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Small Hydro and Low-Head Hydro Power Technologies and Prospects

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Summary

Climate change concerns have brought a renewed focus on increased hydropower production as a potential replacement for electricity from fossil fuels. Hydropower currently accounts for about 6% of the electricity produced in the United States, and the generation of electricity from hydropower produces essentially no emissions of carbon. However, since most of the larger, more traditional hydroelectric resources have already been developed, a clean energy rationale for development of small and low-head hydropower resources may now exist.

Power generation from rivers and streams is not without controversy, and the capability to produce energy from these sources will have to be balanced against environmental and other public interest concerns. That balance can be aided by research into new technologies and forward-thinking regulations that encourage the development of these resources in cost-effective, environmentally friendly ways which recognize that such facilities, once built, can last for at least 50 years.

A feasibility study by the Idaho National Laboratory in 2006 presented an assessment of the potential for development of small and low-head power resources for hydroelectric generation in the United States. Approximately 5,400 of 100,000 sites were determined to have potential for small hydro projects (i.e., providing between 1 and 30 Megawatts of annual mean power). The U.S. Department of Energy estimated that these projects (if developed) would result in a greater than 50% increase in total hydroelectric power generation. Low-head hydropower usually refers to sites with a head (i.e., elevation difference) of less than five meters (about 16 feet).

Run-of-river hydropower facilities generally rely on the natural flow of rivers and streams, and are able to utilize smaller water flow volumes without the need to build large reservoirs. Infrastructure designed to move water in conduits such as canals, irrigation ditches, aqueducts, and pipelines can also be harnessed to produce electricity. Pressure reducing valves used in water supply systems and industry to reduce the buildup of fluid pressure in a valve or to reduce pressure to a level appropriate for use by water system customers offer additional opportunities for power generation.

Several bills currently pending in Congress for climate change mitigation and clean energy seek to establish a federal renewable energy (or electricity) standard (RES). Foremost among these are H.R. 2454, the American Clean Energy and Security Act of 2009, and S. 1462, the American Clean Energy Leadership Act of 2009. Under current proposals, the RES would require retail electric suppliers to obtain increasing percentages of renewable electricity for the power they provide to customers. Although hydropower is generally considered as a clean source of electric power, only hydrokinetic technologies (which rely on moving water) and limited applications of hydropower would qualify for the RES. Given the current language in pending bills, it is unlikely that most new run-of-river low-head and small hydropower projects would meet the requirements for “qualified hydropower” unless these projects are installed at existing non-hydropower dams.

Given the smaller size of projects relative to the costs for development for small and low-head hydropower, incentive rates for electricity produced over time may increase the feasibility of a project based on power sales. As such, with clean energy policy as a driver, government incentives may be helpful. Further development of small and low-head hydropower on a wide scale will likely come only as a result of a national policy intended to promote clean energy goals.

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Introduction

As Congress considers clean energy legislation, one of the options for "green" electricity being discussed is the development of new hydropower resources. Many of these new resources are on small rivers and streams which may not have been considered as candidates for development due to the relatively small amount of electric power which could be produced. Hydropower currently accounts for about 6% of the electricity produced in the United States.[1] Although most of the larger, more traditional hydroelectric resources have already been developed, a clean energy rationale for development of small hydropower (i.e., with a power generation capacity of between 1 and 30 megawatts (MW)) resources may now exist.[2] Characterizing small and low-head hydropower[3] and discussing issues associated with further development of hydropower resources is the focus of this report.

Conventional Hydropower Technologies

The flow of water has been harnessed to produce electricity since the nineteenth century, and by the early part of the twentieth century, almost half of the electricity produced in the United States came from hydropower.[4] But increasing post-war electrical power needs out-stripped available hydro resources and led to the rise of power plants powered by steam from fossil and nuclear fuels.

Storage Plants

Most of the larger hydropower facilities in the United States are "storage plants" that use dams or impoundment areas to store enough water to offset seasonal fluctuations in water flow. Storage plants can provide a constant supply of electricity throughout the year and may have enough water storage capacity to operate a facility for several years. Another approach to hydropower does not usually require significant water storage and depends on the flow of rivers or streams to generate electricity. These are called "run-of-river" plants.

Impoundment of water in reservoirs behind dams allows power generation to be easily controlled, and makes the release of water adaptable to changing levels of demand for electricity. Water flows down a "penstock" or pipe to turn the blades of a turbine-generator (see **Figure 1**). The amount of electricity that can be produced depends on the volume of water flow, and the elevation difference (called "head") between the water's surface and the turbine-generator. The

[1] U.S. Energy Information Administration, Electric Power Annual, *Summary Statistics for the United States, 1997 through 2008*, Table ES1, http://www.eia.doe.gov/cneaf/electricity/epa/epates.html.

[2] DOE has identified approximately 5,677 sites with the potential to generate about 30 GW of power using small-scale hydroelectric technologies. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, *Hydropower Resource Potential*, DOE 2006, http://www1.eere.energy.gov/windandhydro/hydro_potential.html.

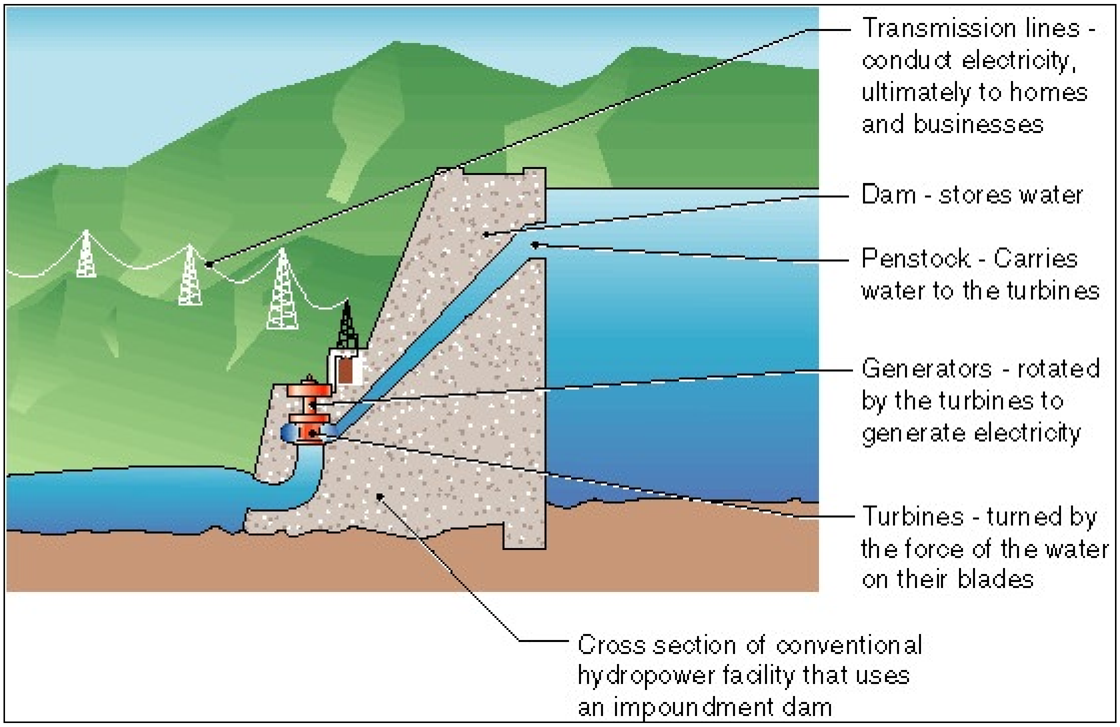
[3] Low-head hydropower usually refers to sites with a head (i.e., elevation difference) of less than five meters (about 16 feet). Sites with less than three meters (about 10 feet) of head are generally referred to as "ultra-low head."

[4] International Energy Agency, *Hydropower Implementing Agreement*, Hydropower Frequently Asked Questions, http://www.ieahydro.org/faq.htm#a4.

power produced can be used locally or sent over transmission lines to industrial or population centers.

Once a facility has been built, hydropower is one of the least expensive sources of electricity to operate since there is no fuel cost. Maintenance of dams and infrastructure is the major ongoing expense to generate electricity. Some dams serve multiple purposes, as water stored for irrigation or flood control purposes can also support recreational activities. Water can be released either to meet changing electricity needs or to maintain a constant water level for other uses.

Figure 1. Impoundment Hydropower



Source: Idaho National Laboratory

Notes: http://hydropower.id.doe.gov/hydrofacts/hydropower_facilities.shtml

Pumped Storage

Another major application of impoundment hydropower is pumped storage. In contrast to conventional hydropower plants which release water after it generates power, pumped storage plants reuse water after it initially produces electricity. Typically, the water flows from the turbines into a second, lower reservoir located below the dam. During off-peak hours (i.e., periods of low energy demand), some of the water is pumped back to the upper reservoir and re-released to generate electricity during periods of peak energy demand.

Run-of-River Plants

Where natural conditions of sufficient water flow and volume exist, electricity can be generated by "run-of-river" hydropower facilities without the need for the creation of a large reservoir. Run-of-river plants can be designed using large flow rates with low head or small flow rates with high head, relying on the natural range of the water flow in a river. Some run-of-river facilities have a dam across the width of a river to impound water, but the impoundment keeps water at levels generally within the river's banks, and water flows over the dam to continue naturally downstream.

Diversion facilities are an example of run-of-river hydropower (see **Figure 2**). These plants channel a portion of a river using a canal or penstock to capture a portion of the river's flow for power generation prior to its release at an outlet downstream.

Figure 2. Diversion Hydropower Facility

Source: Idaho National Laboratory

Notes: http://hydropower.id.doe.gov/hydrofacts/hydropower_facilities.shtml

Environmental Issues Related to Conventional Hydropower

Conventional hydropower has become controversial in recent years due to concerns over potential adverse impacts on the environment. When dams flood significant portions of land upstream, turning rivers into lakes, the change in habitat can affect wildlife and have especially dramatic impacts on migratory fish populations. Similarly, the development of dams can adversely affect water quality, as the clearing of trees can result in soil erosion and landslides which can lead to a buildup of sediments and clogged streams. Spilling water from dams can force atmospheric gases into solution in the basin water below, making the basin water supersaturated. Fish in these waters can be killed when dissolved gases in their circulatory system come out of solution to form bubbles which block the flow of blood through the capillary vessels.[5]

[5] U.S. Environmental Protection Agency, *Quality Criteria for Water 1986*, http://www.epa.gov/waterscience/criteria/library/goldbook.pdf.

Water quality for aquatic life can also deteriorate if reservoirs limit the natural flow of water in summertime. Water can become stratified, with warmer water collecting at the surface and cooler water staying at the bottom. Because the bottom water is isolated from aeration, it loses its oxygen. Many fish cannot live in these conditions. When this deep water passes through hydropower turbines, it is still low in dissolved oxygen and it can also affect the quality of water downstream of the dam. A lack of oxygen in deep reservoir water can also cause certain metals to dissolve more readily from surrounding rocks, and these metals can be released to the downstream river where they can cause water to become toxic.[6]

Even if the water quality is not degraded, major habitat impacts can occur if the natural hydrology of the river is changed (i.e., "in-stream flow" effects). If the amount of water released downstream changes, either on a seasonal basis or even on an hourly basis, adverse effects on fish and other organisms can result.[7] Dams are also associated with a number of other unfavorable environmental consequences, such as the release of soil mercury into aquatic environments, and the release of methane from decaying vegetation, but these effects may be temporary (i.e., less than 10 years).[8]

Hydropower's Untapped Potential

Most dams were built for purposes other than power generation, such as for flood control, crop irrigation, or storage of municipal water supplies.[9] While only about 2,400 of the existing 80,000 dams in the United States are used for hydropower,[10] many of the non-power dams have a significant unharnessed hydropower potential.

Incremental Hydropower

A United States Department of Energy (DOE) study in 2003 indicated that enhancing existing hydro facilities, by adding turbines to dams without any hydro capacity or enhancing existing structures (increasing capacity or adding turbines), is relatively inexpensive. Harnessing this incremental capacity could be achieved at an estimated median cost of $1,600 per kilowatt (kW) (in 2002 dollars).[11]

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[6] The biggest issue in the Northwest has been blocking upstream and downstream movement of fish. Salmon must be able to migrate upstream from the ocean to reproduce in fresh water. Even with the use of fish ladders to help salmon go up over dams and enter upstream spawning areas, the presence of hydroelectric dams essentially has changed the migration pattern of fish. The coho, chinook, and sockeye salmon populations of the Northwest, which once were abundant, are either on or will soon be on the endangered species list. Oak Ridge National Laboratory, *Dams: Multiple Uses and Types*, http://www.ornl.gov/info/ornlreview/rev26-34/text/hydside1.html. (ORNL)

[7] http://www.ornl.gov/info/ornlreview/rev26-34/text/hydmain.html

[8] Alain Tremblay, Louis Varfalvy, and Charlotte Roehm, and Michelle Garneau, *The Issue of Greenhouse Gases from Hydroelectric Reservoirs: from Boreal to Tropical Regions*, Hydro Quebec Production, University of Quebec, 2004, http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_tremblaypaper.pdf.

[9] Idaho National Engineering and Environmental Laboratory, *Hydropower - Partnership With the Environment*, 01-GA50627, June 2001, http://hydropower.inel.gov/hydrofacts/pdfs/01-ga50627-01-brochure.pdf.

[10] Oak Ridge National Laboratory, *Dams: Multiple Uses and Types*, http://www.ornl.gov/info/ornlreview/rev26-34/text/hydside1.html.

[11] The study considered totally undeveloped sites, dams without a hydroelectric plant, and hydroelectric plants which could be expanded to achieve greater capacity. Douglas G. Hall, INEEL, Richard T. Hunt, INEEL, and Kelly S. (continued...)

Small and Low-Head Hydropower

In 2006, DOE's Idaho National Laboratory assessed the potential for developing small and low-head hydroelectric generation in the United States. A set of feasibility criteria was established for "developable resources." These criteria assumed that a dam would not be required, that sites were close to towns or electricity lines and roads, and penstock lengths were based upon those at existing low power and small hydroelectric plants. Although the best areas for exploiting small-scale hydropower are those with steep rivers flowing all year round, approximately 5,400 of 100,000 sites were identified with the potential for small hydro projects (i.e., providing between 1 MW and 30 MW of annual mean power). DOE estimated these projects (if developed) could result in a greater than 50% increase in total hydroelectric power generation.[12]

Since many low-head projects seek to minimize infrastructure and costs, low-head hydro is almost always run-of-river and is designed to operate at optimal river or stream levels. However, during times when water levels are lower than designed-for conditions (perhaps due to low rainfall), such projects may have to shut down.[13]

Water Conduits, Pressure Reducing Valves, and Other Resources

Significant hydropower potential exists at water resources which have been developed to provide water for irrigation or municipal uses, and untapped rivers and streams. Pressure reducing valves (PRVs) are used in water supply systems and industry to reduce the buildup of fluid pressure in a valve, or to reduce pressure to an appropriate level for use by water system customers. PRVs can also be found at distribution points in water conduits, canals, irrigation ditches, aqueducts, and pipelines which can all offer additional power generation opportunities. In certain instances, it may be possible to replace PRVs with a "reverse pump" which can reduce the pressure in a water system while simultaneously generating electricity. A similar concept can generate electricity when water is transferred between reservoirs or is released to rivers to maintain seasonal water levels.[14] Opportunities also exist from the pressurization of water in some municipal and agricultural distribution systems to aid flow. Water is then depressurized on the distribution side when released for use. This depressurization phase could be harnessed to generate power.

Small turbines can be used in waterways and canals where the velocity of water is sufficient to make a project viable. Faster water flow in a canal provides better conditions for the generation of electric power.

(...continued)

Reeves, NPS, et al., *Estimation of Economic Parameters of U.S. Hydropower Resources*, Idaho National Engineering and Environmental Laboratory, INEEL/EXT-03-00662, June 2003, http://hydropower.inel.gov/resourceassessment/pdfs/project_report-final_with_disclaimer-3jul03.pdf.

[12] U.S. Department of Energy - Idaho national Laboratory, Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, DOE-ID-11263, January 2006, http://hydropower.inel.gov/resourceassessment/pdfs/main_report_appendix_a_final.pdf.

[13] Ian Bacon, TV Energy and Ian Davison, Montgomery, Watson & Harza, Low Head Hydro Power in the South-East of England – A Review of the Resource and Associated Technical, Environmental and Socio-Economic Issues, February 2004, http://www.tvenergy.org/pdfs/Final%20Hydro%20Report%2022April04.pdf. (LH Hydro U.K.)

[14] Summit Blue Consulting, LLC, *Small Hydropower Technology and Market Assessment*, Energy Trust of Oregon, January 2009, http://egov.oregon.gov/ENERGY/RENEW/Hydro/docs/SmallHydropowerTechnology-and-Market_Assessment.pdf. (ET Oregon).

Small and Low-Head Hydropower in Public Policy

The physical and operational attributes of a small or low-head hydropower project (primarily its location and size) will largely determine which state or federal regulations the project will be subject to. How a hydropower project delivers its electricity (including who the electric consumer ultimately is) will determine other aspects of regulatory treatment. Many small and low-head hydropower projects may serve single, end-use customers, or may connect into distribution grid networks (i.e. distributed generation), and the rationale for some of these projects will be based more on providing power rather than producing power for sales revenues. Some of the larger small hydropower or low-head projects may connect directly to transmission grids.

Building small or low-head hydropower close to existing electric distribution lines can reduce the costs of projects, especially if these facilities are to serve local loads. Larger hydropower facilities will likely connect to transmission lines, serving more remote loads or producing power for sale on the electricity grid, and may be subject to a greater regulatory burden.

Some of the larger federal hydroelectric projects were originally designed with irrigation or flood control purposes as a primary goal. The addition of power generation equipment was seen as a secondary benefit, with economic development as a motivating consideration for depressed regions of the United States.[15] Rationale for public policy concerning hydropower is now growing to include provision of clean energy, much of this from renewable energy resources and technologies. While the DOE's Energy Information Administration (EIA) classifies hydro as a renewable energy resource,[16] some environmental advocates do not consider "hydropower" as a desired resource because dams and reservoirs may have negative impacts on the environment.[17]

Renewable Energy Definitions in Pending Legislation

Several bills currently pending in Congress for climate change mitigation and clean energy seek to establish a federal renewable energy (or electricity) standard (RES). These include H.R. 2454, the American Clean Energy and Security Act of 2009, and S. 1462, the American Clean Energy Leadership Act of 2009. Under current proposals, the RES would require retail electric suppliers to obtain increasing percentages of renewable electricity for the power they provide to customers. Renewable energy technologies qualifying for the RES would include wind, solar, geothermal, marine or hydrokinetic, biomass, landfill gas, or "qualified hydropower." The sections which define "qualified hydropower" are largely focused on incremental hydropower capacity, and can be essentially summarized as follows:

> H.R. 2454—Title I, Subtitle A, at Section 101 would allow incremental capacity additions or energy efficiency improvements made on or after January 1, 1988, to an existing hydroelectric facility in-service before that date; or, capacity added on or after that date to an existing non-hydroelectric dam provided that capacity does not cause an increase in the water surface elevation solely to accommodate the hydropower project.

[15] Tennessee Valley Authority, *From the New Deal to a New Century*, http://www.tva.gov/abouttva/history.htm.

[16] Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action. See http://www.eia.doe.gov/glossary/glossary_r.htm.

[17] Sarah Phelan, *Hydropower Doesn't Count as Clean Energy*, Earth Island Institute, October 5, 2007, http://www.alternet.org/environment/64445/.

> S. 1462—Title I, Subtitle C, at Section 132 would allow efficiency improvements and incremental capacity additions made on or after January 1, 1992, to an existing non-hydroelectric dam in-service before that date; or, generating capacity added on or after January 1, 2001 (or the date of a state RES) to an existing non-hydroelectric dam provided that capacity doesn't cause an increase in the water surface elevation solely to accommodate the hydropower project. The state of Alaska is additionally allowed to include small hydropower less than 50 MW, to include power from pumped storage, and utilize energy from a lake tap for qualifying hydropower.

The provisions are very similar. Although hydropower is generally considered to be a clean source of electric power, only limited applications of hydropower would qualify to be included in satisfying the RES, i.e., incremental capacity and energy efficiency improvements to existing dams, and capacity added to existing non-hydroelectric dams. Given the current language in these pending bills, it is unlikely that most new run-of-river low-head and small hydropower projects would meet the requirements for "qualified hydropower" unless these projects are installed at existing non-hydropower dams. If these projects are designed to serve only local energy needs, ineligibility for such proposals may not be a concern to project developers. However, assuming that connecting to transmission may be cost-effective, the opportunity to qualify for possible economic and financial incentives under the proposals may be lost. It is possible that the requirements for "qualified hydropower" may change as features of the RES are debated.

Licensing and Regulatory Issues

Background

The Federal Energy Regulatory Commission (FERC) is the primary federal agency responsible for licensing of non-federal[18] hydroelectric projects. Under the Federal Power Act, FERC is authorized to issue licenses for construction, operation, and maintenance of hydropower projects.[19] Original licenses can be issued for a term of up to 50 years. The licensee is given the power of eminent domain to obtain lands or other rights needed to construct, operate, and maintain the hydroelectric project.[20]

FERC also issues licenses for the continuance of an existing project (relicensing), overseeing related environmental matters, and "oversight of all ongoing project operations, including dam safety inspections and environmental monitoring."[21]

> There are very few hydropower projects that are not subject to FERC licensing requirements. A FERC license (or an exemption from licensing) must be obtained for any hydropower project within FERC's jurisdiction, including: projects on a navigable waterway; projects that would use federal land; projects that would use surplus water or water power from a

[18] Congress enacted the Federal Power Act (Part 1) in 1935 to regulate non-federal hydropower projects. Other federal agencies, such as the departments of Agriculture, Defense, Energy, and Interior are responsible for federally-owned and operated dams under their jurisdictions.

[19] 16 U.S.C. § 796.

[20] Federal Energy Regulatory Commission, *Guide to Developing Small/Low-Impact Hydropower Projects*, http://www.ferc.gov/industries/hydropower/gen-info/licensing/small-low-impact/small-hydro.pdf.

[21] Federal Energy Regulatory Commission, *Industries - Hydropower*, January 2010, http://www.ferc.gov/industries/hydropower.asp.

> federal dam; and projects that will affect interstate commerce (those that would be connected to a regional transmission grid).[22]

FERC relicensing requirements may also lead to existing conventional hydropower projects being removed, with small or low-head hydropower projects replacing at least a part of the lost power generation capacity.[23]

Exemptions from FERC Licensing

Some developers of hydropower projects consider FERC's licensing process to be long and arduous, believing that it constitutes a "significant impediment to the development of new sites" with some cases taking as long as ten years to complete.[24] For example, for a new project to generate electricity, a hydrokinetic developer may need 25 different permits from 25 different regulatory agencies. Endangered species, water quality and marine navigation concerns, among dozens of others—must all be satisfied and licensing for a new hydro project can take years.[25]

FERC has responded to such concerns by introducing processes for expedited consideration in recent years,[26] and by allowing eligible hydropower projects to apply for exemptions from FERC's licensing requirements under Part I of the Federal Power Act. For eligible projects, getting an exemption approved is expected to be a simpler process than applying for a license.[27] These exemptions are issued in perpetuity. However, exempted projects are still subject to terms and conditions set by federal and state fish and wildlife agencies, and by FERC, and do not convey the right of eminent domain. Two types of license exemptions exist, for small hydropower projects and water transportation conduits. Conduits that use vast amounts of flowing water, like irrigation canals, aqueducts and water supply or effluent streams can use these flows for power generation.[28]

PURPA[29] and Net-Metering Rules

The Public Utility Regulatory Policies Act of 1978 requires states to implement utility conservation programs and create incentive rates for eligible small power producers and

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[22] Washington State - Governor's Office of Regulatory Assistance , *Federal Energy Regulatory Commission (FERC) License*, http://apps.ecy.wa.gov/permithandbook/permitdetail.asp?id=86.

[23] The Nature Conservancy, *Penobscot River Restoration in Maine*, http://www.nature.org/wherewework/northamerica/states/maine/preserves/art19515.html.

[24] Connecticut Clean Energy Fund, *Run-of-River Hydropower in Connecticut: Opportunities and Challenges for Developers*, September 2007, http://www.ctcleanenergy.com/Portals/0/Hydropower_Report_revised.pdf.

[25] Annie Jia, *RENEWABLE ENERGY: First revenue comes in from new hydropower* , Energy & Environment Daily - ClimateWire, August 27, 2009, http://www.eenews.net/climatewire/2009/08/27/3/.

[26] See http://www.ferc.gov/industries/hydropower/gen-info/licensing/licen-pro.asp.

[27] See http://www.ferc.gov/industries/hydropower/gen-info/licensing/exemptions.asp.

[28] Small hydropower projects are defined for the purpose of FERC license exemptions as projects that are five megawatts or less, that will be built at an existing dam, or projects that use a natural water feature for head or an existing project that has a capacity of five megawatts or less and proposes to increase capacity. Conduit exemptions are authorized for generating capacities 15 megawatts or less for non-municipal and 40 megawatts or less for a municipal project. The conduit has to have been constructed primarily for purposes other than power production and be located entirely on non-federal lands. See http://www.ferc.gov/industries/hydropower/gen-info/licensing/exemptions.asp.

[29] The Public Utility Regulatory Policies Act of 1978 (PURPA), P.L. 95-617.

cogeneration facilities. A small power production facility[30] which meets PURPA's ownership, operating and efficiency standards is called a "qualifying facility" (QF). States set the prices and mandatory purchase requirements under which utilities (under their jurisdiction) must buy from such facilities. Small hydropower facilities qualifying for QF status are eligible for such incentive rates.

Because some small power and low-head projects may serve single customers and connect to electric utility power grids, they may be eligible for "net metering" credit for the power they produce if it is in excess of their needs. According to FERC, in testimony before the U.S. Senate:

> Net metering allows retail customers that own generation to get retail rate credit for their excess generation. Net metering rules are subject to state or local rate jurisdiction unless a FERC-jurisdictional wholesale sale of power occurs. In precedent established in 2001, FERC held that a wholesale sale of power occurs under net metering only if the generator produces more energy than it needs and makes a net sale of energy to a utility over the applicable billing period…. If there are net sales of energy—and the generator is not a QF under PURPA—the generator must comply with the requirements of the FPA for wholesale energy sales. If the generator is a QF, and there are net sales of energy, that net sale must be consistent with PURPA and the Commission's regulations implementing PURPA.[31]

Potential Environmental Impacts of Small and Low-Head Hydropower

In most cases, compared to large hydro, small hydropower generating stations have relatively low environmental impacts because they are constructed in a smaller area, and rarely cause significant shoreline flooding or require large river diversions. Most of the negative environmental impacts of small hydro development can be mitigated by good design and operating practices to avoid interference with seasonal water flows and minimize impacts on fish and flooding patterns. Nonetheless, environmental impacts can occur. Greenfield development at a small hydropower site can cause problems due to dam construction, and operation and flooding of the upstream river. Although flooding is not an issue with small hydro developments at existing dams, the installation of a hydroelectric development, if not operated as run-of-river, can change the flow regime and affect fish and other wildlife and their habitats above and below the dam. Low-head hydropower development also has the potential to affect environmental components such as water quality, soils, and groundwater, as well as terrestrial and aquatic habitats and associated animals and plants, with the construction and operation phases of a project potentially affecting the local environment.[32]

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[30] A small power production facility is a power generating plant of 80 MW or less whose primary energy source is renewable (hydro, wind or solar), biomass, waste, or geothermal resources. http://www.ferc.gov/industries/electric/gen-info/qual-fac/what-is.asp

[31] U.S. Congress, Senate Committee on Energy and Natural Resources, Subcommittee on Energy, Hearing on FERC Interconnection Rulemakings, Small Generator Interconnection, 111th Cong., May 7, 2009, http://www.ferc.gov/EventCalendar/Files/20090507143027-May%207%20Distributed%20Generation.pdf.

[32] Hatch Energy, *Low Head Hydro Market Assessment*, Natural Resources Canada, H-327842, March 2008, http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier.php/codectec/En/H327842.201.01/Low+Head+Market+Assess+Rpt+-+Vol%5E1+Main+Report.pdf. (NRCan).

Research and Development

A report from the Electric Power Research Institute estimated that by 2025, potentially 2,300 MW could come from increased capacity at existing hydro sites, some 2,700 MW could come from new small and low power hydropower projects, and a further 3,000 MW could be developed from in-stream hydrokinetic projects.[33] Given this potential, research focused on small and low-head hydropower may facilitate significant development of new resources.

DOE stated that hydropower R&D in 2010 will continue technology development and testing, environmental impact studies, resource assessment, and cost analyses, even as the Administration's funding request for hydropower in FY2011 was decreased 19% from FY2010 levels.[34] DOE has already embarked on a national assessment of existing conventional hydropower infrastructure to identify opportunities for increased incremental generation, ancillary benefits, and improved environmental performance.[35]

The power generated from the flow of water in low-head projects has lower output for each unit of water flowing through a turbine than higher head applications. With the power output of a turbine/generator largely dependent on head and flow rate, decreased head must be compensated for by increased flow to produce the same amount of power. The size and cost of water conveyance structures and electromechanical equipment depend largely on flow rate. Construction costs can proportionately increase per installed kilowatt for low head developments. While placing a turbine/generator set directly in a stream can reduce the need for structural works, lower head electromechanical equipment usually gives less power per unit of weight. Also, with many low-head hydro projects being subject to a large variation in either the head or the flow, expensive frequency and voltage control equipment is often needed.[36]

Some of the new ideas emerging for low-head hydropower include concepts such as unregulated turbines which vary speed with head or flow, and permanent magnet-type generators (PMG) which produce an output voltage that varies with head and flow. Although varying the output voltage in this way may allow for a greater range of operation, PMG technology faces challenges in achieving electric grid connection approval because of synchronization issues. PMG may see increasing applications to hydropower projects as the cost of producing the magnets from rare earth metals is decreasing with patent expirations, and electronic interfaces are developed to provide synchronization. Other technologies are being developed for very low-head turbines, such as a direct-drive variable speed PMG which can be placed directly in a flow channel with

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[33] National Hydropower Association, *Hydropower's Contribution in Responding to Climate Change*, May 2008, http://files.eesi.org/leahey_050608.pdf.

[34] "DOE's waterpower program focuses on enabling the development and deployment of advanced waterpower technologies to increase water-based electrical generation through marine and hydrokinetic technologies, and by increases in incremental conventional hydropower generation." Department of Energy, FY2011 Congressional Budget Request, DOE/CF-0046. February 2010. http://www.mbe.doe.gov/budget/11budget/Content/FY2011Highlights.pdf.

[35] Hydro World, *Obama Proposes $30 Million for DOE Hydro R&D*, May 11, 2009, http://www.hydroworld.com/index/display/article-display/8532013850/articles/hrhrw/News/Obama_proposes_30_million_for_DOE_hydro_RandD.html.

[36] Hatch Energy, *Low Head Hydro Market Assessment*, Natural Resources Canada, H-327842, March 2008, http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier.php/codectec/Fr/H327842.201.01/Low+Head+Market+Assess+Rpt+-+Vol%5E1+Main+Report.pdf.

approximately four to eight feet of head. This concept can reduce civil works required for intake structures or water conveyance, and the associated cost of those works.[37]

Low-head facilities generally do not have the fish passage, dissolved oxygen, and water quality problems associated with larger hydroelectric facilities because these are generally run-of-river facilities without large reservoirs. Impoundments in general, but more specifically dams, must be cognizant of possible impacts on fish and fish passage solutions—whether they direct fish around and over dams or involve transit through turbine (i.e., fish-friendly turbines)—and still are likely to need new research if injuries to fish and mortality are going to be further minimized. "Low technology" solutions (such as waterwheels), and changed use or design of spillways are seen as ways to reduce fish passage and injury problems. New technologies which efficiently harness low head, run-of-river resources can minimize water impoundment, and in so doing reduce potential dissolved oxygen and sediment problems associated with the use of dams on aquatic ecology.[38]

Technologies for Small Hydro and Low-Head Applications

Run-of-river hydropower facilities can generate electricity by placing a small, mini-, or micro-turbine into a waterway, and do not necessarily require the construction of a large dam. Some hydropower turbine technologies do not need dams to operate, if the flow of water is large enough to turn the turbine. Site conditions will therefore dictate the economics of developing projects. Most of the technologies for high and medium head sites are fairly mature, but low head sites could benefit from innovation and optimization to develop technology that is suitable for the remaining low head resource.[39] This section will look at these smaller hydropower applications and some of the newer hydropower technologies.

Small Hydro Turbines[40]

The choice of turbine will depend mainly on the pressure head available and the design flow for the proposed hydropower project. There are two basic modes of operation for hydropower turbines: impulse and reaction. Impulse turbines[41] are driven by a jet (or jets) of water, and the water is at atmospheric pressure both before and after contact with the turbine blades. Reaction

[37] Ibid.

[38] John Kranda, *Bonneville Dam Fish Passage Facilities*, U.S. Army Corps of Engineers—Portland Distict, April 2008, http://www.nwd-wc.usace.army.mil/PB/MRC/pdf/MRC_Kranda_BONPassage.pdf.

[39] LH Hydro U.K.

[40] U.S. Department of Energy—Office of Energy Efficiency & Renewable Energy, *Types of Hydropower Turbines*, September 2005, http://www1.eere.energy.gov/windandhydro/hydro_turbine_types.html.

[41] There are three main types of impulse turbines: Pelton, Turgo and Crossflow (or Banki). *Pelton turbines* consist of a wheel with a series of split buckets around the rim. Most of the energy in the water goes into propelling the bucket. It is the most commonly used turbine and is generally used in low flow, high head conditions. *Turgo turbines* are similar to the Pelton but the jet is designed to strike the runner at an angle, thus enabling a smaller diameter for an equivalent power. The *Crossflow (or Banki) turbine* has a drum-like rotor with a solid disk at each end. The water transfers most of its momentum to the blades before falling away with little residual energy. See Summit Blue Consulting, LLC, *Small Hydropower Technology and Market Assessment*, Energy Trust of Oregon, January 2009 (ET Oregon), http://egov.oregon.gov/ENERGY/RENEW/Hydro/docs/SmallHydropowerTechnology-and-Market_Assessment.pdf.

turbines run filled with water and use both the angular and linear momentum of the flowing water to turn the rotor.[42]

A water turbine running at a certain speed will draw a particular flow. If there is not sufficient flow in the river to meet this demand, the turbine will start to drain the river and its performance is diminished. It therefore either has to shut down, or it has to change its internal geometry—a process known as "Regulation." Regulated turbines can move their inlet guide vanes and/or runner blades in order to increase or reduce the amount of flow they draw. Propeller turbines are considered best for small hydro projects with a head of 10 feet or less. Larger projects with individual turbine sizes of more than 500 kW, bulb-turbines, and vertical shaft Kaplan turbines are proven solutions.[43]

Turbines can also be classified according to available head at a site, or by power rating. A typical classification system by size is illustrated in **Table 1**.

Table 1. Small Hydro Classifications by Power Rating

Classification	Description
Small hydro	1 - 15 MW; usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand-alone or feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually proving power for a small community or rural industry in remote areas away from the grid.

Source: The Schumacher Centre for Technology & Development, UK.

Micro Hydropower

Projects for micro hydropower are designed to use the water resource available at a specific site. Micro hydropower installations are usually run-of-river systems which do not require a dam, and are sized on the flow available on a year-round basis. An intake structure (with bars or a screen to keep out fish and "debris" floating in the water) channels water via a pipe or conduit down to a turbine before the water is released downstream. The turbine is typically connected directly to a generator or alternator with a control valve to regulate the flow of water and the speed of the turbine. In general, at least three feet of head is needed with water flowing at about 20 gallons per minute for efficient turbine operation. Micro hydropower installations can use the same impulse or reaction turbine technologies as small hydropower, although "modernized" water-wheels are also being used at various sites.[44]

[42] There are two main types of reaction turbines: Propeller and Kinetic. *Propeller turbines* are similar to the propeller of a ship but acting in reverse. A "Bulb" turbine has the turbine and generator housed in a sealed unit which is submerged in the water stream. The "Stratflo" turbine has the generator attached to the perimeter of the turbine. With a "Tube" turbine, the penstock bends just before or after the runner, allowing a straight line connection to the generator. "Kaplan" turbines have adjustable blades. "Francis" turbines direct the water flow radially inward and emerges axially. *Kinetic turbines* also known as "free flow turbines" generate electricity from the kinetic energy in flowing water rather than from the potential energy of the head.

[43] LH Hydro U.K.

[44] State of Oregon, Department of Energy, *Micro Hydroelectric Systems*, November 2009, http://oregon.gov/ (continued...)

New Hydropower Technologies

New ideas are emerging for capturing energy from the flow of water. This section will look at some of the new hydropower technologies designed for use in rivers or inland waterways.

Hydrokinetic Turbines

In-river hydrokinetic electricity is generated by river currents that drive turbines that are anchored to a river bottom or attached to an existing structure such as a bridge foundation. The hydrokinetic turbines being deployed today capture the kinetic energy of a flow of water, such as a tidal stream or river, as it passes across a rotor. As shown in **Figure 3**, some designs look very similar to wind turbines deployed on land which rotate around a horizontal axis. But because water is about 800 times denser than air, hydrokinetic turbines have to be much sturdier than wind turbines.[45] In fact, the first hydrokinetic turbines used in New York's East River failed and had to be redesigned because the tidal forces were much stronger than expected.[46]

Figure 3. Hydrokinetic Turbine

Source: Verdant Power

Notes: http://hydropower.id.doe.gov/hydrokinetic_wave/pdfs/day1/02_axialflow_machines.pdf

(...continued)

ENERGY/RENEW/Hydro/Hydro_index.shtml.

[45] Other, more theoretical concepts have spiral vanes oriented around a central vertical axis in a so-called "eggbeater" design. See Idaho National Laboratory, *Hydrokinetic & Wave Technologies*, October 2005, http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml.

[46] Anthony DePalma, *East River Fights Bid to Harness Its Currents for Electricity* , August 13, 2007, http://www.nytimes.com/2007/08/13/nyregion/13power.html?_r=1&fta=y.

The first hydrokinetic project licensed by FERC went into service in 2009, and was sited at an existing hydroelectric dam on the Mississippi River in Hastings, Minnesota. The 12-foot-diameter, 100 kW turbine (resembling a three-bladed box fan) is designed to work in water flowing in one direction, driven by the water released by the dam. Additional turbines are planned for the site at a later date.

Tidal Turbines

Tidal river estuaries experience high and low tides, with water from the sea sometimes flowing many miles inland with the flood current and back out to sea with the ebb current. Tidal turbines can be located anywhere there is strong tidal flow. Tidal turbines are heavier and more expensive to build but capture more energy.[47] Tidal turbines can capture energy from ebb and flood currents. The largest tidal turbine built to-date has a capacity of 1,000 MW, and is scheduled for field-testing in the waters off northern Scotland in 2010.[48]

Fish-Friendly Turbines

Researchers have developed "fish-friendly" turbines structurally designed to move fish through with reduced impacts. New designs are emerging with capabilities for a range of operations encompassing low head conditions. Research is underway to develop structurally simple, non-regulated designs that would have a low impact on passing fish, and the ability to use a variable speed drive to give a wide range of operations for low-head conditions. Other technologies would use various blade designs to deflect fish and reduce fish damage, or accomplish better pressure distribution across the blades with lower shear stresses in the turbine. Demonstration of these technologies is needed to prove concepts or fine-tune designs.[49]

Challenges and Issues for Projects

Power generation from rivers and streams is not without controversy, and the capability to produce energy from these sources will have to be balanced against environmental and other public interest concerns. That balance can be aided by research into new technologies and forward-thinking regulations that encourage the development of these resources in cost-effective, environmentally friendly ways which recognize that such facilities, once built, can last for at least 50 years.

Hydropower project development depends largely on the characteristics of a particular site. The site will determine what type of improvements and structural works are necessary for a project. Much time and effort generally goes into pre-design evaluations of locations. This is true regardless of the type of technology that will go into the site but for small and low-head hydro, the feasibility study alone may be a significant burden for a project to overcome.

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[47] Ibid.

[48] HydroWorld, *Atlantis Resources Corp. Plans Testing of World's Biggest Tidal Turbine*, December 2009, http://www.hydroworld.com/index/display/article-display.articles.hrhrw.hydroindustrynews.ocean-tidal-streampower.2009.12.atlantis-plans_testing.html.

[49] NRCan.

Many small and low-head hydropower plants will be run-of-river facilities and therefore will be dependent upon river or stream flows. Availability can therefore be an issue since water flow can vary at certain times due to seasonal drought or rainfall conditions. As such, a plant's capacity factor (i.e., the ratio of the actual output of a power plant over a period of time and its output if it had operated at full capacity the entire time) can be diminished. Power generation could conceivably stop altogether if water flows are inadequate.

Hydropower project developers must comply with regulatory requirements. For many small and low-head hydropower projects, the costs of meeting environmental regulations and connecting to the electric grid can constitute a considerable hurdle. Hydrokinetic projects are largely in a demonstration phase. How they will perform technically, or whether they will have adverse impacts on aquatic environments or species is still being determined.

Most independent energy projects are decided on the merits of both a technical and a financial returns analysis. The biggest factor in favor of a hydropower project is the absence of fuel costs, a fact which is responsible for large scale hydro projects delivering some of the cheapest power when levelized[50] costs are considered. Given the likely smaller size of projects relative to the costs of development for small and low-head hydro, incentive rates for electricity produced over time may help make a power-based project feasible. As such, with clean energy policy as a driver, government incentives may be needed to help buttress the financial case. Further development of small and low-head hydropower on a wide scale will likely come only as a result of a national policy intended to promote clean energy goals.

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[50] The present value of the total cost of building and operating a facility over its life, as represented by equal annualized amounts.