

### Quick Facts

- Hydropower is a renewable, efficient, and reliable source of energy that does not directly emit greenhouse gases or other air pollutants, and that can be scheduled to produce power as needed, depending on water availability.
- There are about 78,000 megawatts of hydropower generation capacity in the United States.<sup>1</sup>
- Over the last decade, depending on water availability, hydroelectricity provided 5.8 to 7.2 percent of the electricity generated in the United States and averaged more than 70 percent of the electricity generated annually from all renewable sources, although this share is falling as the renewable capacity from other sources grows.<sup>2</sup>
- More than half of the total U.S. hydroelectric capacity for electricity generation is concentrated in three western states—Washington, California and Oregon—with approximately 26 percent in Washington alone. Canada is a major electricity supplier to New York, New England, the Upper Midwest, the Pacific Northwest, and California.<sup>3</sup>
- Hydropower could offer at least 80,000 megawatts of additional generation capacity.<sup>4</sup> Small, micro, and low hydropower are developing hydro technologies, while the efficiency and capacity of existing hydroelectric generators can be improved. Only about 3 percent of the roughly 80,000 dams in the United States have hydropower plants and can generate electricity.<sup>5</sup>
- Existing hydropower is very inexpensive to operate (generation costs 2 to 4 cents per kilowatt-hour).<sup>6</sup> The levelized cost of electricity of new hydropower projects, of less than 50 megawatts, (6 to 14 cents per kilowatt-hour) and incremental hydropower projects (adding generating capacity to existing dams; 1 to 10 cents per kilowatt-hour) puts them among the least expensive forms of low-carbon electricity.<sup>7</sup>
- The effects of climate change on water availability are expected to affect hydropower generation.

### Background

Hydropower, or hydroelectricity, is electricity generated by the force of moving water in the penstock<sup>8</sup> of a hydropower unit. Turbines are used to capture the kinetic energy of water by converting it to electricity as the falling water spins the turbine. Hydropower plants may be located below reservoirs or built in rivers (called “run-of-the-river” units) with no water storage capacity. Hydropower is considered a renewable source of energy, as it relies on water which is continuously renewed through the natural water cycle.

Hydroelectricity’s low cost, near-zero emissions, and ability to be dispatched quickly to meet peak electricity demand have made it one of the most valuable renewable energy sources worldwide. Hydropower accounts for about 17 percent of the world’s total electricity generation.<sup>9</sup>

Depending on water availability and annual precipitation, hydroelectricity has provided 5.8 to 7.2 percent of the electricity used in the United States in the last ten years and is the largest renewable source of electricity

in the United States.<sup>10,11</sup> U.S. hydropower accounted for 9.1 percent of global hydropower capacity and 8.7 percent of global hydropower generation in 2008 (1.33 percent of global electricity generation from all sources).<sup>12</sup>

### Description

The amount of electricity generated by a hydropower facility depends on three factors: 1) the turbine generating capacity; 2) the turbine discharge flow (the volume of water passing through the turbine in a given amount of time), and 3) the site head (the height of the water source or vertical distance between the highest point of water source and the turbine). The higher the head, the more gravitational energy the water has as it passes through the turbine. Most existing hydropower facilities in the United States can convert about 90 percent of the energy of falling water into electricity, which makes hydropower a technically efficient source of energy.

U.S. hydropower plants are very diverse. They might be located at dams with various storage capacities or be run-of-the-river facilities with no water storage capacity. Their elevation also varies. Only 3 percent of the dams in the United States have hydropower plants and can generate electricity.

Generally, based on the head and storage capacity availability, hydropower plants are categorized as follows:

- **Low-Head High-Storage Hydropower Plants**

These facilities are usually located behind multi-purpose (water supply, flood control, etc.) dams which have hydropower generation as an ancillary benefit. The reservoirs associated with these units are large (high storage capacity) while the head is relatively low at these facilities.

- **High-Head Low-Storage Hydropower Plants**

These facilities are often located behind reservoirs which have hydropower generation as their single objective. The reservoirs associated with these units are small (low storage capacity) while the head is relatively high. These units are usually located at higher elevations.

- **Run-of-the-River Hydropower Plants**

These facilities are usually built on rivers with steady natural flows or regulated flows discharged from upstream reservoirs. These units have little or no storage capacity, and hydropower is generated using the river flow and water head. Run-of-the-river hydropower plants are less appropriate for rivers with large seasonal fluctuations.

- **Pumped-Storage Hydropower Plants**

At these facilities water is stored in a lower reservoir after it is released from an upper reservoir to drive the turbine and generate power. Later, water is pumped back to the upper reservoir for reuse. Pumping water back to the upper pool requires energy (electricity). Pumped-storage systems are considered as flexible sources of electricity generation. These units generate electricity when demand and price are higher (during peak hours) and pump water back to the upper pools when electricity demand and price are lower. Pumped-storage plants are not net energy producers; rather,

they provide energy storage and electricity at its peak demand times (see [Climate Techbook: Energy Storage](#)).

Hydropower plants can also be categorized based on their capacities:

- **Large Conventional Hydropower plants**

These facilities have a generation capacity of more than 30 megawatts. The installed large hydropower capacity in the U.S. is approximately 66,500 megawatts.<sup>13</sup>

- **Small Conventional Hydropower plants**

These facilities have a generation capacity of 1 to 30 megawatts. The installed small hydropower capacity in the U.S. is approximately 8,000 megawatts.<sup>14</sup>

- **Low Power Hydropower Plants**

These facilities have a generation capacity of 100 kilowatts to 1 megawatt. The installed low power hydropower capacity in the U.S. is approximately 350 megawatts.<sup>15</sup>

- **Micro Hydropower Plants**

These facilities have a generation capacity of less than 100 kilowatts.<sup>16</sup>

Electricity demand fluctuates during the day and between months depending on different factors, most importantly the hour of the day and temperature. One of the advantages of hydropower over other sources of electricity (e.g., variable wind and solar power or baseload coal and nuclear plants) is its generation flexibility. Such flexibility enables hydropower to meet sudden fluctuations in demand or help to compensate for the loss of power from other sources. Hydropower can be used for both baseload and peak generation.

### **Environmental Benefit/Emission Reduction Potential**

Hydropower is a clean source of energy, as it burns no fuel and does not produce greenhouse gas (GHG) emissions, other pollutants, or wastes associated with fossil fuels or nuclear power. However, hydropower does cause indirect GHG emissions, mainly during the construction and flooding of the reservoirs. This may be due to decomposition of a fraction of the flooded biomass (forests, peatlands, and other soil types) and an increase in the aquatic wildlife and vegetation in the reservoir.<sup>17</sup> Hydropower's GHG emissions factor (4 to 18 grams CO<sub>2</sub> equivalent per kilowatt-hour<sup>18, 19, 20, 21</sup>) is 36 to 167 times lower than the emissions produced by electricity generation from fossil fuels.<sup>22,23</sup> Compared to other renewables, on a lifecycle basis hydropower releases fewer GHG emissions than electricity generation from biomass and solar and about the same as emissions from wind, nuclear, and geothermal plants.<sup>24</sup>

Hydropower is mainly criticized for its negative environmental impacts on local ecosystems and habitats. Damming a river alters its natural flow regime and temperature, which in turn changes the aquatic habitat. Such a change disturbs the river's natural flora and fauna. Fish are very sensitive to hydropower operations, and fish species (especially migratory species) have been significantly affected by hydropower dams across the United States. Small, low and micro hydropower facilities have much smaller negative environmental impacts than large hydropower facilities, but even they can engender public concern.<sup>25,26</sup>

Studies have estimated significant potential for increased deployment of hydropower in the United States, with additional generation capacity of at least 80,000 megawatts, mostly provided through the development of new small and micro hydroelectric plants (accounting for nearly 59,000 megawatts), development of new hydroelectric capacity at existing dams without hydropower facilities (17,000 megawatts), and generation efficiency improvements at existing facilities (4,000 megawatts).<sup>27</sup> Fully realizing the aforementioned low or high estimates of new hydropower potential might reduce or avoid CO<sub>2</sub> emissions from electricity generation equal to roughly 8.5 percent of total 2003 U.S. CO<sub>2</sub> emissions from electricity generation.<sup>28</sup> In its reference case scenario, the Energy Information Administration (EIA) predicts that between 2009 and 2035, conventional hydropower capacity will average 0.1 percent growth and hydropower generation will average 0.5 percent growth. Its overall share of renewable electricity capacity will fall as other renewable energy sources are deployed.<sup>29</sup>

A 2010 report from the International Energy Agency (IEA) projected that global hydropower production might grow by nearly 75 percent from 2007 to 2050 under business-as-usual but that it could grow by roughly 85 percent over the same period in a scenario with aggressive action to reduce GHG emissions. However, even under this latter scenario, increased hydropower generation is projected to provide only about 2 percent of the total GHG emission reductions from the global electric power sector compared to business-as-usual by 2050 (with all renewable technologies nonetheless providing nearly 33.5 percent of GHG abatement from the power sector).<sup>30</sup> According to IEA, a realistic potential for global hydropower is 2 to 3 times higher than the current production, with most remaining development potential in Africa, Asia, and Latin America.<sup>31</sup> IEA also notes that, while small hydropower plants could provide as much as 150 to 200 GW of new generating capacity worldwide, only 5 percent of the world's small-scale (i.e. small, low, and hydro) hydropower potential has yet been exploited.<sup>32</sup>

### Cost

Existing hydropower is one of the least expensive sources of power since the cost of hydropower is dominated by the initial capital cost of building the facility while the ongoing operating and maintenance (variable) costs are low. Moreover, since hydropower generation does not require burning fuels, operations costs are not vulnerable to fuel price fluctuations. Existing hydropower facilities are very cheap to operate and they can operate for 50 years or more without major replacement.<sup>33</sup> The cost of hydropower is highly site-specific and depends on different factors, including hydrologic characteristics, site accessibility, and distance from transmission. A 2008 study of the cost of new renewable electricity generation in the western United States (where much of the potential for new U.S. hydropower is located) estimated the levelized cost of incremental hydropower at existing dams to be \$0.01 to \$0.10 per kilowatt-hour (kWh) and the levelized cost of new small and micro hydropower to be between \$0.06 and \$0.14 per kWh, making incremental hydropower the least expensive option for new renewable generation and new hydropower roughly on par with new wind and biopower.<sup>34</sup>

### Current Status of Hydropower

At present, there are about 78,000 megawatts of hydropower generating capacity in the United States,<sup>35</sup> enough to supply 28 million households with electricity, or replace 500 million barrels of oil.<sup>36</sup> Pumped-

storage facilities offer an additional to 22,000 megawatts of capacity to that amount.<sup>37</sup> More than half of the total U.S. hydroelectric capacity for electricity generation is concentrated in three western states—Washington, California and Oregon—with approximately 27 percent in Washington alone.<sup>38</sup> There are nearly 2,400 hydropower facilities in the United States, although the United States has roughly 80,000 dams.<sup>39,40</sup> In the past 10 years, hydropower has provided between 5.8 and 7.2 percent of total U.S. electricity, and, in 2010, hydropower accounted for nearly 60 percent of all renewable electricity generated in the United States.<sup>41</sup> The United States has constructed very few new large dams since the early 1980s owing to concerns over their negative impacts on rivers, and the construction of new large hydropower dams is not considered a practical option for increasing hydropower generation due to the environmental impacts and unavailability of proper sites to develop for large-scale hydropower generation.<sup>42</sup>

The U.S. Army Corps of Engineers is the largest hydropower operator in the country, running 75 plants with a total installed capacity of 20,474 megawatts (26 percent of nationwide capacity). These federal plants produce about 100 billion kilowatt-hours a year, nearly a third of the nation's total hydropower output, or enough to serve about ten million households.<sup>43</sup> The privately owned dams in the United States which generate hydroelectric power are under the regulatory authority of the Federal Energy Regulatory Commission (FERC). FERC issues licenses for legal operation of hydropower dams to permit the dam owner to use public waters for hydropower generation. FERC licenses are renewed every 30 to 50 years. License renewal is an opportunity to balance the hydropower benefits against the negative effects of hydropower generation on the health of aquatic and riparian ecosystems.<sup>44</sup>

Currently, 1,010 gigawatts of hydropower generation capacity are in operation globally, and in 2010, 30 gigawatts of new capacity was added.<sup>45</sup> Hydropower accounts for about 16 percent of global total electricity generation<sup>46</sup> and nearly 85 percent of renewable electricity generation (in 2008).<sup>47</sup> As regions, Central and South America generate nearly 64 percent of their electricity from hydropower,<sup>48</sup> and many countries, including several large countries such as Canada and Brazil, rely on hydropower for more than half of their electricity.<sup>49,50</sup> China currently obtains about 16 percent of its electricity from hydropower;<sup>51</sup> from 2005 to 2010, China added almost 100 gigawatts of hydropower capacity,<sup>52</sup> increasing generation by almost 40 percent between 2005 and 2009 (global hydroelectric generation averaged slightly negative annual growth between 2005 and 2008).<sup>53</sup>

### **Obstacles to Further Development or Deployment of Hydropower**

- **Unavailability of Proper Sites for New Large Hydro Facilities**

The best sites for large hydropower generation in the United States have already been developed, and developing new sites for hydropower generation without negative ecological and recreational impacts is challenging. Storage and generation capacity expansions at existing hydropower sites or adding hydropower generation to reservoirs with existing dams that currently lack hydroelectricity generation is more likely.

- **Regulatory Hurdles**

Hydropower is the most heavily regulated electricity generating technology after nuclear power, with

regulatory requirements that may be time-consuming, expensive, and redundant as well as tailored to past experience with large hydropower projects, despite the likelihood that small-scale and incremental hydropower will be most important for future U.S. hydropower growth.<sup>54</sup>

- **Environmental Tradeoffs**

There is a tradeoff between the GHG avoidance or reduction benefits of hydropower and other environmental impacts. Increasing hydropower generation can have negative ecological and recreational impacts. For example, FERC, in an effort to protect riverine ecosystems, has often mandated reduced hydropower production levels under hydropower licenses.<sup>55</sup>

- **Climate Change**

Climate change and the alteration of rainfall and temperature regimes can affect hydropower generation. Hydropower systems with less storage capacities are more vulnerable to climate change, as storage capacity provides more flexibility in operations. Although hydropower systems may benefit from more storage and generation capacity, expansion of such capacities may not be economically and environmentally justified.<sup>56</sup>

## Policy Options to Help Promote Hydropower

- **Price on Carbon**

A price on carbon would raise the cost of electricity produced from fossil fuels relative to the cost of electricity from renewable sources, such as hydropower, and other low carbon technologies.

- **Renewable Electricity Standards**

[Renewable electricity standards](#) (renewable portfolio standards) require electricity providers to gradually increase the amount of renewable energy resources—such as wind, solar, bioenergy, and geothermal—in their electricity supplies, until they reach a specified target by a specified date.<sup>57</sup> The hydropower production growth under these standards is mostly provided through development of small-scale hydropower and this growth is considerably slower than increase in electricity generation from other renewable sources.

- **Economic Incentives**

Different financial incentives (e.g. tax credit bonds, production tax credit, incentive payments<sup>58</sup>) are provided to encourage the growth of hydropower generation, improving efficiency at existing projects, and more reliance on renewable electricity sources in the United States.

- **R&D Efforts**

R&D efforts are required to improve efficiencies, reduce costs and negative environmental impacts, and improve reliability and durability of hydropower technologies. Integration of hydropower systems with other renewable sources (developing hybrid systems) of electricity generation are recommended. There is a need for further R&D to improve equipment designs, investigate different materials, improve control systems, and optimize generation as part of integrated water-

management systems.<sup>59</sup>

Hydropower generation is an ancillary benefit of most dams that currently have it. Absence of reliable hydrological forecasts may result in needlessly foregone hydropower. For instance, a reservoir may be emptied to minimize the flood risks and ensure that flooding does not occur. In that case minimizing flood risks results in loss of hydropower benefits. R&D efforts are required for improving the meteorological and hydrological forecasting abilities for better performance of hydropower systems.

- **Adaptive FERC Licenses**

FERC licenses are issued for periods of 30 to 50 years. Hydrological and ecological changes of hydropower systems during this period may require changes in the license requirements to increase the hydropower and environmental benefits. Adaptive FERC licenses may help to avoid the need to change license requirements and improve the performance of hydropower systems.<sup>60</sup>

### **Related Business Environmental Leadership Council (BELC) Company Activities**

[Alcoa](#)

[Alstom](#)

[American Electric Power](#)

[CH2M Hill](#)

[Duke Energy](#)

[Exelon](#)

[PG&E](#)

[Rio Tinto](#)

[TransAlta](#)

### **Related Pew Center Resources**

[Climate Change 101: Technological Solutions](#), 2011.

[Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards](#), 2006

[Electricity Sector Overview](#), 2011

### **Further Reading / Additional Resources**

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[Low Impact Hydropower Institute](#)

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U.S. Army Corps of Engineers (2009) Hydropower; Value to the Nation ([http://www.vtn.iwr.usace.army.mil/docs/VTNHydropowerBro\\_loresprd.pdf](http://www.vtn.iwr.usace.army.mil/docs/VTNHydropowerBro_loresprd.pdf)).

U.S. Department of Energy, Wind and Hydropower Technologies Program Website, Hydropower ([http://www1.eere.energy.gov/windandhydro/hydro\\_technologies.html](http://www1.eere.energy.gov/windandhydro/hydro_technologies.html)).

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<sup>2</sup> U.S. Energy Information Administration (EIA) (2011) "Net Generation by Energy Source: Total All Sectors." 2011.

[http://www.eia.gov/totalenergy/data/monthly/pdf/sec7\\_5.pdf](http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf)

<sup>3</sup> U.S. Energy Information Administration (EIA) (2010) "Net Generation from Hydroelectric (Conventional) Power by State by Sector, Year-to-Date through December 2010 and 2009." 2011.

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<sup>4</sup> Kosnik, L-R (2008a), "The Potential of Water Power in the Fight against Global Warming in the U.S.," *Energy Policy* (36): 3252-3265. Accessed 1 August 2011. <http://www.umsl.edu/~kosnikl/Saved%20Emissions.pdf>

<sup>5</sup> National Hydropower Association. "Hydro Works for America." Accessed 25 July 2011.

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<sup>6</sup> Idaho National Laboratory. "Hydropower Plant Costs and Production Expenses." Accessed 25 July 2011.

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<sup>7</sup> California Institute for Energy and the Environment (CIEE), *Renewable Energy Transmission Initiative (RETI): Phase IA*. Final Report prepared by Black & Veatch. April 2008. <http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-F.PDF>

<sup>8</sup> A penstock is an intake structure or enclosed pipe that that delivers water to turbines.

<sup>9</sup> U.S. Energy Information Administration (EIA) (2008) "International Energy Statistics – Electricity Generation" Accessed 29 July 2009.

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<sup>10</sup> U.S. Energy Information Administration (EIA) (2011) "Net Generation by Energy Source: Total All Sectors."

[http://www.eia.gov/totalenergy/data/monthly/pdf/sec7\\_5.pdf](http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf)

<sup>11</sup> Ibid.

<sup>12</sup> EIA (2008) "International Energy Statistics." Accessed 29 July 2009. <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm>

<sup>13</sup> Electric Power Research Institute (EPRI) (2007), Assessment of Waterpower Potential and Development Needs ([http://www.aaas.org/spp/cstc/docs/07\\_06\\_1ERPI\\_report.pdf](http://www.aaas.org/spp/cstc/docs/07_06_1ERPI_report.pdf)).

<sup>14</sup> [EPRI](#), 2007.

<sup>15</sup> [EPRI](#), 2007.

<sup>16</sup> [EPRI](#), 2007.

<sup>17</sup> Hydro Quebec (2009) Greenhouse Gas Emissions and Hydroelectric Reservoirs (<http://www.hydroquebec.com/sustainable-development/documentation/ges.html>).

<sup>18</sup> Tremblay A., Varfalvy L., Roehm C. and Garneau M., The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions, Table 1, p. 3 ([http://www.un.org/esa/sustdev/sdissues/energy/op/hydro\\_tremblaypaper.pdf](http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_tremblaypaper.pdf)).

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<sup>22</sup> Tremblay et al. GHG emissions from reservoir flooding are higher in tropical areas, and in other regions reservoirs older than 10 years produce GHG emissions similar to natural lakes.

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- <sup>31</sup> IEA (2008) *Energy Technology Perspectives, Scenarios and Strategies to 2050*, In support of the G8 Plan of Action.
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- <sup>35</sup> EIA, 2011.
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<sup>58</sup> For details on financial incentives see <http://hydro.org/tech-and-policy/policy-priorities/>.

<sup>59</sup> IEA, 2008.

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