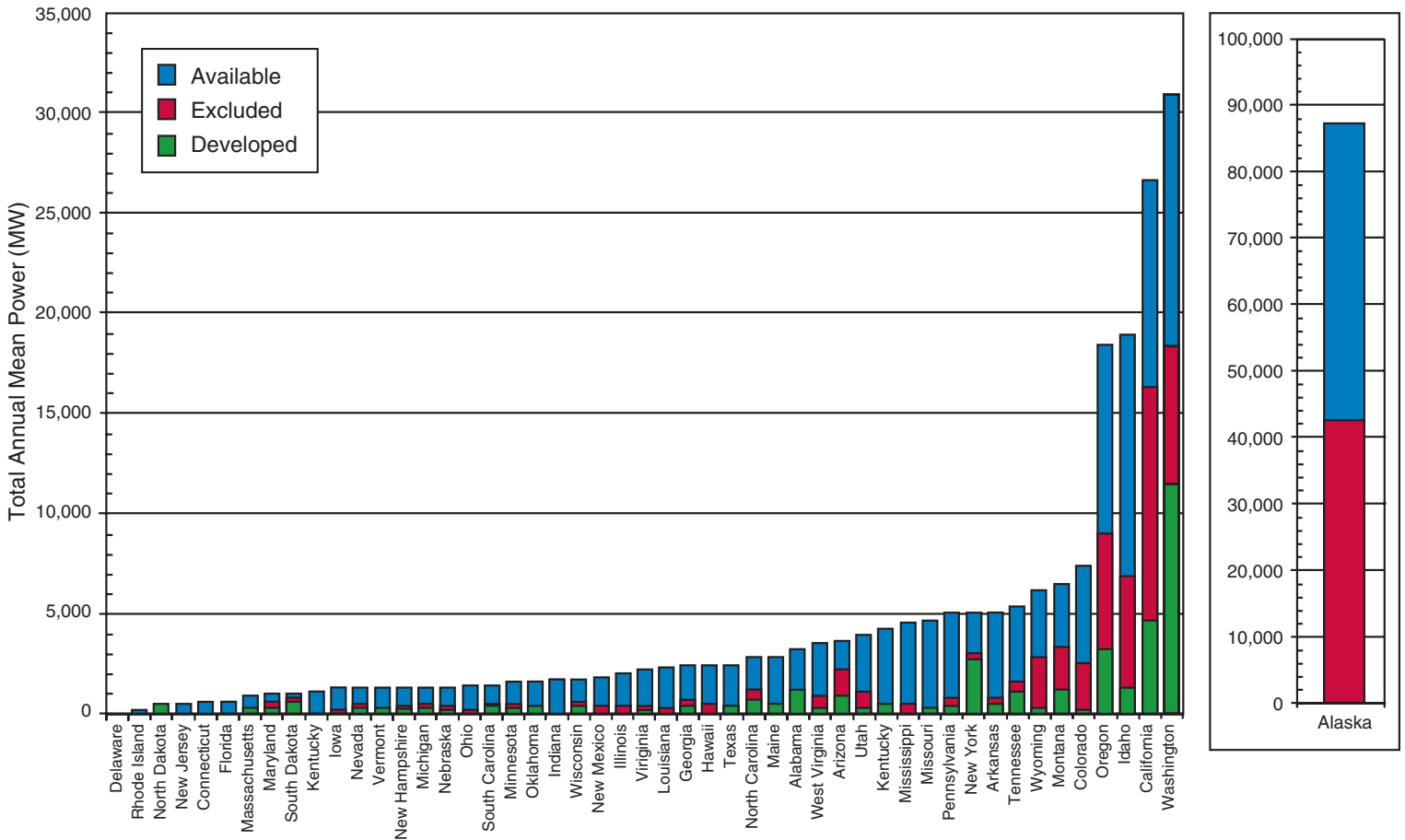
one of our nation's most plentiful renewable resources to produce the electricity we need without endangering the aquatic species and habitats upon which the health of the environment and industries such as fishing and river tourism depend. Unless they find a way to meet this challenge, researchers and industry members feel it is unlikely that much additional hydropower will be added to our generation mix through undeveloped resources.

According to a water energy resources assessment conducted by the U.S. Department of Energy (DOE), the estimated average available power of undeveloped U.S. resources is 170,000 MW. Available resources are resources that have not been developed and are not excluded from development by federal statutes and policies. The Alaska Region contains the largest available potential with slightly less than 45,000 MW. The Pacific Northwest Region has the second highest amount of available potential with almost 40,000 MW. Together these two regions contain about half of the estimated available U.S. hydropower potential.

Low power resources (resources with less than 1 MW of power) make up about 50,000 MW of the total available potential. These resources could be captured using technologies not requiring the use of dams, thus avoiding many of the environmental impacts. Development of about 30 % of these resources would require unconventional systems or microhydro technologies. Partial use of the remaining available potential of approximately 120,000 MW composed of high power (greater than or equal to 1 MW) resources represents an additional source of low power potential that



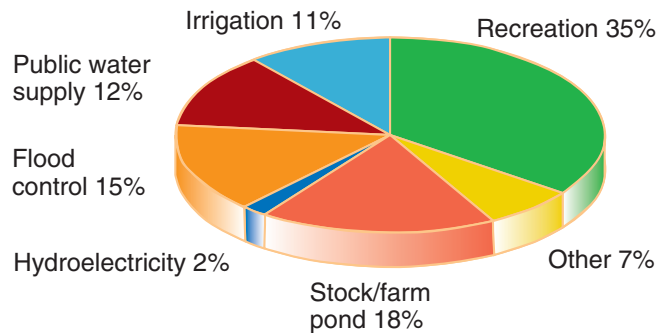
Water energy resource maps for Alaska are typical for the low power resource distribution maps for each state that were produced during resource assessment.



Total power potential of water energy resources in the 50 states. The blue bar segments show the amount of available potential for each state. Green bar segments show the amount of developed potential and red segments show the amount of potential excluded from development.

could be captured using conventional turbine technology in configurations offering the same low impact environmental benefits.

Beyond the recently quantified undeveloped resources, the National Hydropower Association estimates that more than 4,300 MW of additional or “incremental” hydropower capacity could be brought on line by upgrading or augmenting existing facilities. That is enough hydropower capacity to meet the electricity needs of the states of New Hampshire and Vermont. To take advantage of this incremental hydropower, researchers in the U.S. Department of Energy’s Wind and Hydropower Technologies Program are working with industry members to develop advanced, more efficient technologies to upgrade existing plants and improve environmental performance. ♦



Source: U.S. Army Corps of Engineers, National Inventory of Dams
 Primary purposes or benefits of U.S. dams.

Types of Hydropower Plants

Many dams were built for other purposes and hydropower was added later. In the United States, there are about 80,000 dams of which only 2,400 produce power. The other dams are for recreation, stock/farm ponds, flood control, water supply, and irrigation.

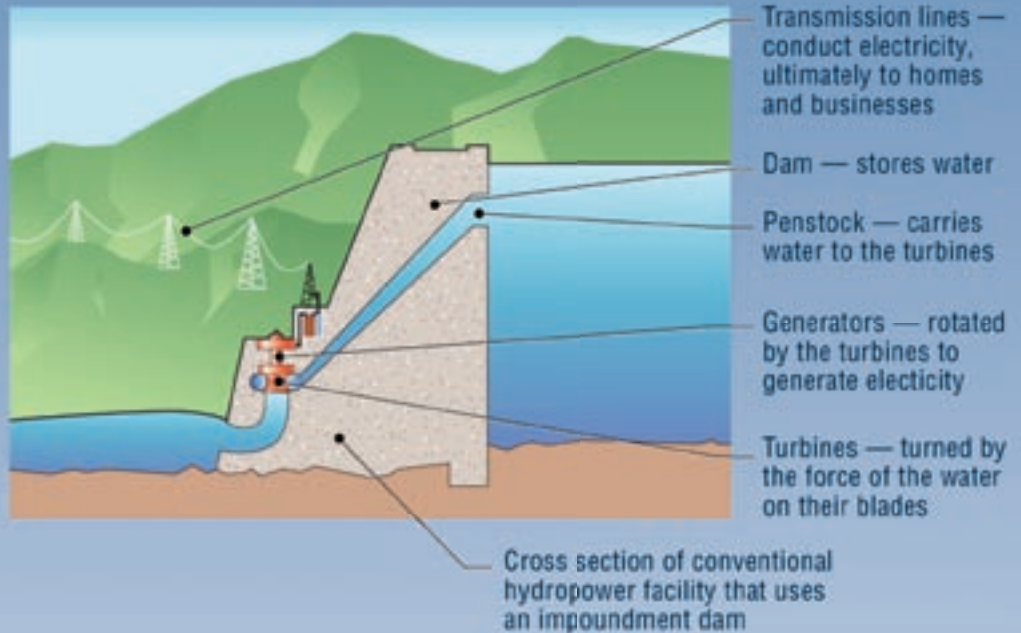
Hydropower plants range in size from small systems for a home or village to large projects producing electricity for utilities.

There are four types of hydropower facilities: impoundment, diversion, run-of-river, and pumped storage. Some hydropower plants use dams and some do not.

Impoundment

The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

An impoundment hydropower plant uses a dam to store water in a reservoir.



The Tazimina project in Alaska is an example of a diversion hydropower plant. No dam was required.



Diversion

A diversion facility channels a portion of a river through a canal or penstock. It may not require the use of a dam.

Run-of-River

A run-of-river project uses water within the natural flow range of the river, requiring little or no impoundment.

Pumped Storage

When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity.

Sizes of Hydroelectric Power Plants

Facilities range in size from large power plants that supply many consumers with electricity to small and micro plants that individuals operate for their own energy needs or to sell power to utilities.

Large Hydropower

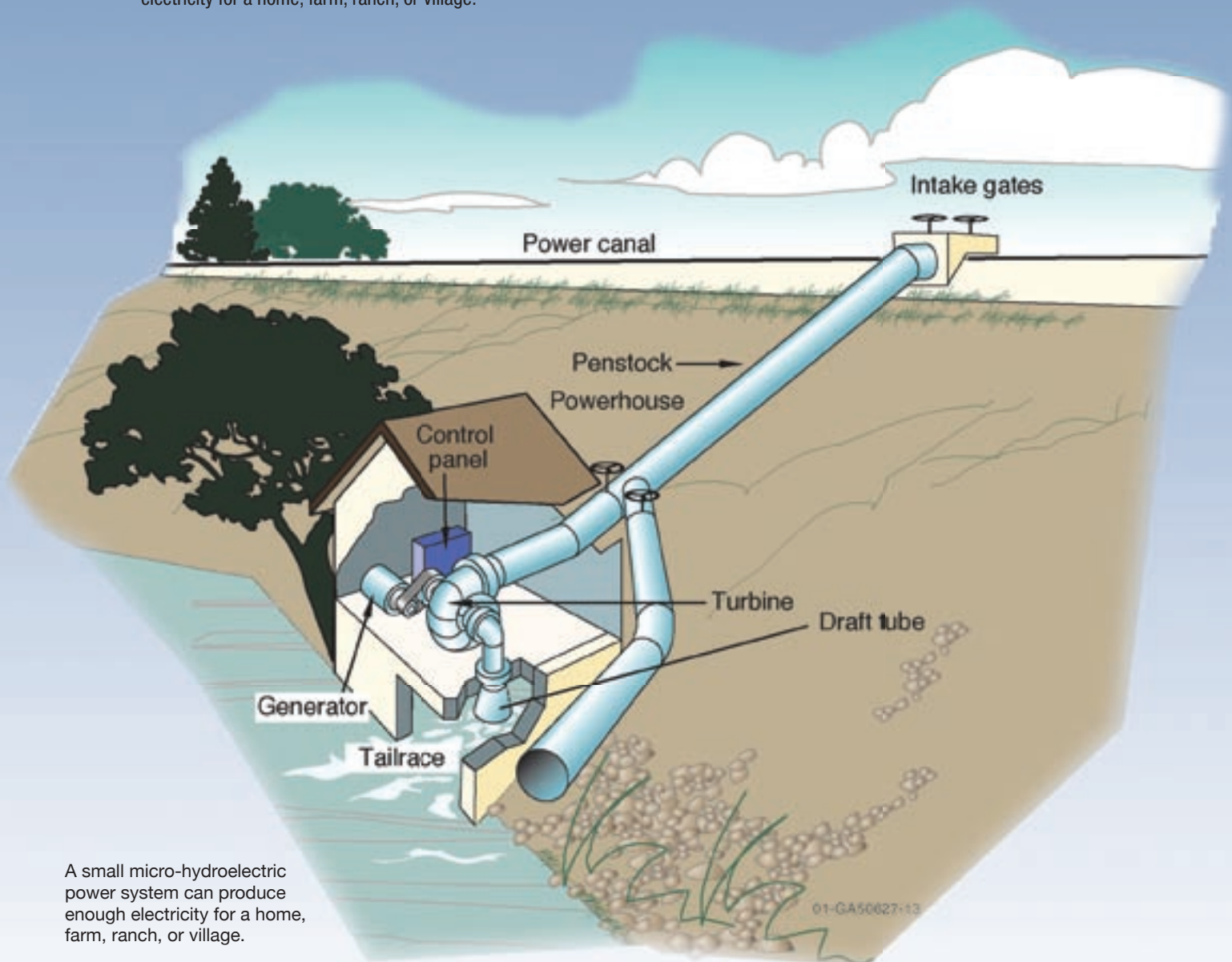
Although definitions vary, DOE defines large hydropower as facilities that have a capacity of more than 30 MW.

Small Hydropower

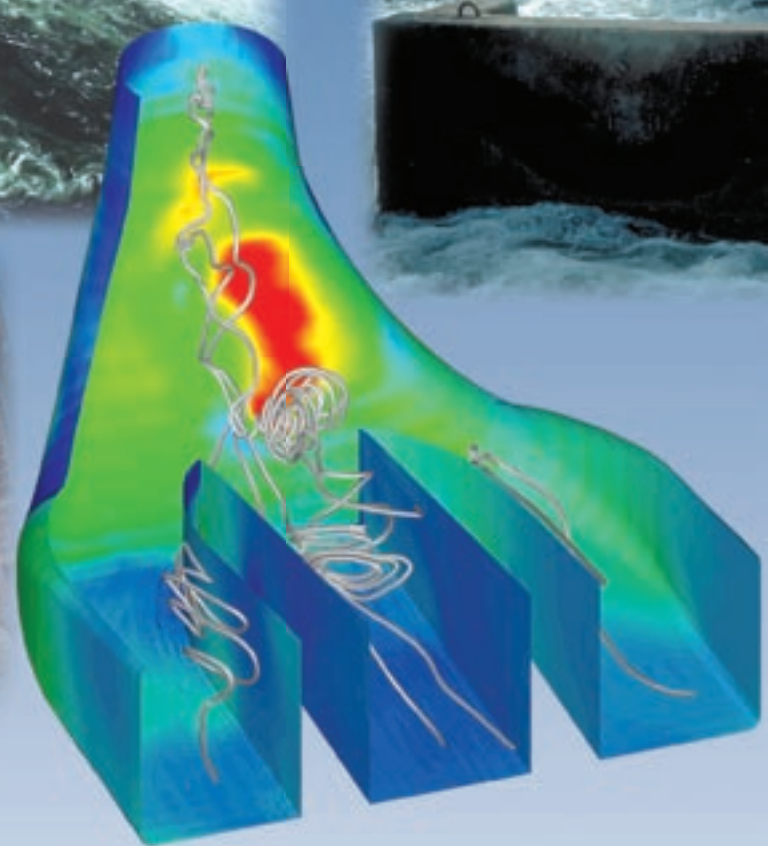
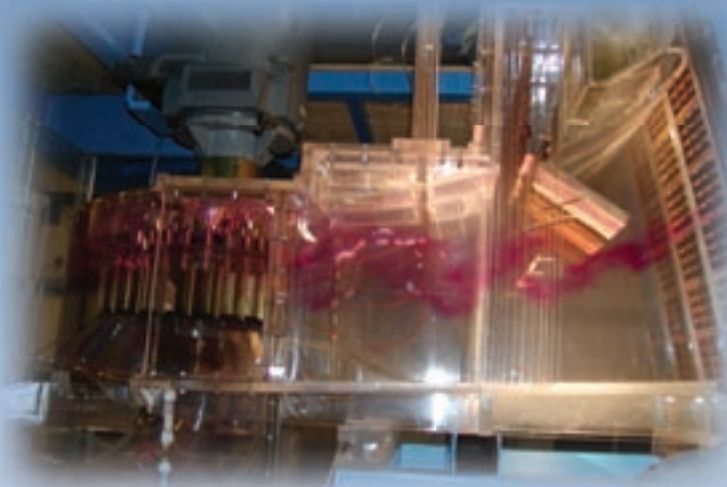
Although definitions vary, DOE defines small hydropower as facilities that have a capacity of 100 kilowatts to 30 MW.

Micro Hydropower

A micro hydropower plant has a capacity of up to 100 kW. A small or micro-hydroelectric power system can produce enough electricity for a home, farm, ranch, or village.



A small micro-hydroelectric power system can produce enough electricity for a home, farm, ranch, or village.



Hydropower researchers work to reduce and eliminate environmental impacts while increasing project efficiencies.

ENHANCING GENERATION AND ENVIRONMENTAL PERFORMANCE

Until about 1980, hydropower research and development (R&D) efforts focused mainly on improving turbine efficiency and reducing noise and vibration that can cause damage to turbine blades. These early R&D efforts led to a 30% increase in turbine efficiencies. In 1993, the U.S. Department of Energy (DOE) initiated an effort to develop advanced hydropower turbine systems (AHTS) to improve the overall performance and acceptability of hydropower projects. Initial funding for the research was provided by DOE, the Electric Power Research Institute (EPRI),



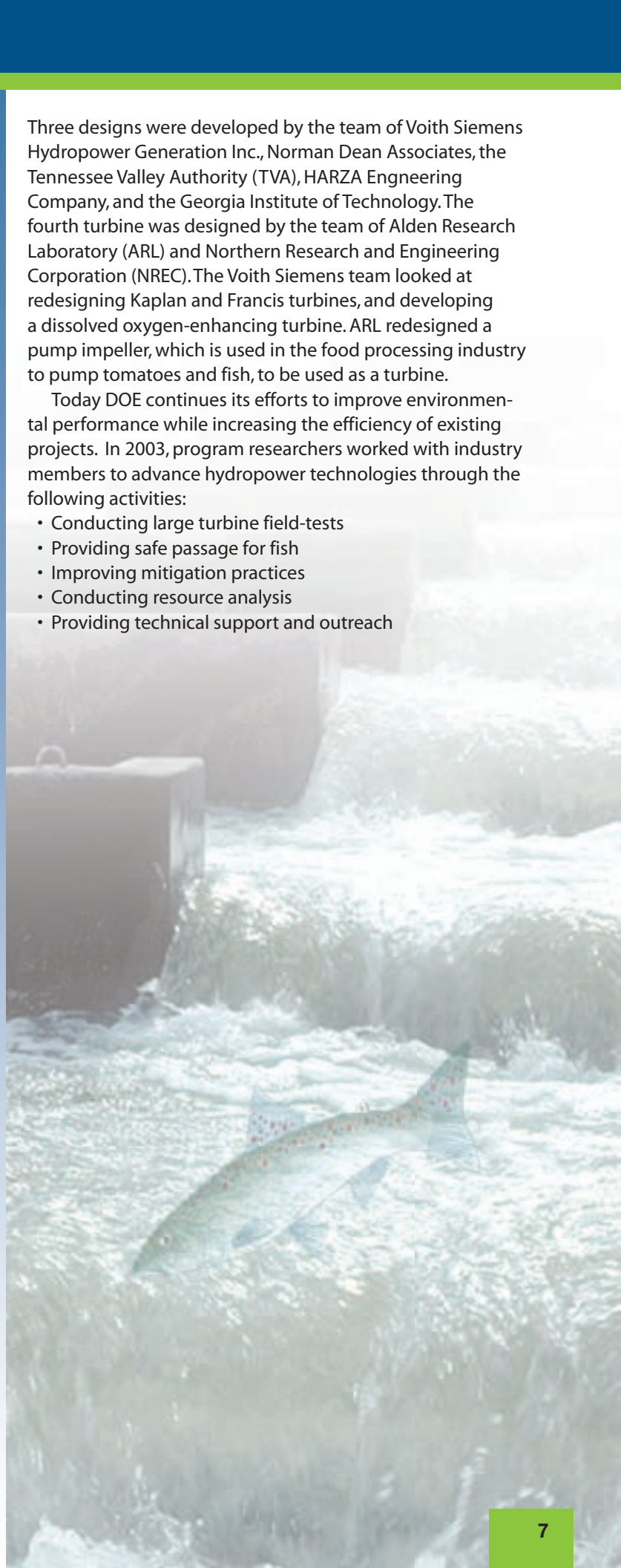
Fish ladders providing safe passage for fish

members of the National Hydropower Association, and the Hydropower Research Foundation. Since then, researchers working under the program have conducted numerous studies on providing safe fish passage upstream and downstream, reducing fish mortality in turbines, increasing dissolved oxygen to improve water quality, improving instream flow/habitat, and assessing the cumulative impact of hydropower development and potential hydropower resources. They also helped produce four new turbine designs.

Three designs were developed by the team of Voith Siemens Hydropower Generation Inc., Norman Dean Associates, the Tennessee Valley Authority (TVA), HARZA Engineering Company, and the Georgia Institute of Technology. The fourth turbine was designed by the team of Alden Research Laboratory (ARL) and Northern Research and Engineering Corporation (NREC). The Voith Siemens team looked at redesigning Kaplan and Francis turbines, and developing a dissolved oxygen-enhancing turbine. ARL redesigned a pump impeller, which is used in the food processing industry to pump tomatoes and fish, to be used as a turbine.

Today DOE continues its efforts to improve environmental performance while increasing the efficiency of existing projects. In 2003, program researchers worked with industry members to advance hydropower technologies through the following activities:

- Conducting large turbine field-tests
- Providing safe passage for fish
- Improving mitigation practices
- Conducting resource analysis
- Providing technical support and outreach



Types of Hydropower Turbines

There are two main types of hydro turbines: impulse and reaction. The type of hydropower turbine selected for a project is based on the height of standing water — referred to as “head” — and the flow, or volume of water, at the site. Other deciding factors include how deep the turbine must be set, efficiency, and cost.

Impulse Turbine

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. There are two types of impulse turbines, the Pelton and the cross-flow.

Pelton — A pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner. Draft tubes are not required for impulse turbine since the runner must be located above the maximum tailwater to permit operation at atmospheric pressure.

Cross-flow — A cross-flow turbine is drum-shaped and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner. It resembles a “squirrel cage” blower. The cross-flow turbine allows the water to flow through the blades twice. The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out. A guide vane at the entrance to the turbine directs the flow to a limited portion of the runner. The cross-flow was developed to accommodate larger water flows and lower heads than the Pelton.

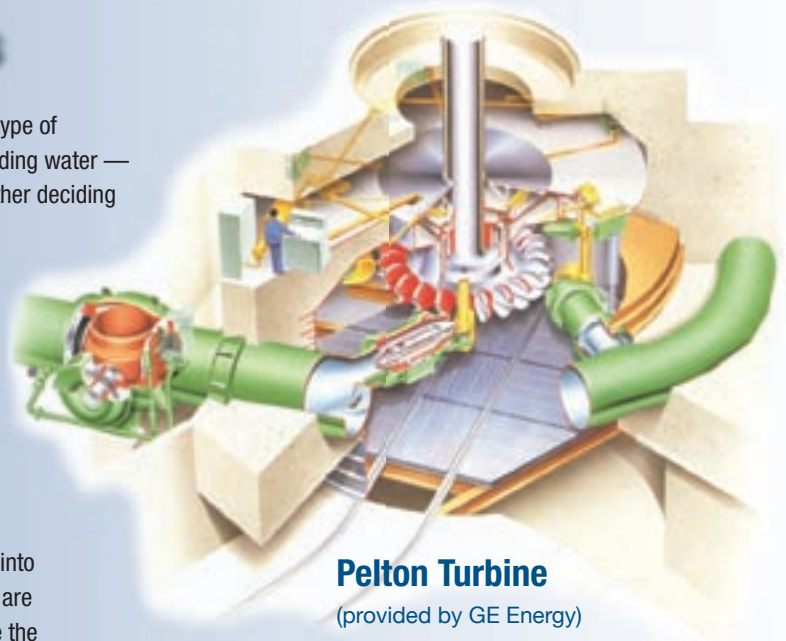
Reaction Turbine

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines.

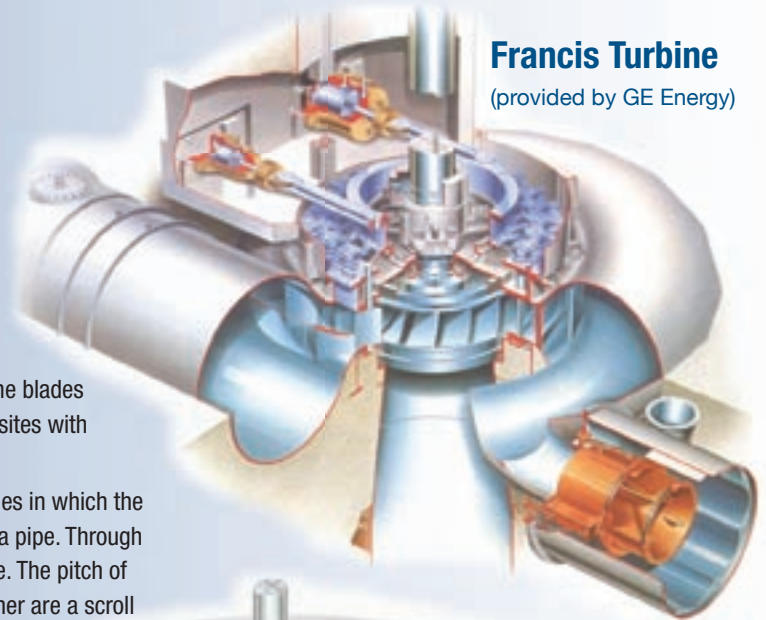
Propeller — A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly. Picture a boat propeller running in a pipe. Through the pipe, the pressure is constant; if it isn't, the runner would be out of balance. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube.

Francis — A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin. Besides the runner, the other major components are the scroll case, wicket gates, and draft tube.

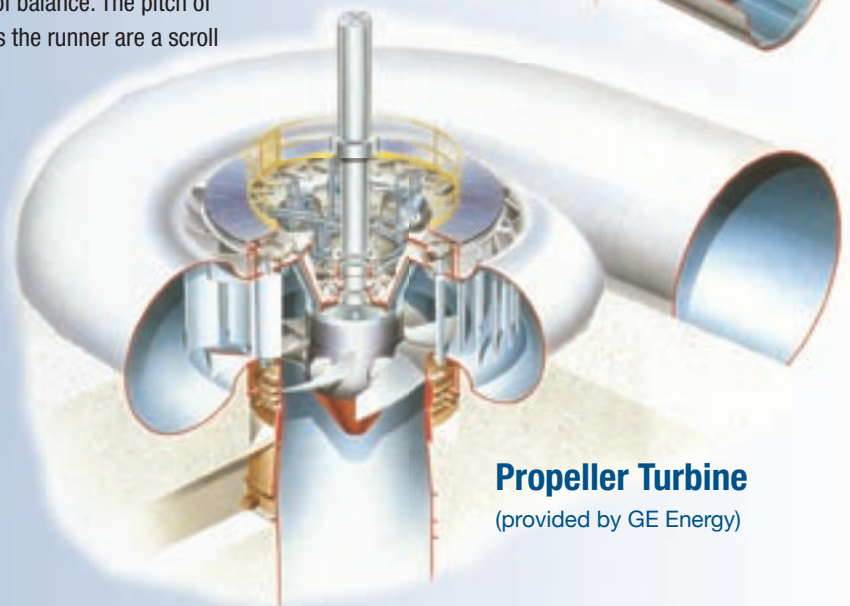
Kinetic — Kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they might have applications in such conduits. Kinetic systems do not require large civil works; however, they can use existing structures such as bridges, tailraces and channels.



Pelton Turbine
(provided by GE Energy)



Francis Turbine
(provided by GE Energy)



Propeller Turbine
(provided by GE Energy)

Large Turbine Field-Testing

To stimulate the development of more environmentally friendly turbine technology, DOE researchers work with industry members to test new generation turbines for efficiency (compared with older machine efficiencies), compatibility with environmental requirements (i.e., dissolved oxygen concentrations and fish passage), and commercial viability. To obtain valid field-test results, researchers first design field test protocols and perform baseline field tests on existing plant equipment and operation. After installing new technology, researchers then repeat the field-tests on the new equipment and analyze the results, comparing test data to the performance objectives and baseline results.

Providing Safe Passage for Fish

Common causes of injury to fish passing through hydroelectric turbines include collisions with different structures and mechanisms inside the dam and squeezing through narrow gaps between fixed and moving parts. In the initial phase of the AHTS research, the Alden Research Laboratory, Inc. (Alden) and its partner, NREC developed a conceptual design for a new hydropower turbine that would minimize both the sources of injury to fish and the penalty on turbine efficiency. The new turbine had fewer blades, less internal pressure, and large flow passages that made it easier for fish to pass through safely.

Because this new turbine was unique, DOE built a prototype model and facility where it could be tested. Construction of the test facility at Alden Research Laboratory (ARL) in Holden, Massachusetts, was completed in FY 2001. Testing operations were completed in January 2003. A final report containing test results was published in September 2003 and is available from the DOE Hydropower Program Web site at <http://www.eere.energy.gov/windandhydro/>.

In the near future, DOE also plans to test two full-sized prototype turbines at hydropower facilities in Washington. The first will be installed on the Wanapum Dam on the Columbia River in Washington, and the second will be installed in the Box Canyon project in northeastern Washington.

Conditions encountered by fish passing through a turbine.

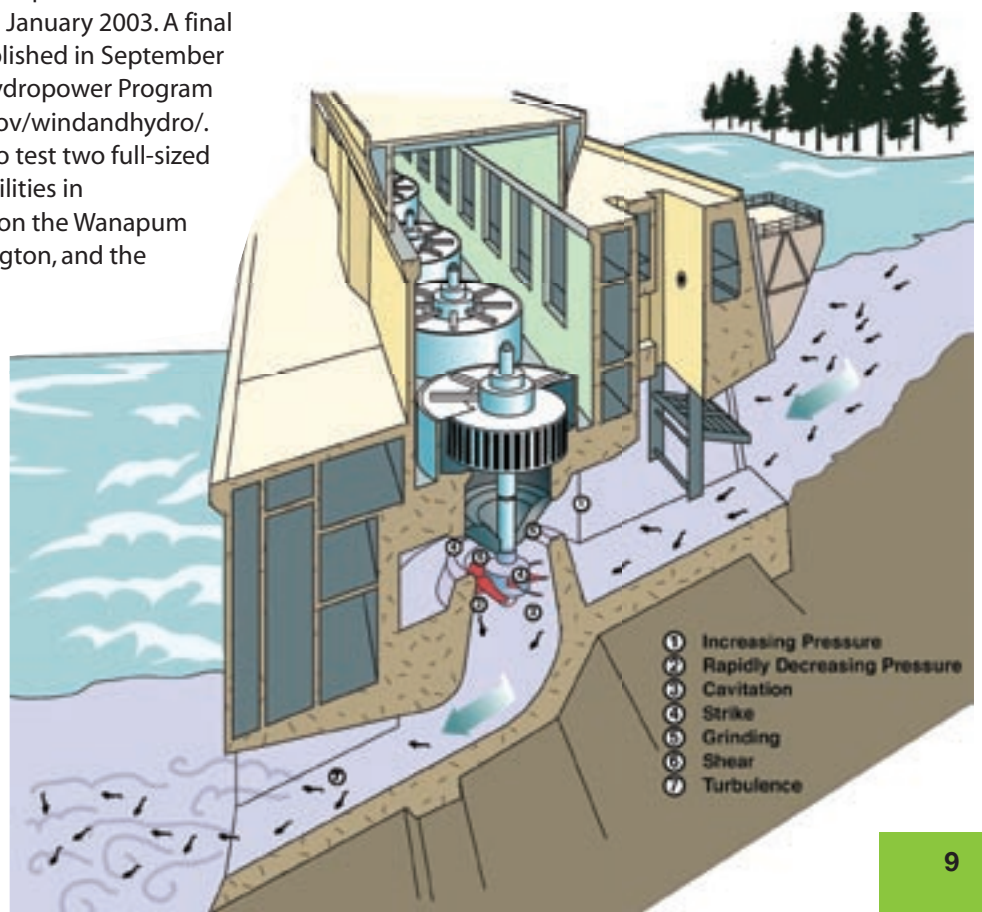
Preventing Fish Collisions

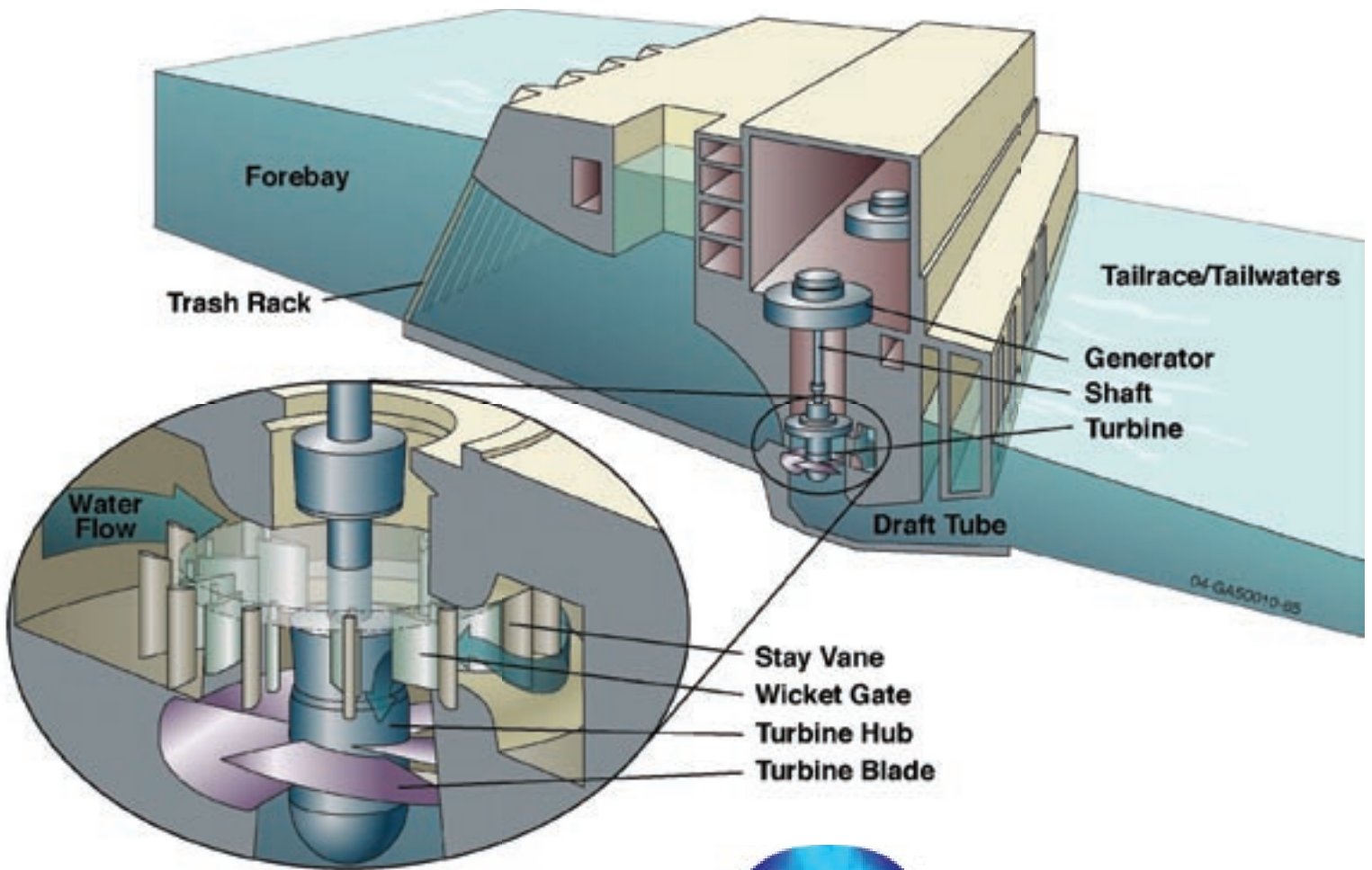
To help prevent collisions between fish and structures like stay vanes and wicket gates (adjustable devices that control the flow of water) as fish pass through the dams, researchers conducted a model study to assess the potential relationship between the locations/configurations of these devices and their effects on fish from 2000 to 2003. A new stay vane and wicket gate design prepared by VATECH HYDRO was incorporated into the Lower Granite project model at the U.S. Army Corps of Engineers (COE) Engineering Research and Design Center in Vicksburg, Mississippi. Two new stay vane and wicket gate arrangements were fabricated for the model, and researchers released and tracked neutrally buoyant beads that duplicated the flow patterns of fish and tracked them using high-speed photography as they passed through the model.

The results of the study showed that when the wicket gates and stay vanes are not hydraulically aligned, they produce turbulent areas that subject fish to high shear forces and increase their potential for striking the trailing edge of wicket gates that protrude over the turbine intake lip.

Reducing Impacts to Fish

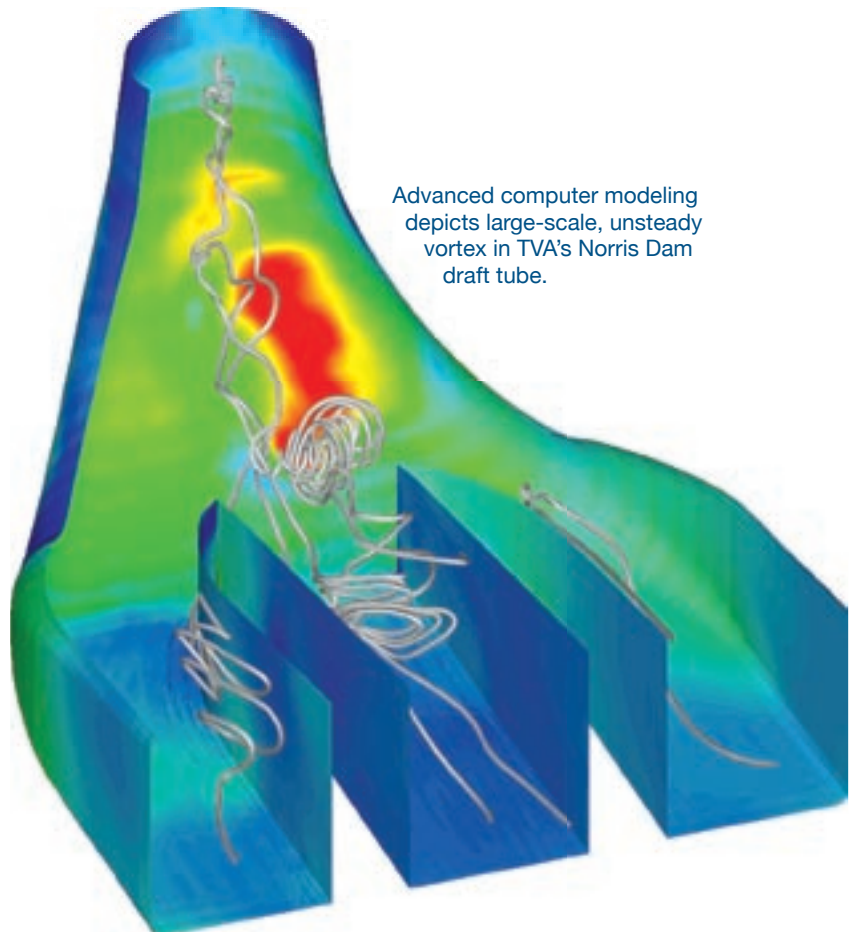
A major focus of the advanced hydropower technology effort is on the quantification of fish injury and mortality associated with potential fish injury mechanisms. Researchers conduct laboratory experiments to gain a better understanding of how fish respond to the stresses that they experience passing through a dam. The information they gain can then be used to define the design criteria of future turbines and possible structure modifications.





Hydropower unit components

A unique combination of computer modeling, field measurements, and laboratory bioassays are being used to develop a better understanding of how fish respond to the extreme turbulence inside hydropower turbines and draft tubes. Oak Ridge National Laboratory (ORNL) and TVA are working together to develop and test new sensor arrays that can be inserted inside draft tubes to measure water velocities and stresses directly. ORNL and Georgia Tech are developing advanced computer models that can predict velocities at very high temporal and spatial resolution, and those models are being validated against field measurements. ORNL and Pacific Northwest National Laboratory (PNNL) are working together to design and conduct controlled laboratory bioassay tests of fish to define no-effect levels of physical parameters that can be used as biological criteria for new turbine designs. This unique combination of approaches is providing high-quality understanding that will improve hydropower's environmental performance.



Advanced computer modeling depicts large-scale, unsteady vortex in TVA's Norris Dam draft tube.

In 2003, researchers at ORNL and PNNL began work on developing the experimental protocols that will help define fish responses to two potential injury mechanisms – turbulence and blade strike. To aid in this research, DOE hosted a Workshop on Turbulence at Hydroelectric Power Plants in Atlanta in June. Its purpose was to bring together investigators performing turbulence research to develop experimental protocols for turbulence experiments. The workshop participants discussed all aspects of turbulence at hydro-power plants, from measurements to modeling to biological responses.

To measure turbulence, researchers track neutrally buoyant beads in a 1:25-scale physical turbine model. These measurements are used to characterize the large-scale turbulence that occurs in turbine draft tubes.

Researchers are also studying how fish are affected by the force of water flowing through the dam. The hydraulic environment inside turbines is another area for which researchers need more information, especially with respect to the time-variable conditions that affect fish. To gain this information, researchers are using computer simulation models, visualization tools, high-speed videos, and 3-D motion analysis to study the effects of the dam's complicated environment on fish as they pass through the turbine and spillways.

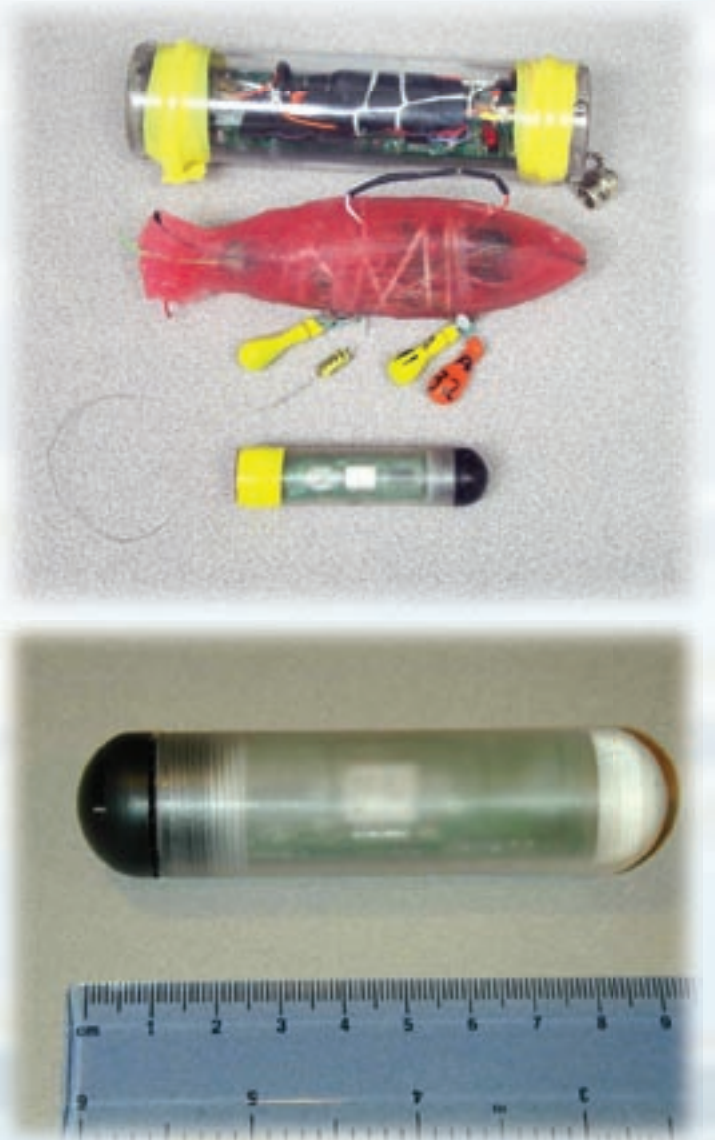
Characterizing Severe Hydraulic Environments

Another tool developed by researchers to measure the physical stresses in a turbine passage is the “sensor fish”. The sensor fish is able to measure the physical stresses in a turbine passage and can be used instead of live fish to gather information. Since initial field trials at McNary Dam in 1999, the sensor fish device has undergone several design changes and has been deployed thousands of times through turbines, sluiceways, and in spillways at Rock Island, Wanapum, McNary, The Dalles, and Bonneville Dams. The device contains a pressure transducer, and three linear accelerometers in a tri-axial configuration, and has approximately the same mass as a yearling salmon smolt (approximately 30 gm).

Improving Mitigation Practices

Degradation of water quality that results from a lack of dissolved oxygen (DO) in the water is one of the most serious environmental impacts facing the hydropower industry. The lack of DO is usually the result of water that stagnates in the reservoir behind the dam. To solve this problem, researchers are conducting a diverse array of environmental studies that include structural, operational, and regulatory measures.

One structural measure tested by researchers at Ameren UE, MEC Water Resources, and Fluent in 2003 was a new retrofit aeration system (RAS) installed at the Osage project on the Bagnell Dam on the Lake of the Ozarks in Missouri. The RAS is a new technical approach to enhance



Sensor fish help researchers measure the physical stresses experienced by fish in a turbine passage.

DO and improve water quality at hydropower facilities. A final report showing the results of the 2003 field tests is expected in 2004.

DOE researchers believe that regulatory measures like bioassessments can also help improve and maintain water quality standards. Bioassessments provide a way to monitor water quality conditions to ensure that discharge limits and water quality permits are having the desired effect. They can also be used to determine whether healthy aquatic communities can be supported downstream despite occasional non-compliances with numerical water quality standards. In addition, bioassessments can help identify the source of non-compliance to better facilitate mitigation measures.

Reduced flow and extreme daily fluctuations in flow have long been recognized as consequences of hydropower production that can have downstream impacts such as the

interruption of spawning cycles of fish communities below hydropower dams. To reduce these downstream impacts, researchers are evaluating the costs and benefits of modified stream flows at several projects. One of the objectives of this research is to evaluate the relationships among flows, water temperatures, and spawning cycles to see if by manipulating the flows, they can increase the fish survival rates and improve the overall health of aquatic environments below the dams.

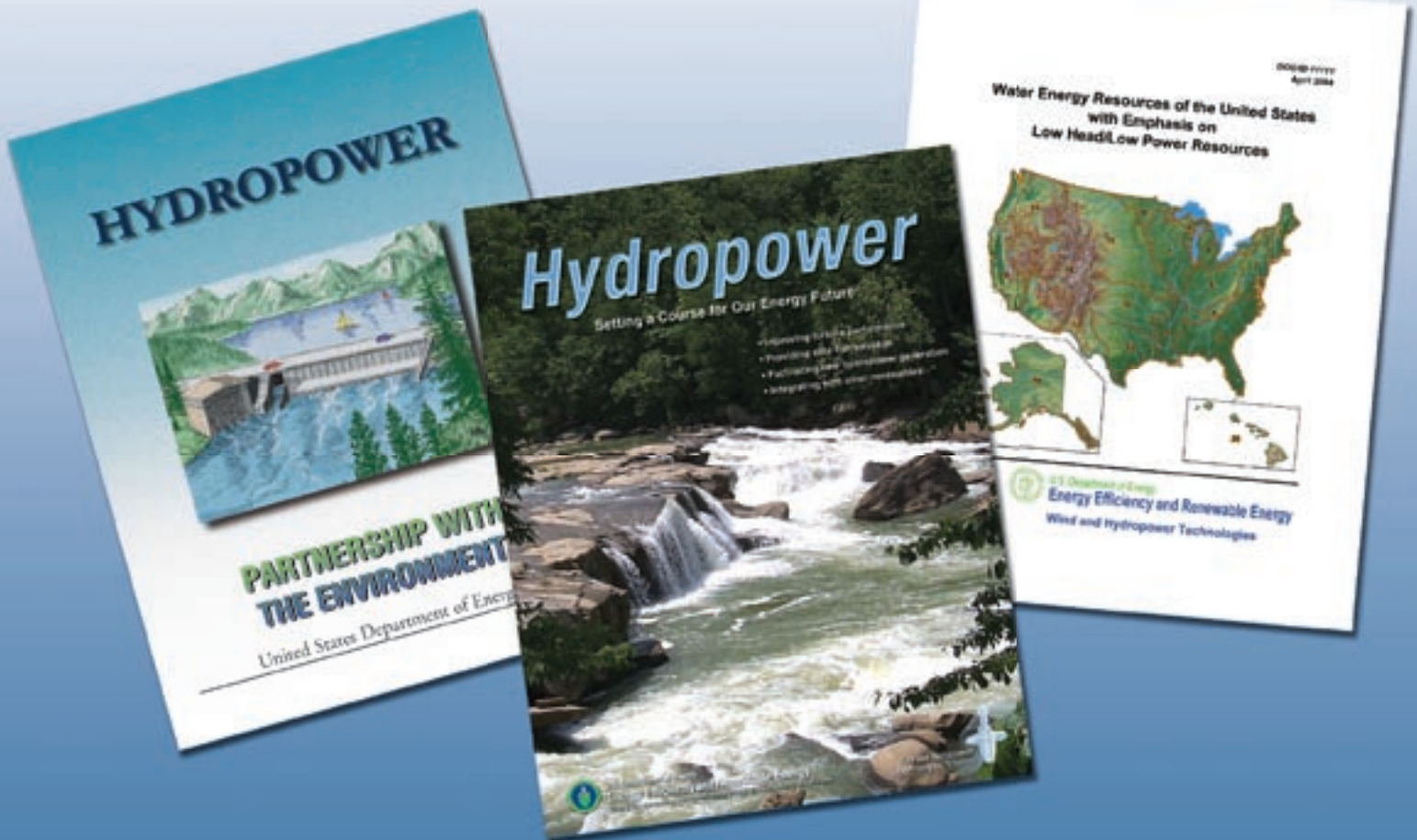
From the Laboratories to the Hydropower Communities

Although DOE researchers work with industry members, conducting a myriad of studies on every aspect of hydropower production from enhancing performance to environmental mitigation, their research would be useless if it didn't reach the hydropower communities. That is why the transfer of new information to the hydropower community has always been an important component of the DOE Hydropower Program. To transfer new information, research-

ers participate in technical conferences and workshops and produce a steady flow of publications, including the Hydropower Program Annual Report and the Hydropower Multi-Year Technical Plan. They also conduct ad hoc meetings to coordinate interagency research activities, and they provide technical assistance to community members.

In 2003, staff from DOE, Idaho National Engineering and Environment Laboratory (INEEL), ORNL and PNNL participated in and served on the organizing committees for several annual meetings, including National Hydropower Association's Annual Conference, held in Washington, D.C., and the biennial Waterpower Conference. In response to invitations, they also provided speakers for briefings at several industry meetings. Other conferences and workshops attended include: the U.S. Climate Change Research Program Workshop; the American Public Power Institute Conference; the Aquatic Invasive Species Summit; the POWER-GEN Renewable Energy Conference; and the Northwest Salmon Recovery Workshop.

To transfer new information to the hydropower community, researchers publish reports on their latest findings.





U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable



EERE Home

Wind & Hydropower Technologies Program

About the Program | Program Areas | Information | Resources | Financial Opportunities | Technologies | Deployment



Search

[Search Help](#) | [More Search Options](#)

[EERE Information Center](#)

NEWS

California Utilities Seek Renewable Energy to Meet New Standard
July 21, 2004

Large Wind Power Plants Proposed for Wisconsin and Nevada
July 21, 2004

Massachusetts Offshore Wind Plant Clears Regulatory Hurdle
July 14, 2004

[More News](#)

EVENTS

2004 DOE Wind Energy Awards
PCF 356 KB
[Download Acrobat Reader.](#)

HydroVision 2004
August 16-20, 2004

[More Events](#)

FEATURES

How a
Wind Turbine
Works



Wind Energy

Wind energy is the world's fastest-growing energy technology. Today, the U.S. has more than 6,300 megawatts of wind generating capacity.



The Wind and Hydropower Technologies Program works with industry to develop the advanced technology needed to convert more of the nation's wind into electricity.

Selected Wind Energy Topics

- [Wind Resources in the Upper Midwest](#)
- [Wind Energy Basics](#)
- [Low Wind Speed Turbine Technology](#)
- [Distributed Wind Energy Technology](#)
- [Wind Powering America](#)
- [Systems Integration](#)
- [Offshore Wind Turbines](#)
- Wind Energy Program Multi Year Technical Plan for 2004 - 2010 (PDF 2.5 MB)
[Download Acrobat Reader.](#)

Hydropower

With 80,000 megawatts of generating capacity, hydropower is the nation's largest renewable electricity source. Working with industry, the Wind and Hydropower



Technologies Program pursues R&D to develop more environmentally friendly technologies to maintain the nation's existing hydropower capacity.

Selected Hydropower Topics

- [Hydropower Basics](#)
- [Advanced Turbine Development](#)
- [Hydropower Integration with other Renewables](#)
- [Low-Head, Low-Power Resource Assessment](#)

Hydropower staff also helped to coordinate technical and interagency meetings with the U.S. Army Corps of Engineers; the United States Society on Dams; the Low Impact Hydropower Institute; the University of British Columbia Research Institute; the National Oceanic and Atmospheric Administration Fisheries Watershed Ecology and Salmon Recovery Program; and the Independent Scientific Advisory Board for the Northwest Power Planning Council.

The Wind and Hydropower Technologies web site at <http://www.eere.energy.gov/windandhydro/> provides another channel through which program researchers provide up-to-date information to community members on the latest technology advancements and current meetings, conferences, and workshops. Many of the latest research reports are posted on the site. It also contains background information about the technology and the program. ♦

The Wind and Hydropower web site at <http://www.eere.energy.gov/windandhydro/> provides current information to the hydropower community.

HYDROPOWER TOMORROW

To achieve the DOE goals of 10% growth in generation at existing plants and harnessing undeveloped hydropower capacity without constructing new dams, DOE researchers are working with industry members to develop new technologies to increase the generation of existing hydroelectric plants. They are also conducting research to develop low power hydropower resources, optimize project operations, and combine hydropower with other renewable technologies such as wind power to provide a stable supply of electricity to our nation's grid.

Developing the Next Generation of Hydropower

To harness undeveloped hydropower resources without using a dam as part of the system, researchers are developing technologies that extract energy from free flowing water sources such as natural streams, tidal waters, ocean currents, canals, municipal water systems, and effluent streams. These free flowing systems generally produce less than a megawatt of power and therefore have been classed as low power hydropower. They may be deployed individually near a small load center such as a small population or an industrial center or they can be deployed as several units at one location or distributed over a section of the water source.

The first step in DOE's low power hydropower development effort is to assess the water energy resources that can be harnessed using low power technologies. A study of these resources that focused on natural streams was published in April 2004. The study provides estimates and locations of these water energy resources and presents this information for each of the 20 U.S. hydrologic regions and each of the 50 states. It estimates that the country's natural stream water energy resources represent an available energy source of approximately 170,000 MW of annual average power after accounting for current hydroelectric generation and areas excluded from hydropower development by federal statutes and policies. Low power resources (less than 1MW) constitute about 50,000 MW of the estimated available power potential; however, partial use of the remaining 120,000 MW of high power resources could also be captured by low power technologies.

In the near term, DOE's low power hydropower assessment will analyze the feasibility of developing identified water energy resources, expanding the resource assessment to include other U.S. water energy assets, and the state



Alaska's Abundant Hydropower Resources

Alaska's vast water energy resources and remote population centers are prime areas for deployment of low power hydropower plants. The state contains 87,000 MW (annual mean power) of resources of which less than 1% has been developed. Approximately half of the resources are located in areas excluded from development by federal statutes and policies, leaving about 45,000 MW of water energy resources available for consideration as new hydropower resources. Low power (less than 1 MW) resources representing 8,000 MW are widely distributed as shown in the power distribution maps on page 3. Adding the nearly 37,000 MW of high power resources, which can be used to supply low power hydropower plants through partial flow diversions, makes water energy a very available source of power that has been under used in the state.

The Tazimina River Hydroelectric Plant (pictured above) located 175 miles southwest of Anchorage, Alaska, illustrates the environmental benefits of low power hydropower plants. The 824-kW plant, which has two turbines, is located next to a scenic falls on the Tazimina River. The plant does not include a dam, but instead diverts 110 cubic feet of river water per second into a subterranean penstock leading to the powerhouse that is also below ground. Since coming into full operation in 1998, the plant has produced an average of 2,630,000 kWh per year. The full generating capability of the plant is slightly more than 6,000,000 kWh per year, but until the interconnected transmission grid is completed in the area, the plant will serve the present isolated market and will not generate at its full potential. In addition, the plant's civil structures were constructed to accommodate a future expansion of an additional 824 kW. It is estimated that the Lliamna-Newhalen-Nondalton Electric Cooperative, which operates the plant, has saved 225,000 gallons of diesel fuel annually that would have been needed to fuel diesel generators. When full operation of the 824 kW plant is realized, diesel fuel savings of 515,000 gallons per year are expected. Low environmental impact coupled with virtually no fuel costs and high performance make this plant an example of the benefits of damless, low power, hydropower generation.

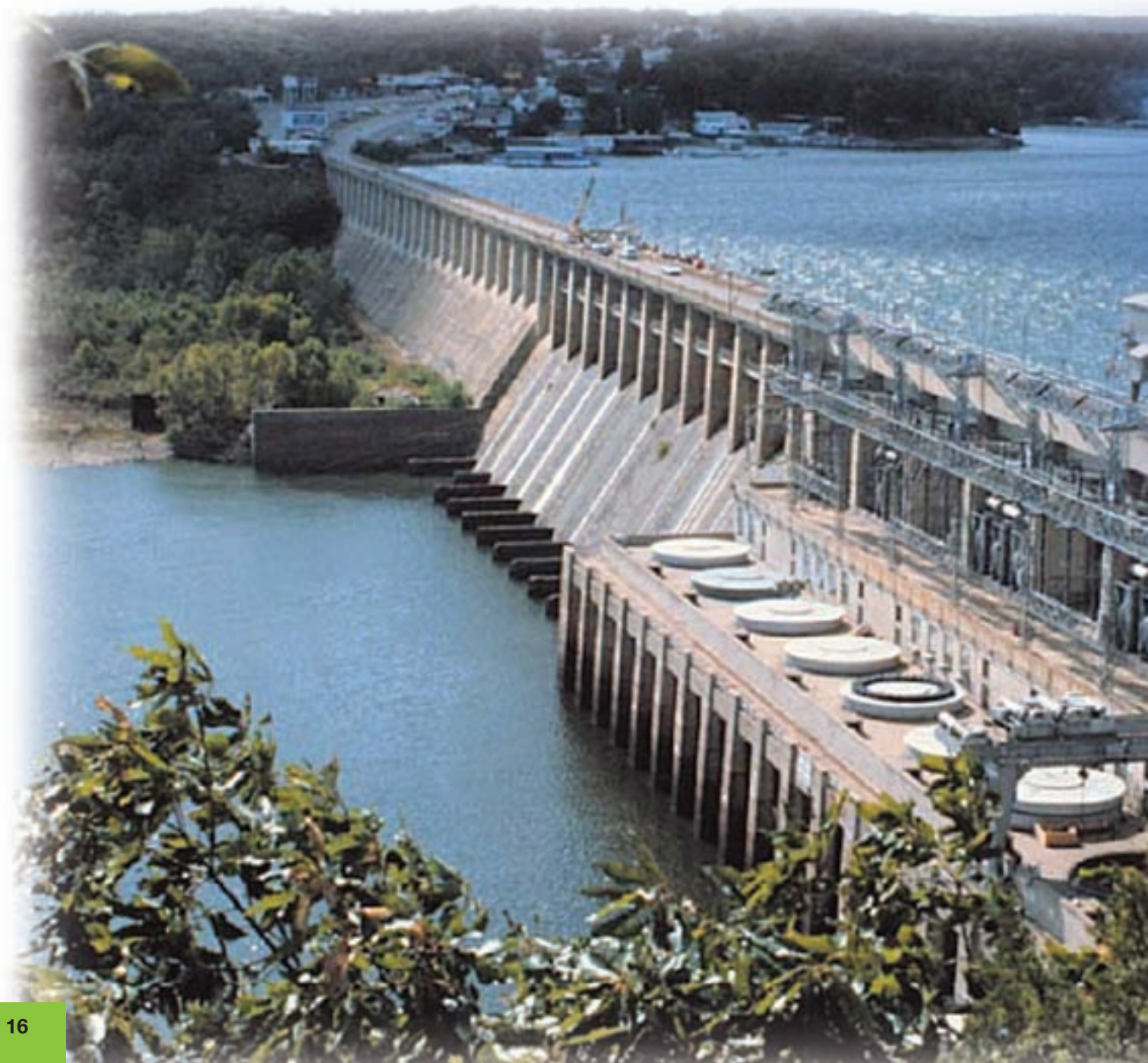
of low hydropower technology. By 2008, DOE plans to facilitate the deployment of several low power demonstration projects to provide experiential information and data. This information will help show private and public power producers how low power hydropower can become a major renewable component in their energy source portfolios.

Integrating Wind and Hydropower Technologies

Fluctuating regional water resources, growing obligations, and market pressures on water uses (need for flood controls, environmental issues, and recreation) are just a few constraints that may limit the growth of hydroelectric production. The Wind and Hydropower Technologies Program has started a research project to examine whether

wind and hydropower technologies can work together to provide a stable supply of electricity to an interconnected grid. Hydropower facilities may be able to act as a “battery” for wind power by storing water during high-wind periods and increasing output during low- or no-wind periods. Similarly, periods of low water resources or policy pressures on water use can be mitigated by using wind to generate power normally generated by the hydropower systems.

DOE initiated the exploration of the possible synergy between wind and hydropower resources in November 2003 when it sponsored an International Energy Agency (IEA) Topical Expert Meeting on the Integration of Wind and Hydropower Systems. Hosted by the Bonneville Power Administration (BPA) in Portland, Oregon, the meeting drew 28 energy experts from the United States, Canada, Norway, and Sweden. The participants delivered 15 presentations



that ranged from high-level national perspectives on wind/hydropower integration to details of specific wind/hydropower projects. The main topic was whether wind and hydropower technologies can work together to provide a stable supply of electricity to an interconnected grid.

Although no formal decision was made concerning the formation of an IEA wind/hydropower integration annex, participants displayed a high level of interest and the possibility was left open to future discussions. In the meantime, DOE plans to conduct an analysis of specific potential and actual generation projects and full watershed basin/electric control areas. The cooperation of federal power management agencies such as BPA and the Western Area Power Administration (WAPA) will be integral to the work.

Optimizing Project Operations

Electricity production can be increased at some hydropower plants by optimizing different aspects of plant operations. These include setting of individual units, multiple unit operations, and release patterns from multiple reservoirs. The objective of such optimization is to increase generation per unit water released downstream of a project.

The first step in water use/operations optimization will be to convene a strategic planning workshop to review the state-of-the-science in hydropower optimization and to refine the research needs in this area. This workshop will be held in 2004, and the results will be published as a research strategy document by the end of the year. ♦

Wind and hydropower technologies can work together to provide a stable supply of electricity to an interconnected grid.





Pacific Northwest National Laboratory

Oak Ridge National Laboratory



Idaho National
Engineering and
Environmental
Laboratory

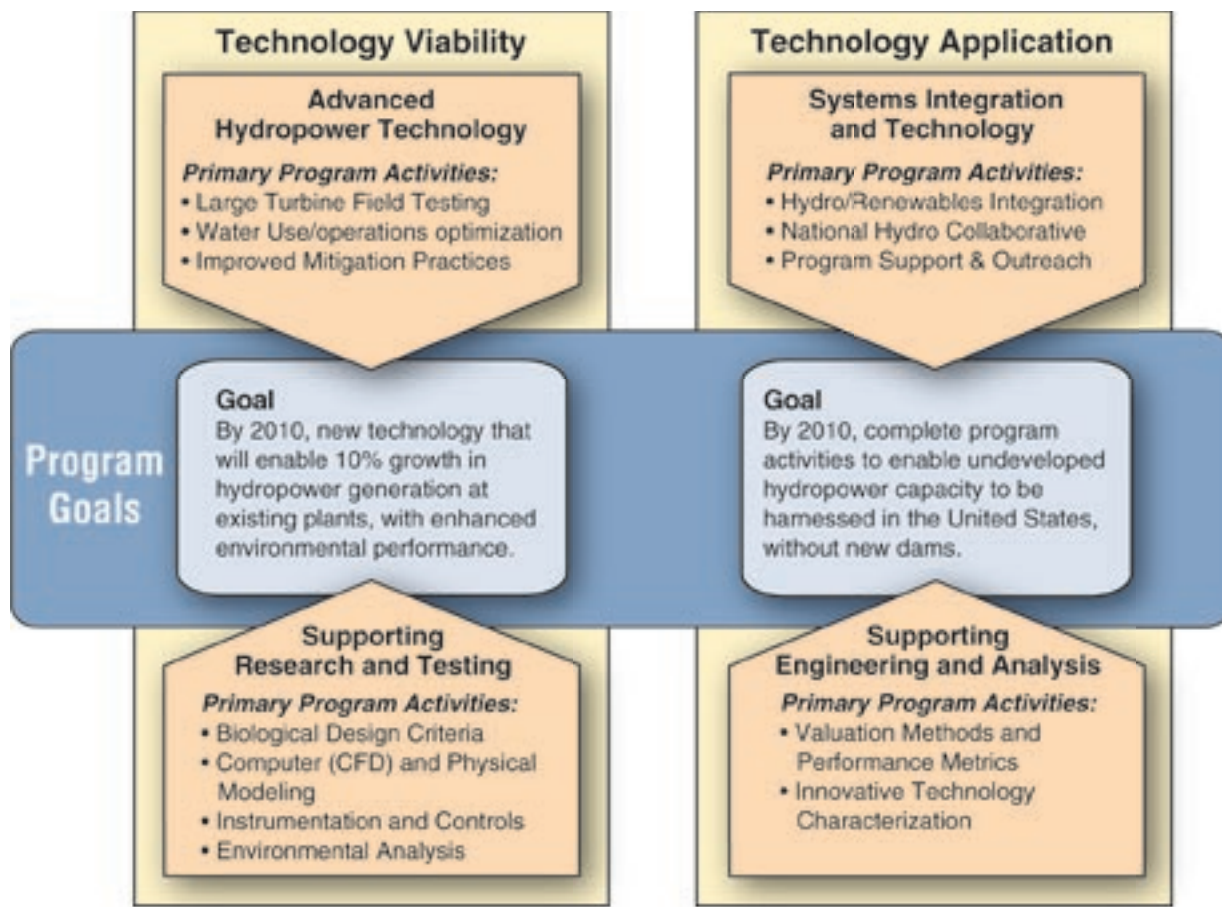


National Renewable
Energy Laboratory



THE FEDERAL WIND AND HYDROPOWER TECHNOLOGIES PROGRAM

The U.S. Department of Energy (DOE) initiated the Hydropower Program in 1976 to support research and development that would provide technical and environmental guidance to improve the operation and development of hydropower facilities in the United States. The Office of Wind and Hydropower Technologies is responsible for planning, organizing, and managing the DOE Hydropower Program. The Hydropower Program is supported by DOE National Laboratories. The Idaho National Engineering and Environmental Laboratory (INEEL) provides engineering support, Oak Ridge National Laboratory (ORNL) provides biological and environmental support, the Pacific Northwest National Laboratory (PNNL) provides technology development and biological/environmental support, and the National Renewable Energy Laboratory (NREL) conducts research on the integration of hydropower and other



renewable energy sources. Over the years, the Program has supported research in small hydropower feasibility; environmental issues and mitigation practices; the development of advanced, environmentally friendly hydropower turbines; and hydropower resource assessments.

The Hydropower Program maintains close working relationships with private industry, national hydropower organizations, regulatory agencies, and other federal agencies (U. S. Army Corps of Engineers, Bonneville Power Administration, Tennessee Valley Authority, U. S. Bureau of Reclamation, U. S. Geological Survey, and National Marine Fisheries Service). These relationships allow DOE to 1) better understand the needs of the hydropower industry; 2) complement research being conducted by others; and 3) leverage research and development funds through cooperative or cost shared agreements.

Mission and Goals

The Program's mission is to conduct research and development (R&D) that will increase the technical, societal, and environmental benefits of hydropower and provide cost-competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity to the nation's energy supply.

The Hydropower Program has two parallel goals with a completion target date of 2010. The program goals are to:

- Develop and demonstrate new technologies that will enable 10% growth in hydropower generation at existing plants with enhanced environmental performance; and
- Conduct analyses and studies that will enable undeveloped hydropower capacity to be harnessed without constructing new dams.

A concerted effort is made to coordinate the DOE R&D with that of other federal agencies and industry, including both private and public entities involved with hydropower development. An open peer-review process involving industry and environmental resource agencies ensures that stakeholders are involved and that high-priority research needs are being addressed. A technical committee is maintained to review progress, evaluate results, and ensure coordination with related R&D activities of other agencies and industry. This technical committee consists of experts from the hydropower industry and state and Federal agencies. In addition, the reviews of specialists who are not members of the technical committee are obtained, when appropriate. Active coordination provides "situational awareness," avoids duplication of research efforts, and creates a synergy among related research effects.

The Hydropower Program is subdivided into two key activity areas, Technology Viability and Technology Application.

The overall purpose of the **Technology Viability** part of the program is to develop new, cost-effective technologies that will enhance environmental performance and achieve greater energy efficiencies. More specifically, this program component consists of the following:

- Testing new turbine technology, analyzing test results, and reporting the test results and conclusions;
- Identifying new technology efficiencies, effectiveness of water use, and opportunities for optimal plant operations;
- Providing basic data and developing computer models that help define conditions of the water column inside an operational turbine; and
- Correlating plant operations with environmental and ecological conditions in the vicinity of hydro projects.

The goal of this work is to provide sufficient data for industry to recognize the value of identified new technologies and select these new technologies for installation at existing projects to increase hydroelectricity generation in the United States.

Technology Application is the second major Hydropower Program activity. Its purpose is to conduct

research and analyses that identify barriers to development and strategies to reduce those barriers. Specifically, this program component consists of the following:

- Quantifying technical issues, economic costs, environmental constraints, and benefits of integrating hydropower and wind operations;
- Pursuing the establishment of a hydropower collaborative with representatives from stakeholders and interest groups to discuss industry issues and direction;
- Providing outreach and information transfer concerning program activities and R&D results to other agencies, industry, non-governmental organizations, and the public;
- Quantifying the varied benefits of hydropower to help the public and policymakers properly position hydropower in future competitive energy development considerations; and
- Facilitating the development of damless hydropower technology to make use of untapped U.S. water energy resources.

The goal of this work is to provide sufficient data by 2010 to enable industry to begin developing the untapped low head / low power potential in the U. S. without constructing new dams. ♦



Workers lower a new hydropower turbine to be installed as part of the Osage Project at the Bagnell Dam on Missouri's Lake of the Ozarks.

Key Contacts

U.S. Department of Energy

Peter Goldman
Office of Wind and Hydropower Technologies
Energy Efficiency and Renewable Energy
EE-2B, 1000 Independence Ave., SW
Washington, D.C. 20585

Jim Alhgrimm
Office of Wind and Hydropower Technologies
Energy Efficiency and Renewable Energy
EE-2B, 1000 Independence Ave., SW
Washington, D.C. 20585
202-586-9806

Idaho National Engineering and Environmental Laboratory

Garold Sommers
EROB
Idaho Falls, ID 83415-3830
208-526-1965

Oak Ridge National Laboratory

Michael Sale
P.O. Box 2008 MS 6036
Oak Ridge TN 37831-6036
865-574-7305

Pacific Northwest National Laboratory

Dennis Dauble
P.O. Box 999/K6-84
Richland, WA 99352

National Renewable Energy Laboratory

Brian Parsons
MS 3811
1617 Cole Blvd, Golden, CO, 80401
303-384-6958.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: www.ntis.gov/ordering.htm

PHOTO CREDITS: Cover Photo — U.S. Army Corps of Engineers/PIX13466. Page ii: INEEL/PIX12811; U.S. Army Corps of Engineers/PIX13467; Eugene Water and Electric Board/PIX11569. Page 1: U.S. Army Corps of Engineers/PIX13468. Page 4: PIX13472. Page 7: U.S. Army Corps of Engineers/PIX13470; U.S. Army Corps of Engineers/PIX13471. Page 11: INEEL/PIX13474; INEEL/PIX13473. Page 13: Bureau of Reclamation/PIX13475. Page 14: INEEL/PIX13476. Page 15: INEEL/PIX13469. Page 16: Garold Sommers/PIX12486. Page 17: GE Wind/PIX12335. Page 18: PNNL/PIX01617; INEEL/PIX13477. Page 19: ORNL/PIX13478; ORNL/PIX13479; NREL/PIX01156

Produced for the



U.S. Department of Energy
**Energy Efficiency
and Renewable Energy**

Bringing you a prosperous future where energy
is clean, abundant, reliable, and affordable

1000 Independence Avenue, SW, Washington, DC 20585

By the National Renewable Energy Laboratory,
a DOE National laboratory

DOE/GO-102004-1981

July 2004

Printed with renewable-source ink on paper containing at least
50% wastepaper, including 20% postconsumer waste