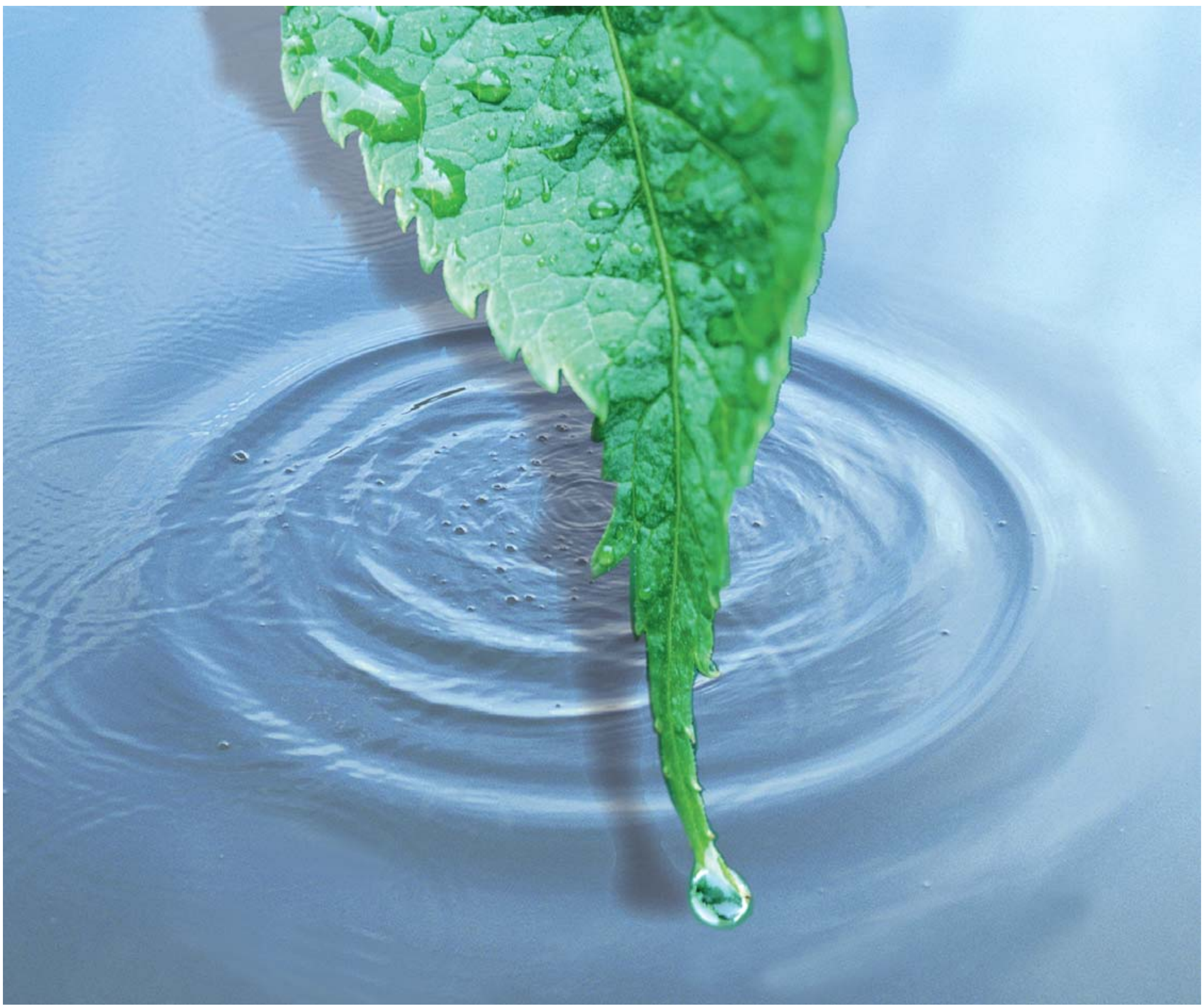
ELECTRIC POWER
RESEARCH INSTITUTE

Assessment of Waterpower Potential and Development Needs



Assessment of Waterpower Potential and Development Needs

1014762

Final Report, March 2007

EPRI Project Manager
D. Dixon

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Bahleda Management and Consulting, LLC

Mary Ann Hosko, Hydropower Consultant

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This report was prepared by

Bahleda Management and Consulting, LLC
515 Colecroft Court
Alexandria, VA 22314

Principal Investigator
M. Bahleda

Mary Ann Hosko, Hydropower Consultant
250 N 24th Street
Camp Hill, PA 17011

Principal Investigator
M. A. Hosko

This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Assessment of Waterpower Potential and Development Needs. EPRI, Palo Alto, CA: 2007. 1014762.

REPORT SUMMARY

Hydropower offers expanding opportunities to increase generation based on renewable, domestic, carbon-free technologies. This report presents a review of the possible contribution of waterpower technologies in the near-term (by 2010) and long-term (by 2025) to the U.S. renewable energy supply. Segments of the waterpower industry include conventional hydroelectric plants and emerging technologies that access the energy in river and tidal currents (hydrokinetic) as well as in ocean waves. The report documents how each segment of waterpower technology can contribute to increased production, discusses research questions that need to be answered to achieve the desired results, and reviews targeted economic incentives that can spur waterpower production.

Background

The Energy Policy Act of 2005 created a stimulus to invest in conventional hydropower capacity gains in the short run and to stimulate demonstration and testing of "next generation" waterpower technologies. However, the case must be made for a continuum of research, development, demonstration, and deployment (RDD&D) along with economic stimuli that provide a stable platform to realize substantive water energy gains over the next 10-15 year period. The act specifically directed the U.S. Department of Energy (DOE) to assess research needs and develop a detailed roadmap for achieving the potential of the nation's waterpower resource. This report provides information to support the DOE's roadmap effort.

Objective

To assess waterpower potential and development needs in support of the DOE's Renewable Energy Research Programs.

Approach

Investigators identified and reviewed pertinent literature, evaluated existing data sources for potential or proposed waterpower energy programs, and consulted with industry personnel having relevant knowledge. During this process, a number of hydroelectric project owners provided details about capacity and efficiency projections and new incremental hydropower at existing facilities. In addition, developers and researchers involved in the next generation waterpower industry were consulted on potential, demonstration site status, necessary RDD&D, obstacles to commercialization, and estimates for real deployment of capacity at commercial quantities. The terminology RDD&D, rather than the traditional R&D (research and development), is used herein to emphasize that in order to realize the potential of the next generation waterpower technologies, widespread demonstration of the concepts will be essential. Information gathered was the used to develop an Advanced Water Energy Initiative (AWEI) that captures real energy production potential through a combined effort of committed RDD&D and economic stimulus. Waterpower industry case studies that demonstrate success as a result of this commitment are also included and reviewed.

Results

The potential increase in generation capacity was conservatively estimated at 23,000 MW by 2025, including 10,000 MW from conventional hydropower, 3000 MW from new hydrokinetic technologies, and 10,000 MW from ocean wave energy devices. Achievement of this potential could be accomplished through the following endeavors:

> Establishing a public-private sector AWEI program, which would provide RDD&D guidance and funding support of $212 million (short-term)) and $377 million through 2015. The AWEI would be designed to achieve near-term conventional hydropower gains, while fostering the development and commercialization of waterpower technologies that produce energy from hydrokinetics and ocean wave resources.
>
> Extending the Production Tax Credit (PTC) and Clean Renewable Energy Bond (CREB) programs to 2015. These economic incentives would foster 1) investment in modernizing the infrastructure at existing hydropower facilities, and 2) installation of new facilities at existing dams.

In addition to these endeavors, although not evaluated in detail in this assessment, regulatory process enhancements that expedite project licensing could also contribute to realizing the potential of domestic hydropower energy resources. The recent technological accomplishments of the waterpower industry, as reviewed in this report, demonstrate likely achievement of this potential.

EPRI Perspective

This report provides information to support public and private sector energy development planning efforts. Specifically, the potential contribution of the waterpower industry to provide renewable, domestic energy supplies in the near- and long-term is documented and the necessary RDD&D to realize waterpower potential is reviewed.

Keywords

Hydrokinetic Technologies
Hydroelectricity
Hydropower
Ocean Energy
Renewable Energy
Waterpower
Energy Policy Act of 2005

EXECUTIVE SUMMARY

Waterpower includes generation from conventional hydroelectric facilities as well as generation from the emerging technologies that access the energy potential of river, tidal, ocean and constructed waterway currents, and the energy of ocean waves and thermal gradients. Existing conventional hydropower generation represents 75 percent of the U.S. renewable energy generation (over 270,000 GWH) and the opportunity exists to expand this resource. The potential for waterpower expansion—at existing hydroelectric facilities, at dams without powerhouses, at new small- and low-power developments, and from the emerging next generation of waterpower technologies—is substantial, as presented and discussed herein. The potential increase in generation capacity is conservatively estimated as 23,000 MW by 2025. This includes:

2,700 MW of new small and low power conventional hydropower (< 30 MW installed capacity);

2,300 MW capacity gains at existing conventional hydropower;

5,000 MW of new conventional hydropower at existing non-powered dams;

10,000 MW from ocean wave energy technologies; and

3,000 MW from hydrokinetic technologies.

These estimates could be significantly increased if economic incentives and regulatory processing for the waterpower technology industry are enhanced. The overall resource potential, based on resource assessments conducted by the U.S. Department of Energy (DOE), EPRI and industry is estimated to range from 85,000 to 95,000 MW.

In the near term or next 5-year period, it is conservatively estimated (Table E-1) that gains in capacity could exceed 700 MW while the next generation of waterpower technologies are developed. Furthermore, existing conventional hydropower can also be enhanced by improvements in generation efficiency, which has been estimated to range from 2 to 5 percent or more. This would increase current annual conventional hydropower generation approximately 5,300 to 14,000 GWH, depending on annual hydrology (current conventional hydropower generation ranges from an average annual low of ~261,000 GWH and an average annual high of ~293,000). By 2025, the total annual waterpower generation will see an increase of ~79,000 to 89,000 GWH, when generation from the emerging waterpower technologies is included. This annual additional generation is equivalent to the current power needs of almost 8 million households based on 2001 DOE residential power consumption estimates[1] or nearly the current annual generation from all other renewable technologies (~89,000 GWH in 2004).

[1] DOE, Energy Information Agency 2001 Resident Energy Consumption Survey. See: ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/enduse_consump2001.pdf

Table E-1
Estimated Waterpower Technology Capacity Gains, 2006-2010 (MW)

Waterpower Technology Class	2006	2007	2008	2009	2010	Cumulative
Capacity gains at existing hydropower facilities	76[2]	90	75[3]	75	59	375
New hydro at existing dams	–	–	–	–	25	25
Small and low power hydro	–	–	–	50	75	125
Hydrokinetic	–	0.2	–	4.8	110	115
Ocean Wave Energy	–	–	3	1	80	84
Yearly Capacity Gain (MW)	76	90.2	78	131	395	724

Realization of the potential requires a concerted effort of research, development, demonstration, and deployment (RDD&D) by the public and private sectors. In the near-term (to 2010), the focus is on maximizing performance of existing facilities along with new capacity additions. This can be achieved through economic stimuli, such as Production Tax Credits (PTCs) and Clean Renewable Energy Bonds (CREBs), and the initiation of RDD&D. Near-term RDD&D includes programs that focus on improved environmental performance and commercialization of new hydrokinetic and ocean energy technologies. In the longer-term, or by 2025, the RDD&D, economic stimuli, and regulatory enhancement will achieve substantial conventional hydropower gains. During this period, the deployment of the next generation of waterpower technologies will also contribute by accessing the hydrokinetic and ocean energy potential.

The initiatives discussed herein support the Energy-Water Nexus Roadmap and are consistent with the directives of the Energy Policy Act of 2005. In fact, the Energy Policy Act of 2005 (Title IX, Section 931) directs the Secretary of Energy to:

> *(D) Hydropower. –…conduct a program of research, development, demonstration and commercial application for cost competitive technologies that enable the development of new and incremental hydropower capacity, adding to the diversity of the energy supply of the United States, including: (i) Fish-friendly large turbines. (ii) Advanced technologies to enhance environmental performance and yield greater energy efficiencies. (E) Miscellaneous Projects. – The Secretary shall conduct research, development, demonstration, and commercial application programs for – (i) ocean energy, including wave energy (…) and (iv) kinetic hydro turbines.*

Commercialization of new technologies and capital-intensive energy projects requires time and RDD&D. For example, over a nearly 30-year period (1978-2006), U.S. wind energy RDD&D has resulted in 9,100 MW of installed wind capacity (Figure E-1). Similar long-term success is projected from an investment in waterpower RDD&D (Figure E-2).

---

[2] Based on certified and pending filings with FERC for Production Tax Credits (PTCs) as of October 2006.

[3] Assumes that PTCs and Clean Renewable Energy Bonds (CREBs) are extended to 2015.

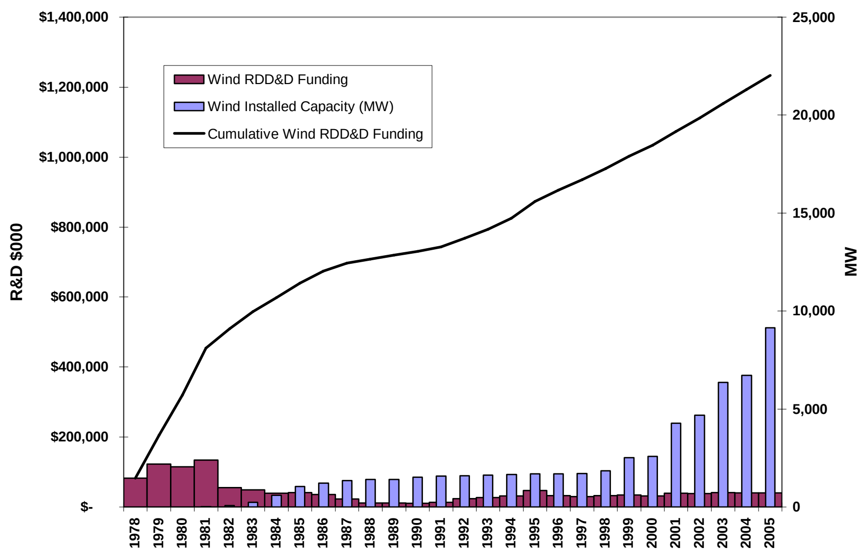


Figure E-1
Wind Energy RDD&D Funding and Realized Capacity: 1978-2006 (DOE/EIA 2006; DOE 2006b; http://www1.eere.energy.gov/windandhydro/wind_budget.html)

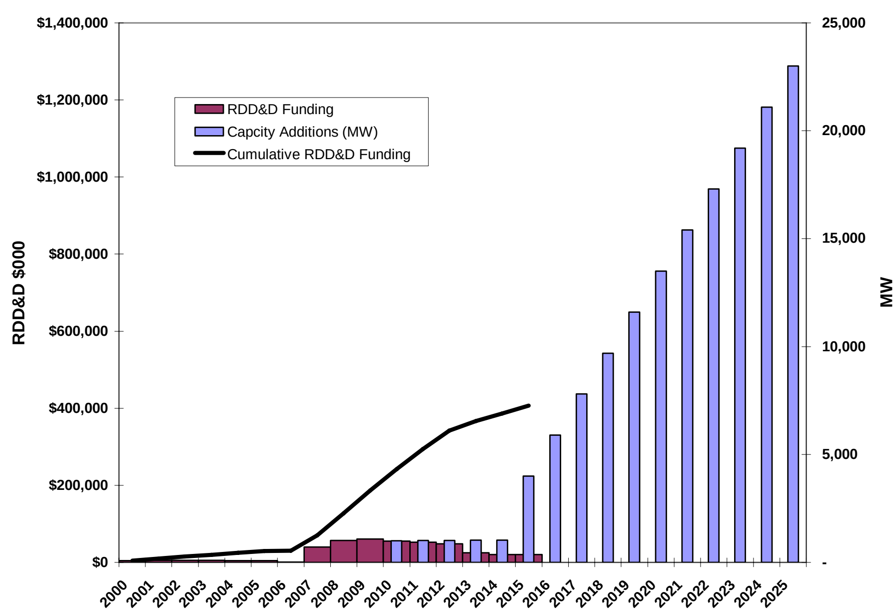


Figure E-2
Estimated Advanced Waterpower Energy Initiative (AWEI) RDD&D Annual (2007 to 2015) Funding and Capacity Gains by 2025

Analyses conducted herein have found that realization of waterpower's potential could be accomplished with the following endeavors:

Establishing a public-private sector program called the Advanced Water Energy Initiative (AWEI), which would provide RDD&D guidance and funding support of $212 million (short-term); $377 million through 2015. The AWEI would be designed to achieve near-term conventional hydropower gains while fostering the development and commercialization of waterpower technologies that produce energy from hydrokinetics and ocean wave resources.

Extending the Production Tax Credit (PTC) and Clean Renewable Energy Bond (CREB) programs to 2015. These economic incentives would foster (1) investment in modernizing the infrastructure at existing hydropower facilities, and (2) installing new facilities at existing dams.

In addition to these endeavors, although not evaluated in detail in this assessment, regulatory process enhancements that expedite project licensing could also contribute to realizing the potential of this domestic energy resource.

The AWEI would provide the requisite structure and guidance for the needed RDD&D discussed herein. This initiative addresses the needs using the successful technology development models employed by other renewable energy sectors, such as wind and biomass. The AWEI would have three major components (Table E-2):

1. Waterpower Realization Committee—to provide the initial guidance and future oversight to benchmark results of the RDD&D in terms of real waterpower capacity and generation gains.
2. Waterpower Performance Initiatives—RDD&D efforts that would improve the efficiency and environmental performance of conventional hydropower technologies.
3. Waterpower Technology Development—RDD&D that would advance hydrokinetic and ocean energy technology development in four program areas.

Table E-2
Advanced Water Energy Initiative Funding ($M)

	Waterpower RDD&D Program Area	2007	2008	2009	2010	Total
1	Waterpower Realization Committee	1	1	1	1	4
2a	Advanced Water Energy Science	13	13	13	13	52
2b	Hydropower Environmental Performance	7	8	8	8	31
2c	Hydropower Operational Performance	6	11	11	11	39
3a	Hydrokinetic Resource Assessment	3	1	0	0	4
3b	Hydrokinetic Environmental Profiling	2	4	4	4	14
3c	Hydrokinetic Technology Improvement	8	19	23	8	58
3d	Advanced Ocean Energy Technology Development	0	0	0	10	10
	Total RDD&D Funding	40	57	60	55	212

Needed near-term (2007 to 2010) estimated RDD&D funding totals $212 million. The long-term estimate through 2015 is $377 million. Implementation of this program requires reestablishing U.S. Department of Energy (DOE) funding for waterpower research, which was eliminated beginning FY 2007. Federal funding support would also contribute to reversing a long-term decline in DOE's budget authority for energy R&D, a decline that the U.S. Government Accountability Office (GAO) has recently noted to have declined in real terms by over 85 percent since 1978[4].

The importance of the PTCs is based on their history of supporting capacity development in the wind industry, as demonstrated in Figure E-3. Conventional hydropower could be expected to follow the same economic incentive trend (Figure E-4). The next-generation waterpower—the hydrokinetic and ocean wave energy technologies that are not yet commercial—will require similar support to achieve their potential.

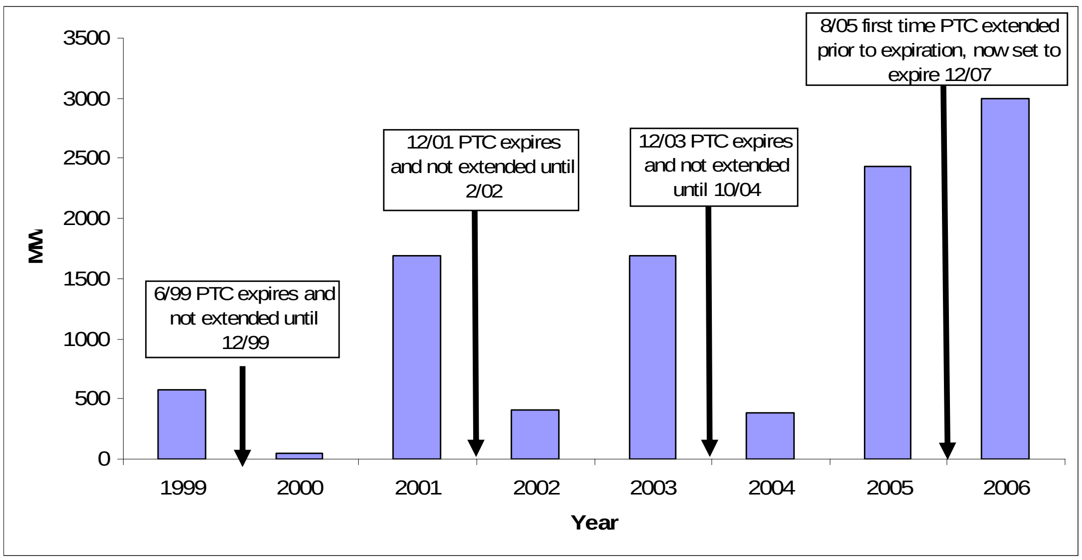


Figure E-3
Effects of PTCs on Wind Power Capacity Additions: 1999-2006
(Source: American Wind Energy Association 2005)

[4] U.S. Government Accountability Office. Report to Congressional Requestors. Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs. December 2006. GAO-07-106.

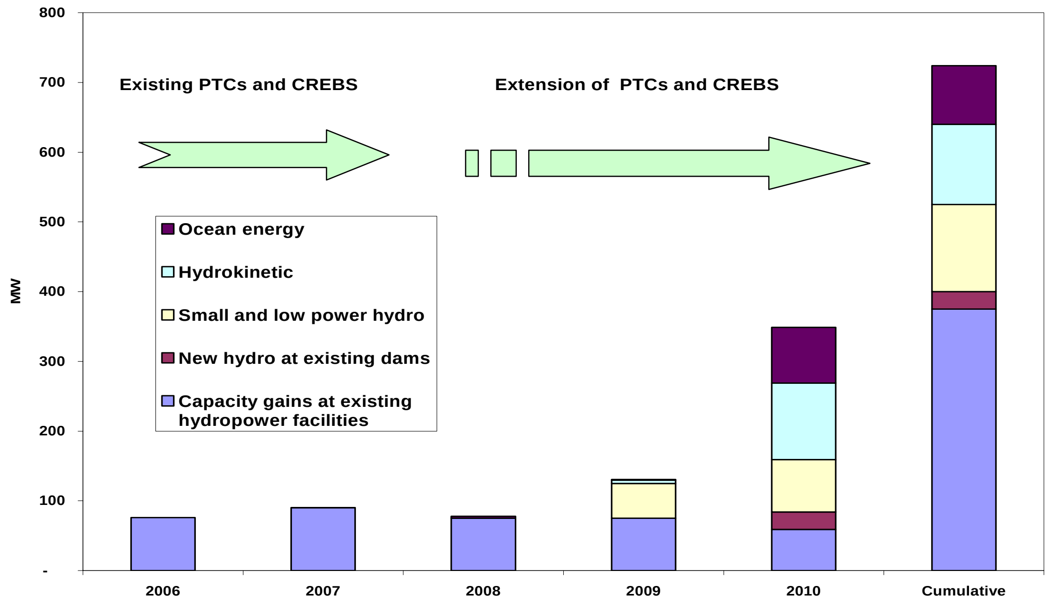


Figure E-4
Potential Short-term Realization of Waterpower Gains from PTCs and CREBS (Source: National Hydropower Association)

By moving down an RDD&D path that embraces all waterpower technologies in a comprehensive manner, the potential presented and discussed herein can be realized. This study estimates that a 10-year $377 million AWEI commitment (averaging $37 million/yr) can yield 23,000 MW of waterpower capacity by 2025. By comparison, the proposed 10-year AWEI funding level is 31 percent of the 28-year funding of the wind industry ($377 million vs. $1,200 million) and could yield more than twice as much installed capacity (23,000 MW vs. 9,100 MW) in a shorter (20- vs. 28-year) timeframe.

ACKNOWLEDGMENTS

EPRI greatly appreciates the special support provided by the following organizations and individuals in developing the scope of the report, identifying and providing information resources, and commenting on earlier drafts of the report:

National Hydropower Association (NHA): Dave Youlen, President; Linda Church Ciocci, Executive Director, Mike Murphy, Chair – New Hydropower Technologies Council

Hydropower Research Foundation (HRF); Steve Brown and Paul Williams, R&D Committee

EPRI also acknowledges the support of the following individuals and organizations whose assistance, advice, and input was extremely helpful in performing this investigation:

Ned Taft and George Hecker, Alden Research Laboratory, Inc., Holden, MA.

Joe Viau and Jeff Auser, Brookfield Power, Liverpool, NY.

Mike Murphy, Devine Tarbell and Associates, Portland, ME.

Roger Bedard and Tom Key, EPRI, Palo Alto, CA.

Steve Brown, Grant County Public Utility District, Ephrata, WA.

Carl Vansant, HCI Publications, Kansas City, MO.

Pat March, Hydro Performance Processes, Inc. Maryville, TN.

Ron Corso, Mead and Hunt, Inc., Arlington, VA.

Paul Williams, Kleinschmidt Associates, Portland, ME.

Michael Sale, Oak Ridge National Laboratory, Oak Ridge, TN.

Sean O'Neil, The Ocean Renewable Energy Coalition, Washington, DC.

Kamau Sadiki, U.S. Army Corps of Engineers, Washington, DC.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

Background

The nation continues to struggle to develop a comprehensive policy that balances the issues of energy security and concern for global climate impacts. There is a strong recognition for a growing need for energy as one of the main drivers of the economy. It is becoming increasingly critical that this energy come from sources that can be relied upon and not overly subject to outside political interests. There is equal recognition that increased energy production by conventional methods will likely add to green house gas emission, which are likely to have effects on the environment and the economy.

Advances in the area of wind generation over the past 30 years has shown us that non-conventional technologies with the proper encouragement can be a significant part of the response to both the need for increased generation and lower environmental impacts. Nameplate wind capacity has gone from virtually zero in the 70s to ~ 10,000 MW in 2006. A series of Federal programs of research and economic incentives has helped the wind industry achieve this significant result. These results demonstrate that the proper combination of research, economic incentive and supportive regulatory structure provide the necessary foundation to support the growth of new energy generation.

In 2005, Congress enacted an Energy Policy Act in part intended to provide encouragement for alternative energy production to respond to both the environmental concern and need for increased energy supply. By providing the legislative basis for improved regulatory processes and extending and, in some cases, expanding the definition for Production Tax Credits (PTCs), Congress reaffirmed the critical partnership between industry and government to address these co-dependent issues of environmental protection and energy production. This report is intended to show the role that waterpower-based energy production can play in responding to the issues of:

- Increased energy production;
- Offsetting greenhouse gas emissions; and
- Improving the performance of technologies utilizing alternative renewable energy resources.

The report presents and discusses the definitions of waterpower technologies to include some of the promising emerging technologies such as instream (hydrokinetic), wave and ocean current devices. How each segment of waterpower industry can contribute to increased production is documented, some of the research questions that need to be answered to achieve the results are discussed, and targeted economic incentives that can spur the deployment of the production are reviewed.

Approach

The investigators identified and reviewed pertinent literature, reviewed existing data sources for potential or proposed waterpower energy programs, and consulted with industry personnel having relevant knowledge. During this process, a number of hydroelectric project owners provided details about capacity and efficiency projections and new incremental hydropower at existing facilities. In addition, developers and researchers involved in the next generation waterpower industry were consulted on potential, demonstration site status, needed research, development, deployment and demonstration (RDD&D), and obstacles for commercialization, as well as estimates for real deployment of capacity at commercial quantities. The terminology RDD&D, rather than the traditional R&D (research and development), is used herein to emphasize that in order to realize the potential of the next generation waterpower technologies, widespread demonstration of the concepts will be needed to realize generation gains. The information gathered was the used to develop a public-private partnership called the "Advanced Water Energy Initiative" that captures real energy production potential through a combined effort of committed RDD&D and economic stimulus. Waterpower industry case studies that demonstrate success as a result of this commitment are also included and reviewed.

Organization of this Report

This report is organized to provide groundwork for understanding how waterpower (or water-based power) can contribute to the renewable energy supplies:

Section 2 is an **Overview of the Waterpower Industry** and contains definitions and classifications that describe the scope of the waterpower technologies. It also reviews the economic incentive programs that have successfully been implemented to stimulate renewable energy development, and the status of the regulatory processes that govern development of the waterpower industry.

Section 3 **Waterpower Potential** reviews and summarizes the extent of the U.S.'s waterpower energy resource that could be exploited for domestic-renewable energy production based on recent government and industry assessments. This includes a potential assessment for each of the waterpower technology categories including conventional hydro, hydrokinetics and ocean energy. The resource assessment is the basis for the estimated generation gains that could be realized by 2025, as discussed in Section 5.

Section 4 **Waterpower Technology Development Needs** reviews three endeavors critical to support waterpower development: (1) research development, demonstration and deployment (RDD&D), (2) economic incentives, and (3) regulatory process enhancement. Included is a review of the Advanced Water Energy Initiative including inclusive waterpower technology development programs, near-term and long-term objectives, and estimated funding needs. Appendix B contains the details of this proposed program.

Section 5 **Waterpower Achievable Capacity Estimates** examines the potential developed in Section 3, and the required support developed in Section 4, to project a realistic, achievable outlook of waterpower capacity and energy gains by 2025.

Section 6 **Waterpower's Relevance to the U.S. Energy Needs** reviews how waterpower can contribute to renewable domestic energy production as well as support other forms of renewable energy production such as from wind energy technologies.

Section 7 is a **Summary** of the assessment's findings including the next steps toward developing the waterpower resource potential.

Section 8 contains **References**.

Appendix A, the **Hydro Industry Experience** reviews the history and accomplishments of recent waterpower industry technology development efforts. Many of these accomplishments form the foundation for future technology development that can access the waterpower potential discussed herein.

Appendix B includes the details on a proposed **Advanced Water Energy Initiative**.

2
OVERVIEW OF WATERPOWER INDUSTRY

What is Renewable Waterpower?

Waterpower is electric energy derived from moving water. It includes generation from conventional hydroelectric facilities as well as generation from the emerging technologies that access the energy potential of river, tidal, ocean and constructed waterway currents, and the energy of ocean waves. A more technical categorization has recently been provided by Bedard (2006):

> Hydrostatic energy is the energy possessed by a body because of its position or location at an elevation (or height, often called head) above a reference or datum, and the principle behind hydropower at dams.
>
> Hydrokinetic energy is derived from the Greek word for water (hydro) and kinetic (of, relating to, or provided by motion). Therefore, hydrokinetic energy is the energy possessed by a body of water because of its motion.

The potential of hydrostatic waterpower technologies – such as conventional hydropower and pumped storage - and the next generation hydrokinetic waterpower technologies – such as instream turbines (river, tidal, and constructed waterways) and ocean wave energy devices are included in this assessment. In terms of water resources, this assessment considers all freshwater bodies, natural or manmade, estuarine tidal currents, ocean currents (e.g., Gulf Stream) and waves. The energy potential of ocean thermal resources, however, is not considered herein.

Hydropower class terminology in common use varies. The conventional hydropower class definitions used in this document are those used in recent U.S. Department of Energy (DOE) documents (Hall and Reeves 2006; Hall et al. 2006). The detailed definitions of the 'next generation' hydrokinetic and ocean energy waterpower technologies are reviewed in EPRI (2005a and 2005b) and Bedard (2006).

In terms of existing technology, the following definitions, more as a matter of convenience than fundamental technology differences, are used:

> Large conventional hydropower – facilities that have a capacity of more than 30 megawatts (MW) with current installed capacity of approximately 66,500 MW.
>
> Small conventional hydropower – facilities that have a capacity of 1 to 30 MW with current installed capacity of approximately 8,000 MW.
>
> Low power hydropower – facilities that have a capacity of 100 kilowatts (kW) to1 MW with current installed capacity of approximately 350 MW.

Micro-hydropower facilities that have a capacity less than 100 kW.

Hydrokinetic technologies use waterpower conversion systems that convert kinetic energy — natural current instream, tidal (bi-directional), and ocean current — to energy. Three main classes of technology include:

1. Natural current instream or River Instream Energy Conversion (RISEC) refers to technologies capturing instream energy potential at dam-less situations.
2. Tidal Instream Energy Conversion (TISEC) occurs due to the moving mass of water with speed and direction as caused by gravitational forces of the sun and the moon on the earth's waters. The energy per second intercepted by an energy conversion device is a function of the frontal area of the device, the density of the water, and the cube of the speed of the water. This technology is bi-directional.
3. Technologies that use constructed waterways and man-made channels as conduits for energy conversion are also possible.

Ocean energy is used to describe all forms of renewable energy derived from the sea including wave energy, tidal energy, ocean current energy, salinity gradient energy and thermal gradient energy. Wave energy is defined as occurring due to movements of water near the surface of the sea. This motion carries kinetic energy, the amount of which is determined by various parameters including the speed and duration of the wind, water depth, fetch, seabed and tides. Wave Energy Conversion (WEC) systems are being tested worldwide (EPRI 2005a). This assessment only evaluates ocean wave and does not consider the potential and RDD&D for the other classes of ocean energy. An excellent glossary of marine energy terminology utilized by the EPRI Ocean Energy Program and published by the Carbon Trust in the UK is available at: http://www.thecarbontrust.co.uk/ctmarine3/res/MarineEnergyGlossary.pdf

Pumped-storage hydropower with an installed capacity of approximately 21,000 MW is a form of energy storage that uses reversible pump-turbine generators to move water from a lower reservoir to an upper reservoir at times when demand for electricity is low. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity. Its flexibility and support to the transmission system make it a very valuable energy storage resource. Because the energy used to pump the water to the upper reservoir relies on other power (usually fossil or nuclear) sources, it is only briefly discussed herein despite its critical role in supporting electric system reliability.

Available Economic Incentives for Renewable Development

For several decades, the energy industry, particularly the renewable energy sector, has relied on and utilized various economic incentives to support the development of capital intensive energy projects. These incentives stimulate investment by reducing the cost side of the equation or increasing the benefit or value side of the equation. To reduce the costs, Production Tax Credits (PTCs) and Investment Tax Credits (ITCs) are available to the private industry energy sector. The corresponding public power sector economic incentive is Clean Renewable Energy Bonds (CREBs). These cost-side incentives can be applied to reduce the costs of developing projects by ameliorating the early year startup costs, while offsetting or deferring taxes. On the value-side of the equation, incentives like Renewable Energy Production Incentive (REPIs) programs and

Renewable Portfolio Standards (RPS) provide support as market incentives that value the produced generation above existing sources. These incentives have been particularly important to renewable technologies that are in the pre-commercialization phases of development.

Production Tax Credits (PTCs) and Investment Tax Credits (ITCs)

The investment and energy production tax credits codified in the Energy Policy Act of 1992 (EPACT 92) as recently amended by the Energy Policy Act of 2005 (EPACT 05) are particularly important to renewable technology development. PTCs and ITCs are available only to private developers and investor-owned utilities (IOUs). The ITC established by EPACT 92 provided credits only for solar, geothermal, or qualifying biomass facilities. The PTC, as established by EPACT 92, applied only to wind and certain biomass facilities.

EPACT 05 provides PTCs for electricity produced from qualifying geothermal, animal waste, landfill gas, municipal solid waste, additional biomass resources and certain small-scale hydroelectric operations for the first 10 years of operation for a facility constructed before December 31, 2007. The rate provided by the PTC is 1.9 cents per kWh for wind, closed-loop biomass, geothermal and solar. The rate is reduced to 0.9 cents per kWh for open-loop biomass (including agricultural livestock waste), municipal solid waste (including landfill gas), hydropower and small irrigation. The investment and production tax credits are exclusive of one another, and may not both be claimed for the same facility.

The EPACT 05 amended the Internal Revenue Code to allow renewable energy tax credits for qualified hydro production. FERC is responsible for certifying baseline production information and the gain in generation derived from project improvements or additions. Qualified hydro includes incremental production attributed to gains from efficiency improvements or capacity additions placed into service after August 8, 2005 and before January 1, 2008 at any hydroelectric project placed in service on or before August 8, 2005.

Clean Renewable Energy Bonds (CREBs)

CREBs deliver an incentive to public entities comparable to PTCs. A CREB is a special type of bond, known as a “tax credit bond,” that offers the equivalent of an interest-free loan for financing qualified energy projects for a limited term. Renewable energy generation projects that qualify for the PTC generally qualify for CREB financing. Specifically, these projects include wind, closed-loop biomass, open-loop biomass (including agricultural livestock waste), geothermal, solar, municipal solid waste (including landfill gas and trash combustion facilities), small irrigation power and hydropower. The CREB program will be available for two years beginning January 1, 2006. It is also subject to a cap of $800 million over the two year period.

The CREB is different from the PTC in that it functions as a financing tool. In contrast, the benefits from a PTC are received only after the facility is financed and electricity is generated. The value of the CREB relative to the PTC varies according to the project. The PTC provides a 10-year stream of tax credits for all of the above listed renewable generation facilities that qualify for CREBs. As previously noted, the rate provided by the PTC is 1.9 cents per kWh for wind, closed-loop biomass, geothermal and solar. The rate provided by the PTC is reduced to 0.9 cents per kWh for open-loop biomass (including agricultural livestock waste), municipal solid waste (including landfill gas), hydropower and small irrigation.

Renewable Energy Production Incentives (REPI)

Renewable Energy Production Incentives (REPI) is part of an integrated strategy in the Energy Policy Act of 1992 (EPACT) to promote increases in the generation and utilization of electricity from renewable energy sources, and to advance renewable energy technologies. This program, authorized under EPACT Section 1212, provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities.

Eligible electricity production facilities are those owned by State and local government entities (such as municipal utilities) and not-for-profit electric cooperatives that started operations between October 1, 1993 and September 30, 2003. Qualifying facilities are eligible for annual incentive payments of 1.5 cents per kilowatt-hour (1993 dollars and indexed for inflation) for the first 10-year period of their operation, subject to the availability of annual appropriations in each Federal fiscal year of operation.

Criteria for qualifying facilities and application procedures are contained in the rulemaking for this program. Qualifying facilities must use solar, wind, geothermal (with certain restrictions as contained in the rulemaking), or biomass (except for municipal solid waste combustion) generation technologies. As part of EPACT 05, these incentives were extended to hydropower (incremental at conventional hydropower sites and free flow instream, tidal, wave and ocean current sites).

Although the effects have been relatively minor, the incentive was paid for 1,172,826 MW-hrs of renewable energy production in 2004 (http://www.eere.energy.gov/wip/repi.html). REPI represents another tool to encourage alternative energy production.

Renewable Portfolio Standards (RPS)

A Renewable Portfolio Standard (RPS) is a legislative requirement that obligates a retail electricity supplier to include some amount of renewable energy resources in its electricity generation portfolio. Retail suppliers can meet the obligation by constructing or owning eligible renewable energy resources or purchasing the power from eligible generators. Initially, most states adopted RPS policies as part of electric industry restructuring, but more recently a number of states have implemented policies by legislation or proceedings that are separate from restructuring activities. However, the one aspect of renewable portfolio standards that is consistent is that there is no consistent standard. Each state has chosen to make the RPS different in terms of what technologies can satisfy the purchase obligation, size limitations, and special set-asides for some technologies.

In general, the programs are intended to provide financial incentives to developers to offset the higher cost of bringing renewable generation on line in the form of addition payment above base rate prices for power. In the case of waterpower technologies, this can be in the form of premiums paid for energy supply. In some states, utilities are required to add a certain percentage of renewable capacity or face a penalty payment to the state. In California, the penalty amounts to $50/MWH based on adding 1 percent of new renewable capacity annually to 2020.

Hydropower Regulatory Process

The 75,000 MW of existing conventional hydropower projects are split almost equally between the federal projects (~37,500 MW) and those that are subject to the Federal Energy Regulatory Commission (FERC) jurisdiction over licensing and regulatory structure (Hall and Reeves 2006). For the approximately 37,500 MW of projects that are licensed by FERC, the compliance and relicensing requirements represent a significant challenge in continuing cost-effective operation. These challenges have included for many projects the length of time to obtain a license, the uncertainties of licensing decisions, and the high costs associated with providing protection, mitigation and enhancement (PME) measures that are required for environmental protection at existing hydropower facilities. Through a timely multi-year Integrated Licensing Process (ILP) (http://www.ferc.gov/industries/hydropower/gen-info/licensing/ilp.asp), FERC recently improved the licensing process to address these concerns and many others. Even with the recently implemented process improvements, the costs of licensing and supporting studies are a major factor in waterpower being able to achieve the potential identified herein.

Nonetheless, the length and costs of the regulatory process for new waterpower development, either at existing dams with existing environmental footprints, or at ‘dam-less’ small and low power facilities, is a major factor in the actual realization of the potential identified in this report. Having said this, it is important to note that this does not have to be the case. In a recent ‘expedited’ case, 2 MW of new waterpower capacity was brought online with a 3-month FERC licensing process at an existing dam (See appendix A for details). While this case is extreme, a 1 to 3 year time period for licensing at existing dams, within an existing environmental footprint, may promote new conventional hydroelectric capacity additions to the national energy supply as opposed to the 5 to10 year processes that are more typical for recent relicensing efforts.

While knowledge and experience in the FERC licensing process in the conventional hydropower industry is extensive, the same is lacking with operators of the next generation waterpower technologies. These new technology operators, therefore, have and will face numerous licensing and technology deployment challenges when operating in the existing regulatory structure. Both FERC and the U.S. Department of the Interior’s Mineral Management Service (MMS) are currently working through the issues of how these new technologies will fit into the agency’s existing regulatory requirement (in the case of FERC) and proposed new guidelines (in the case of MMS). FERC currently has over 20 preliminary permit applications pending, some for competing sites. MMS is not accepting new applications as it looks at formulating its regulatory structure for the outer continental shelf (OCS). In both these situations, communities, technology developers and their potential backers are in an uncertain situation as to what will be the ultimate regulatory requirement for proposed projects, who will have final jurisdiction and how competing agency requirements will be resolved.

For emerging waterpower technologies to be able to fulfill their potential, these issues need to be addressed. The success of the wind energy technologies has demonstrated that one of the keys to the successful evolution of an emerging technology is a regulatory scheme that is proportional to the likely effects and evolves as the technologies and the information base evolves. A proportional regulatory scheme combined with RDD&D funding and incentives similar to other renewable technologies may provide the platform for emerging waterpower technologies to make their rightful contribution to the nation’s energy security.

3
WATERPOWER POTENTIAL

Estimates of the generation potential and the current state of development of each of the waterpower technology classes are presented herein. This will form the basis for short- and long-term projections of increased capacity gains that are predicated on an RDD&D effort and economic stimuli discussed in later sections.

Existing Generating Capacity

In 2006, existing hydropower capacity was ~96,000 MW (split between ~75,000 MW of conventional capacity and 21,000 MW of pumped storage capacity). Hydropower accounted for nearly 9 percent of the country's total electric generating capacity and over 75 percent of the country's renewable energy generation (DOE/EIA 2006). Table 3-1 provides a breakdown of the generating capacity by size and number of facilities.

Table 3-1
Installed Existing Hydropower Capacity (Source: Conner et al. 1998; Hall and Reeves 2006)

Hydropower Class	MW Range	No. of Plants	Installed Capacity (MW)
Large Conventional	>100	~ 253	~ 65,780
Medium	30-100	~ 92	~ 756
Small	1-30	1,179	8,023
Low Power	> 100 kW and <1 MW	864	313
Microhydro	<100 kW	–	–
Total		2,388	74,872
Pumped Storage[1]	No Available	Not Available	~21,000 MW[1]

[1] Pumped-storage capacity it is usually considered an energy storage resource.

Conventional Hydropower Potential

Several recent studies have assessed some of hydropower's future potential (Conner et al. 1998; EPRI 2004, 2005a and 2005b; Hall et al. 2004, 2006; DOE 2006a). This includes potential that could be tapped at existing plants and by developing potential resources with new technologies. The resource potential of conventional hydropower capacity in the following three categories is subsequently discussed:

Additional capacity at existing hydroelectric plants

Development of new small and low power hydroelectric plants

Development of new of hydroelectric capacity at existing dams without powerhouses

A fourth category of potential improvement includes the potential gains in generation efficiency at existing hydroelectric facilities. Table 3-2 summarizes the estimated additional capacity for conventional hydropower.

Table 3-2
Waterpower Existing and Estimated Potential Capacity (MW)

Waterpower Technology	2006 MW	Potential MW
Conventional Hydro		
Large Hydro (>30 MW)	66,535	(3,100)[1]
Capacity Gains at existing large and small hydro	~100[2]	4,300[3]
New Small hydro (>1 MW <30)	8,023	36,000[4]
New Low power hydro (<1 MW[5])	313	22,000[6]
New hydro at existing dams	–	(16,700)[7]
Total conventional hydro	74,871	62,300
Hydrokinetic		
Tidal instream	Demos	300[8]
Instream and constructed waterways	–	12,500[9]
Total hydrokinetic potential	–	12,800
Ocean Energy		
Ocean wave	Demos	10,000 - 20,000[10]
Ocean current	–	No data
Pumped Storage	21,000	Resource not assessed
Total Existing and Potential Waterpower	95,971	85,100 - 95,100

[1] Estimated equivalent capacity addition at existing facilities due to generation efficiency gains based on industry expectation of 4 percent improvement. This value is included in the subsequent row for large and small hydro and is, therefore, excluded from the total.

[2] Based on estimates for gains being considered by FERC as certified for PTCs.

[3] 1998 estimate by DOE (Conner et al. 1998) includes capacity gains from adding new units in existing bays or larger turbines.

[4] Corresponds to 18,000 MWa (mean annual power) estimated by DOE (Hall et al. 2004; DOE 2003) and assumes a 50 percent plant factor.

[5] Included potential defined as conventional, unconventional and microhydro power by DOE (2003).

[6] Corresponds to 11,000 MWa (mean annual power) estimated by DOE (Hall et al. 2004; DOE 2003) and assumes a 50 percent plant factor.

[7] This 1998 figure corresponds to the potential at 2,500 of the more than 79,000 dams in the U.S. and therefore should be considered an ultra-conservative estimate (Conner et al. 1998). It is likely to be included in the 2006 estimates of potential noted above and therefore is excluded from the totals.

[8] EPRI (2005b) examined the tidal instream potential for only 5 states.

[9] A study of U.S. instream potential was made in 1986 (Miller et al. 1986). It did not include an assessment of constructed waterways. It is unclear whether this estimate is MW or MWa and is shown as the smaller figure.

[10] As estimated by EPRI (2005a); the potential could be significantly higher because EPRI (2005a) assumed that only 15 percent of the potential energy could be extracted.

Additional Capacity at Existing Hydroelectric Plants

DOE (Conner et al. 1998) identified 4,300 MW of capacity potential available at existing hydroelectric facilities within the public and private sectors. This potential does not include generation gains that result from efficiency improvements. It is based on equipment additions (e.g., addition of a turbine to an open bay) or increased water usage (e.g., addition of a larger turbine) that results in additional or incremental hydropower capacity. These gains are often achieved during up-rating that occurs through modernization, relicensing, or a restart from a mothball or retirement status. The implementation of these capacity additions is particularly sensitive to improvements in hydropower turbine technology and the availability of economic incentives to support financing the improvement.

Development of Small and Low Power Hydropower

DOE (Hall et al. 2006) estimated the potential for these two categories of conventional hydropower as 29,438 MWa, which included 10,988 MWa for low power class (<1 MWa) and 18,450 MWa for the small hydropower class (between 1 and 30 MWa). The 10,988 MWa for the low power class is further subdivided into subclasses using conventional turbines (21 percent), micro-hydropower (<100 kW) (10 percent), and unconventional systems (6 percent), which may or may not require hydrokinetic type turbines to develop.

This total of 29,438 MWa[5] is an annual average power and not capacity like the numbers noted previously in the text. This corresponds to a capacity potential of 58,000 MW. DOE (Hall et al. 2006) also noted that their stream-based resource assessment did not identify whether there was an existing dam at the potential project sites. The potential capacity probably includes much if not all of the 16,700 MW of potential at dams without power that was the subject of an earlier DOE study (Conner et al. 1998). The 16,700 MW is not included, therefore, in the total waterpower potential (Table 3-2).

Development of New Hydropower at Existing Dams

DOE (Conner et al. 1998) identified 16,700 MW of additional hydropower capacity that is available by adding hydropower to non-hydropower dams where it is environmentally and financially prudent to do so. This estimate corresponds to the potential at only 2,500 of the more than 79,000 dams in the U.S. and, therefore, should be considered an ultra-conservative estimate (Conner et al. 1998). Subsequent DOE studies conducted on small and low power hydropower resource assessments likely include this estimate, therefore, it is not included in the totals presented in Table 3-2.

[5] MWa is the average annual power production potential. Since most conventional hydroelectric plants use only a portion of the available water flow, power plants are usually sized to reflect this difference. In order to compare these estimates with previous DOE studies, a nameplate rating of approximately twice the production potential has been used herein.

Generation Efficiency Gains (Equivalent Capacity)

DOE (Hall et al. 2003) reported that a 6.3 percent generation increase could be achieved from efficiency improvements if plant units fabricated in 1970 or prior years having a total capacity of 30,965 MW are replaced. Based on work done for the Tennessee Valley Authority (TVA) and other hydroelectric plant operators, a generation improvement of 2 to 5.2 percent has also been estimated for conventional hydropower (75,000 MW) from installing new equipment and technology, and optimizing water use (March 2005a and 2005b; personal communication, Patrick A. March, Principal Consultant, Hydro Performance Processes Inc., October 10, 2006).

In order to compare these potential generation estimates, an equivalent capacity calculation is required. This is accomplished by taking an average annual hydropower generation, increasing it by the estimated annual generation gain (2 to 6.3 percent, as noted above), dividing by 8,760 hours in a year and adjusting for a average hydropower capacity factor of 40 percent (DOE estimates a capacity factor range of 40-50 percent; see http://hydropower.inel.gov/hydrofacts/plant_costs.shtml) to result in an 'equivalent capacity addition' value in MW as follows:

> The long-term (1995-2005) average annual hydro generation is 291,000 GWH (EIA 2006; see http://www.eia.doe.gov/emeu/aer/contents.html), but varies widely with annual hydrology (e.g., 2004 data shows 268,000 GWH) and is produced by approximately 75,000 MW operating at a capacity factor of 40-44 percent.
>
> The reported potential range for efficiency gains is 2 to 6.3 percent (NOTE: tests to date indicate that higher efficiency gains may in fact be possible – tests on the new Wanapum advanced hydropower turbine have found a 4 percent efficiency gain). For purposes of this calculation, a 4 percent gain is assumed.
>
> A 4 percent gain in average annual hydropower generation results in a total generation increase to 302,600 GWH or approximately 11,000 GWH per year improvement.
>
> Based on a capacity factor of 40 percent, 3,100 MW is the 'equivalent capacity addition' from generation of 11,000 GWH.

Total Conventional Hydropower Potential

Table 3-2 summarizes the total resource potential for conventional hydropower as 62,300 MW which would be an 83 percent increase in installed capacity. Based on the assumptions used, the estimate is considered conservative and, furthermore, this estimate does not include equivalent capacity additions from efficiency improvements presented in the previous subsection.

Hydrokinetic Energy Potential

The assessment of water resources with hydrokinetic energy potential has been limited to date, although the preliminary studies indicate a significant resource is available. Tidal Instream Energy Conversions (TISEC) potential was examined in a series of EPRI (2005b) studies. The studies examined the potential for only five states (Alaska, Washington, Oregon, Maine, and Massachusetts) and several sites in Canada. The total resource potential for these locations amounts to approximately 300 MW.

The potential of natural river instream conversion (RISEC) using 'dam-less' technologies has also only been investigated on a limited basis. A 1986 study (Miller et al. 1986) estimated the total potential as 12,500 MW although it is unclear if this means annual energy MWa[6] or capacity. If annual generation, this would imply a capacity of 25,000 MW at an average capacity factor of 50 percent. Because of the uncertainty, this assessment conservatively assumes the lower value of 12,500 MW. The uncertainty of this estimates, and the lack of a clear definition of the resource clearly points to the need for further research.

Water flow in man-made channels or constructed waterways (irrigation and water supply canals) is another form of hydrokinetic potential; however, no assessment of the extent of the resource has been made to date.

Ocean Energy Potential

Ocean energy includes energy extracted from waves, tidal flow, ocean currents (e.g., Gulf Stream), salinity gradients and ocean thermal gradients. This assessment, except for energy from tidal sources as previously discussed, focused only on the potential, status and needed RDD&D of ocean wave energy.

EPRI (2005a) examined the potential for the development of this technology for domestic energy supply. Based on an assumed capacity factor of 15 percent, EPRI (2005a) estimated that 10,000 to 20,000 MW of wave energy capacity is available. Some key attributes of ocean energy as compared to tidal energy are (Bedard 2006b):

Wave Energy Key Attributes	Tidal Energy Key Attributes
High power density	High power density
Forecasting possible at an hourly and even daily scale	Long term predictability and reliability based on lunar cycles
Minimal aesthetic issues – technologies have low freeboard or profile and are deployed at or over the horizon	Minimal aesthetic issues – submerged
Large resource	Smaller resource, though potential not fully assessed

Pumped Storage Potential

The pumped-storage facilities currently in operation amount to 21,000 MW of installed capacity. Many facilities have undergone FERC relicensing and modernization and represent to their owners an extremely significant system resource for energy storage, stability, reliability, and ancillary services. There has not been any recent assessment of the U.S.'s pump storage potential. While several large pumped storage projects were investigated and licensed in the

[6] MWa is the average annual power production potential. If the report examined MWa the comparable MW value would be approximately twice the potential.

1990s, they were not constructed due to the inability to justify market incentives to cover the large capital and environmental costs associated with their construction and operation (Stewart and Lindell 2005). This was before the institution of RPSs and more significant intermittent renewable generation development. Future development of pump storage including its integration with intermittent renewable energy technologies such as wind turbines could be a significant contribution to our domestic energy portfolio. Wind energy advocates have identified the need for wind/hydropower integration (i.e., more storage) as a means to solve intermittency problems and support the further expansion of wind resources (see: http://www1.eere.energy.gov/windandhydro/hydro_sys_integ_tech.html#renew).

Summary of Waterpower Potential

Table 3-2 summarizes the potential by technology or resource category for additional national waterpower capacity. Included is an estimate for generation gains due to efficiency improvements, expressed as an 'equivalent capacity addition' value, at existing hydro facilities. This generation improvement of approximately 11,000 GWH per year is equivalent to capacity addition of 3,100 MW (assuming a 40 percent capacity factor). This equivalent value is likely included in DOE's (Conner et al. 1998) potential capacity estimates for large and small hydro and, therefore, is excluded from the total potential estimate.

4
WATERPOWER TECHNOLOGY DEVELOPMENT NEEDS

The estimates of the waterpower resource potential described in the previous section are not likely to be attained without a concerted effort of RDD&D, economic incentives and regulatory changes. These are described herein and lay the framework for the estimates of realized waterpower capacity that follow in Section 5.

Research, Development, Demonstration, and Deployment Needs

The RDD&D efforts discussed herein are a precursor to a more thorough DOE assessment consistent with the directive in the Energy Policy Act of 2005. Specifically, EPACT 2005 (Title IX, Section 931) directs the Secretary of Energy to:

> *Conduct a program of research, development, demonstration and commercial application for cost competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity of the energy supply of the United States, including: (i) Fish-friendly large turbines. (ii) Advanced technologies to enhance environmental performance and yield greater energy efficiencies. (…) The Secretary shall conduct research, development, demonstration, and commercial application programs for – (i) ocean energy, including wave energy (…) and (iv) kinetic hydro turbines.*

This Congressional intent is conflicted by the fact that effective FY 2007, the DOE budget authority for hydropower research has been eliminated. The intent is also inconsistent with a long-term decline in federal funding for energy R&D. In fact, since 1978, DOE's total budget authority for energy R&D has declined by over 85 percent (GAO 2006). Margolis and Kammen (1999a,b and 2001) note a similar trend (58 percent decline between 1980 and 1995); however, more importantly they note the importance of R&D to technology development by documenting the correlation between R&D spending and patent application. Margolis and Kammen (1999a,b and 2001) found that inputs (R&D funding and research infrastructure) and outputs (innovations in energy technologies) are closely linked, and that the energy sector under-invests relative to other technology-intensive sectors of the economy. In fact, the high-tech drugs and medicine, professional and scientific equipment, and communication equipment sectors all exhibit R&D intensities that are more than an order-of-magnitude above the 0.5 percent of sales devoted to R&D in the energy sector. Establishing and RDD&D program, as subsequently discussed, therefore, is essential to realization of the waterpower industry's potential.

The following highlights key RDD&D needs including a reasonable schedule to attain realistic capacity gains in each of the waterpower technology areas. Specific topics included:

Background on previous waterpower RDD&D.

RDD&D program needs.

Overview of a potential Advanced Water Energy Initiative (AWEI) program to guide technology and manage waterpower technology development.

Previous Waterpower RDD&D Programs

Conventional Hydropower

The DOE Hydropower Program has supported research and development since 1976 to improve operation and development of hydropower facilities in the U.S. Since inception, the program has supported R&D for low power systems, research on environmental issues and mitigation practices, development of advanced and environmentally friendly hydropower turbines and, more recently, waterpower resource assessments. These DOE programs have been successful in stimulating the hydropower industry to develop new hydropower efficiency methods and fish-friendly turbine designs, however, the most recent DOE multi-year plan (DOE 2003) outlined a completion strategy that was not funded. The consequences of this non-funding have resulted in a failure to attain the potential the U.S. waterpower resources offer. Table 4-1 summarizes the DOE proposed annual (FY 04-10) hydropower research and development appropriation request; however, effective with FY07, program funding was discontinued.

The DOE Hydropower Program's current biennial report for FY 2005-2006 (DOE 2006a) summarizes the accomplishments to date, however, the history of DOE funding of waterpower RDD&D has been at significantly lower levels than other renewable technologies. The 2006 and 2007 DOE commitments have been directed at closing the program completely (see Section 6).

Table 4-1
DOE Hydropower Multi Year Funding Profile (Millions $) (Source: DOE 2006a)

DOE Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Advanced Hydropower Technology	5.6	2.8	3.3	2.9	3.2	3.3	2.0
Supporting Research and Testing	1.1	2.0	1.9	2.2	1.2	1.1	0.5
Systems Integration and Technology Acceptance	0.5	1.7	1.7	1.8	2.5	2.5	1.5
Supporting Engineering and Analysis	0.3	0.9	0.6	0.6	0.6	0.6	0.6
Total Multi Year Technical Plan	7.5	7.4	7.5	7.5	7.5	7.5	4.6
Actual Appropriations	4.6	4.9	0.5	TBD	TBD	TBD	TBD

Hydrokinetic

The EPRI (2005b) tidal energy reports represent the only recent U.S. RDD&D conducted in this area. These reports were a result of a public (state and provincial government) – private (utility) collaboration to examine the hydrokinetic resource with some in-kind support at the federal level. There has been no federally funded direct RDD&D in this area, and some limited state-funded efforts at initial demonstrations are pending. Moreover, as documented in previous sections, there clearly is an increasing need to examine the potential resource in detail.

After the completion of the EPRI tidal instream reports, a great deal of activity was noted in the filing of FERC preliminary permits for nearly 22 tidal and wave current projects (FERC 2006). At least 21 utilities, public power producers, cooperatives and developers are currently active with this technology. While this activity is significant, the technology is still considered pre-commercial and in the testing phase.

Verdant Power is deploying the first tidal demonstration project in U.S. The Roosevelt Island Tidal Energy (RITE) Project is being developed in the East River in New York City. Two 200 kW demonstration project turbines were deployed in late 2006. Four more units are scheduled of deployment in March 2007. Verdant will conduct 18 months of studies to assess, among other items, the environmental impacts of turbine operation. Verdant intends to file a FERC license application that could be expanded to 300 turbines capable of generating a total of 10 megawatts, enough power for about 8,000 average U.S. homes.

Ocean Energy

The 2006 EPRI (2005a) ocean energy reports represent the only RDD&D conducted in the U.S. in this area. These reports were a result of a public (state and provincial government) – private (utility) collaboration to examine the ocean energy resource with some in-kind support at the federal level. There has been no federally funded RDD&D in this area, and some limited state-funded efforts at initial demonstrations are pending. Internationally, however, there have been several programs of RDD&D directed at examining the ocean energy resource, these include programs sponsored by the United Kingdom's Department of Trade and Industry (http://www.supergen-marine.org.uk/page.php?5), the Carbon Trust (http://www.carbontrust.co.uk/default.ct)and most recently proposals for marine energy development projects sponsored by the Scottish Executive (http://www.scotland.gov.uk/Topics/Business-Industry/infrastructure/19185/ROSConsWaveTidal06PDFP).

EPRI (2005a) reports that the wave (and tidal) technologies have a pre-commercial development status as compared to wind technologies which are much more mature and considered commercial. Demonstration units (rated at 500-1,000 kW; enough for 225-380 homes) still need to be deployed and tested. Commercial sizing is based on producing 300,000 MWH/year which will be achieved through clusters of wave energy conversion (WEC) devices. A possible configuration includes 180, 750 kW devices to produce a 135 MW wave farm plant. By comparison, a similar 2 or 3 unit 135 MW run-of-river conventional hydropower plant at 40 percent capacity factor yields approximately 470,000 MWH/year.

Several recent filings for preliminary permits for ocean energy projects have been made to FERC. These projects are pilot-scale projects intended to assess technology performance and preliminarily examine potential environmental impacts. Example projects include (EPRI 2005a):

AquaEnergy's Makah Bay Offshore Wave Energy Pilot Project – a proposed 1 MW pilot wave energy project located off the coast of Washington State. The project will consist of four buoys generating 250 kW each. The project is currently in the FERC licensing process (http://elibrary.ferc.gov/idmws/search/results.asp; initial letter of intent filed with FERC April 23, 2002).

Ocean Power Technologies' (OPT) Reedsport Wave Park – a proposed 50 MW project off the coast of Oregon. The FERC preliminary permit application was accepted in July 2006 and permit issuance is pending (http://elibrary.ferc.gov/idmws/search/results.asp; preliminary permit application filed July 14, 2006).

Waterpower Information Sources for RDD&D Programs

The waterpower industry has been examining RDD&D needs and opportunities since the early 1990s; not only to support the Department of Energy – Hydropower program funding requests, but also to identify research needs in both the public and private sectors. Multiple sources of information exist from several recent forums, as subsequently discussed, which have examined conventional hydropower as well as the new waterpower technology development needs.

Conventional Hydropower

Most recently, the waterpower industry has participated in a National Energy-Water Roadmap Program (http://www.sandia.gov/energy-water/roadmap_process.htm) initiated in 2005, as requested in Congressional FY 2005 appropriations. The purpose of the Energy-Water Roadmap Program is to assess the effectiveness of existing programs within DOE and other Federal agencies in addressing energy and water related issues, and to assist the DOE in defining the direction of research, development, demonstration, and commercialization efforts to insure that the following are adequately and efficiently being addressed in the future:

1. Energy-related issues associated with providing adequate water supplies, optimal management and efficient use of water, and
2. Water-related issues associated with providing adequate supplies, optimal management and efficient use of energy.

The primary product from the Energy-Water Roadmap process will be a report published in late 2006 summarizing needs, prioritization criteria, major gaps, innovative technical approaches and associated research needs, R&D priorities and strategies, and associated policy, regulatory, and economic assessments (DOE Sandia National Labs 2006).

In May 2006, the waterpower industry along with multi-disciplinary science and government agency representatives participated in a Technological Innovations Forum that was conducted to identify various R&D projects that would support energy-water development in the future. The results of the Renewable Energy (Group 5) Technical Innovations R&D programs were published in October 2006 (DOE 2006a) and included several key recommendations for conventional hydropower improvements and new hydrokinetic technologies, in terms of site assessments and demonstration support. The details of the programs formed the basis (and format) for much, but not all of what is contained in the proposed AWEI (Appendix B). The results of the Renewable Energy Group Technical Innovations R&D programs will be a part of the Energy –Water Nexus report to Congress that is due in December 2006 (DOE in press).

Other sources of information on the conventional hydropower RDD&D needs are included in:

The 2003 DOE Hydropower Multi-Year Technical Plan (DOE 2003) that identified ~$7.5million of RDD&D commitment to hydropower technologies through 2010;

The DOE Hydropower Program Biennial Report for FY 2005-2006 (DOE 2006a);

Hydropower industry R&D forum reports (HCI 2002, EPRI 2002).

Hydrokinetic Technologies

The ongoing EPRI Tidal In Stream Energy Conversion (TISEC) program (EPRI 2005b) outlined several areas for research and development, including institutional support such as financing, permitting, public awareness, monitoring global progress, device cost reduction studies, improvements in efficiency and reliability, identification of sites, electrical interconnection with utility grids and controls, and studies of effects of technology on environment. In September 2006, EPRI also submitted a proposal to DOE that identified four specific studies needed to advance the development of TISEC and River (RISEC) technologies; while meeting the Section 913 requirements of EPACT 2005, including resource site surveys and feasibility studies.

Additional information sources on RDD&D needs include:

The Energy-Water Nexus Program (http://www.sandia.gov/energy-water/) - Renewable Energy Group Technical Innovations R&D included several work items (5-9b and 5-11) dedicated to resource assessment and technology demonstration of hydrokinetic resources; including man-made channels. This report was due to be delivered to Congress in December 2006 (DOE 2006a);

"What's the Future of Instream Flow?" a recent paper in *HydroReview* (Coutant and Cada 2005) that particularly focused on the environmental challenges that must be overcome or addressed to advance instream flow technology development and deployment;

Ocean Renewable Energy Coalition (OREC)(http://www.oceanrenewable.com/) recommendations for needed hydrokinetic and ocean research presented to the Departments of Energy and Interior (OREC 2006a, 2006b); and

Hydropower Industry R&D Forum reports (HCI 2002, EPRI 2002).

Ocean Energy Technologies

EPRI Wave and Tidal Energy Conversion reports (EPRI 2005a and b) identified RDD&D needs, including studies on:

Institutional support for financing, permitting, public awareness, monitoring global progress.

Wave Energy Conversion (WEC) device cost reduction.

Improvements in efficiency and reliability.

Identifying demonstration and deployment sites.

Electrical interconnection with utility grids and controls.

Effects of technology on marine life and shoreline processes.

As a follow-up to these recommendations, a recent EPRI (2006) proposal to DOE identified three specific wave energy resource studies to advance the technology for wave energy resources, site surveys and feasibility. In addition, it included an examination of hybrid wind-wave systems and the preparation of an Ocean Energy Roadmap (consistent with the requirements of EPACT 2005, Section 913).

Two other sources of information for RDD&D needs for ocean energy technology development include:

The Ocean Renewable Energy Coalition (OREC) recommendations for $60 million of funding by 2010 (OREC 2006a, 2006b);

International activities – the experience and commitment to an advanced ocean energy research program being conducted overseas that incorporates a number of programs to bring ocean technologies to the full commercial potential (e.g., http://www.supergen-marine.org.uk/news.php).

While the U.S. program has consisted of efforts primarily by individual waterpower developers, ocean energy research in the United Kingdom has received significant government funding. This funding provides a benchmark of the level of effort that the U.S. may need to invest to develop technologies to access its ocean energy resources. The UK has invested and completed ocean energy research amounting to (personal communication - Gary Shanahan, Director, Emerging Technologies for UK Department of Trade & Industries):

25 million pounds from 1999 to 2005 (~$47 million).

50 million pounds from 2006 to 2008 (~ $95 million).

42 million pounds to support developed prototypes (not R&D) (~$80 million).

8 million pounds to support infrastructure projects and address environmental issues (~$15 million).

The UK's Carbon Trust (http://www.carbontrust.co.uk/about) has also supported a project of 3 million pounds ($5.7 million) on ocean energy research and the Scottish Executive recently unveiled new proposals to support marine energy development projects. This includes an 8 million pound (~$15 million) investment to kick-start the Scottish marine power industry and a further 6 million pound (~$11.4 million) investment fund to support Scottish firms wishing to develop marine power technologies.

Proposed Advanced Water Energy Initiative (AWEI)

FY 2006 closeout of the DOE hydropower research program leaves several unfinished projects, many objectives unattained, and no research foundation to support and develop the technologies to access the U.S.'s instream and ocean renewable energy resource. This has occurred despite the clear Congressional mandate in EPACT 2005 for additional hydropower research. Closeout of the DOE hydropower program and failure to appropriate funds to address the EPACT 2005 hydropower provisions is forcing the waterpower industry to take a hard look at program accomplishments, program failures and the basic applied science and technology demonstration that is still needed to achieve realistic waterpower gains from all three classes of waterpower technologies. This may be best accomplished by re-inventing a public-private sector collaborative as the Advanced Water Energy Initiative (AWEI). This initiative would address the needs using the successful technology development models employed by other renewable energy sectors such as wind and biomass.

An Advanced Water Energy Initiative (Appendix B) would have three major components:

> Waterpower **Realization** Committee—to provide the initial guidance and future oversight to benchmark results of the initiative in terms of real waterpower capacity potential and generation gains that are a result of RDD&D.
>
> Waterpower **Performance** Initiatives—RDD&D efforts that improve the efficiency and environmental performance of conventional hydropower technologies. This is summarized in three program areas:
>
> WPRD 1 Advanced Water Energy Science;
>
> WPRD 2 Hydropower Environmental Performance;
>
> WPRD 3 Hydropower Operational Performance.
>
> Waterpower **Technology Development** —RDD&D that would advance hydrokinetic and ocean energy technology development in four program areas:
>
> WPRD 4 Hydrokinetic Site Assessment;
>
> WPRD 5 Hydrokinetic Environmental Profiling;
>
> WPRD 6 Hydrokinetic Technology Improvement;
>
> WPRD 7 Advanced Ocean Energy Programs.

A detailed presentation of each of these programs is contained in Appendix B. Near-term (2007 to 2010) and long-term (by 2015) funding needs, and the benefits that would result from each programmatic area are presented in Table 4-2 and graphically in Figure 4-1. This program amounts to a commitment of $212 million for the short-term (2010) and a total commitment of $377 million to support efforts through 2015. Although front end loaded, the program identifies research needs of less than $38 million/year.

Table 4-2
Advanced Water Energy Initiative Project and Funding Detail

ID	Title	2007-2010 R&D ($M)	Total R&D ($M) 2015	Benefits
	Waterpower Realization Committee	4	9	All Technologies
WPRD 1	1-A Water Energy Science	24	32	
	1-B Meteorological forecasting and optimal dispatch	8	14	All technologies
	1-C Integration and control of renewable energy technologies	20	32	All technologies
WPRD 2	2-A Complete design, testing of fish-friendly turbines	16	24	Environmental performance and new development
	2-B Bioengineering for fish passage and mitigation	8	12	Supports existing/ new units
	2-C Water quality mitigation technology	4	5	Supports existing/ new units
	2-D Advanced weirs for flow re-regulation and aeration	3	3	Supports existing/ new units
WPRD 3	3-A Hydro operation decision support analysis	16	24	All technologies
	3-B Demonstration testing of advanced hydro turbine systems	15	25	Supports efficiency gains and environmental performance
	3-C Advanced electrical equipment for renewable integration	8	13	All technologies
WPRD 4	Hydrokinetic resource assessment	4	4	All hydrokinetic technologies
WPRD 5	Hydrokinetic environmental profiling	14	34	All hydrokinetic technologies
WDRD 6	Hydrokinetic technology improvement (instream, tidal, conduit)	58	86	All hydrokinetic technologies
WPRD 7	Advanced Ocean Energy	10	60	Ocean technologies
	Total AWEI RDD&D Program	**212**	**377**	**Achieves up to 23,000 MW and possibly more of Waterpower by 2025**

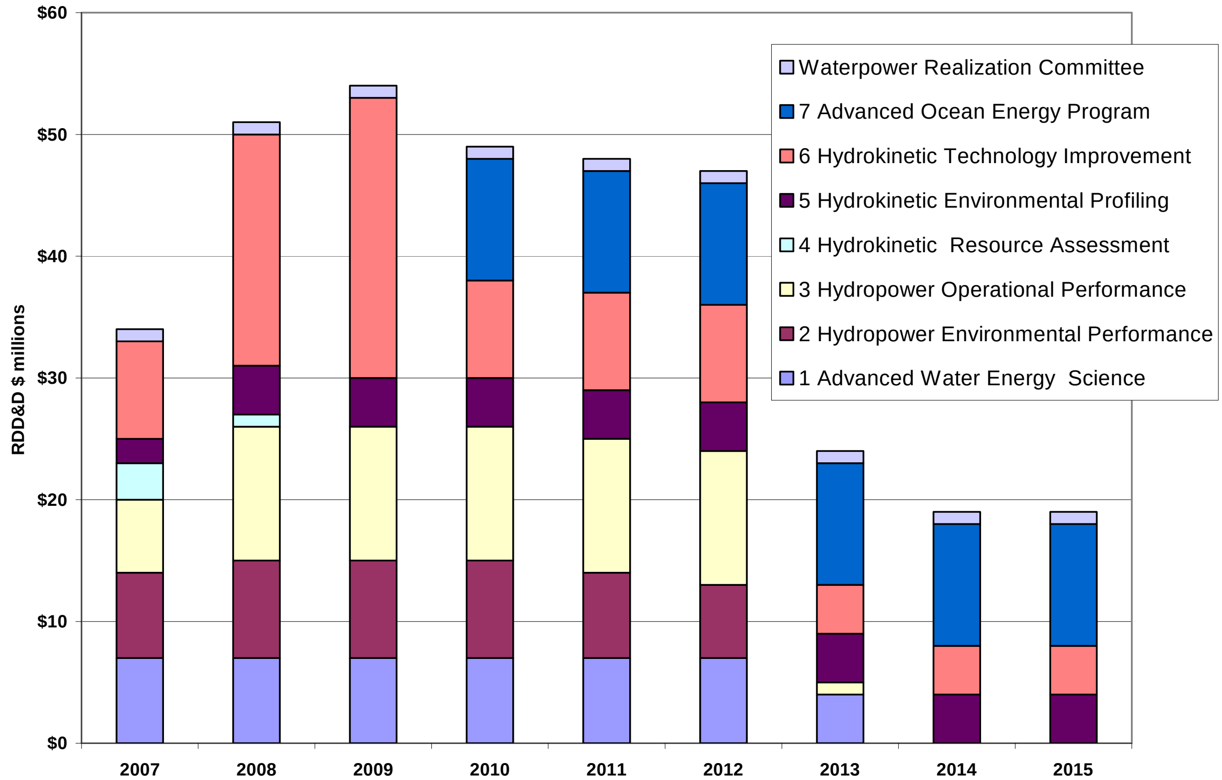


Figure 4-1
Advanced Water Energy Initiative Funding 2007 to 2015

Economic Incentives

Since enactment of EPACT 2005, the hydropower industry has been able to use the incentives to spur the expansion of existing hydro plants. Appendix A discusses several of the projects that have taken advantage of this program. However, it is unrealistic to expect that the addition of generating units to existing hydropower projects and non-hydro dams can occur within the relatively short (28-month) timeframe allowed because of the long lead times associated with:

Project design;

Permitting and licensing; and

Fabrication and installation of major components.

In an October 2006 update of activity under the PTC and CREB programs, the National Hydropower Association (NHA 2006) conducted an ad hoc survey of its membership regarding development plans. The results are summarized in Table 4-3. The survey indicates that at least 166 MW of capacity gains can be achieved during the 28-month window. More importantly, nearly 450 MW of planned projects need an extension of the PTC deadline to qualify. Similarly, CREBS applications represent an additional 175 MW of new waterpower capacity that could be achieved with incentive timetables that better match the permitting, design and fabrication realities.

Table 4-3
Hydropower Applications and Estimated MWs for PTCs and CREBS – October 2006 (Source: National Hydropower Association)

PTC/CREBs Status	# of Projects	MWs
Projects FERC certified	5	76
Certification pending	8	15
Projects that intend to file for certification	11	75
Total by January 2008	24	166
Additional results that could be achieved with balanced timetables		
CREB applications	2+	~175
Projects that need PTC extension to make application	13	~445

Economic incentives like PTCs and CREBS are directly linked to capacity and efficiency development. It is clear from the experience of the wind energy industry that PTCs promote development. According to the American Wind Energy Association (AWEA 2006), as shown on Figure 4-2, capacity growth in the wind energy industry significantly increases when PTCs are available and growth abruptly slows when economic stimuli are not available. This pattern has also been noted in a recent Government Accountability Office (GAO 2006) study where they report that the uncertainty about the PTC's availability has created a 'boom-and-bust' cycle for installing new wind power capacity – installation of new capacity fell dramatically in years when the authorization for the tax credit expired and its renewal was delayed, as compared with years when it was available without interruption. This pattern is also true for the waterpower industry—or any renewable energy technology where uncertainties and risks prevail in the early years of demonstration and commercialization.

Growth in wind development has been due to a combination of technology improvement (aided by research support) spurred by direct incentives as seen in Figure 4-2. Both conventional and emerging waterpower technologies can be expected to follow similar patterns. In the case of conventional hydropower, because of its more established status it is positioned to immediately respond to appropriately timed economic stimuli.

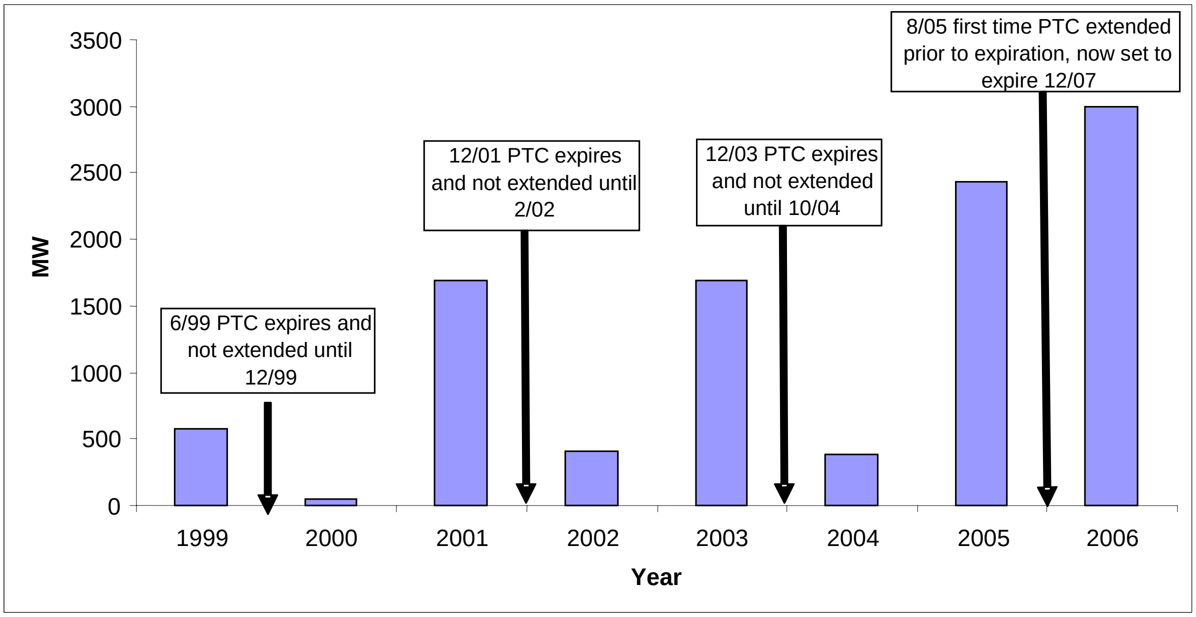


Figure 4-2
Effects of PTCs on Wind Power Capacity Additions: 1999-2006 (Source: American Wind Energy Association)

Regulatory Support

It has taken over 100 years to develop the 75,000 MW of conventional hydropower capacity in the U.S. Approximately 37,500 MW of this existing capacity is regulated by FERC (Hall and Reeves 2006). Two of the key drivers affecting the estimate of potential capacity gains are (1) the timeframes for development of capital intensive projects and (2) environmental impact protection, mitigation and enhancement (PM&E) in part due to regulatory timeframes and the long lead times needed for capital-intensive waterpower projects. The following subsections describe the implications of regulatory timeframes on project implementation.

Timeframes for RDD&D to Effect Performance Improvements

The Grant Public Utility District (PUD) Wanapum Advanced Hydropower Turbine System (AHTS) program (http://www.gcpud.org/aboutus/news.htm#advanced) is an example of the present day commercial demonstration and testing timeframes in a FERC regulatory framework. The Wanapum Project is located on the Columbia River has had long-term issues associated with protecting downstream migrating juvenile Pacific salmon (Brown and Garnant 2006). By the 1990s, Wanapum's turbines needed major rehabilitation or replacement because of several structural and hydraulic deficiencies. Salmon protection issues and the need for turbine replacement led Grant County PUD engineers and biologists to consider potentially solving two issues at once via installation of an environmentally advanced hydropower turbine design developed in the DOE hydropower program (Čada 2001; Coutant et al. 2006)(also see: http://hydropower.inel.gov/turbines/index.shtml). The design and implementation of the AHTS program at the 10 turbine unit project required both FERC and federal and state resource agency approval including year-long testing and monitoring periods.

The total timeframe encompassing 14 years will be as follows:

Year 1-5	Design, manufacture and baseline biological evaluation in support of a FERC license application for the project.
Year 6	Phase I installation (2005) of a single 90-MW advanced or "fish friendly turbine."
Year 7	One year of environmental performance testing compared to an old unit, including FERC application for Phase II turbine replacements.
Year 8-10	Phase II turbine replacements (4 units), each unit requiring 9 months to install (3 years to install 360 MW).
Year 11	One year environmental performance testing period, before application for approval of the final 5 unit installation.
Year 12-14	Phase III final turbine replacements (~2012-2014) at the 10-unit plant (1,038 MW).

Testing to date has demonstrated an increased power output of 14 percent (4 percent efficiency gain plus a 10 percent capacity gain), increased water use efficiency by an average 3 percent, and fish survival slightly better than achieved with older units. When all ten turbines are replaced, power production will increase by 14 to 20 percent while continuing to provide safe downstream passage of juvenile fish (Brown and Garnant 2006).

Timeframes for Developing New Conventional Hydropower

A generalized timeframe for developing new hydropower at existing dams is difficult to postulate. In one case, expedited (3 month) FERC regulatory approval yielded 2-MWs in 13 months (see Appendix A New Small Hydropower at Existing dams - Expedited Licensing Results in Jobs, Energy). This has to been seen as an exception to a process governed by environmental concerns and long leads times for major capital equipment.

PTCs have allowed some owners to apply for and implement in relatively short timeframes some capacity improvements. Most of these projects are likely not linked to long lead-time components and may have been in preliminary planning stages in anticipation of the passage of EPACT 2005. The EPACT 2005 specified 28-month (July 2005 to January 2008) timeframe is typically too short for the project design, financing, procurement, manufacture and installation activities of capital-intensive projects. Extension of the PTCs to a time period reflective of the period involved to implement capital-intensive projects would likely encourage additional development.

5
WATERPOWER ACHIEVABLE CAPACITY ESTIMATES

This section presents conservative estimates of achievable capacity gains in each of the classes of waterpower technologies. The estimates in this section include potential that could be tapped by:

Installing additional hydro capacity at existing hydroelectric plants,

Efficiency improvements at existing facilities,

Developing new small and low power hydroelectric plants,

Developing new hydro capacity at existing dams without powerhouses,

Developing hydrokinetic projects in natural streams, tidal areas, ocean currents, and constructed or man-made waterways, and

Developing ocean energy projects that harness wave power and ocean thermal resources.

The projected contribution by each technology class is summarized in Table 5-1. The total projection of 23,000 MW represents a conservative estimate of the possible addition to installed capacity by 2025. Figure 5-1 provides a projected timetable for this potential development for each technology class. Early gains in waterpower generation are derived from conventional waterpower technology improvements and development with emerging technologies making greater contributions as research and incentive programs provide stimulus. The long term potential (beyond 2025) for the emerging technologies may be even greater but the projection was beyond the scope of this effort. The subsections that follow provide details on the methods, data and assumptions used to derive the projections.

Table 5-2 summarizes the gain in giga-watt-hours (GWH)/year of generation. By 2025, generation improvements from all waterpower sources could amount to as much as 119,000 GWH or a 40 percent increase in current waterpower generation. This potential represents a third more generation then produced by all other renewable sources as reported in 2004 (89,000 GWH) (DOE/EIA 2006) and does not include the potential out-year growth beyond 2025.

Table 5-1
Estimated Waterpower Capacity Gains (MW) by 2025

Waterpower Technology	2006	Potential	By 2010	By 2015	By 2025
Conventional hydropower					
Large hydro (>30 MW)	66,536		0[1]	0[1]	0[1]
Capacity gains at existing large and small hydro	~100[2]	4,300[3]	375[4]	1,000	2,300
New small hydro (>1 MW <30)	8,023	36,000[5]	25	500	2,000[6]
New low power hydro <1 MW[7]	313	22,000[8]	100	350	700[9]
New hydro at existing dams	–	(16,700)[10]	25	500	5,000[11]
Conventional hydro potential realized			525	2,350	10,000
Hydrokinetic					
Tidal instream	Demos	300[12]	115	300	3,000[13]
Instream and constructed waterways	–	12,500[14]	0	30	RNA[15]
Hydrokinetic potential realized			115	330	3,000[13]
Ocean energy (wave)	Demos	10,000 - 20,000	84	1,000[16]	10,000
TOTAL	**74,972**	**85,100 - 95,100**[17]	**724**	**3,680**	**23,000**

1 Construction of new large hydropower dams is not projected, however, large hydro will have efficiency improvements that add to annual generation not capacity.

2 Based on estimates for gains being considered by FERC as certified for PTCs.

3 1998 estimate by DOE (Conner et al. 1998) includes capacity gains from adding new units in existing bays or larger turbines.

4 Assumes that the activity noted applying for PTCs would be realized, for a total of 53 percent by 2025.

5 Corresponds to 18,000 MWa (mean annual power) estimated by DOE (Hall et al. 2004; DOE 2003) and assumes a 50 percent plant factor.

6 Small hydropower development could range as high as 20,000 MW with economic incentives and expediting licensing.

7 Includes potential defined as conventional, unconventional and micro-hydropower by DOE (2003).

8 Corresponds to 11,000 MWa (mean annual power) estimated by DOE (Hall et al. 2004; DOE 2003) and assumes a 50 percent plant factor.

9 Low power potential could be attained using conventional technology; however, it is economically difficult to develop.

10 This 1998 figure corresponds to potential at 2,500 of the more than 79,000 dams in the U.S. and, therefore, should be considered an ultra-conservative estimate (Conner et al 1998). It is likely to be included in the 2006 estimates of potential noted above and, therefore, is not included in the total.

11 This figure represents 30 percent of the potential developed within 20 years, based on the assumptions in Section 2. This figure could range as high as 10,000 MW with favorable economic conditions.

12 EPRI (2005a) examined the tidal instream potential for only 5 states.

13 Assumes that hydrokinetic (tidal, instream and constructed waterways) RDD&D is conducted and regulatory licensing is expedited.

14 U.S. instream potential was assessed by Miller et al. (1986). It did not include an assessment of constructed waterways.

15 RNA = resource not assessed.

16 Assumes RDD&D and regulatory licensing is expedited.

17 Excludes the 16,700 MW at existing dams since this potential is likely contained in the small hydro estimates.

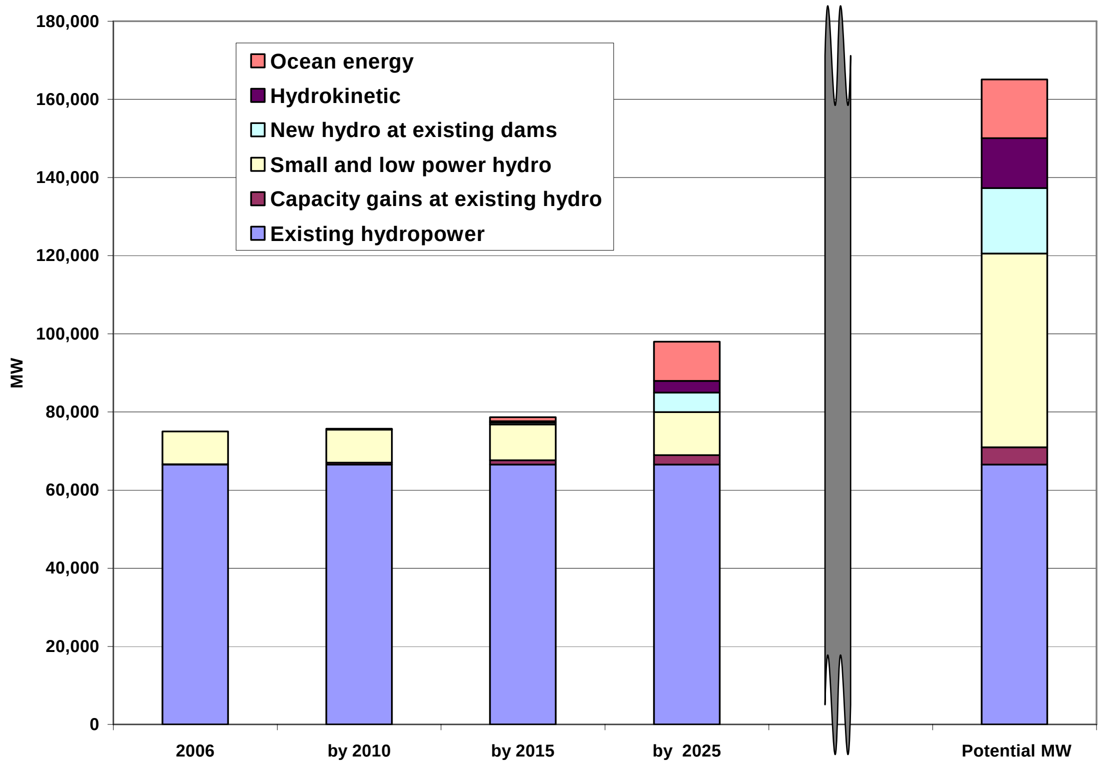


Figure 5-1
Estimated Waterpower Capacity Potential and Realized Gains by 2025 (MW)

Table 5-2
Estimated Waterpower Capacity (MW) and Generation (GWH) Gains by 2025

Waterpower Technology	2006		2025		
	Existing Capacity (MW)	Average Hydropower Generation (GWH)	Projected Incremental Capacity (MW)	Projected Waterpower Generation (GWH)	Projected Incremental Generation (GWH)
Conventional Hydropower (efficiency)	–	261,000 - 293,000[1]	–	266,000 - 308,000[2]	5,000 - 15,000
Conventional Hydro (capacity)	75,000	–	10,000	~36,000[3]	36,000
Hydrokinetic	Demos	–	3,000	8,700[4]	8,700
Ocean Energy	Demos	–	10,000	29,000[5]	29,000
Total	**~75,000**	**261,000 - 293,000**	**23,000**	**339,700 - 381,700**	**78,700 - 88,700**

[1] Historical 11-year average generation (1995 to 2005) from EIA; a low average (for 6 years, 2000 to 2005) is 261,000 GWH.

[2] Estimate assumes that existing hydropower facilities will improve generation efficiency by modernizing generating equipment and optimizing water use. These generation efficiency improvements are conservatively estimated to range from 2 to 5.2 percent (personal communication, Patrick A. March, Principal Consultant, Hydro Performance Processes Inc., October 10, 2006) (Note: an advanced turbine at the Grant County PUD Wanapum Project is attaining a 14 percent improvement (4 percent efficiency improvement plus 10 percent capacity increase; Brown 2006) and DOE estimates that improvements could average 6.3 percent (Conner et al. 1998)).

[3] Assumes an average capacity factor of 40 percent for conventional hydropower.

[4] Assumes a conservative capacity factor of 30 percent for hydrokinetic facilities.

[5] Assumes a conservative capacity factor of 33 percent for ocean energy facilities.

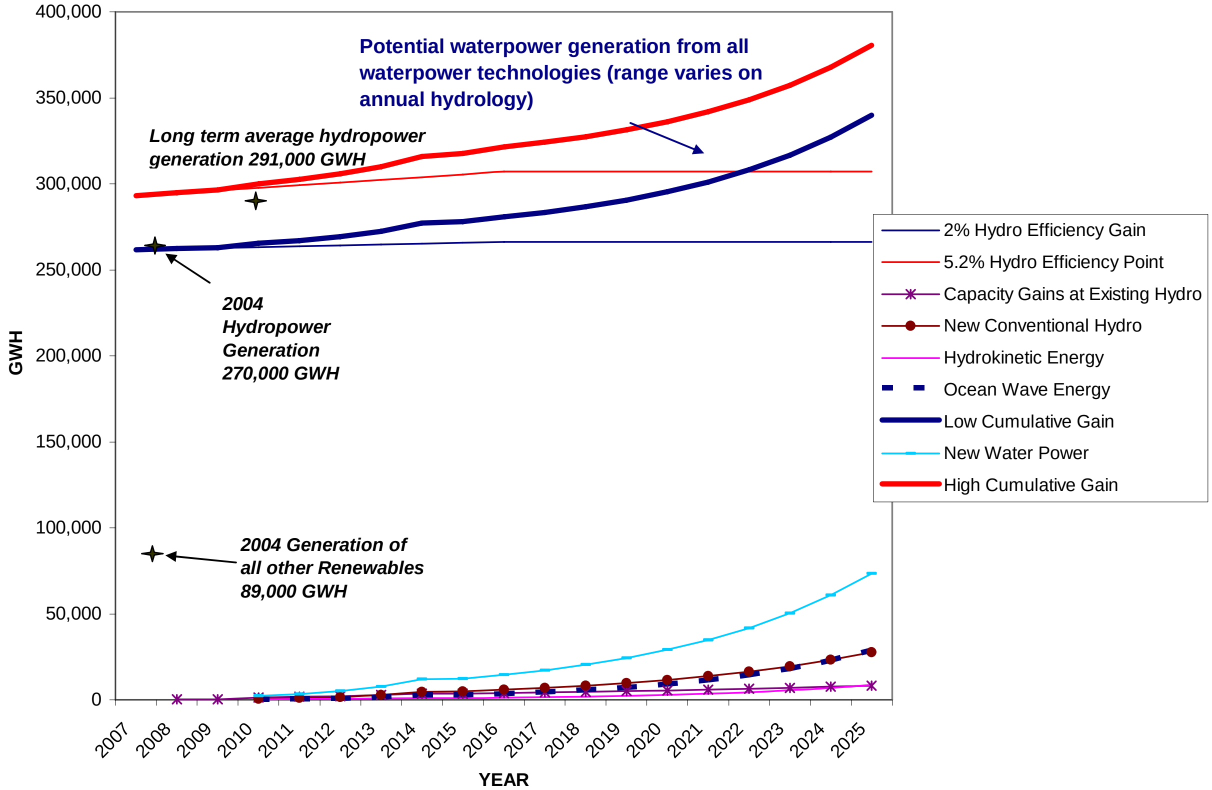


Figure 5-2
Projected Waterpower Generation Gains (GWHs)

Conventional Hydropower Projections

In examining potential and postulating development, it is important to recognize that the hydroelectric plant ownership plays an important role in realizing new capacity and energy gains. A recent study of hydroelectric plant ownership noted the following (Hall and Reeves 2006):

> *The principal characteristic of U.S. hydroelectric plant ownership is the private sector (private utility and non-utility owners, cooperatives, and industrial owners) owns most of the 2,388 plants (69%), but the public sector (federal and non-federal public owners) owns most (73%) of the 74,872 MW of capacity. Private owners that are not utilities own 38% of the plants corresponding to only 4% of the total capacity, while private utilities own 31% of the plants corresponding to 24% of the total capacity. Seven federal agencies own the largest fraction of the total capacity (51%). Non-federal publicly-owned plants constitute 24% of the plant population corresponding to 22% of the total capacity.*

This existing distribution of plant ownership (Table 5-3) and the investment incentives available to each significantly affects the likelihood of development and the potential that can be achieved. While the projection opportunities are general in nature, they form the foundation for the estimated development potential for each category of waterpower development. For example, in the federal sector, new hydropower development at existing federal dams is a possibility, particularly since the work currently being conducted by the USACE and the Department of Interior will identify opportunities (personal communication, K. Sadiki, USACE National Hydropower Business Development Program Manager, September 7, 2006). The likelihood of a federal entity developing new hydropower, however, is considered 'less likely' due to federal fiscal constraints and policy objectives. Private utilities, given economic stimuli like PTCs and the renewable green markets that are developing, are likely candidates for developing the potential estimated herein.

The magnitude of hydropower plants owned by the private sector/non-utility (38 percent) with an installed 3,000 MW of capacity seems to represent a likely area for hydropower expansion for small (>1 and <30 MW) hydropower. This class of ownership, however, is widely dispersed, and geographically distant and constrained. Future development at significant scale is considered possible but less likely since it would require significant outreach efforts to induce development on a wider scale.

Table 5-3
Opportunities for Hydropower Development

Hydropower Ownership[1]	% of Plants[1]	Installed Capacity (MW)[1]	Opportunities for Development			Use of PTCs CREBs REPIs and RPS
			Efficiency and Capacity Gains at Existing Plants	New Hydro at Existing Dams and Small Hydro	Low and Micro-Hydro[2]	
Public – Federal	7%	37,500 (51%)	Yes and likely[3]	Possible but less likely	Less likely	Not applicable
Public – non Federal	24%	16,500 (22%)	Yes and likely[4]	Possible with incentives	Possible	REPIs, RPS CREBs
Private – utilities	31%	18,000 (24%)	Yes and likely[5]	Possible with incentives	Possible	REPIs, RPS, PTCs
Private – non-utilities (cooperatives), industrials	38%	3,000 (4%)	Yes but less likely	Possible with incentives	Possible	REPIs, RPS, PTCs, CREBs[6]

[1] Reference (Hall and Reeves 2006).

[2] Capturing low-power potential will require significant public outreach.

[3] Advanced Hydro Turbine System (AHTS) is being considered at federal sites.

[4] AHTS is being tested, but still needs completion RDD&D.

[5] AHTS for small plants, still in design, and needs RDD&D funding to go to demonstration.

[6] Electric cooperatives are eligible for economic incentives (CREBs).

Potential Hydro Capacity at Existing Hydroelectric Plants

DOE identifies 4,300 MW (Conner et al. 1998) of capacity potential at existing hydropower facilities within the public and private sectors. This potential does not include added generation due to efficiency gains. It is based on equipment additions (e.g., addition of a turbine to an open bay) or increased water usage (add a larger turbine) that results in additional or incremental hydropower capacity. These gains are often achieved during up-rating that occurs through modernization, relicensing, or a restart from a mothballing or retirement. These capacity additions are particularly sensitive to improvements in hydro turbine technology and the availability to use economic stimuli to finance the improvement.

Table 5-1 summarizes projections of capacity gains in this category assuming:

A significant portion of 37,500 MW of existing hydro capacity (public non-federal and private) can be attained if continued economic stimulus and RDD&D to support small turbine technology advancements is maintained.

Industry will achieve 53 percent (2,300 MW) of the 4,300 MW of potential by 2025. This estimate is based on the level of current activity that was reported by the National Hydropower Association (NHA) and presented in Table 4-3 (~1,000 MW could be added by 2015).

These assumptions are conservative and reasonable based on the current activity underway as a result of PTCs and CREBs.

Development of Small and Low Power Hydropower

DOE (Hall et al. 2006) estimated the potential for small and low power conventional hydropower as 29,438 MWa[7], which included potential estimates of 10,988 MWa for low power class (<1 MWa) and 18,450 MWa for the small hydro class (between 1 and 30 MWa). This total is an annual average power and not capacity. This annual generation corresponds to a capacity potential of 58,000 MW. This stream-based resource assessment did not identify potential project sites where there is an existing dam. The potential capacity, therefore, probably includes much if not all of the 16,700 MW of potential at dams without power that was the subject of an earlier DOE study (Conner et al. 1998) as subsequently discussed.

Relative to the balance of the estimated potential (58,000 - 16,700 = 41,300 MW), the 2006 DOE study (Hall and Reeves 2006) of hydroelectric plant ownership noted the following:

> *There is a disparity between the number of non-utility private owners which make up about 60% of the owners and the amount of capacity they own, which is only 4% of the total U.S. hydroelectric capacity. Given the unlikelihood of the development of large hydropower projects in the present U.S. environment, hydroelectric growth is dependent upon the development of distributed generation using low power and small hydro class plants.*

---

[7] MWa is the average annual power production potential. Since most conventional hydroelectric plants use only a portion of the available water flow, power plants are usually sized to reflect this difference. In order to compare these estimates with previous DOE studies, a nameplate rating of approximately twice the production potential has been assumed herein.

> *For significant growth to occur, there will have to be a dramatic increase in the number of these plants and probably an accompanying increase in the number of plant owners. Most states already have significant numbers of these classes of plants indicating that the hydroelectric industry has the experience necessary for further expansion in a favorable economic climate.*

Although the waterpower industry has the experience necessary for further expansion in a favorable economic (and regulatory climate), this assessment projects a modest development potential (Table 5-1) using the following assumptions:

For the small hydro (>1 to <30 MW) facilities, development can occur with economic incentives and existing conventional technology. The primary constraints are the regulatory lead times required and economics. These limiting factors will likely keep development to 2,000 MW by 2025. One of the overriding constraints is that the RDD&D for the 'fish-friendly' turbine design for this class of project has not been completed. The design of the Alden/Concepts NREC turbine that was part of the DOE Advanced Hydro Turbine System (AHTS) program has undergone some limited research and development (Cook et al. 2003; Sale 2006), but demonstration and deployment to a commercial level has not occurred (see Appendix A).

Low power hydropower estimates are based on the history of low power hydroelectric development. During 1983 through 1989, DOE supported a "Pumps as Turbines" research and development project that fostered development of small hydropower sites. Anecdotal evidence indicates that the submersible turbine manufacturer Flygt sold 95 turbines to be installed at 42 sites in the U.S. for a total capacity of 59 MW. These sites ranged in head from 10 to 80 feet and up to 400 KW per unit. With a track record of 59 MW within 6-7 years and other evidence from the FERC Hydroelectric Power Resource Assessment (HPRA) database as noted by Hall et al. (2006), this suggests that nearly 600 low power plants came on line during the 1980s. A modest projection of 100 MW near-term and 700 MW by 2025 is, therefore, included in this assessment. This represents a 53 percent increase in the current installed capacity. Because of the distributed nature of these facilities, and the environmental, regulatory, and economic requirements that inhibit development, broader economic expansion is likely to be difficult.

While the potential in the DOE (2003) defined category of conventional, unconventional and micro-hydro power is substantial (41,300 MW), estimates herein assume a modest development scenario. Small hydropower development using existing and enhanced technology could range as high as 20,000 MW given favorable economic conditions and regulatory policies.

Development of New Hydro at Existing Dams

DOE identified 16,700 MW of additional hydropower (Conner et al. 1998) capacity that could be achieved by adding hydropower to non-hydropower dams where it is environmentally and financially prudent to do so. Under the Energy Policy Act of 2005, DOE, USACE, and DOI- Bureau of Reclamation were tasked to estimate the potential for new incremental hydropower development at existing federal facilities. The final report is expected in February 2007, however, preliminary results from USACE indicate that at existing USACE facilities a potential of 2,200 MW of hydroelectric capacity could be installed within the existing dam footprint (personal communication, K. Sadiki, USACE National Hydropower Business Development Program Manager, September 7, 2006).

A basis for estimating future development is the historical activity during the 1980s. Three economic conditions were present in the late 1970s and early 1980s:

DOE was providing low-interest hydropower feasibility study loans. A 1986 DOE study (DOE and M-K Engineers 1986) found that 240 feasibility studies were done, 41 license applications filed and at least 23 projects were developed at existing dams in the 1980s. The completed projects range in generating capacity from 660 to 24,000 kW and in gross hydraulic head from 10 to 470 ft, representing 185 MW.

Production and Investment Tax Credits and Accelerated Depreciation were available for qualified energy projects including hydropower. These incentives required that the plants were placed into service before December 31, 1989.

Availability of PURPA contracts to developers further allowed for a favorable market condition for hydropower development by providing an attractive price per MWH to purchase power in lieu of building new large central station capacity.

By examining the FERC database for projects that were licensed/built during this time period, 1,880 MW of capacity was added in the 1980s. At least 585 MW appear to be a direct result of expedited regulatory process and the economic stimuli. This project development conservatively represents 30 percent of the projects brought on line and licensed at existing dams during the period.

A different set of conditions now exist, both positive and negative, that effect the realization of new capacity at existing dams. On the positive side, the nation’s need for increased domestic energy and the interest in renewable technologies are positive influences. On the negative side are multiple jurisdictional requirements, which tend to add time and cost to bringing new capacity on line.

In order for a private or public utility or private developer to invest in a capital project, several factors need to be considered. These include:

The potential advancements in small-turbine environmental performance (brought about by RDD&D);

Continuing renewable (utility) market value conditions that include the economic incentives discussed herein, particularly PTCs, REPIs and RPS standards that include waterpower as a renewable energy resource; and

Regulatory process improvements that streamline the licensing of projects.

Capacity developments for small hydropower at existing dams as presented in Table 5-1 are based on the following assumptions:

An additional 30 percent of the 16,700 MW or 5,000 MW of potential at existing dams could be developed by 2025 given appropriate economic incentives and expedited regulatory processing.

100 MW by 2010 and potentially 500 MW by 2015 are achievable with economic incentives and expedited regulatory processing.

Summary Total Conventional Waterpower Capacity Gain

The estimates in each of the classes of conventional hydropower are summarized in Table 5-4.

Table 5-4
Estimated U.S. Conventional Hydropower Capacity Gain by 2010, 2015 and 2025 (in MW Rated Capacity)

Conventional Hydropower Class	2006	2010	2015	2025
Large hydro (> 30 MW)	66,535	0[1]	0[1]	0[1]
Capacity gains at large and small hydro	~100[2]	375[3]	1,000	2,300
New small hydro (>1 MW <30)	8,023	25	500	2,000[4]
New low power hydro < 1 MW[5]	313	100	350	700[6]
New hydro at existing dams	–	25	500	5,000[7]
Total	~75,000	525	2,350	10,000

[1] Large hydro will have efficiency improvements that impact generation not capacity additions.

[2] Based on estimates for gains being considered by FERC as certified for PTCs.

[3] Assumes that the NHA (2006) reported activity on projects applying for PTCs will be realized.

[4] Small hydropower development using existing and enhanced technology could range as high as 20,000 MW given favorable economic incentives.

[5] Included potential defined as conventional, unconventional and micro-hydro power by DOE (2003).

[6] While low power potential could be harnessed using conventional technology, it is economically difficult to develop and, therefore, this estimate assumes a little over a doubling in realized capacity.

[7] This figure represents 30 percent of the potential developed within 20 years. This figure could range as high as 10,000 MW with favorable economic incentives.

Hydrokinetic

EPRI (2005b and 2006) and OREC (2006a, b) estimated near-term tidal deployments based on recent activity of private developers (Table 5-5). The estimates for the next five years are based on the understanding of industry experts and activity at FERC in terms of viable developers filing realistic plans for preliminary permits as of October 2006. The estimated forecast is based on the following observations and assumptions:

FERC (or other jurisdictional authority) licensing of hydrokinetics and treatment of tidal instream facilities is in a state of flux.

Economic incentives such as PTC’s and CREBS will assist in demonstration and developments.

RDD&D for assessment and site analysis, environmental performance, demonstration, and technology improvement, will positively effect the development.

While no assessment of potential deployment of river instream energy projects or man-made channels exist, it is assumed that with regulatory support and some RDD&D that gains in capacity would be achieved. A technical obstacle needing to be overcome is that instream riverine technologies require currents at 6-7 feet per second (fps) to achieve cost effective energy extraction. The average velocities in most manmade channels are 3-4 fps. Therefore, some sort of flow concentrator or civil works structure that accelerates flow is necessary to achieve development. For this technology, a nominal 30 MW of growth is assumed, pending additional RDD&D.

Table 5-5
Estimated U.S. Tidal Instream Energy Capacity Gain 2007 through 2011 (in MW Rated Capacity) (EPRI 2005b; Personal Communication, R. Bedard, EPRI, October 3, 2006)

Developer	Project Name-Site	2007	2008	2009	2010	2011
Verdant Power[1]	East River, NY	0.2	-	4.8	10	15
Ocean Renewable Power Company, LLC (ORPC)[2]	Western Passage, ME				50	
Gulf Stream Energy, Inc and Golden Gate Energy Company or another entity[3]	Golden Gate, CA				50	50
Tacoma Power/Snonomish County Public Utility District (SNOPUD)[4]	Admiralty Strait, WA					50
TBD[5]	Cook Inlet, AK					2
Total Annual Capacity	-	0.2	0.0	4.8	110	117
Total cumulative capacity	-	0.2	0.2	5	115	232

[1] Assumes the ultimate extractable rated capacity of the Roosevelt Island Tidal Energy (RITE) East River demonstration project is 30 MW as projected by the developer Verdant Power.

[2] Assumes that ORPC will be able to utilize the system and environmental work done by Verdant and overseas entities and will be able to get regulatory approval without a pilot plant.

[3] Assumes that based on initial site analysis that Golden Gate site is one of the most economically and politically advantageous sites in the U.S., and will be developed.

[4] Assumes that either Tacoma Power (FERC preliminary permit holder) or another entity (e.g., SNOPUD) will pursue the upper Puget Sound potential.

[5] Assumes that due to the low density of tidal instream resource potential in Alaska that a pilot plant does get implemented in this 5-year time frame.

A projection of 3,000 MW by 2025 from all forms of hydrokinetic technologies is included in Table 5-1.

Ocean Energy

EPRI (2005a) reports the U.S. wave energy resource potential at approximately 2,100 TWH/yr. EPRI (2005a) further estimated, as summarized in Table 5-6, a near-term 5-year estimate based on permit applications to FERC as of October 2006. RDD&D funding support, economic stimuli, and expedited regulatory processing for wave energy technologies could lead to the resources development much like the same did for the wind energy industry. It took the wind energy industry 25 years to achieve 50 GW worldwide and about 10,000 MW in the U.S. by 2005.

Table 5-6
Estimated U.S. Offshore Wave Energy Capacity Gain 2007 through 2011 (in MW Rated Capacity) (EPRI 2005a; Personal Communication, R. Bedard, EPRI, October 3, 2006)

Developer	Project Name- Site	2007	2008	2009	2010	2011
Finavera[1]	Makah Bay, WA	-	1			
Energetech[2]	Point Judith, RI	-	2			
Ocean Power Technology (OPT)[3]	Reedsport, OR	-	-	-	50	
TBD[4]	Lincoln County OR	-	-	-	-	30
Oregon State University (OSU)[5]	Lincoln County OR RDD&D Facility	-	-	1		
TBD	Northern CA	-	-	-	30	
TBD	Hawaii	-	-	-	-	100
Total Annual New Capacity	-	-	3	1	80	100
Total Cumulative Capacity	-	-	3	4	84	184

[1] Finavera, an Irish Company, recently acquired AquaEnergy, and an application for a pilot plant license is likely. Assumes at this time that a pilot plant will be funded but it will not be built out into a commercial plant in the near future due to lack of local demand and transmission infrastructure.

[2] Assumes FERC allows Energetech to sell electricity from the pilot plant and does not make them reimburse Narragansett Electric for electricity that they do not generate and sell.

[3] Assumes that OPT will be able to utilize the system and environmental work done by Finavera and overseas entities and will be able to get a license without a pilot plant.

[4] Lincoln County has filed an application with FERC for a half dozen offshore wave plants in their coastal state waters.

[5] Assumes that OSU is successful at getting the funding for a wave energy RDD&D plant at Newport OR and that the plant typically has about 1 MW of devices operating at any one time.

Projected generation gains by 2015 and 2025 from ocean energy technologies are summarized in Table 5-1.

Summary of Achievable Waterpower Generation

Potential generation gains through 2025 were estimated based on the capacity estimates previously presented projected at an assumed conservative capacity factor range of 30 to 40 percent for the various waterpower technologies (EPRI 2005a,b). Included in the generation gains are anticipated efficiency improvements estimated to range from 2 to 5.2 percent at existing hydro facilities (March 2005a and 2005b; personal communication, Patrick A. March, Principal Consultant, Hydro Performance Processes Inc., October 10, 2006). The results are summarized on Table 5-2, and represent a conservative range of waterpower generation of 280,000 to 309,000 GWH by 2025. A range is presented because of the wide variability in annual hydrologic conditions that affect hydropower generation statistics. The generation gains presented in Figure 5-2 are from two different sources: (1) generation gains that could be achieved at existing conventional hydroelectric facilities of approximately 15,000 GWH and (2) generation gains from new hydropower at existing dams and projections from next generation waterpower technologies of approximately 73,000 GWH. Figure 5-2 depicts a range of potential generation increase of approximately 46,000 – 119,000 GWH. These projections were based on the following assumptions:

> The existing hydroelectric generation is bounded on the high end by the historical 11- year average (1995-2005) of 293,000 GWH and on the low end by the average for 6 years (2000-2005) of 261,000 GWH as reported by EIA (2006).
>
> Existing hydropower facilities will improve generation efficiency through modernization or relicensing. These generation efficiency improvements can range from 2 to 5.2 percent or more (personal communication, Patrick A. March, Principal Consultant, Hydro Performance Processes Inc., October 10, 2006).
>
> Projected capacity development for new waterpower technologies is converted to generation by applying a rule-of-thumb capacity factor for each of the waterpower technologies. These include:
>
>> An average capacity factor of 40 percent for conventional new hydropower (DOE estimates a capacity factor range of 40-50 percent; see http://hydropower.inel.gov/hydrofacts/plant_costs.shtml);
>>
>> A conservative capacity factor of 30 percent for hydrokinetic facilities (EPRI 2005b); and
>>
>> A conservative capacity factor of 33 percent for ocean energy facilities (EPRI 2005a).

The generation gains estimated with this approach are lower than estimates by DOE (Hall et al. 2006) for small and low power hydropower. Hall et al. (2006) notes that:

> *It is concluded from the study results that there are a large number of opportunities for increasing U.S. hydroelectric generation throughout the country that is feasible based on an elementary set of feasibility criteria. These opportunities collectively represent a potential for approximately doubling U.S. hydroelectric generation (not including pumped storage), but more realistically offer the means to at least increase hydroelectric generation by more than 50%.*

By way of comparison, a 50 percent increase in hydroelectric generation would be approximately 130,000 GWH based on a 2004 hydroelectric generation benchmark of 263,000 GWH (EIA 2006). The estimated gain herein of 46,000 to 119,000 GWH annually by 2025 is, therefore, considered to be highly conservative.

6
WATERPOWER'S RELEVANCE TO U.S. ENERGY NEEDS

Several key issues of relevance to the U.S.'s current and future energy goals and of relevance to this assessment include the need for:

Immediate and long-term renewable capacity,

Integration of renewable capacity with the grid,

Reasonable timeframes for development and deployment of new renewable technologies,

Energy security.

In addition, it is increasingly being recognized that carbon emission reductions are needed to address global climate change concerns. Waterpower, per the estimates developed herein, can address many of these issues and make significant contributions to achieving the nation's energy needs and environmental protection challenges.

In the short-term (present to 2015), conventional hydropower with enhanced environmental and efficiency performance can begin to immediately address these issues. As RDD&D advances, the emerging waterpower technologies will further contribute (by 2025) to our renewable energy supply. The linkage between near-term achievable results, primarily from existing technologies supported by economic stimuli and longer-term development supported by a program of RDD&D that focuses on developing the next generation of environmentally protective waterpower technologies forms the basis of the projections in capacity and generation presented herein.

Outlook for U.S. Renewable Generation

Today, conventional hydropower is the nations leading source of renewable generation. Table 6-1, compiled from DOE-Energy Information Administration (2006) statistics, shows the percentage breakout by renewable technology. The projections contained herein – 23,000 MW of new waterpower capacity by 2025 – would add an additional projected gain of 46,000 to 119,000 GWH annually by 2025.

Existing hydropower, furthermore, can enhance the performance of intermittent renewable generation and support their expansion, by providing energy storage and system integration options. The RDD&D initiated by DOE and reported in their 2006 biennial report (DOE 2006a) needs to be continued if intermittent renewable generation (like solar and wind) is to be effective in the electric power grid at increased commercial volumes.

Table 6-1
U.S. Renewable Generation (MWHs) 2000 to 2004 (DOE/EIA 2006)

Renewable Technology	Annual Generation (MWHs x 10^6)					
	2000	**2001**	**2002**	**2003**	**2004**	**%**
Conventional Hydroelectric	275.6	217.0	264.3	275.8	269.6	75%
Biomass	60.7	57.0	61.5	61.3	60.0	17%
Geothermal	14.1	13.7	14.5	14.4	14.4	4%
Solar	0.5	0.5	0.6	0.5	0.6	<1%
Wind	5.6	6.7	10.4	11.2	14.2	4%
Total	356.5	294.9	351.3	363.2	358.8	100%

Waterpower RDD&D Relevance to Other Renewable Technologies

Waterpower RDD&D programs outlined in the Advanced Water Energy Initiative also has direct relevance to other renewable technology development and operation. Waterpower RDD&D supports, for example:

Electric system integration and load firming for technologies that utilize renewable resources such as wind and solar energy.

Energy storage development and utilization (including for advanced pump storage) to further firm and optimize intermittent renewable technology generation.

Developing environmentally-friendly turbine designs, advances in computational fluid dynamics (CFD) modeling, prototype testing tools and procedures.

Developing meteorological forecast tools, and data storage and use techniques.

Energy-Water Nexus Roadmap Program objectives that are focused on providing efficient and adequate water use and supply for energy and consumptive use needs.

Availability of Waterpower Generation

Conventional hydropower can provide a significant short-term contribution of renewable energy with economic incentive programs that are structured according to the realities of project design, financing, permitting and licensing, and implementation. This would be accomplished through capacity additions and generation efficiency improvements; however, PTC and CREB programs need extension beyond 2008 (http://www.awea.org/newsroom/releases/Congress_extends_PTC_121106.html; credit was extended for one year on December 12, 2006). The short-term achievable generation is shown on Figures 6-3 and 7-1. This generation is consistent with environmental protection objectives and eligible under the FERC certification guidelines.

The next generation waterpower technologies (hydrokinetic and ocean energy devices) require a longer-term RDD&D period. These technologies are in the early development and demonstration phase, similar to where the wind industry was in the 1980s. In order for these technologies to be deployed, even to the conservative generation estimate presented herein, significant private and public investment will need to take place. An examination of the successful history of the wind industry provides a perspective on this challenge. The wind industry has gone from virtually zero capacity to ~10,000 MW of nameplate capacity in less than 30 years. Figure 6-1 illustrates the annual and cumulative DOE investment in wind energy R&D (noted on the right Y-axis) to achieve the current (2004) 9,100 MW of installed wind capacity in the U.S. This achievement took 28 years (1978 to 2005) with annual DOE R&D investments ranging from early-year funding of $82 to $134 million per year to a low of $11 million in 1990. Average annual DOE R&D appropriation has been $47 million to support wind energy technology development. Wind energy generation is further projected to grow at approximately a 2,500 to 3,500 MW annual rate (AWEA 2006).

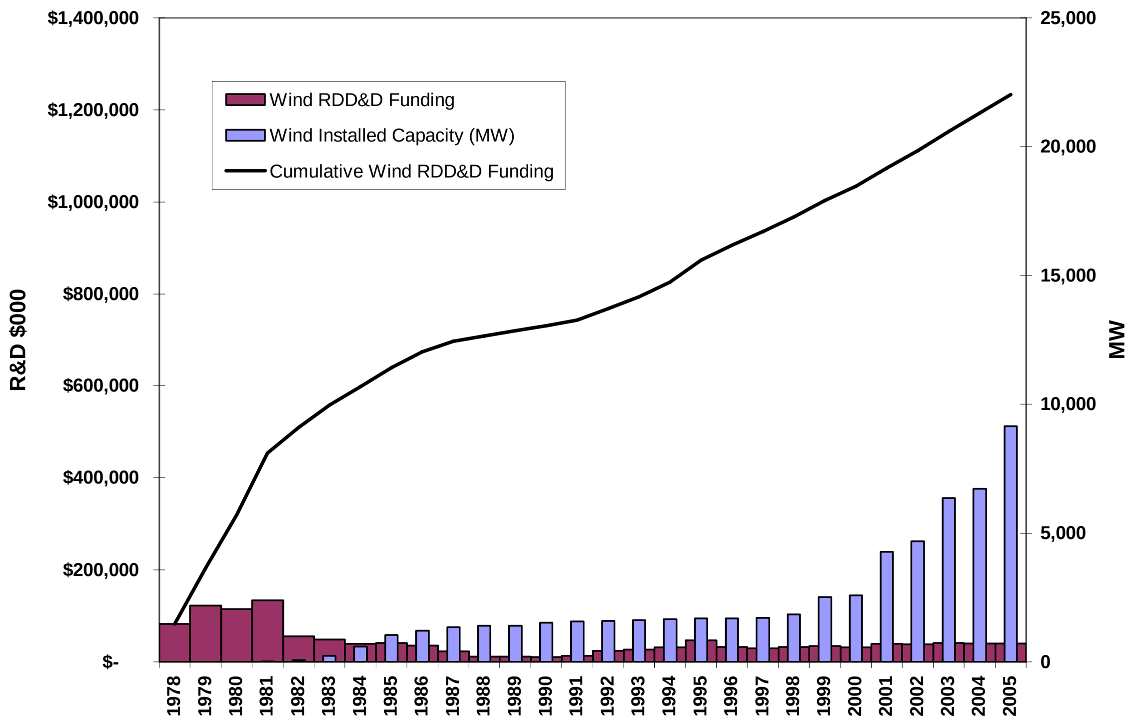


Figure 6-1
Wind Energy R&D and Realized Capacity (DOE/EIA 2006; DOE 2006b; http://www1.eere.energy.gov/windandhydro/wind_budget.html)

The history of funding of DOE hydropower R&D has been at significantly lower levels than for wind technology and, most recently, the 2006 and 2007 funding have been directed at closing the hydropower program completely. Figure 6-2 illustrates the annual and the cumulative commitment of R&D funding to each technology over the years 1978-2006.

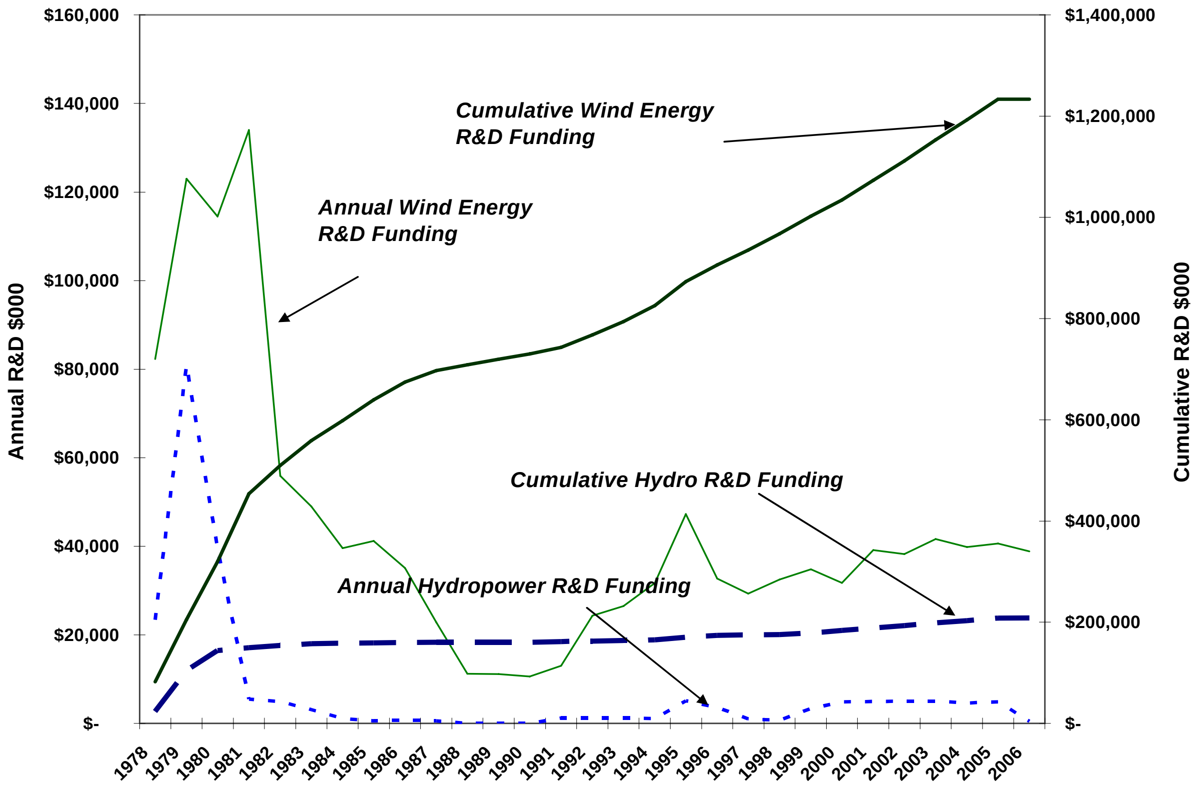


Figure 6-2
Hydropower and Wind RDD&D Funding 1978-2006 (DOE/EIA 2006; DOE 2006b; http://www1.eere.energy.gov/windandhydro/wind_budget.html)

Patterned on the history of the wind energy program, the Advanced Water Energy Initiative (AWEI) continues and expands on the momentum of the previously successful but incomplete DOE programs bridging the gap until next generation technologies are commercially available. The AWEI offers a consolidated program that describes both short-term (to 2010) and longer-term (to 2015) programs that will provide the necessary technological impetus to realize growth of capacity on more of a continuum by taking advantage of near term opportunities in conventional hydropower leading to the longer term potential that emerging technology represents. These programs would support the waterpower industry through a 10-20 year development program.

The estimated annual and cumulative costs of the AWEI and the estimated associated capacity gains are presented in Figure 6-3. This program amounts to a short-term commitment by 2010 of $212 million and a long-term commitment by 2015 of $377 million. An average annual commitment over the 10 year period of $37.7 million is estimated to result in 23,000 MW or more of additional capacity.

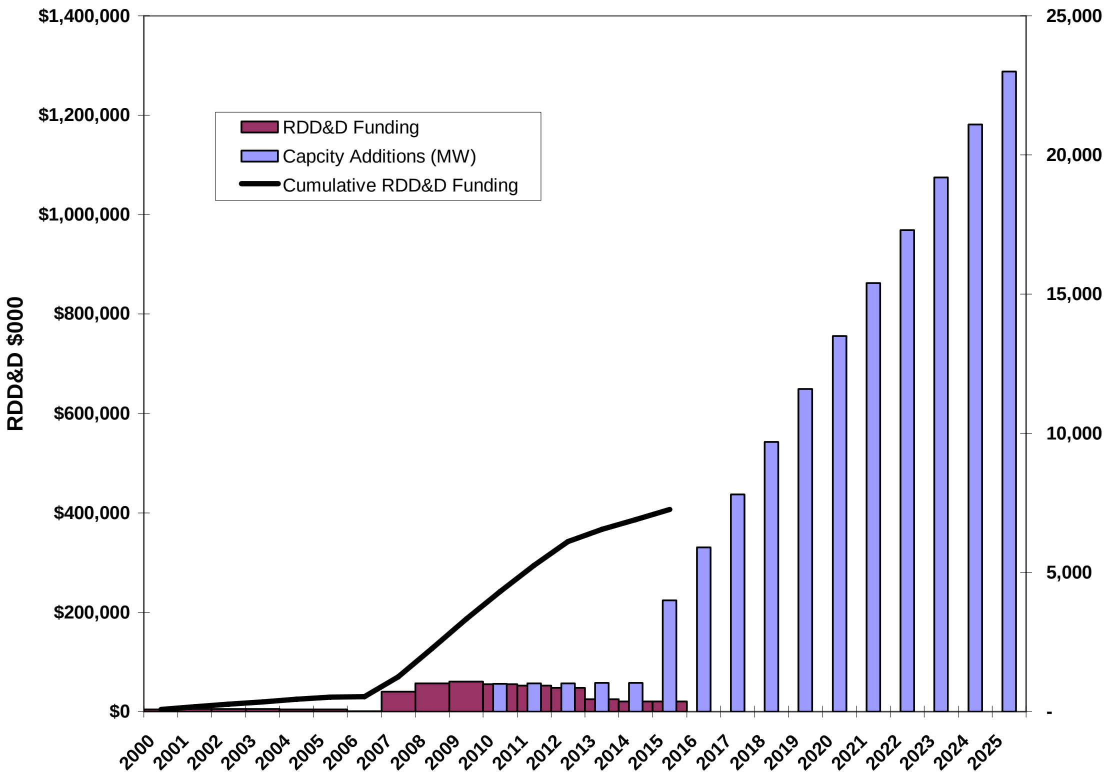


Figure 6-3
Estimated Advanced Waterpower Energy Initiative (AWEI) RDD&D Annual (2007 to 2015) Funding and Capacity Gains by 2025

Waterpower's Relevance to Carbon Emissions

Green house gas (GHG) or carbon emissions by waterpower energy technologies are minimal relative to emissions from fossil-based technologies. Energy gains from waterpower technologies as projected herein avoid increases that would be expected if the gain is derived from fossil-based technologies. This is true for both conventional hydropower technology improvement and expansion and emerging waterpower technologies since neither is dependent on increasing existing reservoir sizes. Improving capacity through up-rating and efficiency improvements will have the effect of increasing available megawatt hours of generation without changing reservoir size therefore producing no net increase in GHG production that might be attributed to the decay mechanisms in the reservoir (Tremblay et al. 2005). GHG production from reservoirs remains a controversial topic and unresolved technical issue (Harvey 2006; Cullenward and Victor 2006; Fearnside 2004, 2006; Rosa et al. 2004, 2006; IRN 2006 and http://www.irn.org/programs/greenhouse/index.php?id=resemissions.html). Significant emissions may be highly dependent on geographic location such as tropical and sub tropic regions (Tremblay et al. 2005). Hydrokinetic and wave energy technologies require no impoundments, therefore, the issue is not relevant.

DOE/EPA (2000) reports that coal-based electricity production results in 1.341 lbs of CO_2/kWh which is equivalent to 4.917 units of carbon (http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf). Table 6-2 presents estimates of the amount of carbon that can be offset by electricity derived from adding waterpower-based generation in lieu of fossil-based production. This calculation assumes that:

National average is 1.341 lbs CO_2/kWH for coal production based on DOE/EPA (2000) estimates.

1 MW of hydro x 50 percent capacity x 95 percent availability x 365 day x 24 hrs = 4,161 MWH/yr.

4,161,000 kWH/yr x 1.341 lbs CO_2/kW-hr = 5,579,901 lbs CO_2/yr (2,790 tons CO_2/yr reduction for each new MW of hydro capacity (if it is assumed that the capacity factor is 35 percent, the estimate is 1,953 tons of CO_2/yr reduction per MW)).

For Table 6-2, 1.341 lbs CO_2/kW hr x 1,000,000 kWH/GWH/2,000 lbs/ton = 670.5 tons of CO_2/GWH.

CO_2 x 12/44 (atomic ratio) = carbon units; therefore, 670.5 tons CO_2 x 12/44 = 183 tons carbon units/GWH of hydro generation.

Table 6-2
Potential Carbon Offset Realized through Waterpower Gains[1]

Waterpower Technology	2006 Existing Waterpower		2025 Projected Waterpower	
	Hydropower Generation (GWH x 10^3)	Carbon Offset Units (Tons x 10^6)	Waterpower Incremental Generation (GWH x 10^3)	Incremental Carbon Offset Units (Tons x 10^6)
Conventional Hydropower (efficiency improvements)	261 to 293	47.7 to 53.6	5 to 47	0.91 to 8.6
Conventional Hydropower (capacity increase)	–	–	~36	~6.6
Hydrokinetic	–	–	8.7	1.6
Ocean Energy	–	–	29	5.3
Total	**261 to 293**	**47.7 to 53.6**	**~79 to 120**	**~14.4 to 22.1**

[1]See Table 5-2 for derivation of projected incremental generation estimates.

Waterpower and Domestic Energy Security

Expanded use of waterpower technologies can also contribute to the nation's energy security. Based on EIA data for 2005 (http://www.eia.doe.gov/overview_hd.html), oil still accounts for 3 percent of the nation's electricity production, approximately 122,000 GWHs. Approximately 585 barrels of #2 fuel oil are required to produce 1 GWH of electrical power (http://www.energy.gov/energysources/oil.htm). Table 6-3 presents the number of barrels of oil that could be offset from future electric generation from waterpower. This offset oil could be used to supply other national needs without requiring additional imports.

Table 6-3
Potential Oil Use Offset through Waterpower Gains[1]

Waterpower Technology	2006 Existing Waterpower		2025 Projected Waterpower	
	Average Hydropower Generation (GWH X 10^3)	Equivalent Oil Offset (Barrels/yr x 10^6)	Waterpower Generation (GWH x 10^3)	Equivalent Oil Offset (Barrels/yr x 10^6)
Conventional Hydropower (efficiency improvements)	261 to 293	152.7 to 171.4	5 to 47	2.93 to 27.5
Conventional Hydropower (capacity increase)	–	–	~36	21.1
Hydrokinetic	–	–	8.7	5.1
Ocean Energy	–	–	29	17.0
Total	**261 to 293**	**152.7 to 171.4**	**~79 to 120**	**46.0 to 70.6**

[1]See Table 5-2 for derivation of projected incremental generation estimates.

7
SUMMARY

While the clear Congressional directive in the Energy Policy Act of 2005 (EPACT 05) to examine hydropower technologies is stated, this report is only a precursor to a more comprehensive DOE study necessary to fully respond to the directive (Section 931 of EPACT 05) to:

> *"conduct a program of research, development, demonstration and commercial application for cost competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity of the energy supply of the United States, including:* ***(i) Fish-friendly large turbines. (ii) Advanced technologies to enhance environmental performance and yield greater energy efficiencies.*** *(…) The Secretary shall conduct research, development, demonstration, and commercial application programs for –* ***(i) ocean energy, including wave energy (…) and (iv) kinetic hydro turbines."[bold is emphasis added]***

This EPRI study was not designed to respond to the full range of needs specified in the EPACT 05 mandate to the DOE. The scope of this EPRI study is to highlight some of the needs, the potential results and achievable timeframes for a comprehensive program of:

- Research, development, demonstration and deployment (RDD&D), and
- Economic stimuli and incentives.

Regulatory process enhancement, although not examined in-depth in this assessment, could further contribute to achieving the waterpower energy potential. Several key next steps in these areas that would advance the realization of the waterpower potential are subsequently summarized.

RDD&D Commitment

DOE's EPACT 05 mandate can be achieved with adequate funding and a more comprehensive analysis of the RDD&D needs by the Department conducted in conjunction with industry support. An initial list of RDD&D needs has been provided herein as a starting point to support planning and collaboration. Additional steps that would advance the realization of the waterpower potential include:

- Beginning a dialogue with DOE and DOI on a near-term Advance Water Energy Initiative (AWEI) that incorporates the RDD&D needs discussed herein and those that will be further identified.
- Actively seek a funding solution that concurrently supports the completion of RDD&D for conventional hydropower efficiency gains, enhanced environmental performance, and development of the EPACT mandated 'roadmap' for the next generation waterpower technologies.

Continue supporting work in the Energy-Water Nexus implementation plans that embrace many of the RDD&D needs discussed herein including those associated with insuring the future availability of water for energy production.

Initiate efforts to have the estimates of waterpower potential included in the Energy Information Administration's Annual Energy Outlook and NEMS modeling programs (see Appendix A).

By moving down a RDD&D path that embraces all waterpower technologies in a comprehensive manner, the potential presented and discussed herein can be realized. This study estimates that a 10-year $377 million AWEI commitment (averaging $37 million/yr) can yield 23,000 MW of waterpower capacity by 2025. By comparison, the proposed 10-year AWEI funding level is 31 percent of the 28-year funding of the wind industry ($377 million vs. $1,200 million) and could yield twice as much installed capacity (23,000 MW vs. 9,100 MW) in a shorter (20- vs. 28-year) timeframe.

Economic Incentives

The link between economic stimuli and renewable energy capacity development is documented herein. Investment requirements far exceed the stimulus but incentives are needed to attract industry to make the necessary commitments. The experience of the wind industry demonstrates the need for economic stimuli and the direct link to near-term gains.

Extension of PTCs and CREBs for the waterpower industry will support expanded and more effective efficiency improvements and technology development. The industry requires extensions to accommodate the time frames that are consistent with permitting, design and construction of capital-intensive incremental and new waterpower technologies. The existing 28-month timeframe for development, even at existing hydroelectric facilities, is not compatible with the existing regulatory structure and the design-procurement-manufacture-installation process that is required for both small and large hydroelectric projects.

Additionally, increasing the PTC to 1.9 cents/kwh, consistent with other renewables in the PTC program, would further encourage development of efficiency improvements and deployment of incremental systems. Broadening the definition to incorporate hydrokinetic and wave energy technologies would accelerate their development and deployment. Figure 7-1 illustrates the potential short-term realization of waterpower capacity gains from an extension of PTCs (and the public sector CREBs) and the longer term potential if the credits are extended and the definitions broadened to incorporate emerging waterpower technologies.

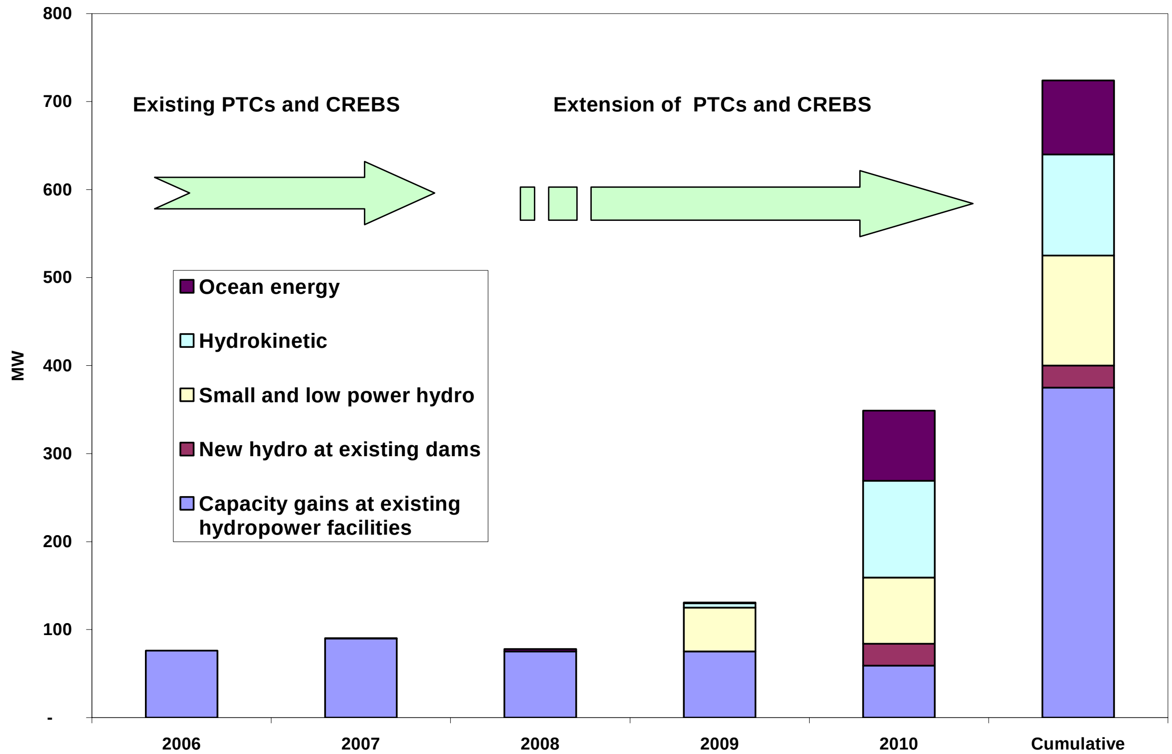


Figure 7-1
Potential Short-Term Realization of Waterpower Gains from PTCs and CREBS

Regulatory Enhancement

The realization of the full waterpower energy potential may be further accelerated with enhancements to the existing regulatory structure. Although not examined in depth in this study, existing regulatory processes and environmental protection study requirements may be a significant hindrance to technology development and deployment. FERC and DOI Mineral Management Service process revisions that reflect the timeframes required for technology design, development and deployment could accelerate achievement of the waterpower energy potential.

8
REFERENCES

American Wind Energy Association (AWEA) website: www.awea.org, September 2006.

Bedard, R. 2006. HydroKinetic Energy "Lay of the Land", Presentation at DOE Hydrokinetic Workshop, October 26, 2006. Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop, October 26-28, 2005, Washington, D.C. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program, Washington, D.C. Proceedings can be downloaded at: http://hydropower.inl.gov/hydrokinetic&wave/.

Brown, S. R. 2006. Innovations in turbine design and fish protection at Wanapum, USA. Hydropower & Dams Issue 4.

Brown, S. R., and G. M. Garnant. 2006. Advanced-design turbine at Wanapum Dam improves power output, helps protect fish. HydroReview Special Report. April 2006.

Čada, G. F. 2001. The development of advanced hydroelectric turbines to improve fish passage survival. Fisheries 26(9):14-23.

Conner, A. M., J. E. Francfort, B. N. Rinehart. 1998. U.S. Hydropower Assessment Final Report. Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID. December 1998. DOE/ID-10430.2. Report can be downloaded at: http://hydropower.inel.gov/resourceassessment/index.shtml.

Cook, T. C., G. E. Hecker, S. V. Amaral, P. S. Stacy, F. Lin, and E. P. Taft. 2003. Final report – pilot scale tests Alden/Concepts NREC Turbine. Holden, MA. Prepared for U.S. Department of Energy, Washington, DC. Contract No. DE-AC07-99ID13733.

Coutant, C. C. and G. F. Cada. 2005. What's the future of instream flow? HydroReview 24(6) p. 42. HCI Publication, Inc., Kansas City, MO.

Coutant, C. C., R. Mann and M. J. Sale. 2006. Reduced Spill at Hydropower Dams: Opportunities for More Generation and Increased Fish Protection. U.S. DOE Wind and Hydropower Technologies Program. ORNL/TN-2005/179, September 2006.

Cullenward, D. and D. G. Victor. 2006. The dam debate and its discontents. Climatic Change 75:81-86.

Dresser, T. J., C. L. Dotson, R. K. Fisher, Jr., P. Heisey, D. Mathur, J. R. Skalski, and R. L. Townsend. 2006a. Wanapum Dam advanced hydro turbine upgrade project: Part 1 – passage survival and condition of yearling Chinook salmon through an existing and advanced hydro turbine at Wanapum Dam, Mid-Columbia River, USA. Paper presented at HYDROVISON 2006, Portland, OR. HCI Publications, Inc., Kansas City, MO.

Dresser, T. J., C. L. Dotson, R. K. Fisher, Jr., M. J. Graf, M. C. Richmond, C. L. Rakowski, T. J. Carlson, D. Mathur, and P. Heisey. 2006b. Wanapum Dam advanced hydro turbine upgrade project: Part 2 – evaluation of fish passage test results using computational fluid dynamics. Paper presented at HYDROVISON 2006, Portland, OR. HCI Publications, Inc., Kansas City, MO.

Electric Power Research Institute (EPRI), Palo Alto, CA: 2002. TR-113584-V6. Directions for Hydro Research and Development. Hydropower Technology Roundup Report Volume 6.

Electric Power Research Institute (EPRI), Palo Alto, CA: 2004. TR-113584-V9. Hydropower Valuation: Appraising Hydro as a Provider of Energy, Ecocultural, and Socioeconomic Benefits.

Electric Power Research Institute (EPRI), Palo Alto, CA: 2005a. EPRI E2I EPRI Global WP 009 – U.S. Rev 1, January 2005. EPRI Wave Energy reports. 2004 Offshore Wave Power Project: A Compelling Case for Investing in Wave Energy RDD&D, Final Summary Report.:

EPRI WP-001-U.S., WEC Device Performance Estimation Methodology

EPRI WP-002-U.S., WEC Economic Assessment Methodology

EPRI WP-003-HI, Hawaii Site Survey

EPRI WP-003-ME, Maine Site Survey

EPRI WP-003-OR, Oregon Site Survey

EPRI WP-003-WA, Washington Site Survey

EPRI WP-004-NA, TISEC Device Survey and Characterization

EPRI WP-005-U.S., System Design Methodology

EPRI WP-006-HI, Hawaii System Level Design Study

EPRI WP-006-ME, Maine System Level Design Study

EPRI WP-006-MA, Massachusetts System Level Design Study

EPRI WP-006-SFA, SF California System Level Design Study - Pelamis

EPRI WP-006-SFB, SF California System Level Design Study - Energetech

EPRI WP-007-U.S., Environmental Issues Study

EPRI WP-008-USA, Regulatory Issues Study

Electric Power Research Institute (EPRI), Palo Alto, CA. 2005b. EPRI TP-008-NA – January 2005. EPRI Tidal Energy Reports: EPRI Tidal In Stream Energy Conversion (TISEC) Project, Final Summary Report:

EPRI TP-001-NA, TISEC Resource/Device Performance Estimation Methodology
EPRI TP-002-NA, TISEC Economic Assessment Methodology
EPRI TP-003-MA, Massachusetts Site Survey
EPRI TP-003-ME, Maine Site Survey
EPRI TP-003-NB, New Brunswick Site Survey
EPRI TP-003-MA, Nova Scotia Site Survey
EPRI TP-004-NA, TISEC Device Survey and Characterization
EPRI TP-005-NA, System Design Methodology
EPRI TP-006-AK, Alaska System Level Design Study
EPRI TP-006-WA, Washington System Level Design Study
EPRI TP-006-CA, California System Level Design Study
EPRI TP-006-MA, Massachusetts System Level Design Study
EPRI TP-006-ME, Maine System Level Design Study
EPRI TP-006-NB, New Brunswick System Level Design Study
EPRI TP-006-NS, Nova Scotia System Level Design Study
EPRI TP-007-NA, North America Environmental and Regulatory Issues

Energy Information Administration (EIA). 2006. Annual Energy Review. Table 8.2a, Electricity Net Generation: Total (All Sectors), July 2006. Washington, D.C. (see: http://www.eia.doe.gov/emeu/aer/contents.html).

Fearnside, P. M. 2006. Greenhouse gas emissions from hydroelectric dams: reply to Rosa et al. Climatic Change 75:1-2.

Fearnside, P. M. 2004. Greenhouse gas emissions from hydroelectric dams: controversies provide a springboard for rethinking a supposedly "clean" energy source: an editorial comment. Climatic Change 66:1-2.

Federal Energy Regulatory Commission (FERC). 2006. Website: www.ferc.gov September 2006. Washington, D.C.

Hall, D. G., and K. S. Reeves. 2006. A Study of United States Hydroelectric Plant Ownership. Idaho National Laboratory, Idaho Falls, ID. Report INL/Ext –06-11519. Report can be downloaded at: http://hydropower.inel.gov/resourceassessment/index.shtml.

Hall, D. G., et al. 2006. Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants. Idaho National Laboratory, Idaho Falls, ID. DOE-ID-11263. Report can be downloaded at: http://hydropower.inel.gov/resourceassessment/index.shtml.

Electric Power Research Institute (EPRI). Palo Alto, CA: 2006. A 21st century DOE Ocean Energy Program. Technical Proposal to the U.S. Department of Energy dated September 15, 2006.

Hall, D. G., et al. 2004. Water Energy Resources of the United States with Emphasis on Low/Head Low Power Resources. Idaho National Laboratory, Idaho Falls, ID. DOE/ID-11111. Report can be downloaded at: http://hydropower.inel.gov/resourceassessment/index.shtml.

Hall, D.G., R.T. Hunt, K.S. Reeves, and G. Carroll, G. 2003. Estimation of Economic Parameters of U.S. Hydropower Resources. INEEL/EXT-03-00662, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID. Report can be downloaded at: http://hydropower.inel.gov/resourceassessment/index.shtml.

Harvey, L. D. D. 2006. The exchanges between Fearnside and Rosa concerning the greenhouse gas emissions from hydroelectric power dams. Climatic Change 75:87-90.

HCI Publications (HCI). 2002. Final Report Part 1 R&D Recommendations; Part 2 – Summary of Current Projects 2001 Hydro R&D Forum: Paths to the Future for Research and Development. February 2002. HCI Publications, Inc. Kansas City, MO.

Hecker, G. E., and G. S. Allen. 2005. An approach to predicting fish survival for advanced technology turbines. HydroReview, November 2005. HCI Publications, Inc., Kansas City, MO.

International Rivers Network (IRN). 2006. Fizzy science: loosening the hydro industry's grip on reservoir greenhouse gas emissions research. Berkeley, CA. www.irn.org.

Kamberg, M-L. 2005. Earning "low-impact" certification: experiences and insights. HydroReview October 2005. HCI Publications, Inc., Kansas City, MO.

Low Impact Hydropower Institute (LIHI). 2006. website: www.lowimpacthydro.org, January 2007.

March, P. A. 2005a. Opportunities for Incremental Hydropower. DOE/EPA Renewable Energy Modeling Workshop on Hydroelectric Power, Washington, DC, May 10, 2005. Presentation can be downloaded at: http://www.epa.gov/cleanenergy/renew_series.htm.

March, P. A. 2005b. Real-Time Environmental Optimization: A New Frontier for Performance and Profitability. Knoxville, TN. [personal communication, October 10, 2006].

Margolis, R., and D. M. Kammen. 1999a. Underinvestment: the energy technology and R&D policy challenge. Science 285:690-692.

Margolis, R., and D. M. Kammen. 1999b. Evidence of under-investment in energy R&D in the United States and the impact of Federal policy. Energy Policy 27:575-584.

Margolis, R. M., and D. M. Kammen. 2001. Energy R&D and innovation: challenges and opportunities for technology and climate policy. *In* S. Schneider, A. Rosencranz, and J. Niles. A reader in climate change policy. Island Press, Washington, D.C.

Miller, G., J. Francheschi, W. Lese, and J. Rico. 1986. The Allocation of Kinetic Hydroelectric Conversion Systems (KHECS) in USA Drainage Basins: Regional Resource and Potential Power - Final Report. Department of Applied Science, New York University, NY. August 1986. NYU/DAS 86-151. Report prepared for U.S. Department of Energy.

National Hydropower Association (NHA). 2006. Member survey finds megawatts and jobs. NHA Today, October 23, 2006. Washington, D.C.

Ocean Renewable Energy Coalition (OREC). 2006a. Ocean Renewable Overview, October 2006. Washington, D.C.

Ocean Renewable Energy Coalition (OREC). 2006b. The Solution – OREC Funding Recommendations. July 2006. Washington, D.C.

Odeh, M. 1999. A summary of environmentally friendly turbine design concepts. U.S. Department of Energy, Idaho National Laboratory, Idaho Operations Office, Idaho Falls, ID. DOE/ID-13741. Report can be downloaded at: http://hydropower.inel.gov/turbines/index.shtml.

Rosa, L. P., M. A. dos Santos, B. Matvienko, E. O. dos Santos, and E. Sikar. 2004. Greenhouse gas emissions from hydroelectric reservoirs in tropical regions. Climatic Change 66:9-21.

Rosa, L. P., M. A. dos Santos, B. Matvienko, E. Sikar, and E. O. dos Santos. 2006. Scientific errors in the Fearnside comments on greenhouse gas emissions (GHG) from hydroelectric dams and response to his political claiming. Climatic Change 75:91-102.

Sale, M. J., G. F. Cada, and D. D. Dauble. 2006. Historical perspective on the U.S. Department of Energy's Hydropower Program. Paper presented at HYDROVISON 2006, Portland, OR. HCI Publications, Inc., Kansas City, MO.

Stewart, E.H. and J.E. Lindell. 2005. New Pumped Storage in California: Olivenhain-Hodges, Hydro Review, HCI Publications, Inc., Kansas City, MO. November 2005.

SuperGen UK. 2006. Website: www.supergen.org; September 2006.

Tremblay, A., L. Varfalvy, C. Roehm, and M. Garneau (Editors). 2005. Greenhouse gas emissions – fluxes and processes: hydroelectric reservoirs and natural environments. Springer, Berlin.

U.S. Department of Energy (DOE). 1997. Development of Environmentally Advanced Hydropower Turbine System Design Concepts. U.S. Department of Energy, Idaho National Laboratory, Idaho Falls, ID. Contract DE-AC07-96ID13382. July 1997. Report can be downloaded at: http://hydropower.inel.gov/turbines/index.shtml.

U.S. Department of Energy (DOE). In Press. Energy-Water Science and Technology Research Directions: essential elements for a reliable energy future. U.S. Department of Energy, Washington, DC. (draft in review as of Oct. 1, 2006, with plans for DOE publication in early 2007).

U.S. Department of Energy (DOE) Wind and Hydropower Budgets. www.cfo.doe.gov/budget/index.htm, www.eia.doe.gov/oiaf/servicerpt/subsidy/research.html, www.eia.doe.gov/cneaf;renewable.energy.annual/chap05.html, www.eia.doe.gov/oiaf/servicerpt/subsidy/appendix.html.

U.S. Department of Energy (DOE). 2003. Wind and Hydropower, Technologies Program. Hydropower Multi-Year Technical Plan. Washington, D.C. October 22, 2003.

U.S. Department of Energy (DOE) Sandia National Labs. 2006. Energy-Water Nexus website: www.sandia.gov/energy-water/.

U.S. Department of Energy (DOE), Energy Information Administration (DOE/EIA). 2006. Renewable Energy Annual Report 2005. Washington, D.C. February 2006. www.eia.gov/renewables. http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf; http://www.eia.doe.gov/fuelelectric.html

U.S. Department of Energy (DOE) and Morrison-Knudsen (M-K) Engineers, Inc. 1986. Small-Hydropower Development: The Process, Pitfalls, and Experience, Volume III: Technology Development Projects Summary and Analysis, NTIS No. DOE/ID-12254-1 (V.3). 1986.

U.S. Department of Energy (DOE). 2006a. DOE Hydropower Program Biennial Report for FY 2005-2006. Office of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program, Washington, D.C. ORNL/TM 2006/97 July 2006.

U.S. Department of Energy (DOE). 2006b. Annual Energy Outlook 2006 with Projections to 2030. Report # DOE/EIA-0383 (2006). Washington, D.C. February 2006.

U.S. Department of Energy (DOE)/U.S. Environmental Protection Agency (EPA). 2000. Carbon Dioxide Emissions from the Generation of Electric Power in the United States. Washington, DC. http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf

U.S. Government Accounting Office (GAO). 2006. Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs. Report to Congressional Requestors. Washington, D.C. GAO-07-106. Report can be downloaded at: http://www.gao.gov/new.items/d07106.pdf

UK Renewables website: www.ukrenewables.com/documentation/DTI_Gary_Shanahan.pdf

A
HYDRO INDUSTRY TECHNOLOGY DEVELOPMENT REVIEW

The following case histories demonstrate capacity, efficiency and environmental improvements that have been achieved by the hydropower industry as a result of economic stimuli and waterpower RDD&D. These examples support claims of realistic development, investment by private industry, and electric energy supply to the grid, which results in job formation and economic stimulation.

These case histories include:

The preliminary results from the DOE **Advanced Hydro Turbine-Large Turbine** "fish friendly" design at Grant County PUD which projects an improved fish survival rate, a 3 to 4 percent gain in water-use efficiency, and a 14 percent increase in power output. The results of this RDD&D could potentially be achieved at 20,000 MW of existing hydropower plants. The USACE is currently examining a similar project at one of their Snake River plants—the USACE Ice Harbor Dam is in the early stages of demonstration of the efficiency improvements. Completion of the environmental research and further demonstration projects is required to fully realize the generation benefits described for large hydro in this report.

The potential improvements that could be achieved from the DOE **Advanced Hydro Turbine-Small Turbine** "fish-friendly" design. This completely different design for small hydro facilities projects improved fish survival rates, and improved efficiencies and capacity expansions. This new concept—the Alden/NREC turbine design (Cook et al. 2003) is being considered at a developmental site in New York State. The Small Turbine AHTS - Brookfield Power Demonstration project could potentially increase capacity by >25 percent while improving fish passage. This design is expected to impact potentially 3,700 MW of small projects that require enhanced environmental performance and can form the basis for adding new hydro at existing dams. This RDD&D program needs to be continued to achieve these results.

New Small Hydropower at Existing dams – Expedited Licensing results in Jobs, Energy at a small existing plant in New York.

Hydropower Activity under the PTC and CREBS programs – the hydro industry is taking advantage of both of these programs with and estimated over 300 MW of new activity. Moreover, hydro owners have indicated that at least 450 MW more could be achieved if PTCs were extended for several more years.

Non-Federal Development at Federal Facilities – There is a history of non-federal development of new hydropower in the 1980s at existing dams. This development could be repeated, given economic incentives and expedited regulatory processing.

Treatment of Waterpower Technologies in the National Energy Outlook describes the oversight to include any of the potential outlined in this report in the Nations Energy Modeling and Outlook reporting Model, administered by EIA (NEMS) framework.

Advanced Hydro Turbine System (AHTS) RDD&D at Grant County PUD

This project involves installing new Advanced Hydro Turbine Systems (AHTS) at the Grant County PUD Wanapum Project. The effort commenced in 2004 and is planned for completion by 2014. The Kaplan turbine minimum gap runners (MGRs) are design to improve fish passage survival and increase efficiency.

Results: July 2006 (Brown 2006; Brown and Garnant 2006; Dresser et al. 2006a, 2006b):

First full scale demonstration of advanced hydro turbines for large scale (90 MW units)

High fish survival was achieved (98 percent).

Increased power output by 14 percent.

Water use efficiency improvements averaged 3 to 4 percent.

Three key lessons learned about hydropower RDD&D:

Government DOE RDD&D funding facilitates industry cooperation and promotes significant private sector investment:

- Under the AHTS program, DOE provided RDD&D funding input of ~$15 million between 1999-2005 (Sale 2006).
- The hydropower industry provided RDD&D seed money investment (EPRI and the National Hydropower Association's Hydropower Research Foundation (HRF) $500,000).
- Grant County PUD investment estimated at least $153 million through 2014.
- Government RDD&D must be leveraged by industry support. A $15 million government investment required at least 10-fold industry investment to lead to an improved fishery and 14 percent improvement in generation—or over 400,000 MWH per year of renewable energy.

Hydropower RDD&D implementation requires a long-term commitment to realize improvements:

- Design and manufacturing of large scale turbines required at least 5 years, performance testing and installation 1 year; once operational, monitoring and efficiency tests as well as environmental/biological criteria assessment continued for at least a year until the build out was complete. Total ~15 years for completion of RDD&D to build out.

Results are site specific but possible at other sites.

Grant County PUD, as a result of the efficiency and performance improvements and fish survival achieved is planning to install similar advanced turbines at their Priest Rapids Project beginning in 2017 and extending through 2023, based on the operating life of individual units.

U.S. Army Corps of Engineers' Ice Harbor Dam Turbine RDD&D

The success of Grant PUD has prompted others to consider advanced turbine rehabilitations at conventional units. In May 2006, the U.S. Army Corps of Engineers (USACE) sought expressions of interest and comments on a proposed design and acquisition program to develop an "environmentally friendly" advanced hydropower turbine (HCI Hydrowire 2006). The USACE and Bonneville Power Administration (BPA) reported that they are considering a partnership with industry to continue work on the advanced design.

The USACE will continue RDD&D efforts on advanced hydropower turbines even though funding has been discontinued by DOE. The USACE and BPA report that their efforts would continue the development of advanced turbine design techniques and employ proof of concept testing to demonstrate fish friendly or environmentally enhanced performance. The resulting prototype turbine will replace Unit 2 at the 603-MW Ice Harbor Dam on the Snake River in Washington when complete.

Small Turbine AHTS – Brookfield Power Demonstration

In November 2005, professionals from the waterpower industry, federal and state resource agencies, and non-governmental organizations gathered in Albany, NY to discuss a proposed installation of an advanced hydropower turbine prototype at a Brookfield Power NY hydropower project. Brookfield Power is considering installing the prototype at its 38.8-MW School Street project on the Mohawk River in Cohoes, NY. Installation of the prototype would increase project capacity to almost 50 MW. This represents an incremental gain in capacity of approximately 12 MW, or a 24,000 MWH per year generation gain (~20 percent annual generation gain).

Brookfield's plan calls for installing the DOE developed Alden/Concepts NREC advanced turbine design based on studies that indicate the design offers high fish survival rates for small plants like School Street (Cook et al. 2003). Pilot scale testing indicates fish survival through a full-size prototype might be 94 to 100 percent depending on fish species and length (Hecker and Allen 2006). It is estimated that the turbine would have maximum power efficiency up to 90.5 percent; however, design improvements could increase this potential.

The original objectives of the DOE turbine design development study were to increase fish survival during passage through the turbine to greater than 96 percent and to achieve a competitive power conversion efficiency of at least 90 percent (for the turbine only)(Cada 2001). The selected turbine design point is representative of typical hydropower turbines in the U.S. with operating flow of approximately 1,000 cfs and head up to 80 to 96 feet (Odeh 1999).

The following is an approximate task timeline for development and installation of the prototype turbine at School Street. Initiation of development and installation activities is dependent upon resolution of project relicensing issues and RDD&D support from DOE and/or industry:

Year 1-2: turbine redesign for increased power using computational fluid dynamics (CFD) modeling by redesigning the scroll case and wicket gate to improve the flow to the turbine

Year 2: design of turbine/generator hardware and preparation of construction drawings

Year 2-4: powerhouse and penstock design and construction (Brookfield project)

Year 3-4: turbine/generator construction (~$6 million – Brookfield)

Year 5: turbine testing for fish survival (~$1 million RDD&D).

The Alden/Concepts NREC turbine (Cook et al. 2003) is expected to be applicable to nearly 3,700 MW of small existing units in the 5-20 MW range and also provide some improvement in generation efficiency (exact performance not yet determined). For those companies with facilities in this category that could be up-rated or have new equipment installed, there is the added incentive offered by the 2005 Energy Policy Act and various state Renewable Portfolio Standards (RPS) or Renewable Energy Credit (REC) programs to add significant economic value to existing hydroelectric facilities.

New Small Hydropower at Existing Dams – Expedited Licensing Results in Jobs and Energy

The Oswegatchie Power plant in Edwards, NY was originally built in 1913 with capacity of 0.8 megawatts. The project was taken out of service in 1992. A recent upgrade was performed by the licensee/owner, Erie Boulevard Hydropower, L.P (EBH). Key to this development was the Federal Energy Regulatory Commission (FERC) license amendment application that was finished in only 3 months, allowing the project to be operational in 13 months. EBH filed a license amendment application on June 29, 2001 and FERC issued the order amending the license on September 17, 2001; construction began immediately thereafter.

The $3.3 million upgrade boosted capacity to 2 MW; 1 MW can provide enough power to serve approximately 750 households and, furthermore, the Oswegatchie plant upgrade increases amount of ‘green’ power potentially available to New York State. Local contractors employed an average of 20 local union workers, mostly millwrights, electricians and carpenters, and subcontracted labor from other NY firms to complete the upgrade.

Anticipated average annual power production is 9,555 MWH/year compared to original annual power production of 5,700 MWH/year. Environmental enhancements include new trash rack spacing to minimize turbine fish mortality and minimum flows in the bypass section of the Oswegatchie River to maintain fish and invertebrate community habitat. The implementation of this type of small hydro at existing dams is an example of what the hydropower industry can develop when the regulatory process is streamlined.

Hydropower Activity Under the PTC and CREBS

The 2005 Energy Policy Act amended the Internal Revenue Service Code to allow renewable energy tax credits for qualified hydropower production. FERC is responsible for certifying baseline production information and the gain in generation derived from project improvements or additions. Qualified hydropower includes incremental production attributed to gains from efficiency improvements or capacity additions placed into service after August 8, 2005, and before January 1, 2008. Several projects have taken advantage of the PTCs as discussed in Section 4 and more capacity could be developed if the PTC was extended.

In June 2006, FERC certified PacifiCorp's 161-MW Klamath project as eligible for a renewable energy production tax credit. The project (No. 2082) in Oregon and California reported that a runner replacement on Unit 2 in the J.C. Boyle development would result in a 2.6 percent net increase in efficiency. Brookfield Power also has approved plans for 10 projects to add a total of 15.6 MW of incremental capacity to ten projects at a cost of $28.8 million to take advantage of the production tax credit. Brookfield's Piney (Pennsylvania) Project was the second project to be certified. A runner replacement at this project resulted in a 7 percent increase in annual generation. These projects will add ~58,500 MWHs of annual renewable generation. Brookfield reports that these projects are both economic and have minor added environmental footprint, since they add capacity at existing projects and require minimal civil works. Four more projects are also being considered provided PTCs are extended.

Non-Federal Development at Federal Facilities

During the 1980s, development at Federal facilities was stimulated as a result of a variety of economic and institutional factors. The U.S. Army Corps of Engineers reports (personal communication, K. Sadicki, USACE National Hydropower Business Development Program Manager, September 7, 2006) that at 47 Federal facilities, approximately 1,957 MW of hydropower was developed by non- federal entities (and licensed by the FERC). These plants, generating ~6,600 GWH of renewable energy a year, were developed by private investment, conservatively estimated at $1,500/kw. This estimate equates to $2.85 billion of capital cost and construction jobs to support.

The developers were utilities, electric cooperatives, and private developers, working in conjunction with the USACE under a 1982 FERC/Department of the Army Memorandum of Understanding (MOU). The MOU required that developers work with individual USACE Districts to develop MOUs for construction and operation of the facilities. The MOUs also required that the costs for the USACE participation in these projects be recompensed, as is the cost of power at the USACE facilities, as required under the Federal Power Act. These facilities, with nearly 20 years of operating experience since construction, serve as a model for government-industry cooperation that can continue for development of untapped resources at federal facilities.

Under the Energy Policy Act of 2005, DOE, USACE and the Department of Interior (DOI) were tasked to estimate the potential for capacity development and efficiency improvements at existing federal facilities and also examine the potential for non-federal development at existing federal dams. The final report is expected in April 2007; however preliminary findings follow (personal communication, K. Sadiki, USACE National Hydropower Business Development Program Manager, September 7, 2006):

Table A-1
Existing and Potential Capacity Gains (MW) at Federal Hydropower Facilities

Federal Entities	Existing Capacity	Potential Capacity Gains with Efficiency Improvements	Potential New Hydropower at Existing Facilities
USACE	Federal: 20,000 Non-federal 1,957	~4,000 MW (20%) ~400 MW (20%)	– ~ 2,200 MW (116%)
Bureau of Reclamation	Federal 16,400 Non-federal NA	To Be Determined	To Be Determined
TVA	Federal 6,700 Non-federal 0	To Be Determined	To Be Determined

Hydropower Environmental Protection Certification

The Low Impact Hydropower Institute (LIHI 2006) certification (Kamberg 2005; also see: http://www.lowimpacthydro.org/) is a voluntary environmental assessment/certification program that has gained significant momentum and industry participation in recent years. Once certified, the owner or operator can market the power from the facility to consumers as produced by a certified Low Impact Hydropower Facility. LIHI certification may also qualify the power produced for other "green" energy certification programs, such as the Green-E Renewable Electricity Program (http://www.green-e.org/) or Renew 2000 in the Pacific Northwest (http://www.cleanenergyguide.org.nz/) or utility "green" pricing programs. In addition, certification as Low Impact qualifies the power for a beneficial rating under the Power Scorecard electricity grading program (http://www.powerscorecard.org/). Projects certified must meet LIHI's low impact determination in the following criteria areas:

River flow

Water quality

Fish passage and protection

Watershed health

Endangered species protection

Cultural resources

Recreation use and access; and

Dam removal assessment.

The projects must successfully complete LIHI's formal review process, which includes a public comment period, review by an independent technical consultant or LIHI staff, consultations with state and federal natural resource agencies, and evaluation by the LIHI Governing Board, including leaders in the river conservation and renewable energy fields (LIHI 2006).

Successful examples include the Island Park Hydroelectric Project (FERC No. 2973) constructed between September 1992 and July 1994 on the existing U.S. Bureau of Reclamation's Island Park Dam in Idaho originally constructed in 1939. The Island Park Project was originally certified by LIHI in 2001 and was the second hydropower project to be certified in the program. LIHI also recently (http://www.lowimpacthydro.org/whatsnewarticle.asp?x=40) certified the Allegheny Electric Cooperative's (AEC) Raystown Hydroelectric Project (William F. Matson Generating Station; FERC No. 2976). AEC operates the 21-MW (rated capacity) facility, which is located at the U.S. Army Corps of Engineers (USACE) Raystown Dam. The hydroelectric station, completed in 1988, is operated in cooperation with USACE. The project is located on the Raystown Branch of the Juniata River, about 5.5 miles upstream from its confluence with the Juniata River and 92 miles above the confluence of the Juniata River with the Susquehanna River. Raystown Dam and Raystown Lake are located in south central Pennsylvania in Huntingdon County, near the borough of Huntingdon.

These projects and numerous others that have received LIHI certification demonstrate that development of incremental hydropower at existing dams can be done in an environmentally acceptable way; both licensed by FERC and subject to the additional scrutiny of an independent green certification board like LIHI. As of January 2007, 23 owners of hydroelectric plants in the U.S. hold certificates from LIHI in recognition of environmentally friendly operations and improvements and 6 additional projects have certification applications under review (http://www.lowimpacthydro.org/cf.asp). The certificates cover 70 facilities with a combined capacity of more than 1,800 MW in 15 states).

Treatment of Waterpower Technologies in the National Energy Outlook

The Energy Information Administration (EIA) which is responsible for the National Energy Model System (NEMS) acknowledges in its Annual Energy Overview 2006 that that it is currently treating the reality of next generation waterpower with caution and currently not including any expectations in its NEMS analyses (DOE/EIA 2006):

> *"Hydropower: In addition to ocean-based wind power technologies, there are a number of technologies that could harness energy directly from ocean waters. They include wave energy technologies (which indirectly harness wind energy, in that ocean waves usually are driven by surface winds), tidal energy technologies, "instream" hydropower, and ocean thermal energy technologies. Although a number of wave energy technologies are under development, including some that may be near pre-commercial demonstration; the publicly available data on resource quantity, quality, and distribution and on technology cost and performance are inadequate to describe the specifics of the technologies. A handful of tidal power stations around the world do operate on a commercial basis, but prime tidal resources are limited, and the technology seems unlikely to achieve substantial market penetration unless more marginal resources can be harnessed economically. Instream hydropower technologies generally use freestanding or tethered hydraulic turbines to capture the kinetic energy of river, ocean, or tidal currents without dams or diversions. As with wave energy technologies, while some of these technologies appear to be in fairly advanced pre-commercial development, there is insufficient available information to support reasonable market assessment within the NEMS framework."*

While conventional hydropower is considered in the NEMS framework, projections are nominal compared to the potential estimated herein:

> *"Conventional Hydroelectricity: The conventional hydroelectricity sub module represents U.S. potential for new conventional hydroelectric capacity 1 megawatt or greater from new dams, existing dams without hydroelectricity, and from adding capacity at existing hydroelectric dams. Summary hydroelectric potential is derived from reported lists of potential new sites assembled from Federal Energy Regulatory Commission (FERC) license applications and other survey information, plus estimates of capital and other costs prepared by the Idaho National Engineering and Environmental Laboratory (INEEL). Annual performance estimates (capacity factors) were taken from the generally lower but site-specific FERC estimates rather than from the general estimates prepared by INEEL, and only sites with estimated costs 10 cents per kilowatt-hour or lower are included in the supply. Pumped storage hydro, considered a nonrenewable storage medium for fossil and nuclear power, is not included in the supply; moreover, the supply does not consider offshore or instream (non-impoundment) hydro, efficiency or operational improvements without capital additions, or additional potential from refurbishing existing hydroelectric capacity."*

Waterpower's potential, therefore, is not currently being considered in the NEMS framework. Estimates presented herein may provide the data and evidence such that waterpower can be included in the NEMS framework.

B
ADVANCED WATER ENERGY INITIATIVE

Waterpower Realization Committee

The proposal for an Advanced Water Energy Initiative (AWEI) includes the establishment of a Waterpower or Water Energy Realization Committee to direct and measure the progress of RDD&D. This committee, made up of representatives from industry, government resource agencies and non-governmental organizations would guide RDD&D efforts and monitor progress to ensure the realization of the capacity gains. Modeled after DOE's successful Wind Energy Coordinating Council, the Committee would measure on an annual basis the capacity gains from the various initiatives and make recommendations for refinement of the program, as necessary. The estimated committee operating costs are $1 million annually or $9 million total by 2015.

WPRD 1: Advanced Water Energy Science

Basis: Previous Hydropower RDD&D Forums; Energy-Water Nexus.

Scope:

1-A Water energy science

1-B Meteorological forecasting and optimal dispatch of energy/water systems

1-C Integration and control of renewable energy technologies

Estimated cost: $78 million over 9 years.

WPRD 1-A Water Energy Science

Basis: Previous Hydropower RDD&D Forums; Energy-Water Nexus.

1-A Estimated Cost: $32 million total over 10 years

Statement of Need: the waterpower industry has identified the need for advance scientific techniques to support:

Flow measurement – $2 million for 4 years

Modeling – $2 million for 5 years

Advanced material science – TBD

Turbine materials – $5 million for 5 years

Generator materials – $10 million for 10 years

Summary Scope of Work:

1. Flow measurement – Efficient, productive, and environmentally responsible operation of hydropower and water systems requires cost-effective flow measurement. Accurate flow values are needed for a variety of operation and environmental performance topics such as the flow environment in intakes (mean field, turbulence, time availability of the mean).

2. Modeling – The objective is to establish a program that will improve hydraulic modeling techniques for a variety of hydraulic structures. Different scale-up methods and techniques are commonly used in model testing of hydraulic structures and equipment. Improvement of these methods would support improvements of existing structural configurations and the design of new technologies.

3. Turbines – Improved Material Technologies: cavitation and abrasion reduces the runner's life, its performance, as well as draft tube life. Abrasion due to sediment loads has similar wear effect on runners, draft tubes, and penstocks. The objective of this research would be to develop better materials resistant to cavitation and erosion damage. Possible areas of investigation include ceramic overlays, thermal plasma, and intake liner systems.

4. Generators – Improved Stator Core Material: stator cores are now made by stacking thin sheets of iron. These thin sheets often present edges and corners at the slots, which score the insulation on stator bars. These cause weak points that shorten the life of the stator winding. The objective of this research is to find one or more materials suitable for use as stator core; build one prototype stator core; and study it over a period of years. This would improve generator efficiency and prevent failures.

WPRD 1-B Meteorological Forecasting and Optimal Dispatch of Energy/Water Systems

Basis: Energy-Water Nexus Research Area 5-13. Develop short, intermediate, and long-term forecasts and projections of regional meteorological conditions and integrate with optimal dispatch of energy and water systems.

Estimated Cost: $14 million over 7 years.

Statement of Need:

1. Integration of wind and other intermittent renewable energy resources with hydropower and pumped storage holds significant promise for maintaining energy reliability, however, accurate forecasting tools are not fully developed and need further RDD&D to provide accurate forecasts of next-hour and next day and longer generation with adequate lead times.

2. Global climate change creates considerable uncertainty for future regional patterns of precipitation and other conditions that affect water availability and renewable generation.
3. Integrated forecasts with optimal dispatch of energy and water systems to reduce water consumption and maximize renewable energy generation.

Research Objective

1. Develop improved near-term (hours to days) forecasts of meteorological conditions that affect aquifer, river, and other sources of water supply and renewable energy generation.
2. Develop long-term (decades to centuries) projections of meteorological conditions that determine aquifer, river, and other sources of water supply and renewable energy generation.
3. Develop strategies for integrating forecasts of wind and other intermittent generation and load with scheduling and operation of electricity generation, transmission, and river and aquifer management systems.

Summary Scope of Work:

1. Near-term forecasting of meteorological conditions: Complete RDD&D on short- and intermediate-term meteorological forecast algorithms used by wind and solar energy forecasting services to provide more accurate forecasts of same day and longer term hourly forecasts of energy generation. Demonstrate forecast algorithms via application by utility and/or regional system operators, including integration with hydro and river system models, such as Tennessee Valley Authority, Bonneville Power Administration, and others. This research activity will identify needs for improved meteorological data and instrumentation.
2. Long-term projections of (1) effects of decadal and other cycles, global climate change, and other factors on regional meteorological conditions and (2) future regional electricity and water demand, energy and electricity supply mix, and fuel costs. Assemble existing scientific knowledge and data related to decadal cycles and global climate change effects on regional meteorological conditions. Assess the information for completeness and applicability, and develop additional information or models as needed. Use river and aquifer models to forecast effects on river and aquifer resources based on forecasts of meteorological conditions, water consumption, and other factors. Forecast regional seasonal temperature, precipitation, wind, and other conditions. Develop regional projections of wind, solar, and hydro generation by season, year and the coming decades. A challenge will be the requirement for regional climate projections that can be coupled with resource models, particularly hydrologic. Develop resource maps for potential energy generation via wind, solar, and hydropower.
3. Integration of meteorological information and load, energy price, and other forecasts with energy and water system operations. Develop strategy and define metrics for optimization of energy and water systems. Develop optimal control algorithms to dispatch renewable energy, energy storage, and other electricity generation and transmission grid resources in coordination with operation of the river and aquifer systems. Evaluate performance of alternate strategies and algorithms using regional electricity system and river and aquifer models. Identify promising strategies and algorithms that best meet the objectives of reducing fresh water consumption and maximize alternative energy use.

WPRD 1-C Integration and Control of Renewable Energy Technologies

Basis: Previous hydro R&D forums (HCI 2002, EPRI 2002) and Energy-Water Nexus Research Area 5-12.

Estimated Cost: $32 million over 6 years.

Statement of Need:

Widespread adoption of renewable energy technologies and their integration with water-resource management and treatment requires the development of advanced integration and control mechanisms.

Research Objective:

Develop and commercialize the technologies, methodologies, and system applications that maximize the value of renewable energy and water resources.

Impact/Benefits:

The realization of resource sustainability through increased renewable energy utilization, water efficiency, security, and economic viability and associated reduction in negative environmental effects.

Summary Scope of Work:

Develop and demonstrate hybrid control systems to include real time pricing, resource optimization and optimal economic value methodologies. Develop control methods and mechanisms for renewable energy technologies, including:

1. Algorithm development
2. Scalable/modular control mechanisms
3. Off-grid hybrid electric/water systems
4. Integrate peripheral technologies including wind, photo-voltaics (PV), geothermal, thermal, hydro, desalination, purification, and pumping.

WPRD 2 Hydropower Environmental Performance

Basis: Energy-Water Nexus Research Area 5-2, 5-3 and 5-4.

Scope:

2-A Complete the design, testing and commercial viability assessment of fish friendly turbines

2-B Bioengineering for fish passage

2-C Water quality mitigation technology

2-D Advanced weirs for flow re-regulation and aeration

Estimated Cost: $44 million over 6 years.

WPRD 2-A Complete RDD&D for Fish-Friendly Turbines

Estimated Cost: $24 million over 6 years.

Basis: Energy-Water Nexus Research Area 5-1 and 5-7.

Statement of Need:

Protection of fisheries resources and maximizing hydropower generation. Hydropower's potential is not fully realized because significant water is diverted to fish passage structures. RDD&D on fish-friendly turbine development offers the opportunity to address both issues simultaneously. While progress has been made to date as discussed herein; significant work remains to realize the potential that exists.

Research Objective:

Fish friendly turbine concepts are either partially designed and tested with no commercial implementation (Alden/Concepts NREC turbine)(Cook et al. 2003) or have been designed and deployed but subjected to limited in-situ evaluation (Voith-Siemens design at Wanapum Power Plant, Grant County PUD, WA)(Brown and Garnant 2006; Sale 2006). Primary research objectives include (1) complete RDD&D associated with the Alden/Concepts NREC turbine and (2) continue in-situ testing of the Voith-Siemens turbine at Wanapum.

Summary Scope of Work:

1. Continue prototype Alden/Concepts NREC turbine (Cook et al. 2003) development in preparation for commercialization.
2. Perform power efficiency testing.
3. Perform additional fish survival testing.
4. Evaluate materials and manufacturing techniques and develop cost options.
5. Continue testing at Wanapum for at least one more year.
6. Deploy and evaluate the Alden/Concepts NREC design at School Street Project, NY or other location.
7. Solicit deployment and testing applications from other potential sites.

WPRD 2-B Bioengineering for Fish Passage and Entrainment Mitigation

Basis Energy-Water Nexus Research Area 5-2 and 5-3.

Estimated cost: $2 million per year for 6 years

Statement of Need:

> Fish movements upstream and downstream are blocked by hydropower structures and fish are entrained into hydropower turbines and water intakes resulting in mortality. Technology solutions to reduce this mortality and entrainment are expensive and ineffective in many cases. New, more cost-effective solutions are needed.

Research Objective:

> Develop and field-test new technology to reduce fish mortalities at hydropower facilities and improve upstream and downstream fish passage. Focus on improving the scientific understanding of fish behavior related to hydraulic conditions and using fish behavior in designing new engineering solutions.

Impact/Benefits:

> Demonstration of cost-effective technologies for fish protection will reduce public and regulatory resistance to new hydropower development (conventional and non-conventional). Development costs and cost-of-energy can be reduced with innovative technology solutions.

Summary Scope of Work:

1. Conduct basic research on the effect of hydraulic processes (velocity, pressure, shear) on fish movement including development of biocriteria for key species that can be used for improvements in civil structure (turbines, fishways, fish screens) to improve survival and passage efficiency.
2. Utilize biocriteria in the development of new turbine and fish passage designs.
3. Conduct demonstrations of new technology to determine effectiveness in real-world applications.

WPRD 2-C Water Quality Mitigation Technology

Basis: Energy-Water Nexus Research Area 5-4.

Estimated Cost: $1 million per year for 5 years.

Statement of Need:

> Dissolved oxygen (DO) and water temperature are two water quality problems often encountered at hydropower projects. Mitigation is often expensive and/or requires water to be diverted away from hydropower turbines, resulting lost energy. New, more cost-effective and less water intensive solutions are needed.

Research Objective:

> Develop and demonstrate innovative technologies, including aerating turbines; study how to optimize design and operation to minimize costs, maximize energy values, and maximize environmental benefits.

Impact/Benefits:

> Water use for energy production could increase if less is used in water quality mitigation.

Summary Scope of Work:

1. Review state of the art, document, and identify gaps/opportunities for improvement, including quantification of lost power – cover issues including selective withdrawal for temperature management and aerating turbines.
2. Develop new designs/technology and target test sites for technology deployment and testing.
3. Conduct cost-shared demonstrations of new technology to determine performance and O&M costs.

WPRD 2-D Advanced Weirs for Flow Re-Regulation and Aeration

Basis: Energy-Water Nexus Research Area 5-10.

Estimated Cost: $2 million over 3 years.

Statement of Need:

> Variable flows below hydropower projects can have adverse environmental effects on fish habitat and sediment transport during peaking operations. Re-regulating weirs can be used to stabilize river flows and also aerate waters with low DO.

Research Objective:

> Optimize the engineering designs of weirs and demonstrate how they can be used to improve the efficiency of existing projects and reduce environmental effects.

Impact/Benefits:

New technologies that enable more hydropower peaking will increase generation and allow hydropower to complement or firm-up intermittent energy from other renewables (e.g., wind and solar). Wind-hydro integration, where feasible, will have a net increase in energy system use of water.

Summary Scope of Work:

Hydraulic design studies, coupled with model tests and prototype demonstrations. Technical approach review; synthesize and publish past work; identify range of sites where peaking operations are currently happening; design appropriate solutions; deploy and demonstrate technologies such as improved weirs.

WPRD 3 Hydropower Operational Performance

Scope:

3-A Hydropower operation decision support analysis.

3-B Demonstration testing of AHTS to increase use of efficient designs.

3-C Advanced electrical components for renewable integration.

Estimated Cost: $62 Million over 8 years.

WPRD 3-A Hydro Operation Decision Support Analysis

Basis: Energy-Water Nexus Research Area 5-5 and 5-6.

Estimated Cost: $4 million per year for 6 years.

Statement of Need:

Need to understand the hydropower generation sensitivity to variability in (1) climatic/meteorologic/hydrologic processes; (2) variability in operational constraints imposed by environmental regulations and other multiple water use objectives (e.g., flood control, recreation), and (3) power demand.

Research Objectives:

Develop decision support models for scheduling hydropower facility operation and planning. This includes analysis and determination of sources of generating variability that are spatially and temporally dependent.

Impact/Benefits:

Increased overall energy system efficiency plus enhanced value of water resources utilization. Results will also reduce uncertainties in system operations leading to less conservatism in operating practices.

Summary Scope of Work:

1. Analyze and determine sources of hydropower generating variability across spatial (local to regional) and temporal (hours to seasons to years) scales.
2. Develop improved climate/meteorological/stream flow forecast models.
3. Incorporate improved understanding and forecast models into optimization and decision support models.
4. Demonstrate benefits of deploying improved decision support models to optimize the value of limited water resources for hydropower operations and energy production. For example, a pilot project that demonstrates the ability to increase overall system efficiency resulting in increased power production while meeting other water use objectives.

WPRD 3-B Demonstration Testing of AHTS to Increase Use of Efficient Designs

Basis: Energy Water Nexus Research Area 5-7.

Estimated Cost: $5 million per year for 5 years.

Statement of Need:

Advanced technologies on the threshold of implementation often are stalled because prospective users cannot justify implementation risks. Specific hydropower-related technologies where the facilitation of technology transfer could yield significant benefits are:

Installation of variable/adjustable speed turbines.

Installation of Kaplan-type advanced hydropower turbines.

Installation of hydro plants at existing (non-hydro) dams and reservoirs.

Other advanced technologies will also likely need pilot testing support to achieve implementation.

Research Objective:

Foster implementation of available advanced technologies that can positively influence energy supply and water conservation from existing and new hydropower installations.

Impact/Benefits:

Advanced technologies have high potential for adding to national supplies of hydroelectric power (without diminishing water supplies).

Summary Scope of Work:

Identify key advanced technologies that are near-ready for implementation.

Support pilot testing to provide implementation experience.

WPRD 3-C Advanced Electrical Equipment for Renewable Integration

Basis: 2001 Hydro R&D Forum *Paths to the Future for Research and Development* (HCI 2002)

Two programs:

3C1 - Variable Speed Generators (RDID 1-15), and

3C2 - High Voltage Generation (RDID 3-23).

3C Estimated Cost: $13 million total over 7 years.

Statement of Need:

1. Variable speed generator technology to assist the U.S. electric utility system to respond to flexibility needs for power systems powered by base load and hydropower, as well as integrating intermittent renewables such as solar, wind and hydrokinetics into the power mix.
2. Technologies to eliminate the generator breaker and transformer failure.

Research Objective:

Demonstrate the advantages of variable speed technology at an existing hydropower or pumped storage facility.

Develop, install and test a prototype HV generator for reliability, maintenance and efficiency.

Impact/Benefits:

Variable speed technology at hydropower facilities would increase efficiency and reliability by providing ancillary services to the electric grid, a needed component for renewable integration.

Installation of a HV generator at hydropower facilities would increase efficiency by removing the electrical component losses (transformers and breakers).

Summary Scope of Work:

1. Identify an appropriate demonstration site.
2. Design and write specifications, install system, evaluate performance and report on operational results.

WPRD 4 Hydrokinetic Resource Assessment

Basis: Ocean Renewable Energy Council (OREC) 3 -year plan (OREC 2006b), EPRI (2006) research proposal to DOE.

Estimated Cost: $4 million over 2 years.

Statement of Need:

In the U.S., the preliminary estimate of waterpower potential from kinetic energy systems in free flowing rivers is about 12,500 MW (based on an 1986 study). Tidal and ocean technologies are significantly greater—10,000 to 50,000 MW as estimated by EPRI. These advanced next generation technologies are on the threshold of implementation, but require some additional site assessment and mapping program to outline the criteria for development of the resource in the U.S.

Research Objective:

Complete resource assessment and criteria protocol for hydrokinetic sites in the U.S. and make it available to potential developers, similar to the resource assessment for small hydropower completed by DOE (Hall et al. 2004 and 2006).

Impact/Benefits:

Formal siting assessments will assist developers in applying advanced technologies to privatized sites, thus advancing the deployment of next generation waterpower projects.

Summary Scope of Work:

Identify key advanced technologies criteria for siting and map potential areas within U.S.

WPRD 5 Hydrokinetic Environmental Profiling

Basis: 2001 Hydropower R&D Forum (HCI 2002) issues RDID 4-1 and 4-11.

Estimated Cost: $34 million.

Statement of Need:

> Advanced technologies on the threshold of implementation often are stalled because prospective users cannot justify implementation risks and lack of knowledge among developers regarding the environmental and institutional barriers.

Research Objective:

> Develop minimum time environmental data collection and analysis techniques for use in site evaluation of hydrokinetic machines.

Impact/Benefits:

> Research would result in standardized monitoring techniques for evaluating the environmental impacts of hydrokinetic technologies use of which will expedite the development, optimization and deployment of the technologies and realization of the energy potential.

Summary Scope of Work:

> Identify key advanced technologies ready for implementation.
>
> Support pilot testing to provide implementation experience.

WPRD 6 Hydrokinetic Technology Improvement

Basis: Energy Water Nexus Research Area 5-8, 9, and 11 as well as OREC (2006b) 3-year plan.

WPRD 6-A Conduct proof of concept and demonstrations of instream kinetic systems.

WPRD 6-B Conduct proof of concept and demonstrations of tidal/wave energy systems.

WPRD 6-C Develop and test kinetic hydropower and pressure systems for manmade conduits (open and closed systems).

Estimated Cost: $86 million over 10 years.

WPRD 6-A Conduct Proof of Concept and Demonstrations of Instream Kinetic Systems

Estimated Cost: $55 million over 9 years.

Statement of Need:

Kinetic waterpower systems (i.e., systems requiring minimal civil works, dams, or tidal barrages including such technologies as horizontal and vertical axis turbines, paddle wheels, lift or flutter vanes, and venturi devices) offer significant energy potential. These systems, which operate in the "free-flowing" water currents of rivers and tidal straits, also are referred to as "instream" energy systems. Instream or kinetic waterpower systems require test support and demonstration funding to support development, deployment and realization of their potential.

Research Objective:

Determine proof of concepts with single prototype units and demonstrate operational viability and environmental effects with pre-commercial multiple unit projects.

Impact/Benefits:

Given the reliability and predictability of water flows and how close to "load pockets" these systems can be sited, the effects and benefits are an excellent source for distributed generation; base power for integrated and hybrid renewable energy systems; an opportunity for co-location with water purification systems, irrigation pumping, and for aeration of anoxic waters; and a domestic resource to help states meet their renewable portfolio standards (RPS) and energy needs.

Summary Scope of Work:

Identify universities, labs, and other entities where proof of concepts might be conducted. Help establish or collaborate with testing centers such as the UK's European Marine Energy Centre (EMEC) and National and Renewable Energy Centre (NaREC), and Canada's Cornwall Ontario River Energy (CORE) Project, where operational tests can be conducted and environmental effects can be assessed.

WPRD 6-B Conduct Proof of Concept and Demonstrations of Tidal/Wave Energy Systems

Basis: Energy-Water Nexus Research Area 5-9b and OREC (2006b).

Estimated Cost: $22 million per year for 4 years.

Statement of Need:

Wave energy systems (including such technologies as oscillating water columns (OWC) and wave energy devices (WED) have significant domestic energy potential. These systems require test support and demonstration funding to support development, deployment and realization of their potential.

Research Objective:

Determine proof of concepts with working single prototype units and demonstrate operational viability and environmental effects with pre-commercial multiple unit projects.

Impact/Benefits:

Tidal energy is a predictable and reliable resource for distributed base power and to support water supply from desalination systems. Along with energy from wave power systems, these technologies are a domestic energy resource to help states meet their renewable portfolio standards (RPS) and energy needs.

Summary Scope of Work:

Identify universities, labs, and other entities where proof of concepts might be conducted. Help establish or collaborate with testing centers such as the UK's European Marine Energy Centre (EMEC) and National and Renewable Energy Centre (NaREC), and Oregon State University's wave energy center, where operational tests can be conducted and environmental effects can be assessed.

WPRD 6-C Develop and Test Kinetic Hydropower and Pressure Systems for Manmade Conduits (Open and Closed Systems)

Basis: Energy-Water Nexus Research Area 5-11.

Estimated Cost: $9 million over 5 years.

Statement of Need:

The nation's irrigation and water conveyance systems are a potential source of electricity generation if technologies can be developed to harness their potential. Instream turbines or kinetic waterpower systems can also operate in the "accelerated-flow" waters of manmade open conduits such as canals and aqueducts. Pressure systems can operate in closed systems such as pipes. These technologies require funding to support RDD&D to access the energy potential of irrigation and water conveyance systems.

Research Objective:

Determine proof of concepts with working single prototype units and demonstrate operational viability and environmental effects with pre-commercial multiple unit projects.

Impact/Benefits:

> The reliability and predictability of water flows and the widespread occurrence of water conveyance systems offers a domestic resource for local energy supply and to help states meet their renewable portfolio standards (RPS).

Summary Scope of Work:

> Identify universities, labs, and other entities where proof of concepts might be conducted. Help establish or collaborate with testing centers where operational tests can be conducted and environmental effects can be assessed.

WPRD 7 Advanced Ocean Energy

Estimated Cost: $60 million over 6 years (after initial combined effort).

Basis: SuperGen Advanced Ocean Program and overseas research commitments (SuperGen UK 2006; http://www.supergen-marine.org.uk/news.php).

Statement of Need:

> Federal funding of a sustained ocean energy RDD&D program and required regulatory activities would enable the U.S. to leverage its technological superiority in shipbuilding and offshore oil and gas production, creating jobs and diversifying these maritime industries toward developing new domestic energy supplies and capturing an emerging global export market.

Research Objective: Develop ocean wave energy technology industry to commercial deployment level.

Impact/Benefits: Intent to capture a significant portion of the 10,000 to 20,000 MW of ocean energy potential that EPRI (2005a) has identified.

Summary Scope of Work:

1. 7A – Marine Resources and Converters: appraisal of the energy resource and interaction between converters and fluid environment; development of methodologies for device evaluation and optimization.
2. 7B – Energy Conversion, Delivery and Storage: marine energy conversion and power conditioning; chemical conversion and transport of marine energy, network interaction of marine energy, novel control systems for marine energy converters.
3. 7C – Environmental and Cost modeling: lifetime economics, economic, environmental and social effects of new marine technologies for the production of electricity.
4. 7D – Field Deployment: moorings and foundations; full-scale field validation, laboratory testing procedures of tidal current energy devices.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

Program:

Hydropower Environmental Issues

Printed on recycled paper in the United States of America

1014762

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com