Hydropower: The Largest Source of Renewable Energy

Course No: R03-003

Credit: 3 PDH

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Chapter 8. Hydropower

8.1 Introduction

Hydropower has been a source of U.S. electricity since 1880. Although additions to hydropower capacity have been small since 1995 (see Figure 8-1), it is currently the largest source of renewable electricity generation in the United States, representing approximately 7% of total electricity generation. Historical growth in conventional hydropower capacity[37] is shown in Figure 8-1. The trend in hydropower development is reflected in the history of annual generation[38] shown in Figure 8-2. The variability in generation after 1975 reflects both variations in water availability and, especially, the implementation of environmental and fishery-related water management practices and constraints.

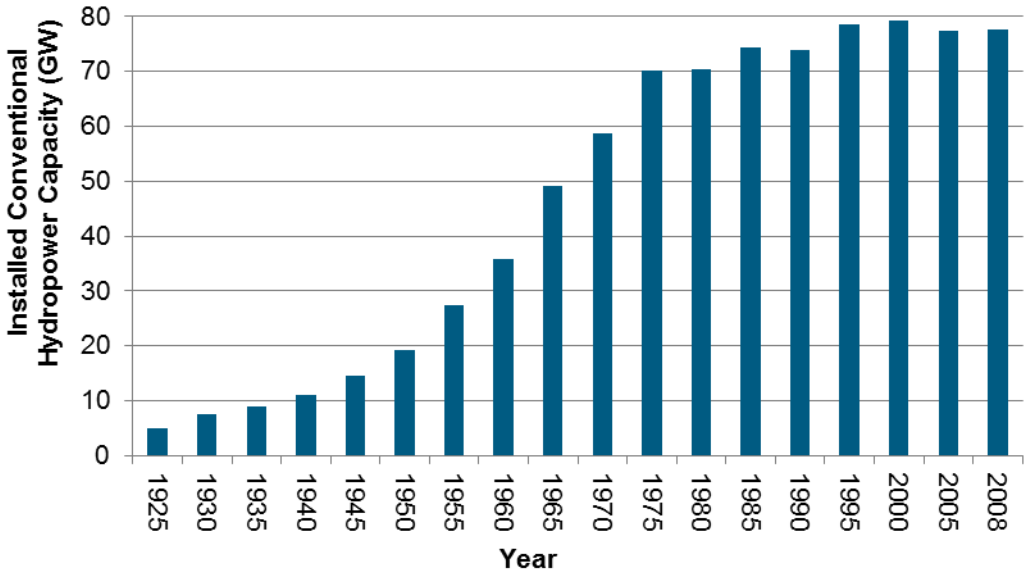

Figure 8-1. Capacity of conventional hydropower in the United States, 1925–2008

Source: Idaho National Laboratory

The current U.S. fleet of hydroelectric plants consists of slightly more than 2,200 conventional plants having a total installed capacity of approximately 78 GW and 39 pumped-storage plants with an installed capacity of slightly more than 20 GW (EIA 2008). Of the conventional plants, only approximately 15% are large plants with installed capacities greater than 30 MW, but they comprise 90% of the total installed capacity. The remaining conventional plants (more than 1,800 plants) are small plants with nameplate capacities of 30 MW or less. Approximately 70% of the conventional plants are privately owned, and 75% of total capacity is owned by federal and non-federal public owners, such as municipalities, public power districts, and irrigation

[37] This does not include pumped-storage capacity; existing and potential pumped-storage hydroelectric plants are discussed in Chapter 12.
[38] This includes pumped hydropower generation.

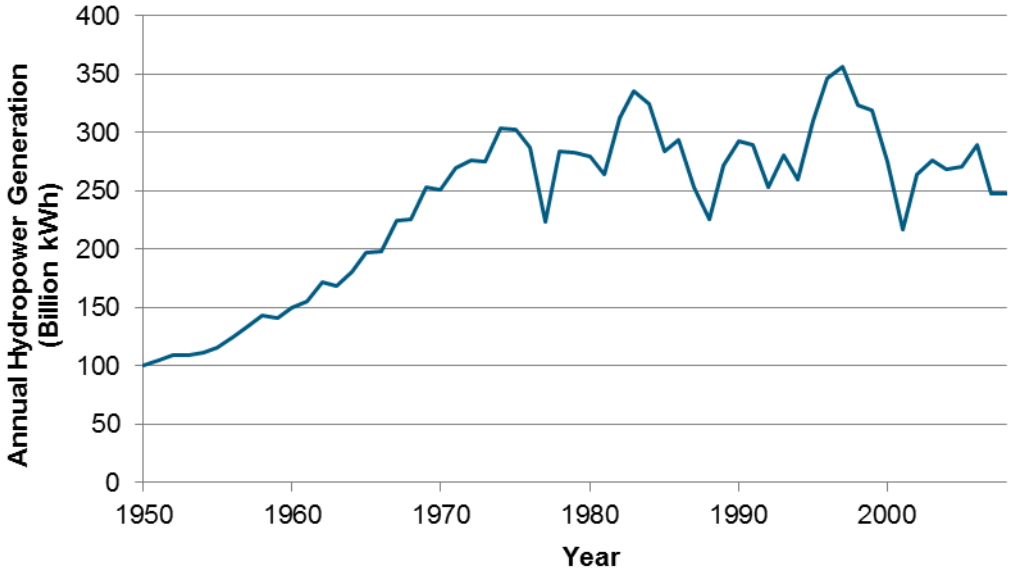

Figure 8-2. Annual hydropower generation, 1950–2008

Source: Idaho National Laboratory

districts. Hydroelectric plants are sited in all U.S. states except Mississippi (see Figure 8-2), with the greatest number being in California and New York. Washington and California have the greatest total installed capacities (Hall and Reeves 2006).

Hydropower potential used in RE Futures was limited to high-priced potential projects because the requisite data and information for lower price potential projects were unavailable. Lower-cost opportunities to increase hydropower capacity include: (1) retrofitting and upgrading equipment at existing hydroelectric plants, (2) the addition of power generation at existing non-powered dams, and (3) the use of constructed waterways (canals, water supply and treatment systems, and industrial effluent streams) as power resources. These resources are anticipated to be lower-price options because they have lower licensing and construction costs compared to "greenfield" sites. To include potential projects in RE Futures, three types of information are needed: location, capacity potential, and estimated project cost. A complete set of this information is not available for the lower-price potential projects. Studies funded by the DOE Water Power Program and the U.S. Bureau of Reclamation are currently being performed to obtain this information and will be available by 2013. This information will enable substantial updating of the hydropower supply curve (capacity versus unit development cost), and it is expected to make hydropower a more attractive option at a lower price point. This information will be of significant value for any future grid analyses, particularly given the ability of hydropower with reservoir storage to provide dispatchable power that can be used to provide ancillary services and enable greater penetration of variable renewable electricity sources.

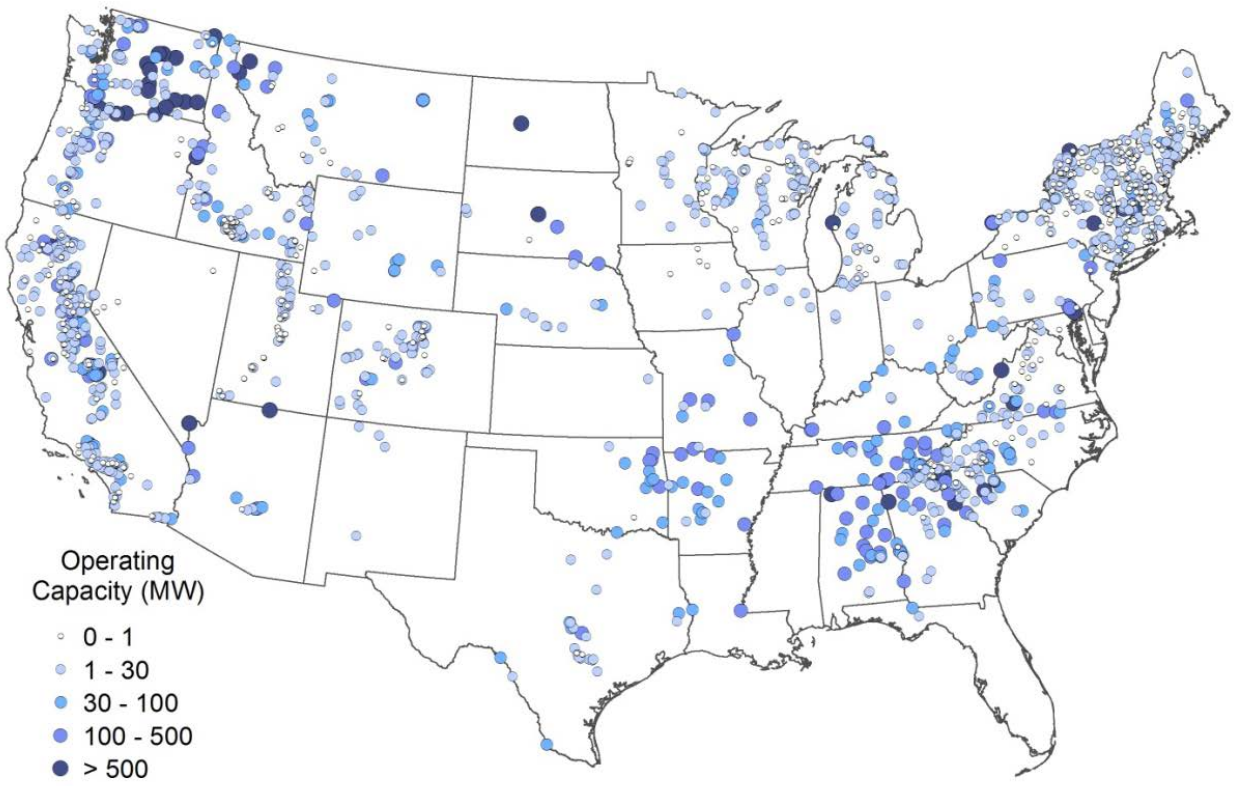

Figure 8-3. Map of hydroelectric plant locations in the United States

Data Source: Homeland Security Infrastructure Program 2010

8.2 Resource Availability Estimates

A conventional hydropower assessment of "natural streams" in the 50 U.S. states has recently been performed (Hall et al. 2004) and enhanced (Hall et al. 2006). An assessment of the power potential of explicitly adding generation at non-powered dams is under way; however, this power potential is implicitly included in the natural streams assessment for potential project sites corresponding to stream reaches[39] where a dam already exists. Additional assessments—planned and under way—address the potential for installing in-stream hydrokinetic turbines on natural streams, the potential for using constructed waterways, and the identification of sites for new pumped-storage plants.

The methodology used to perform the aforementioned conventional hydropower assessments couples the hydraulic head of a stream reach (elevation change from the upstream to the downstream ends of the reach) with an estimated reach flow rate to estimate the reach power potential. Power potential is reported as annual average power because the flow-rate estimates are derived from regression equations based on gauge-station flow rates over a 30-year period of record. Annual average power potential values are converted to potential installed capacity

[39] *Stream reaches* are stream segments between confluences. Some natural reaches were divided into smaller segments in the natural streams assessment.

values by assuming a capacity factor of 50% (0.5), which is the approximate national annual average capacity factor for hydroelectric plants (Hall et al. 2003). The use of "reach power potential" implies a development model using a stream-obstructing dam whether it is an existing or new structure.[40]

The geographic scope of RE Futures was limited to the 48 contiguous U.S. states. Therefore, the stream-reach database was screened to remove Alaskan and Hawaiian resources. Reaches having capacity potentials of less than 500 kW also were eliminated because they are unlikely to be economically feasible, and they contribute relatively little to the total gross power potential. The remaining potential project sites were further screened to remove sites in zones where development is unlikely to occur due to federal land use designations (e.g., national parks and monuments) or to being located in environmentally sensitive areas. Data from the Conservation Biology Institute (2003) were used to define the environmental exclusion zones. After removal of sites having capacity potentials less than 500 kW and those located in exclusion zones the total capacity potential of the remaining sites was 266 GW. This group of sites was further reduced by making subtractions to account for the number and total capacity of existing hydroelectric plants and questionable potential projects, as described in Section 8.3.3.2. After having made all of the described reductions, there were approximately 62,000 individual potential sites having an aggregate of 152 GW of capacity potential.

8.3 Technology Characterization

8.3.1 Technology Overview

Water behind a hydropower dam contains potential energy that can be converted to electricity in the hydropower plant. Potential energy is converted to kinetic energy as the water passes from its source through a penstock. The kinetic energy of the water is converted to mechanical energy as the water spins a turbine, which may be a simple waterwheel (e.g., Pelton and crossflow turbines), a reaction turbine (Francis turbine), a propeller-like device (e.g., simple Kaplan and bulb turbines), or a complex turbine with blades that can be adjusted during operation (articulated Kaplan turbine). The turbine is mechanically connected to a generator (see Figure 8-4), which converts the mechanical energy into electrical energy. Electricity produced in this way is commonly referred to as hydroelectricity. The capacity to produce hydroelectricity is dependent on both the flow through the turbine (typically measured in cubic feet per second or cubic meters per second) and the hydraulic "head." Head is the height measured in feet or meters; the headwater surface behind the dam is above the tailwater surface immediately downstream of the dam.

The articulated Kaplan turbine shown in Figure 8-5 illustrates the maturity of hydropower technology. This modern 100-MW unit is the product of a century of technology refinement. Figure 8-6 is a conceptual illustration of the cross section of a large hydroelectric plant that includes a dam that impounds water. This illustration represents one among the several plant configurations that are widely used for implementing hydropower, not all of which include a dam or a reservoir.

[40] Although site-specific assessments of the technical reasonableness are planned, they have not yet been performed.

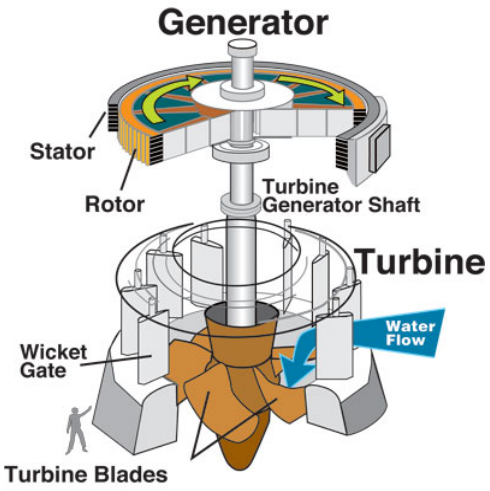

Figure 8-4. Typical hydropower turbine and generator

Courtesy of U.S. Army Corps of Engineers

Figure 8-5. An advanced modern hydropower turbine being lowered into position

Courtesy of Grant County Public Utility District

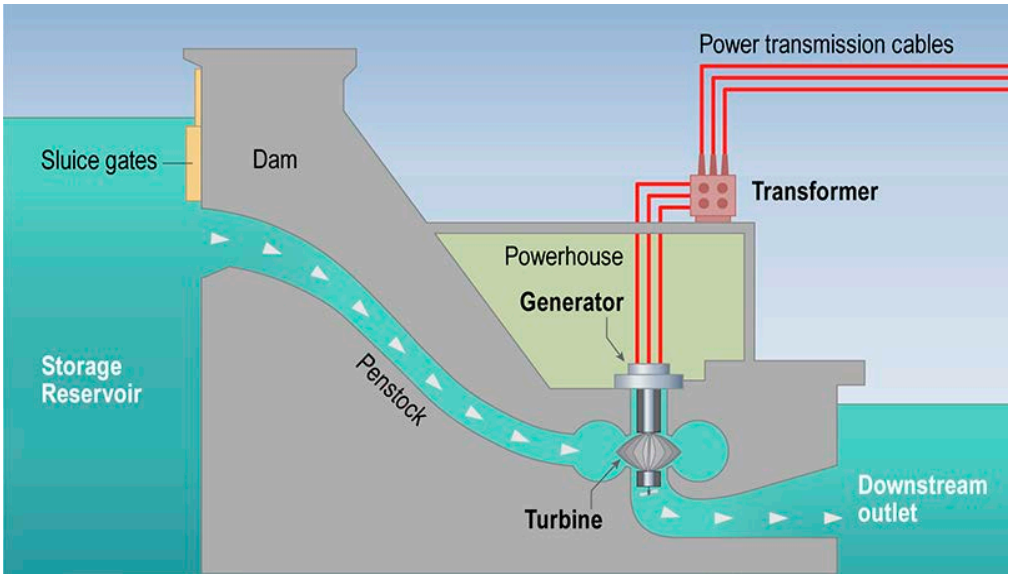

Figure 8-6. Cross section of a large hydroelectric plant

The two primary categories of conventional hydropower plants are "run-of-river"[41] and "storage" projects. A run-of-river project might or might not use a reservoir to create hydraulic head for generating power. For run-of-river projects, the flow rate of water through the turbines is very nearly the same as the rate at which water enters the reservoir from the river. A storage project uses a reservoir to increase the height of the water, but also stores water to shift the generation of power to the times or seasons having the greatest need for electricity. Water storage enables a project to vary generation and dispatch electricity to meet demand. In addition to electricity

[41] A run-of-river hydropower plant is a type of hydroelectric facility that uses the river flow with very little flow alteration and little or no storage of the water to generate electricity.

generation, storage projects commonly serve other functions such as flood protection, domestic and irrigation water supply, recreation, navigation, and environmental protection. These functions often dictate how the hydropower plant can be operated, resulting in less than optimal operation from an electricity generation perspective.

Hydroelectric plants vary in size and configuration. Plants in the U.S. fleet range from having installed capacities from 1 kW to more than 6,000 MW (FERC 2005). Large plants like that at Wanapum Dam shown in Figure 8-7 are typical of the public image of hydroelectric plants, but in reality they make up only about 15% of all hydropower plants in the U.S. fleet (Hall and Reeves 2006). At the other end of the size spectrum are small hydroelectric plants like the Fall River plant shown in Figure 8-8. These plants typically have very small footprints and often blend into the landscape. The Fall River plant is an example of one that does not incorporate a dam, has a very small footprint, and is not visible from the surrounding countryside. There is essentially no lower limit in plant size. Although small plants are useful for distributed generation, economic feasibility can be questionable with the cost of obtaining an operating license for non-federal projects.

Figure 8-7. Large hydroelectric plant

Courtesy of Grant County Public Utility District

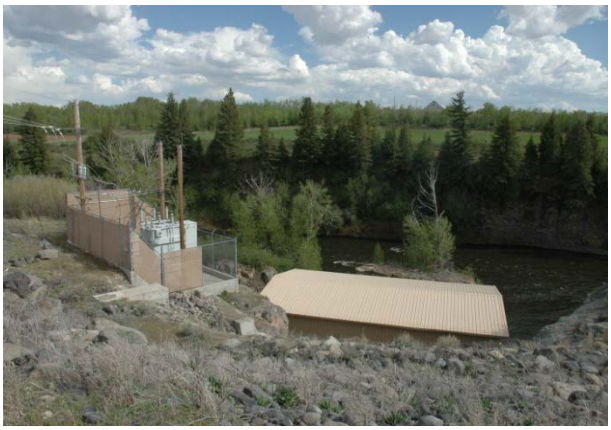

Figure 8-8. Small hydroelectric plant

Courtesy of Idaho National Laboratory

8.3.2 Technologies Included in RE Futures Scenario Analysis

For the purposes of the RE Futures scenario analysis, conventional run-of-river hydroelectric plants were assumed to be installed to capture the available hydroelectric power potential (described in Section 8.2). A run-of-river plant typically incorporates a dam that creates a reservoir encompassing part of a stream or river channel. The dam creates an operating head; however, the entire water flow into the reservoir more or less simultaneously flows out of the plant.[42] In fact, for run-of-river plants, the balancing period over which inflow and outflow are equalized typically ranges from a few minutes to an hour or two. The capacity potential of sites

[42] Due to the coarse time resolution of the ReEDS model and the unpredictability of future dispatch schedules, dispatch of currently existing hydroelectric plants is constrained only by season in the ReEDS model, while new hydropower plants are considered run-of-river in ReEDS with constant output in each season. See Short et al. (2011) for details.

located in exclusion zones defined by federal land use or environmental sensitivities (as discussed in Section 8.2) were not included in the supply curves used in the ReEDS modeling.

Dams for run-of-river plants were assumed to be installed at the downstream end of each reach identified in the resource assessments. Therefore, the dam captures the hydraulic head of the reach and, consequently, its power potential as estimated in the assessments. No credit was taken for sites having an existing non-powered dam. In addition, no attempt was made to gang successive reaches on the same watercourse to define a single potential project. The conservative approach of assuming that each reach is a separate project tends to overestimate development cost because a series of small projects each having higher unit development costs will have a higher total cost than a single aggregated project representing the same total capacity potential. No assessments were made of the technical reasonableness or economic feasibility of particular potential projects (e.g., projects involving the unlikely damming of major rivers and projects that require unreasonably long dams because of relatively flat terrain). The highest-capacity potential projects that unrealistically assumed the damming of major rivers, however, were removed from the supply curves as described in Section 8.3.3.2.

8.3.3 Technology Cost and Performance

Future capital cost, performance (generally represented as capacity factor), and operating costs of electricity generating technologies are influenced by a number of uncertain and somewhat unpredictable factors. As such, to understand the impact of renewable electricity technology cost and performance improvements on the modeled scenarios, two projections of future renewable electricity technology development were evaluated: (1) renewable electricity –evolutionary technology improvement (RE-ETI) and (2) renewable electricity – incremental technology improvement (RE-ITI). In general, RE-ITI estimates reflect only partial achievement of the future technical advancements and cost reductions that may be possible, while the RE-ETI estimates reflect a more complete achievement of that cost-reduction potential. The RE-ITI estimates were developed from the perspective of the full portfolio of generation technologies in the electric sector. Black & Veatch (2012) includes details on the RE-ITI estimates for all (renewable and non-renewable) generation technologies. RE-ETI estimates represent technical advances currently envisioned through evolutionary improvements associated with continued R&D from the perspective of each renewable electricity generation technology independently. As a mature technology, hydropower was not projected to achieve cost or performance improvements in either RE-ITI or RE-ETI estimates. In fact, the only cost difference between the two cost projections for hydropower is a slight difference in variable O&M costs. It is important to note that these two renewable energy cost projections were not intended to encompass the full range of possible future renewable technology costs; depending on external market conditions or policy incentives, anticipated technical advances could be accelerated or could achieve greater magnitude than what is assumed here[43]. Cost and performance assumptions used in the modeling analysis for all technologies are tabulated in Appendix A (Volume 1) and Black & Veatch (2012).

[43] In addition, the cost and performance assumptions used in RE Futures are *not* intended to directly represent DOE EERE technology program goals or targets.

8.3.3.1 Cost of Electricity Production

The inherently long asset life of hydropower facilities represents an important economic attribute. Hydropower projects are able to recover costs before the end of their actual service life. These projects have no fuel cost, robust equipment, and extremely low operating costs after the debt service is paid. A privately developed hydropower project typically will have a debt payment structure for 10 to 17 years,[44] while a publicly funded project would have a slightly longer term. Upon retirement of the debt service, the only costs are O&M costs, and the cost of life extension of the equipment and structures. The cost of power is reduced significantly after the debt is repaid. For a micro or small hydropower project, the cost of power drops to less than $1/MWh, and for large-scale projects to less than $0.5/MWh.[45] Because of federal and private hydropower, states with significant older hydropower resources have been able to moderate their wholesale cost of power.

8.3.3.2 Development Costs

The resource supply curve provided for ReEDS modeling was based on the resource availability data described in Section 8.2. The cost of developing each of the potential project sites (stream reaches) was estimated using escalated versions of the cost curves from a study of hydropower economic parameters (Hall et al. 2003).[46] The cost curves are least squares curve fits of historical cost data. Because the cost of hydropower licensing is a significant component of the cost of developing a hydroelectric plant, the estimated cost of developing a site included both the cost of obtaining an operating license and the cost of constructing the plant. Figure 8-9 shows the original cost-estimating curve for licensing, and Figure 8-10 shows the original cost-estimating curve for construction; both are in 2002 U.S. dollars. The unit development cost of each site was obtained by dividing its estimated development cost by its potential installed capacity. Unit cost was found to have an inverse relationship to installed capacity (that is, higher-capacity plants have lower unit-development costs and vice versa). The unit costs of all sites before accounting for existing capacity and unrealistic projects on large rivers ranged from $2,000/kW to $5,600/kW. Hydroelectric plants are complex facilities composed of civil, mechanical, and electrical components. A bottom-up estimate of plant cost depends on the plant design, which relates to the topography, geology, and hydrology at the site. The cost of plants—even for plants of the same installed capacity—varies widely, as shown in Figure 8-10. Estimating the cost of constructing future plants must rely on the average cost of entire plants unless a specific plant design at a specific site is to be estimated considering all aspects of the plant design. Future reductions in development costs also are difficult to estimate because of the maturity of the technology. It is conceivable that less expensive construction techniques, the use of advanced materials, and reductions in the cost of electrical components will reduce future development

[44] Figure based on actual experience of numerous load applications, 2009–2010.

[45] The costs of energy presented here differ from the costs of energy presented in Section 8.4 due to differences in financing assumptions and differences over the operating years considered. All dollar amounts presented in this report are presented in 2009 dollars unless noted otherwise; all dollar amounts presented in this report are presented in U.S. dollars unless otherwise noted.

[46] Escalated version of licensing cost from Hall et al. 2003 = 720,000∗capacity potential $(MW)^{0.7}$, and escalated version of construction cost from Hall et al. 2003 = 4,400,000∗capacity potential $(MW)^{0.9}$ for undeveloped sites in 2008 U.S. dollars.

costs. The cost of licensing some plants might be reduced in the future, but which plants will have reduced licensing costs and how much the cost will be reduced cannot be predicted.

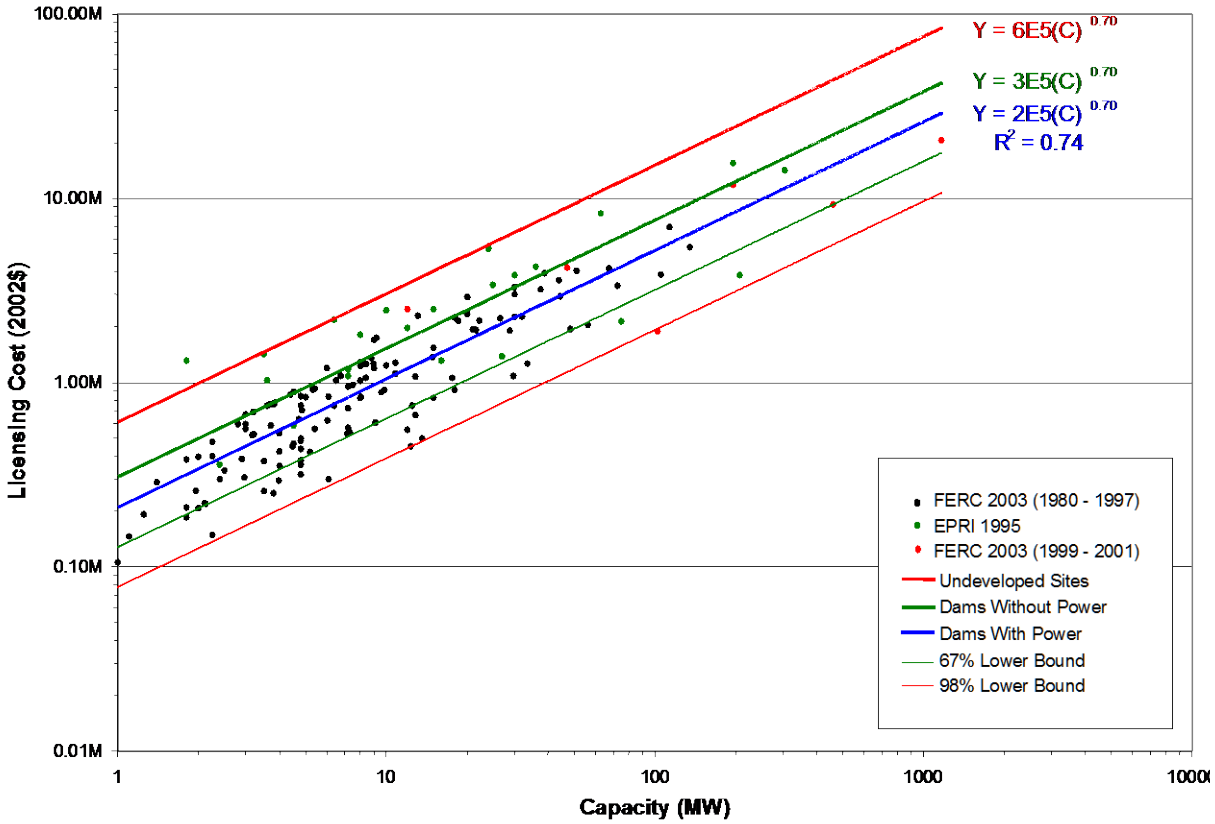

Figure 8-9. Original operating license cost-estimating curve (2002$)

Source: Idaho National Laboratory

The locations of potential projects were intersected with the boundaries of the 134 balancing areas (BAs) of the ReEDS model (see Volume 1 and Short et al. 2011) yielding the total potential capacity in each BA. Supply curves in the form of histograms provided the amount of potential capacity that could be developed in $1,000 increments of unit cost for each BA. A uniform unit cost in the middle of the increment was assigned to all of the capacities in the increment (e.g., $2,500/kW was assigned to all capacities having unit costs ranging from $2,000/kW to $3,000/kW).[47] The locations of all existing conventional hydroelectric capacity—based on the county in which the facility is located (not plant geographic coordinates) according to the EIA's 2008 listing of U.S. hydroelectric plants (EIA 2008)—were intersected with the BA boundaries. The currently existing total plant capacity was removed from the BA supply curve beginning with potential capacity at the lowest unit cost and advancing through the supply curve until an amount of potential capacity equal to the amount of currently installed capacity in the BA was removed. Sites with lesser unit costs corresponded to potential sites on larger rivers, which are likely not realistic dam sites. These potential sites effectively were removed from the

[47] All RE Futures modeling inputs, assumptions, and results are presented in 2009 dollars unless otherwise noted.

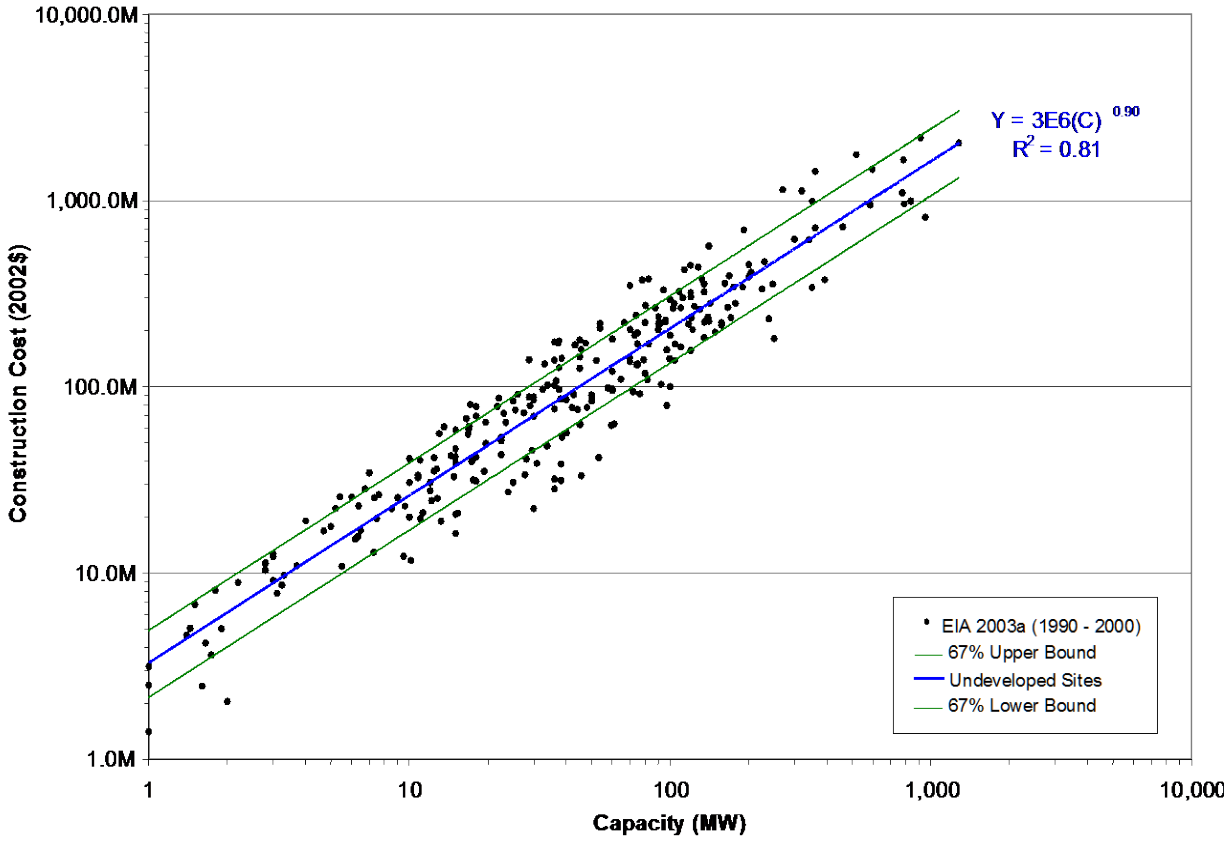

Figure 8-10. Original construction cost-estimating curve (2002$)

Source: Idaho National Laboratory

supply curves by removing all capacity having assigned unit costs of $2,500/kW. After this adjustment was made, the unit costs of potential capacity ranged from $3,500/kW to $5,500/kW.

Summary cost curves for the total population of potential sites before and after adjustment are shown in Figure 8-11. Prior to adjustment, the potential sites constituted 266 GW of potential capacity, with assigned unit costs ranging from $2,500/kW to $5,500/kW. After adjustment for existing capacity and removal of unrealistic projects, the potential capacity of the remaining sites was 152 GW with assigned unit costs of $3,500/kW to $5,500/kW. The potential was then further adjusted to account for the regional annual capacity factors used in ReEDS compared with the capacity factor of 50% assumed to convert potential annual average power values from the resource assessment to capacity potentials. This adjustment resulted in 228 GW of available new hydropower capacity considered in the modeled scenarios. While this adjustment modified the capacity potential, it preserved the generation estimate (in megawatt-hours) for each site from the resource assessment.[48]

[48] The assumption of a different capacity factor to convert potential annual average power (MWa) from the resource assessment to capacity potential (MW) at a site does not change the estimated annual generation since the new capacity factor was used to calculate annual generation (MWh) [generation (MWh) = annual average power (MWa)

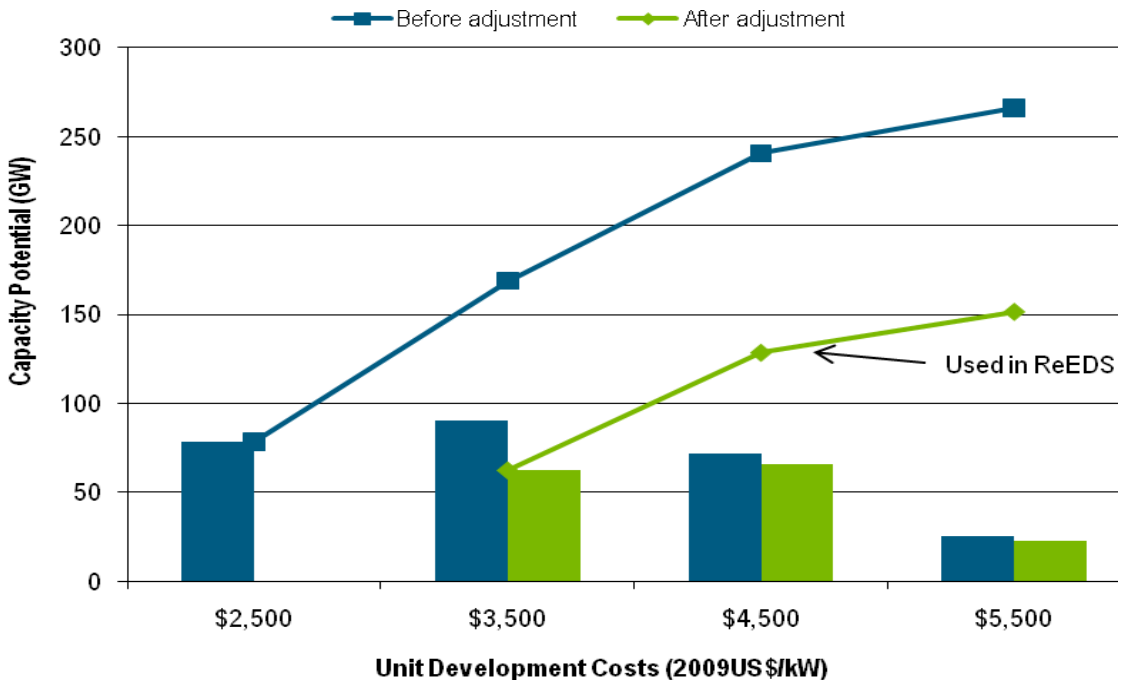

Figure 8-11. Cost supply curve for hydropower in the United States

Source: Idaho National Laboratory

The BA cost curves provided for ReEDS modeling contain notable conservative factors. The cost of developing all sites in the supply curves was based on the full construction costs of developing a "greenfield" site. No credit is taken for a site at which a non-powered dam might exist. Accounting for these sites would provide a significant amount of capacity at lower unit costs, both because of the savings in civil works construction and because of a (most likely) reduced cost of obtaining an operating license. Each of the potential sites corresponds to a single stream reach that is assumed to be developed as a separate project. There are cases in which multiple successive reaches have been identified as potential project sites. These reaches could be considered contributory to a single project having a unit cost less than the unit costs of the individual smaller projects. Due to the lack of resource availability data, potential projects on constructed waterways[49] have not been included. These projects also could offer lower unit costs because of reduced licensing costs and, quite likely, lower installation costs due to the relatively lesser complexity of the project. The inclusion of projects on constructed waterways also would increase overall capacity potential.

8.3.3.3 Operation and Maintenance

The basic technologies used for conventional hydroelectric and pumped-storage projects can be described as mature. Civil, mechanical, and electrical elements of well-built plants are robust;

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* 8,760 hours] is the same as [generation (MWh) = capacity factor*capacity (MW)*8,760 hours] where [capacity (MW) = annual average power (MWa)/capacity factor].

[49] Constructed waterways include irrigation canals, municipal water supply and water treatment systems, and industrial effluent streams.

some century-old hydroelectric plants continue in regular service—relying, for the most part, on the same structures and equipment that first were placed in service. By following generally accepted industry guidelines and good practices, long-term reliable operation with minimal forced outages routinely is achieved in hydroelectric plants of all ages and sizes.

Currently, most hydropower stations are unmanned and rely on remote monitoring and operation. Centrally dispatched crews often perform maintenance. Routine maintenance typically is conducted during regular working hours. Major overhauls—usually required after about 15–20 years of operation—are scheduled to minimize or eliminate plant unavailability (e.g., overhauls can be performed during a low-water-flow period). Moving parts exposed to water flow, such as turbine blade surfaces, could require frequent attention (e.g., annually) if the water carries heavy sediment burdens that cause surface erosion, or if operating conditions result in significant cavitation (a phenomenon that can damage surfaces).

It is common for various mechanical, electrical, and control equipment in a hydroelectric or pumped-storage plant to be upgraded or replaced during the plant's lifetime. Although it is rare to replace turbine casings (parts of which often are enclosed in concrete), turbine runners[50] often are replaced after 30–40 years of service. It is not unusual for an original runner to have been made from cast iron, and the replacement to be made of stainless steel. It also is common for the replacement to be more efficient and produce more power. Generators rarely are replaced; more often, they are rewound to provide greater power output using new, improved insulation because the old insulation degrades over time and due to electrical stress.

Control systems are now usually upgraded frequently, as compared to previous electro-mechanical plant equipment. In the mid-twentieth century, state-of-the-art electro-hydraulic controls could be expected to last essentially forever with proper maintenance. The newer controls have brought with them power imperatives in terms of plant operation (especially, for example, in connection with remote operation and monitoring), electrical grid operation, and direct labor savings in terms of plant O&M staffing. Moreover, it has become problematic for most plant owners to retain the expertise needed to keep older (often arcane) control systems adequately functional. This has led to a rapid transition to digital control technology, which was introduced and implemented over the past 20 years and is now at the heart of modern power-plant control systems.

Fixed O&M costs were assumed to be $14.90/kW/yr, and variable O&M costs were assumed to be $6/MWh under the RE-ITI projections used in the modeling analysis. RE-ETI technology cost projections were identical with the exception of lower ($3/MWh) variable O&M costs.[51]

8.3.4 Technology Advancement and Deployment Potential

Although hydropower turbine manufacturers incrementally have improved turbine technology to improve efficiencies, the basic design concepts have not changed for decades. This section discusses opportunities to advance the technology and deploy new facilities.

[50] The turbine runner is the shaft or hub with attached blades or buckets—the *turbine* in lay terms.
[51] Lower O&M estimate based on escalated value from Hall et al. 2003.

8.3.4.1 Technology Advancement Potential

Most U.S. hydroelectric and pumped-storage projects are several decades old. Although there are some newer plants, the average age of a project is 40–50 years.[52] Many plants have been upgraded and modernized. Nonetheless, much opportunity remains for improving older plants by replacing obsolete equipment and making other changes to improve operability, efficiency, and environmental performance. For projects subject to Federal Energy Regulatory Commission (FERC) licensing (which includes all investor-owned projects), relicensing after approximately 30–50 years often leads to thorough project modernization.

Rehabilitation and upgrading of existing facilities can prove to be extremely cost-effective, often ranging from approximately $200/kW to approximately $600/kW, which is a fraction of the cost of new facilities. Modernization often leads to a facility's increased power output and energy production. Increases of 3%–15% are not uncommon.[53]

Conventional hydroelectric and pumped-storage technologies generally are considered to be mature. Nonetheless, important advances have been made in recent years due to the application of newer materials and, especially, due to computer technology advances. Newer materials have contributed to longer component lifetimes. Computer technology has led to more efficient and more effective controls for plants. Use of computer-aided design tools, such as computational fluid dynamics software, has produced advanced designs, such as for hydraulic turbines. The Advanced Hydropower Turbine System program—undertaken through a partnership of industry and DOE—led to improved turbines that are both more "fish friendly" and more efficient. Several of these multimillion-dollar machines have been installed on the Columbia River in Washington. Research is continuing on fish-friendly turbine concepts that hold promise for broad application. Notwithstanding the many improvements made in the past, more opportunities remain for improving hydroelectric (including pumped-storage) technologies and their application.

8.3.4.2 Deployment Potential

Potential opportunities for improvement and additional deployment of hydroelectric projects include existing facilities and "greenfield" developments.

8.3.4.2.1 Existing Facilities

The installed capacity of conventional hydroelectric power plants (approximately 80 GW)[54] in the United States is greater than the total capacity of all other renewable technologies. Small improvements in efficiency and effectiveness to conventional hydropower facilities can lead to substantial benefits nationally. Moreover, good opportunities for making beneficial improvements occasionally arise during the lifetime of a facility.

One important opportunity within this category is project redevelopment. Essentially, an old project is replaced with a new and better project. A current example is that of the Holtwood

[52] Estimate based on FERC license and federal hydropower project lists.
[53] Estimates based on actual experience.
[54] Figure from National Hydropower Association. The term *conventional* is used to differentiate from pumped-storage hydropower, which is not included in the 80 GW total capacity figure.

Hydroelectric Plant, which has been in continuous operation with minimal upgrading for more than a century. An expansion project in 2010 increased the output from 108 MW to 233 MW. The expansion takes better advantage of the hydraulic potential at the site than did the original development. Funding made available through the American Recovery and Reinvestment Act of 2009 played a critical role in advancing the long-planned redevelopment.

Although few improvements are of the magnitude and scope of the Holtwood project, gains are being made at many hydropower and pumped-storage facilities. Numerous opportunities remain that—within a suitable policy framework—could bring sizable new power resources into the U.S. power supply.

8.3.4.2.2 Greenfield Developments

8.3.4.2.2.1 Large-Scale Conventional Hydropower Potential

In most areas of the United States, the best sites suitable for the development of large hydroelectric projects (more than 50 MW) either have already been developed or are considered preempted from development. The majority of large hydropower projects are publicly owned, most of which by the federal government. The U.S. Army Corps of Engineers has 75 hydropower projects with 20,474 MW of capacity; the Bureau of Reclamation has 58 projects with approximately 15,000 MW; and the Tennessee Valley Authority has 30 projects with 5,191 MW. Together, these projects provide approximately 40,000 MW of federally owned and operated capacity. Some large hydropower projects are owned by non-federal public entities. For example, Grant County Public Utility District in Washington owns two large hydropower plants—the 1,038-MW Wanapum project and the 855-MW Priest Rapids project.

Preemption of potential sites from hydropower development includes both actual and de facto preemption. Actual preemption is a result of laws that prevent development (e.g., the federal Wild and Scenic Rivers Act of 1968),[55] thus establishing a mechanism by which Congress can exclude certain river reaches from development. More than 11,000 river miles currently are protected under the Act. De facto preemption is a consequence of both practical and political factors. Practical factors include preemption due to preexisting development. Populated or otherwise developed areas often create difficulties with new hydroelectric development. Today, any attempt to develop a large hydropower project that inherently requires commitment of substantial land areas and river resources is a very controversial undertaking. Regardless of the support garnered for such a project, a project proposal usually draws significant opposition. The intensity of opposition—and its effects on broader public opinion—often poses a difficult obstacle.

8.3.4.2.2.2 Small-Scale Conventional Hydropower Potential

For RE Futures, a demarcation between large-scale and small-scale hydropower was established at 50 MW. As a practical matter, no such demarcation exists. Nonetheless, there is a qualitative difference between large, visible, high-consequence projects such as the 2,080-MW Hoover Dam on the Colorado River and the thousands of smaller projects that often are relatively inconspicuous.

[55] Wild and Scenic Rivers Act, Public Law 90-542, 90th Cong. (October 2, 1968).

Development of small-scale (less than 50 MW) projects is more likely to be undertaken by private developers. A project with costs on the order of $100 million and installed capacity of approximately 50 MW is a significant project for a private hydropower developer. This is in contrast to a utility power supplier, which might deem a project of 50 MW or less as too small and likely not worthy of pursuit. However, many thousands of potential opportunities for small-scale "greenfield" hydropower development exist in the United States.[56] Additionally, existing dams that currently do not have hydroelectric facilities might offer good opportunities for power development. Moreover, a great number of closed conduits and canals could have potential for the addition of hydropower facilities. Although these constructed waterways have not been assessed to determine their hydropower potential, a number of hydroelectric installations already are installed on them.

Additional assessment and verification to ascertain "ground truth" for potential sites in all categories is an important step if they are to be pursued. A single inventory of available small-scale hydropower facilities that lists potential sites on a state-by-state basis would assist such an effort. The Idaho National Laboratory developed the Virtual Hydropower Prospector, a Web-based tool that can provide a useful platform for collecting, displaying, and evaluating resource information.[57]

8.4 Output Characteristics and Grid Service Possibilities

The range of plant sizes is large, from approximately 1 kW to more than 6,000 MW (FERC 2005). The output from hydropower plants depends on the type of plant, water availability (seasonal variation and annual variability), and stream flow requirements for navigation, irrigation, and environmental protection. Run-of-river plants have little water storage capability and therefore operate principally as baseload plants. While the output of these plants may be subject to seasonal variability, their output varies over long enough timescales to make them predictable contributors to the electricity supply and thus easily integrated into the grid. Larger plants with water storage capability have both the capability to generate independent of seasonal water availability and provide load following and ancillary services. Pumped-storage hydropower plants, which are discussed in Chapter 12, are particularly suited to load following and providing firm capacity. A particularly important capability of hydropower is its ability to start with no available grid power and rapidly ramp to full continuous generation.

By considering future power system requirements, the benefits associated with changing the operating parameters, making specific upgrades, or adding new hydropower resources can be identified and valued. To identify these values, DOE funded (with industry cost-share) a team led by EPRI to quantify the full value of hydropower to the transmission grid.[58] This investigation is scheduled to be completed in 2012.

[56] Estimate based on a resource assessment by the Idaho National Laboratory.
[57] For more information, see the Virtual Hydropower Prospector at http://hydropower.inl.gov/prospector/.
[58] Funding Opportunity Number DE-FOA-0000069, Topic Area 4.

8.5 Deployment in RE Futures Scenarios

As discussed in Section 8.1, hydropower is currently the largest of all contributors of renewable resources to the U.S. generation mix. In 2050, hydroelectric power continues to play a significant role in all of the RE Futures scenarios described in Volume 1. Table 8-1 and Figure 8-12 show the variation in 2050 installed hydropower capacity between the six (low-demand) core 80% RE scenarios and the high-demand 80% RE scenario. In addition, Table 8-1 shows the hydropower contribution of the total 2050 generated electricity for each of these scenarios. Cumulative installed capacity for hydropower, including the capacity that is currently operational (78 GW in 2010 not including pumped-storage capacity), ranged from 81–174 GW and the hydropower contribution to the percent of total generated electricity ranged from 8.3%–16%. Hydropower deployment showed modest sensitivity to many of the different system constraints modeled; however, it was most affected by the assumed cost and performance of renewable technologies. As hydropower is a relatively mature technology, it was estimated to have no cost or performance improvements over the 40-year study period. The scenario results indicate that the deployment of hydropower under an 80% RE-by-2050 scenario depended strongly on the relative cost of the other renewable technologies. For example, the 80% RE-ETI Scenario relied on technology cost projections where all renewable technologies experienced cost reductions or performance improvements over time except for hydropower. As such, hydropower deployment was very limited in this scenario, with only a few gigawatts of *new* capacity installed over the 40-year period. In contrast, hydropower deployment exceeded 170 GW (nearly 100 GW of new capacity) in the 80% RE-NTI Scenario, where no cost or performance improvements were assumed for any renewable technology. As shown in Figure 8-12, hydropower also realized significant deployment in the high-demand 80% RE scenario, where electricity demands were significantly higher than in the other low-demand scenarios.

Table 8-2. Deployment of Hydropower in 2050 under 80% RE Futures Scenarios[a,b]

Scenario	Capacity (GW)	Generation
80% RE-NTI	174	16.0%
High-Demand 80% RE	141	10.3%
Constrained Transmission	124	11.8%
Constrained Flexibility	124	12.2%
80% RE-ITI	114	11.4%
Constrained Resources	104	10.3%
80% RE-ETI	81	8.3%

[a] See Volume 1 for a detailed description of each RE Futures scenario.

[b] The capacity totals represent the cumulative installed capacity for each scenario, including currently existing hydropower capacity (approximately 78 GW in 2010).

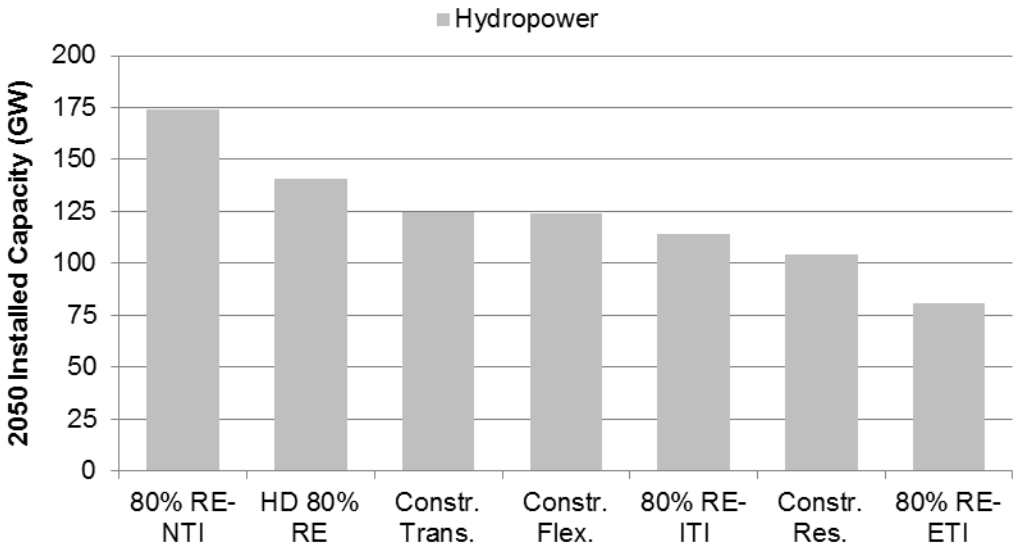

Figure 8-12. Deployment of hydropower technologies under 80% RE scenarios

As described previously, the greatest amounts of new hydroelectric capacity additions were required in the 80% RE-NTI scenario, in which the installed hydropower capacity in 2050 more than doubled the current existing capacity in the contiguous United States. Generation from hydropower increased to almost 16% of total generation in 2050, compared to approximately 7% in 2010.[59] Although growth in hydropower has been modest over the past few decades, the 80% RE-NTI scenario showed annual growth of almost 1 GW/yr (equivalent to one large coal-fired or nuclear power plant) from 2010 to 2020, with annual investments of approximately $1.7 billion/yr (see Figure 8-13). From 2020 to 2040, significant growth in hydropower capacity was indicated, with an average annual growth of approximately 2–4 GW/yr during that time and investments of approximately $9 billion–$10 billion/yr. In this scenario, growth in hydropower installations continued and even accelerated in the last decade of the study period. Annual installations peaked in 2050 with more than 7 GW/yr installed and a decade-averaged investment of nearly $19 billion/yr.

Hydropower resources are available in nearly every state; however, higher-quality resources are predominantly located in the Northwest, California, and the Northeast. Figure 8-14 shows the installed hydropower capacity (including the existing capacity today) in 2050 for the 80% RE-NTI scenario. The ReEDS-selected capacity was most prevalent in the Northwest, where water resources coupled with mountainous terrain are relatively abundant. Significant deployment of hydropower also occurred in New York, New England, and California.

[59] The hydropower generation or percent generation values quoted in this chapter include all electricity imported from Canada. In contrast, the quoted capacity figures only include existing and new plants that are located within the contiguous United States. Assumed electricity imports from Canada make up approximately 2% of U.S. electricity demand in 2050 under the low-demand assumption. See Short et al. (2011) for description of treatment of electricity imports in the models.

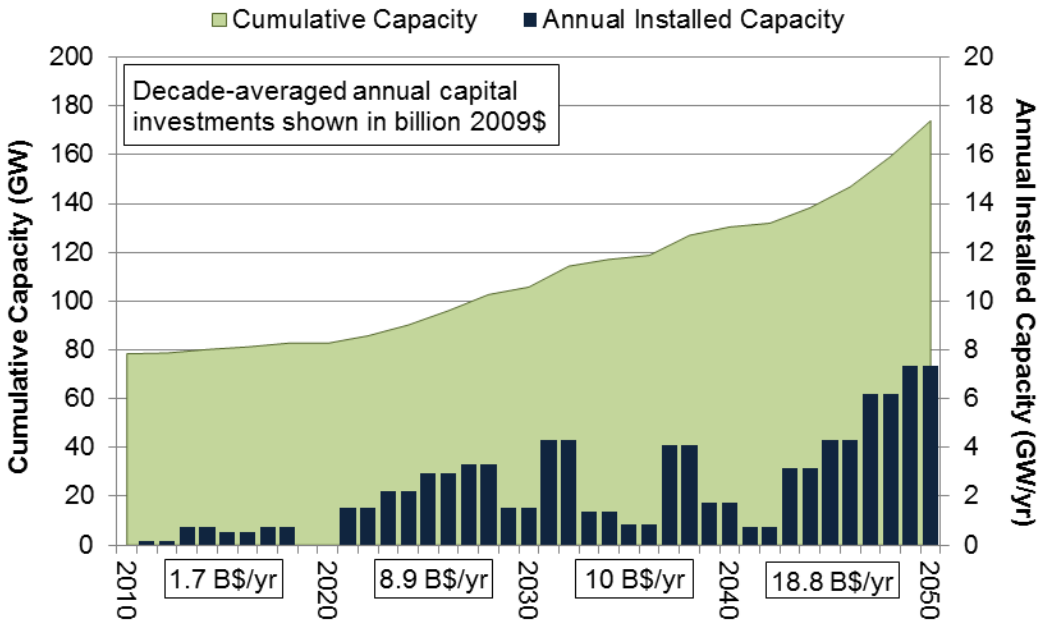

Figure 8-13. Deployment of hydropower in the 80% RE-NTI scenario

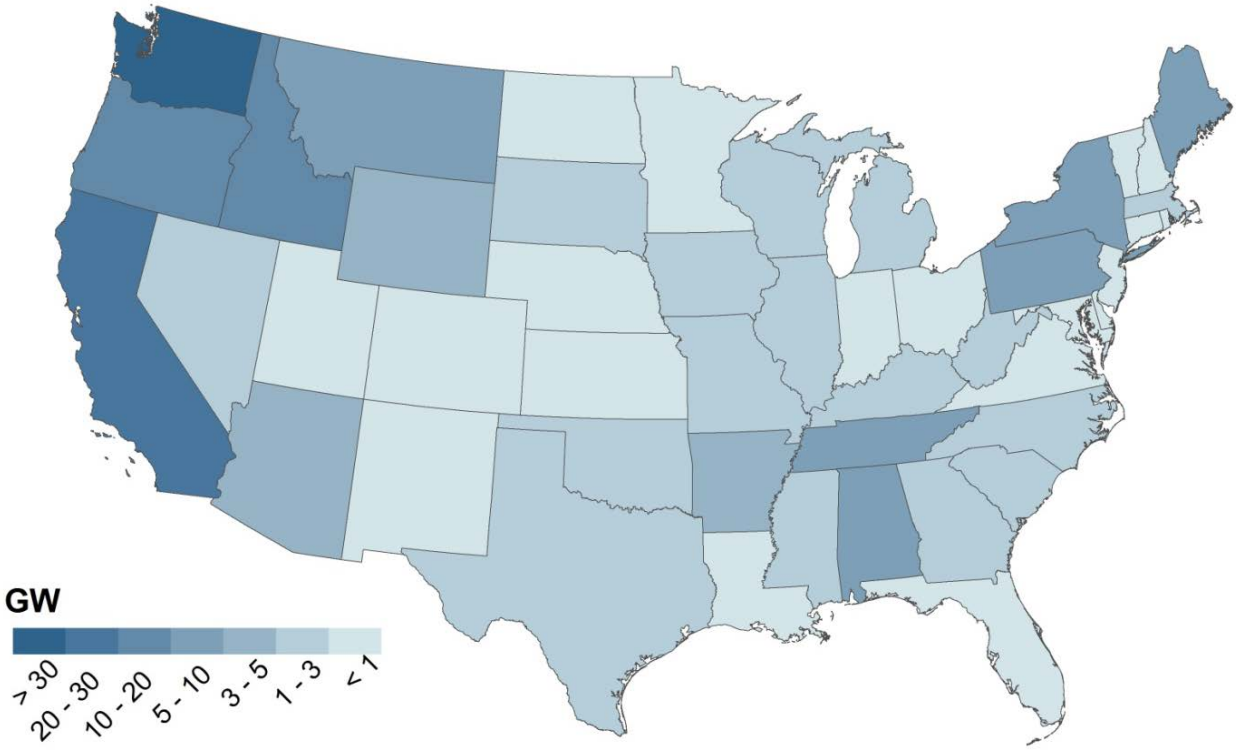

Figure 8-14. Map of hydropower capacity deployment in 2050 in the 80% RE-NTI scenario

Figures 8-13 and 8-14 show deployment results for only one of many model scenarios, none of which was postulated to be more likely than any other. In addition, as a system-wide

optimization model, ReEDS cannot capture all of the non-economic and, particularly, regional considerations for future technology deployment. Furthermore, the input data used in the modeling is also subject to large uncertainties. As such, care should be taken in interpreting model results, including the temporal deployment projections and regional distribution results; uncertainties certainly do exist in the modeling analysis

8.6 Large-Scale Production and Deployment Issues

There are no technology-related issues associated with large-scale deployment of conventional hydropower technologies because they are mature technologies. Hydropower plants generate minimal emissions and few solid wastes; however, they can alter the aquatic environment in a number of ways. Additional deployment will require significant capital investment and long lead times. Because the primary materials of construction for hydropower projects are cement and steel, hydropower is not likely to experience bottlenecks from material constraints. However, siting and permitting are key challenges in deploying new hydropower plants.

8.6.1 Environmental and Social Impacts

Hydroelectric power production largely is free of several major classes of environmental effects associated with non-renewable energy sources. Hydroelectric projects can affect the environment by impounding water, flooding terrestrial habitats, and creating barriers to the movements of fish and aquatic organisms, sediments, and nutrients. Alteration of water flows also can affect aquatic and terrestrial habitats that are downstream of dams.

Table 8-3. Potential Environmental Benefits and Adverse Effects of Hydropower Production

Benefits	Adverse Effects
• No emission of sulfur and nitrogen oxides • Few solid wastes • Minimal effects from resource extraction, preparation, and transportation • Flood control • Water supply for drinking, irrigation, and industry • Reservoir-based recreation • Reservoir-based fisheries • Enhanced tailwater fisheries • Improved navigation on inland waterways below the dam	• Inundation of wetlands and terrestrial vegetation • Emissions of greenhouse gases (CH_4, CO_2) from flooded vegetation at some sites • Conversion of a free-flowing river to a reservoir • Replacement of riverine aquatic communities with reservoir communities • Displacement of people and terrestrial wildlife • Alteration of river flow patterns below dams • Loss of river-based recreation and fisheries • Desiccation of streamside vegetation below dams • Retention of sediments and nutrients in reservoirs • Development of aquatic weeds and eutrophication • Alteration of water quality and temperature • Interference with upstream and downstream passage of aquatic organisms

8.6.1.1 Land Use

The land use of a hydroelectric plant installation is highly variable based on the plant capacity, configuration, and installation site. For example, a run-of-river plant[60] where a dam is obstructing the river in a deep canyon can result in almost no inundation. It would only require land for equipment storage and for an electrical yard if the powerhouse were located in the dam. One estimate of the land requirements of this type of facility is about 1 hectare for a 10-MW facility. The Saskatchewan Energy Conservation and Development Authority listed the land use of a 10-MW hydroelectric plant as 1 hectare or approximately 2.5 acres in 1994.[61] Over the range of modeled 80% RE scenarios this corresponds to an additional land requirement of 80–175 km^2. Conversely, a run-of-river plant located on relatively flat terrain could require a long dam and create a sizeable reservoir even though its volume is not intended to vary. Research to estimate inundation associated with individual projects is needed.

8.6.1.2 Water Use

The creation of a reservoir floods terrestrial vegetation and displaces resident populations—both wildlife and human—within the flooded area. The significance of flooding depends on the size and location of the reservoir.

Most adverse environmental effects of dams are related to habitat alterations. Reservoirs associated with large dams can inundate large areas of terrestrial and streamside (riparian) habitat and can displace local residents. Diverting water from stream channels or curtailing reservoir releases to store water for future electrical generation can dry out riparian vegetation. Insufficient water releases degrade habitat for fish and other aquatic organisms in rivers below dams. Water in reservoirs is stagnant as compared to water in free-flowing rivers. Consequently, water-borne sediments and nutrients can be trapped, resulting in the undesirable proliferation of algae and aquatic weeds (eutrophication). In some cases, water spilled from high dams can become supersaturated with nitrogen gas, resulting in gas-bubble disease in aquatic organisms inhabiting the tailwaters.

Hydropower projects can have other direct effects on aquatic organisms. Dams can block upstream movements of fish, which can have severe consequences for migratory species.[62] Fish moving downstream might be drawn into the power-plant intake flow. Such entrained fish are exposed to physical stresses as they pass through turbines, which can cause disorientation, physiological stress, injury, and mortality. (Research and development on fish-friendly turbines has reduced rates of fish injury and mortality.)

Hydropower reservoirs also produce benefits. A primary benefit is the ability gained to produce—and often to store—energy. Reservoirs typically create water surface areas that are larger than the original river channels that they flood. Consequently, reservoirs can provide more

[60] A run-of-river hydroelectric plant is one for which the stream flow rate downstream of the dam is equal to the stream flow rate upstream of the dam at all times; hence, there is no dispatchable impoundment of water. The natural stream flow either passes through the turbines or passes the dam via the spillway.
[61] Saskatchewan Energy Conservation and Development Authority. This does not include any flooded area.
[62] Anadromous fish are born in fresh water and spend most of their lives in saltwater before returning to fresh water to spawn. Catadromous fish live in fresh water and enter saltwater to spawn.

habitat area for waterfowl and, in arid regions, can create permanent sources of drinking water for wildlife. Human populations often benefit from additional, non-power uses for hydropower reservoirs, such as reliable sources of water for drinking, industry, and agriculture; flood control; recreation; and fisheries. Very large reservoirs—whether used for hydropower or other purposes—are qualitatively different from smaller reservoirs in that they can affect the character of entire regions. Reservoir creation requires careful planning to minimize and mitigate effects on both naturally existing and human populations.

8.6.1.3 Emissions and Waste

Hydroelectric generation does not lead to the emission of toxic contaminants (e.g., mercury) or to the emission of sulfur and nitrogen oxides that can cause acidic precipitation. Although construction of hydropower projects could result in temporary emissions—including dust and emissions from equipment.

Hydroelectric power plants generate few solid wastes. Land might be required for the disposal of material dredged from reservoirs or for the disposal of waterborne debris. The amounts of land needed for such disposal, however, are small compared with conventional energy sources and such materials are generally not toxic. Many other environmental effects that are associated with the overall fuel cycles of non-renewable energy sources, including resource extraction, fuel preparation, and transportation, are minor or nonexistent for hydroelectric power.

8.6.1.4 Life Cycle Greenhouse Gas Emissions

Hydropower projects long have been assumed to emit fewer GHGs than fossil fuel-based energy plants. This assumption seems to be correct for the vast majority of U.S. reservoirs. It now is recognized, however, that the decomposition of inundated vegetation and other organic matter within a reservoir can result in GHG emissions that can continue for decades after initial flooding. In some tropical regions of the world, the GHG emissions from hydroelectric reservoirs appear to be significant. The amount of GHGs released from a hydropower reservoir vary greatly depending on geography, altitude, latitude, water temperature, reservoir size and depth, depth of turbine intakes, the specifics of hydropower operations, carbon input from the river basin, and reservoir construction (e.g., whether vegetation was cleared from the reservoir before inundation). GHGs also are emitted during the extraction, transportation, and manufacturing of raw materials used for hydropower components, as well as during construction and decommissioning of hydropower facilities.

In the estimation of life cycle GHG emissions of the 80% RE-ITI scenario presented in Appendix C (Volume 1), the GHG emissions from hydropower facilities were not considered. Although this assumption leads to an underestimation of the true GHG emissions from the RE Futures scenarios, the magnitude of underestimation is small (less than 5%) for three reasons:

- Little hydropower capacity was added or decommissioned under the 80% RE-ITI scenario evaluated (<3% of cumulative capacity additions to 2050).[63]

[63] A larger amount of new hydropower capacity was deployed in some of the other RE Futures scenarios (see Table 8-1), which would lead to greater life cycle GHG emissions. These life cycle GHG emissions for hydropower

- Most of the existing hydropower capacity in the United States has been in place for decades; therefore, GHG emissions associated with the existing plants have already occurred.
- Ongoing reservoir-related GHG emissions are likely zero or near zero as any inundated biological material has long-since decayed.

8.6.1.5 Mitigation and Minimization

Construction and operation of hydroelectric plants might require efforts to minimize and mitigate potentially deleterious effects by incorporating structural design features, prescribed operating practices, or both. Although effects requiring minimization or mitigation are site-specific, this section discusses some of the issues that often are addressed.

Water-quality effects that occur during construction of hydroelectric plants and reservoirs can be managed by well-known engineering practices, including soil stabilization techniques and storm-water retention dikes. In most cases, long-term effects that occur during operation of a hydropower project are of greater concern than short-term effects that occur during its construction.

Maintaining water temperatures within desirable ranges—especially for the tailwater discharged from a hydropower plant—is not technically difficult. However, it can require significant capital and operating expense. Devices such as propellers have been used to break up thermal stratification in small reservoirs. For large reservoirs, multi-level intakes allow water to be withdrawn and mixed from different depths so that water of the appropriate temperature can be discharged into the tailwater.

In a variety of instances, increasing dissolved oxygen concentrations in discharged waters is necessary to protect fish and other aquatic species. Structural alternatives for accomplishing this include the use of specially designed "aerating" turbines. Dissolved oxygen levels also can be increased through modifications in dam operations, including fluctuating flow releases, spilling surface water from the tops of dams, and mixing flow by using multi-level water intakes.

Nitrogen gas supersaturation downstream from hydropower projects can negatively affect fish and aquatic species. Conditions that contribute to nitrogen supersaturation include project designs in which high-velocity tailwaters from a high dam discharge into a deep plunge pool so that air bubbles dissolve in the water under elevated pressures. One proven method for preventing nitrogen gas supersaturation is to install "flip lips." Flip lips are structures installed at the base of the spillway that redirect the spilled water into a horizontal plane so that it does not descend deep into the plunge pool. Keeping spilled tailwater (with entrained air bubbles) near the surface reduces the opportunity for excess nitrogen gases to dissolve into the water.

Mitigating alterations in the nutrient balance of a river or reservoir is possible but often costly and complicated. Excess growth of large aquatic plants can be controlled by mechanically harvesting the plants or by introducing herbivorous fish, but microscopic planktonic algae are

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would, however, be offset by lower life cycle GHG emissions from other technologies that would be deployed to a lesser extent.

difficult to control. To limit algal production, it often is easier to take steps to reduce the input of nutrients from the watershed or to flush nutrients from the reservoir.

The simplest way to mitigate adverse sediment and nutrient trapping in a reservoir is to dredge as needed. Numerous mechanical and hydraulic dredging techniques can serve this purpose. Sediments located in some reservoirs can be flushed through pipes or notches in the dams. Large reservoirs impound enough water so that sediments can be flushed at any time, but in smaller reservoirs, sediments only can be flushed during floods and other high-streamflow events.

Releasing a predetermined amount of water down a river channel often is required to sustain the in-stream uses of water, including uses related to fish and wildlife communities, streamside vegetation, recreation, aesthetics, water quality, and navigation. Providing flows downstream from a storage reservoir or hydroelectric diversion is simple; water can be spilled from the dam instead of being diverted to a pipeline or stored in a reservoir. Releasing water to support in-stream uses below the dam usually makes that water unavailable for electricity generation; therefore, hydropower operators are interested in providing sufficient—yet not excessive—releases. Methods have been developed to ascertain the in-stream flow requirements for many in-stream water uses. Although a variety of in-stream flow assessment methods are available to help determine how much water needs to be released, the needs of biological resources often are difficult to assess with a desirable degree of accuracy.

Dams pose physical barriers to upstream-migrating fish. Many hydroelectric projects have implemented ways to assist upstream fish movement. Methods include the use of fish ladders, trap-and-haul operations, and fish elevators. All methods of facilitating upstream fish passage slow upstream movement to some extent.

Fish migrating downstream past a hydropower project have three primary routes available. Fish can be (1) drawn into the power-plant intake flow (entrainment) and passed through a turbine, (2) diverted via bypass screens into a gatewell and then moved to a collection facility or the tailrace, or (3) passed over the dam in spilled water. Recent modifications made to dams to decrease the number of turbine-passed fish include guiding migrating fish towards spillbays[64] and using surface bypass systems and behavioral guidance walls. Ice and trash sluiceways also have been modified to provide surface passage routes for migrating fish.

Turbine-passed fish are exposed to physical stresses from pressure changes, shear, turbulence, and blade strike that can cause injuries. In the best existing turbines, up to 5% of turbine-passed fish can be injured or killed, and mortalities in some turbines can be 30%. New design concepts under development show promise of reducing mortality of turbine-passed fish to 2% or less in circumstances that would permit installation of these advanced designs.

8.6.2 Manufacturing and Deployment Challenges

8.6.2.1 Manufacturing and Materials Requirements

Hydroelectric plant construction takes a variety of forms—from adding a relatively small powerhouse to an existing non-powered dam, to installing a large dam and powerhouse and

[64] A spillbay is a structure that delivers water over or around a dam or other obstruction.

creating a large reservoir. In the small hydropower case, many designers could undertake the planning, the civil construction likely would be similar to other industrial construction, and equipment probably could be supplied by any one of several dozen suppliers. The building of large hydropower projects—several hundred megawatts and larger—greatly reduces the number of sources for engineering, construction, and equipment supply. For example, it is unlikely that there are more than 10 manufacturers worldwide for large turbines or generators. Indeed, many of the resources for undertaking large projects tend to be supplied from international sources.

Key equipment needed for hydropower plants includes hydraulic turbines, generators, transformers, and monitoring and control equipment. Other equipment includes spillway gates, intake gates, hoisting equipment, trash racks, trash rakes, powerhouse cranes, and fish-protection systems. For new "greenfield" developments, the civil construction of the dam, powerhouse, and roads usually represents the dominant expense. The cost of equipment tends to represent a relatively small part of overall project cost. For larger plants, turbines invariably are specially designed for a specific project. When turbine runners are replaced (e.g., during upgrading), the replacement is also a customized design. Smaller hydropower plants tend to rely on standardized designs. In many instances, large castings needed for turbine runners and other turbine-generator components no longer can be manufactured in the United States and must be sourced offshore.

Manufacturing capabilities for hydropower plant equipment have expanded worldwide, especially in developing countries. China, India, and Brazil each have had notable expansion in their capabilities for supplying hydropower equipment. There is significant hydropower equipment manufacturing in the United States, and a small part of production (10% to 15%)[65] serves international markets. Most of the U.S. supply is focused on serving the existing base of installed plants—providing equipment for maintenance, repair, upgrading, modernization, and improving environmental performance.

8.6.2.2 Deployment and Investment Challenges

New hydropower and pumped-storage projects are capital intensive. Consequently, large projects are almost exclusively in the domain of public financing. This is a worldwide pattern; it does not occur exclusively in the United States. Private developers can undertake smaller hydropower projects, but commercial financing terms generally are not favorable for hydropower. Although projects can be expected to have very long lifetimes—30 years or more—without requiring significant reinvestment, securing hydropower project financing for even a 20-year term is difficult.

During the 1980s, tax incentives and rapid depreciation allowances were major factors leading to the development of approximately 800 hydropower projects in the United States. Incentives that motivate investment and subsidize power production during the early years of a hydroelectric plant continue to be effective mechanisms for stimulating hydropower development.

For comparable public investments in incentives and subsidies, hydropower is very economically competitive as a source of renewable electricity in terms of dollars per kilowatt or dollars per kilowatt-hour. This is true for new projects and especially for existing projects. Due to the large

[65] The figure represents National Hydropower Association information.

installed base of existing hydropower, there are many opportunities for relatively small investments in upgrades and modernization to yield significant results in terms of increased power- and energy-production capabilities.

Federally owned projects face unique barriers. Unlike privately owned projects—in which improved performance can increase revenues, which in turn, can be used to pay for performance enhancements—federal projects for the most part do not have a performance-revenue connection. Instead, the vast majority of power revenues from federal hydropower projects flow into the federal treasury. Most of the funding to pay for operation, maintenance, and repairs comes from congressional appropriations. This "business model" fails to provide incentives that lead to maximizing performance.

8.6.2.3 Human Resource Requirements

There is no standardized method of estimating current or future personnel requirements for renewable energy technologies, and no new large hydropower plants have been built in the United States in recent years. However, Navigant Consulting (2009) assessed employment in the hydropower industry for various types of hydropower projects, including modifications to existing plants, addition of power production at non-powered dams, and development of greenfield sites. The assessment estimated that 2.8–13.2 full-time-equivalent jobs are required per megawatt generated. It projected that the majority of future hydropower jobs—both direct and indirect—will be in the Western region, which has the largest hydropower potential, followed by the Northeast because of its manufacturing base.

8.7 Barriers to High Penetration and Representative Responses

Several barriers constrain high penetration of conventional hydroelectric generation, and various responses have been used or could be considered, as enumerated in Table 8-3. These issues are categorized in three major areas: R&D, market and regulatory, and environmental and siting. Barriers and their representative responses are listed for each of the sub-areas.

Table 8-4. Barriers to High Penetration of Hydropower Technologies and Representative Responses

R&D	Barrier	Representative Responses
Resource Assessment	None; currently funded by DOE Water Power Program	Identify potential development sites (natural streams, existing non-powered dams, constructed waterways) Estimate developable power potential and levelized cost of energy
Turbine Development	Cost of researching advanced materials for turbine runners	Assist advanced materials research for turbine runners and other components
	Cost of retrofitting existing runners with those made of advanced materials	Incentives or other assistance for retrofits
System Components	Cost of advanced control system development	Support or other assistance for advanced control system development
	Cost of retrofitting existing control systems with advanced systems	Provide incentives or other assistance for retrofitting control systems

Market and Regulatory	Barrier	Representative Responses
FERC Licensing	Project characteristics that will allow fast-track licensing or exemption, thus reducing the time and cost of obtaining an operating license have not been defined	Implement identification of fast-track project characteristics Determine and possibly expand FERC latitude under the Federal Power Act
	Benchmarking U.S. hydropower licensing against processes used in peer countries to identify ways to further reduce the time and cost of obtaining an operating license while ensuring appropriate safeguards	Benchmark licensing processes here and abroad If necessary, amend the Federal Power Act to implement changes in the licensing process or requirements
	Each developer must research or produce environmental data needed to obtain a FERC operating license which, in many cases, is so expensive that it renders the project economically unviable	Compile an environmental data library that can be used by all hydropower stakeholders
Market	Hydropower ancillary services[66] are not sufficiently compensated	Modify energy pricing to ensure proper compensation of all ancillary services, either through the action of public utility commissions or via state or federal legislation
Environmental and Siting	**Barrier**	**Representative Responses**
Dam and Reservoir	Inundation of wetlands and terrestrial vegetation	Reduce the size of the storage reservoir; create alternate wetlands
	Emissions of GHGs from flooded vegetation at some sites	Reduce the size of the storage reservoir; clear vegetation from flooded area
	Conversion of a free-flowing river to a reservoir	No mitigation available
	Replacement of riverine aquatic communities with reservoir communities	No mitigation available
	Displacement of people and terrestrial wildlife	Relocation
	Retention of sediments and nutrients in the reservoir	Periodically flush or dredge the reservoir
	Interference with upstream and downstream passage of aquatic organisms	Install fish ladders or elevators for upstream passage Improve downstream passage survival with screens, bypasses, or fish-friendly turbines

[66] Ancillary services include load following, frequency regulation and other operation reserves, and black-start capability.

River	Alteration of river flow patterns below the dam	Release environmental flows in a natural seasonal pattern, and avoid rapidly varying flow releases
	Loss of river-based recreation and fisheries in impounded area	No mitigation available; enhance reservoir fisheries and recreation
	Desiccation of streamside vegetation below the dam	Release environmental flows in a natural seasonal pattern
	Development of aquatic weeds and eutrophication	Employ herbivorous fish, herbicides, mechanical removal, light-blocking dyes, and other vegetation-control measures
		Reduce sediment and nutrient input to the reservoir
	Alteration of water quality and temperature	Reduce the size and depth of the storage reservoir
		Control the depth from which water is released by multiple outlets
		Employ aerating turbines

8.7.1 Market and Regulatory Barriers

Extensive requirements are in place for obtaining the licenses and approvals necessary for constructing or modifying a FERC-jurisdictional hydroelectric or pumped-storage project.[67] No other generation source, except nuclear power, bears a comparable regulatory burden. Gaining approvals and a FERC license typically takes five years or more. Renewal of a FERC license ("relicensing") typically involves a multi-year process that can approach the time required for the original license. Owners must also obtain multiple approvals from other federal, state, and local authorities.

Efforts to simplify and streamline the FERC licensing process have been made in recent years and resulted in improvements. However, the process has inherent complexities because of the multiple interests represented. Proposals for simplifying and streamlining selected categories of development currently are being put forth, including the addition of hydroelectric generation at existing private and federal dams within suitable parameters. Such projects would be considered for a FERC license exemption and permitting requirements and approvals would be streamlined. It is important for the industry to continue to pursue efforts aimed at facilitating beneficial hydropower and pumped-storage development.

8.8 Conclusions

Hydropower, the largest source of renewable electricity generation in the United States, is one of the most mature sources of renewable power, with costs that are competitive with conventional fossil energy plants. Conventional run-of-river plants have little water storage capability and therefore operate principally as base-load plants. Larger plants with water storage capability have both the capability to generate independent of seasonal water availability and provide load following and ancillary services, such as firming variable generation (e.g., wind and solar generators). Hydropower resources are available in nearly every state; however, higher-quality

[67] FERC jurisdiction does not apply to federally owned facilities.

resources are predominantly located in the Northwest, California, and the Northeast. Hydroelectric power played a significant role in all of the RE Futures scenarios evaluated.

As hydropower is a relatively mature technology, it was estimated to have no cost or performance improvements over the 40-year study period. However, because most U.S. hydroelectric and pumped-storage projects are several decades old, opportunities to improve older plants include replacing obsolete equipment and making other changes to improve operability, efficiency, and environmental performance. In addition, less expensive construction techniques, the use of advanced materials, and reductions in the cost of electrical components could reduce future development costs.

The most important issues for future large-scale deployment of new hydropower plants are the high capital cost of new hydropower projects and the lengthy licensing and approval process, which typically takes five years or more. The primary environmental impacts of hydroelectric projects include impounding water, flooding terrestrial habitats, and creating barriers to the movements of fish and aquatic organisms, sediments, and nutrients. Alteration of water flows also can affect aquatic and terrestrial habitats that are downstream of dams. Proactive mitigation strategies to streamline the licensing process and address environmental concerns are needed to ensure hydropower contributes to a high-renewable electricity future.

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