8

Hydropower: Past and Future

In 1966, at the age of 72, Mao Zedong famously swam in Asia's longest river, the Yangtze, to demonstrate his vigor and the strength of the Cultural Revolution. A dip in the fast-moving waters a decade earlier had inspired him to write a poem about how a dam on the Yangtze—a project that had been envisioned for flood control as early as 1919 by the founder of the Republic of China, Sun Yat-sen—could change the world. In 1994, some 18 years after Mao's death, construction began on what would become the largest hydroelectric project ever seen: the Three Gorges Dam.

First online in 2003 and fully completed in 2012, the 600-foot-tall Three Gorges Dam has an estimated electricity generating capacity of 22,500 megawatts. Its annual output of some 83 million megawatt-hours is equal to the power from burning 45 million tons of coal or running 12 nuclear reactors. Yet despite its major electricity contribution, the monumental dam—like many of the 300 mega-dams worldwide—has had a profound environmental, social, and economic impact.

The problems associated with the Three Gorges Dam are highly visible. Its construction flooded 244 square miles and displaced over 1.4 million people. The Chinese government's promise to provide them with a home and life after relocation comparable to their previous livelihoods in economic terms has simply not materialized. The new reservoir has decimated plant and animal species unique to China and continues to trigger seismic activity and deadly landslides. The total bill has yet to be paid, but it could reach some $88 billion, not including the full environmental and human damage.

China's State Council, the equivalent of the U.S. Cabinet, has publicly recognized some of the project's shortcomings, stating that "although the Three Gorges project provides huge comprehensive benefits, urgent problems must be resolved regarding the smooth relocation of residents, ecological protection, and geological disaster prevention."

Around the world, more than 150 countries are grappling with hydropower's costs and benefits as they tap the energy in falling water to help run their economies. Of the world's 45,000 large dams—those standing more than four stories high—some 8,600 are equipped to generate electricity. In 1980 hydropower accounted for 20 percent of global electricity production. Since then the share has fallen to 16 percent, about enough to power the United States.

Global hydroelectric generating capacity in 2013 totaled 1 million megawatts. New dams are adding roughly 30,000 megawatts a year. Since 1965, the world's hydroelectric generation has expanded fourfold, growing steadily at about 2.8 percent a year through 2003 and then increasing to 3.7 percent between 2003 and 2013. The recent acceleration was boosted by a string of new large projects coming online in China.

Indeed, although hydroelectricity use is widespread, most of the generation is concentrated in a handful of large countries. With half the world's large dams, China is out in front, having nearly quadrupled its hydropower output between 2000 and 2012. China generates nearly as much electricity from hydropower as the next three countries—Brazil, Canada, and the United States—combined. After these three come Russia and India, followed by Norway, Venezuela, Japan, and France.

Many smaller countries get all or nearly all of their electricity from rivers. Paraguay, for example, gets 100 percent of its electricity from hydro generation. For Ethiopia, the figure is 99 percent. With work now under way on the 6,000-megawatt Grand Ethiopian Renaissance Dam on the Blue Nile, one of Africa's costliest infrastructure projects, this country's heavy dependence on hydropower will remain high even as energy demand climbs. Other countries that get nearly all their electricity from hydropower include Bhutan, the Democratic Republic of the Congo, Lesotho, Mozambique, Nepal, Norway, and Zambia.

Venezuela depends on hydropower for 60–70 percent of its electricity, which comes as somewhat of a surprise since it is a leading oil producer. Its Guri Dam, which was constructed in two phases between 1963 and 1986, has a generating capacity of more than 10,000 megawatts. It is to Venezuela's advantage to use hydro-generated electricity as much as possible so that it can export its oil. Hydropower also supplies over half the electricity in Austria, Ecuador, New Zealand, Peru, and Switzerland—all countries with mountainous topography.

Brazil has a high hydropower ranking thanks to its abundance of rivers, including the vast network of rivers in the Amazon basin that take water from the Andes to the Atlantic Ocean. Hydroelectric dams typically supply roughly 80 percent of the country's electricity. Among them is the Itaipu Dam located in the southern part of the country, which is easily the world's most productive dam. Its 20 generating units each have a capacity of 700 megawatts. Despite having a smaller capacity, Itaipu generally outperforms China's Three Gorges because of a more consistent year-round flow. Its record-breaking 2013 production of 98.6 million megawatt-hours of electricity could power the global economy for almost two days. Itaipu alone supplies 17 percent of Brazil's electricity and 75 percent of Paraguay's.

Like Brazil, Canada has many rivers—from its easternmost province of Newfoundland to British Columbia on its Pacific coast. Hydropower accounts for close to 60 percent of Canada's electricity consumption, and several of its dams rank among the world's largest. The Robert-Bourassa Dam on the La Grande River in northern Quebec stands as tall as a 53-story building and has a generating capacity of 5,616 megawatts. The 2,790 megawatt-W.A.C. Bennett Dam on the Peace River in British Columbia created the Williston Lake when it was built in the 1960s. It is one of 31 hydroelectric generating stations that produce 95 percent of that province's electricity.

Since Canada covers such a vast geographic area but has only 35 million people, it is well positioned to export surplus electricity to the United States, much of it going south from Ontario to New England and densely populated New York State. Canadian exports meet the electricity needs of roughly 10 million Americans.

Canada is not the only country to export a surplus of hydroelectricity. For Bhutan, a small and sparsely populated country of just 766,000 people in the eastern Himalayas, hydropower accounts for one fifth of the gross domestic product. Since the country produces far more hydroelectricity than it can consume, it sells the surplus to neighboring power-hungry India. Bhutan is building still more dams to expand electricity exports. For the

Bhutanese economy, electricity is the principal export and a major source of foreign exchange earnings.

Two of the world's largest dams in terms of reservoir size are located in Russia, where hydropower accounts for 17 percent of the country's electricity portfolio. Russia's largest source of hydropower is the 6,000-megawatt Krasnoyarsk Dam on the Yenisey River, which, like most of Russia's rivers, flows north into the Arctic Ocean. The Bratsk Dam, in Siberia, stands more than 410 feet high. Constructed between 1954 and 1964, it has a generating capacity of 4,500 megawatts.

The world's most voluminous reservoir is Lake Kariba, created by a dam on the Zambezi River in Zimbabwe. The dam supports a generating capacity of 1,470 megawatts, accounting for roughly 60 percent of hydropower generation—the principal source of electricity—in Zimbabwe and Zambia.

Another of the world's largest reservoirs is Lake Volta, created by the Akosombo Dam located on the Volta River in Ghana. This vast lake, behind a dam some 374 feet tall, contains a wealth of fish that provide livelihoods for some 300,000 local fishers. Despite the reservoir's huge size, the dam has a generating capacity of only 1,020 megawatts.

Every country has its own hydrological story. For the United States, the 10 largest dams were all built between 1930 and 1975. The Hoover Dam, built on the Colorado River in Nevada and completed in 1936, was a product of the public works projects of the Great Depression. So too was the Grand Coulee Dam—the nation's largest—completed in 1941 on the Columbia River in the state of Washington. With a generating capacity of 6,800 megawatts, it can satisfy the power needs of some 2.3 million homes. Construction of these two dams was an important part of U.S. economic history, creating jobs during the height of the Depression.

Hydropower accounts for 7 percent of U.S. electricity generation and 51 percent of what is considered to be renewable. The top hydroelectric generating states are Washington, Oregon, California, and New York, followed by Alabama, Tennessee, Montana, and Idaho. Regionally, the Northwest has the largest share of U.S. hydropower capacity. Much of it comes from dams on the Columbia River, which originates in the Canadian Rockies and flows through Washington and Oregon en route to the Pacific Ocean. The generating capacity of dams on the Columbia and its tributaries, including the huge Grand Coulee Dam, totals 29,000 megawatts and accounted for 44 percent of U.S. hydroelectric generation in 2012.

Altogether the United States has more than 80,000 dams of varying sizes that have been built on rivers and small streams. Fewer than 3 percent of these, however, are used to generate electricity; the bulk were constructed for flood control, irrigation, or turning wheels on mills that are no longer operating. Installing turbines and converting this water flow into electricity can provide some of the cheapest power available from any source. Senator Ed Markey from Massachusetts, a member of the Senate Environment and Public Works Committee, has noted that "with thousands of existing dams currently not creating any power, existing dams in need of upgrades, and new technologies being developed to safely capture river currents, an additional 60,000 megawatts [of hydro generation] is achievable within the next 15 years." For reference, this is equal to the generating capacity of 60 nuclear power reactors.

The Oak Ridge National Laboratory estimates much more conservatively that 54,000 existing U.S. dams that are not yet equipped to generate electricity could be renovated to produce an additional 12,100 megawatts of electricity. Much of this potential is concentrated in the Southeast and lower Midwest, where neither solar nor wind energy resources are well developed yet.

At the same time that the U.S. government is exploring options for repowering or upgrading existing dams, decommissioning of older dams is freeing up some impeded rivers. The conservation group American Rivers calculates that over the last quarter-century nearly 900 dams have been taken down in the United States. Since 2007, U.S. waterways have lost an average of at least one dam each week, primarily in New England and the Great Lakes vicinity, as well as in California and the Pacific Northwest. The dismantled dams are mostly smaller, not producing much if any power, and oftentimes are costlier to maintain than to remove.

As dams have come down, fish and other wildlife have returned. The largest American dam removals thus far have been two on Washington State's Elwha River: the 108-foot high Elwha Dam, which came down in 2011, and the 210-foot tall Glines Canyon Dam, in 2014. After disrupting the river flow for over a century, the dams' demise is bringing hope for a renewed salmon run. Europe is also restoring a number of rivers, including tearing down dams on France's longest river, the Loire, and Spain's large Douro River.

These dam removals serve as a reminder of the pros and cons of hydropower as an energy source. Its principal attractions are that it is renewable and usually reliable. It meshes nicely with wind and solar energy, since it can run nearly continuously, as weather allows, or be ramped up quickly to offset fluctuations in wind and solar production. Beyond power generation, dams can also provide water storage, flood control, and irrigation water. Thus in some cases, in addition to providing energy security, they can also contribute to food security.

Hydropower's drawbacks, however, are causing some people to reexamine its role. Hydropower dams and the reservoirs they create generally flood vast areas, displacing whole communities of people and inundating historical sites and cultural legacies. The flooding can eliminate local plant and animal species, reducing the biological diversity of the planet. Dams also weaken the resilience of river ecosystems, impede sediment flows, and threaten the stability of downstream land. They can cause downstream lakes and wetlands to shrink or disappear and can interrupt the movement of fish and other creatures. Water in reservoirs and rivers slowed by dams warms more quickly than water in free-flowing rivers, threatening temperature-sensitive aquatic life. So while irrigation from a reservoir's water can increase crop production, the dam may cause the collapse of fisheries, important sources of protein.

Hydropower production itself is subject to disruption by drought. This was recently seen in Brazil, which in 2014 endured electricity blackouts when hit by the worst drought in 80 years. In the same year, severe drought in California halved hydropower's contribution to the state's electricity output. Precipitation extremes—both droughts and floods—increase the risks that hydropower may not pay dividends. Nigeria's Kainji Dam has missed its hydropower production target by as much as 70 percent due to water fluctuations from droughts and floods.

Although it is renewable, hydropower production is not climate-neutral. The vast amount of concrete used to build a megadam has a large carbon footprint. Less obvious are the emissions of methane—a potent global warming gas—from decomposing plant material in flooded reservoirs and trapped behind dams. The full impact varies depending on geography and local conditions, but some studies have shown that the climate impact of hydropower reservoirs can exceed that from power plants that burn fossil fuels.

Furthermore, building dams and their reservoirs can trigger seismic activity. Over 100 earthquakes worldwide have been linked to reservoir-induced seismicity, including the devastating May 2008 quake in China's Sichuan Province that killed a reported 80,000 people. Christian Klose, a researcher at the consultancy Think Geohazards, says that the massive amount of water that accumulated behind the Zipingpu Dam, located a mile from a major fault zone, "amplified the strain on the earth's crust." A number of studies by U.S. and Chinese scientists, drawing on experience in China and elsewhere, agree that the dam—a government project—could have caused the 7.9-magnitude earthquake. A 2013 magnitude 7.0 quake on the same fault line may also have been dam-induced.

Dam-building strains economies as well as geology. A 2013 study by an Oxford University team warns developing countries that turning to hydropower to meet electricity needs is a gamble. Brazil's enormous $20-billion Itaipu Dam, for instance, experienced a 240 percent cost overrun by the time it came online in 1984, a sum so large that it left the country financially impaired for three decades. The Oxford survey of 245 dams built around the world since 1934 showed that the final cost of building dams typically comes in at about double the original budget. In addition, 80 percent of projects failed to meet their construction schedule.

Two of the authors underline these risks in a *Wall Street Journal* op-ed, noting that "because megadams take 8.6 years on average and often more than 10 years to build [not including the full development time], these projects don't ease urgent energy crises. The long lead time makes the projects especially vulnerable to currency volatility, inflation, political tensions, swings in water availability and electricity prices." The bottom line is that in building dams, as with nuclear power plants, cost overruns and schedule failure are the rule, not the exception. Governments may be better off choosing more flexible infrastructure—like wind and solar power—to aid their development.

Despite the economic downsides, new hydropower development may be on an upturn. Looking at proposed projects around the world, a team led by Christiane Zarfl, now of the Universität Tübingen, and Alexander Lumsdon of the Freie Universität Berlin counted at least 3,700 dams of over 1 megawatt capacity planned or under construction around the world, mostly in emerging economies. Were they all to be built, global hydroelectric capacity would increase from close to 1 million megawatts to 1.7 million megawatts. While most of the dams would be small or mid-sized, the 847 proposed large dams (those over 100 megawatts) account for 93 percent of this potential power capacity increase.

This corresponds to the International Energy Agency's projections for hydroelectric generation increasing 70 percent by 2040. A fifth of this growth is expected in China, which has some 200 potential hydropower projects in the pipeline, mostly in its southwest. The rest of the projected hydropower growth would come from a scattering of large dams being built in countries such as Brazil, Pakistan, and Turkey and in sub-Saharan Africa, as well as from numerous small hydro facilities under construction in southern Asia and Latin America.

Brazil is working on a number of dams in the Amazon. One of the three large ones under development, the Belo Monte, is expected to have a robust power capacity of 14,000 megawatts. Like many of the planned Amazonian dams, it has proved contentious because it would displace native communities and disrupt an incredibly biodiverse landscape. Additional loss of forest in the Amazon from infrastructure development and inundation from dams can have profound repercussions on the hydrology of the entire region. The Amazon serves as a sort of hydrological pump, recycling rainfall inland from the Atlantic coast. If forest loss, fragmentation, and drying increase to the point that the Amazon's ability to recycle rainfall weakens, not only will hydropower potential be reduced, but the entire ecosystem could be in jeopardy. The forest could be transformed from a major carbon storehouse to a major carbon emissions source.

An increasing share of hydropower investment is international. For example, Brazilian and Indian companies are building dams around the world. South Korean companies are investing in hydropower facilities in Pakistan. But no one is doing more hydropower internationally than China. After dam projects fell out of vogue by traditional development funders like the World Bank in the 1990s, Chinese lenders and businesses stepped in, and they now are involved in more than 200 hydroelectric projects in dozens of countries, according to data from the nongovernmental organization International Rivers. About half the projects are in Southeast Asia. In 2011, for example, the government of Laos granted Sinohydro access to the entire Nam Ou river basin, where it plans to develop seven dams.

The China Three Gorges Corporation, one of China's largest hydropower developers, is among the many Chinese firms taking dam-building experience abroad, with active projects in Pakistan, Myanmar, Laos, and Russia. As the market for new dams in China is becoming saturated, the company is also diversifying into new energy forms, importantly wind and solar. By 2020, the company expects its hydro projects to total 70,000 megawatts of installed capacity, with an additional 20,000 megawatts in wind farms and other "new energy."

As of late 2014, companies from China are vying with those from other countries, including Spain and South Korea (which is working with Canada), for development rights to a major project on the Congo River in Africa, one of the world's major remaining hydropower frontiers. Two dams, Inga 1 and 2, were built at the Inga Falls in western Democratic Republic of the Congo in 1972 and 1982. The new project, called the Grand Inga, has an enormous potential power generating capacity estimated at 40,000 megawatts.

If harnessed, this energy from the Congo River would dramatically expand Africa's electricity production. The World Bank, the African Development Bank, and other financiers are looking at the project as a way to support economic development, with the aim of raising living standards throughout the region.

On the one hand, the river's energy is renewable and abundant in an energy-starved part of the world. But on the other hand, groups like International Rivers point out that much of the electricity from the Grand Inga development will likely go to industry and far-off cities, rather than to the people of the Democratic Republic of the Congo, many of whom live in rural areas far from any sort of electric grid. Already South Africa has signed up to buy more than half of the electricity to be generated by the new project's first phase, the Inga 3 dam. Then there are the usual negatives associated with large dams, including the inundation of land, the associated displacement of people, and the disruption of river transportation. Another concern is that the Inga 1 and 2 dams have not been well maintained and are putting out only 40 percent as much power as initially anticipated. The World Bank is helping to fund their rehabilitation, but even that endeavor has run into delays and cost overruns. Building the world's largest dam complex in the world's poorest country, one perennially plagued by corruption, is not without risk.

Rachel Kyte, World Bank Group vice president and special envoy for climate change, believes the move away from hydro a decade ago, at a time when many were questioning its net contribution, was a mistake. Given the need for electricity in so many developing countries, she thinks funding hydro can be justified. That is certainly conceivable, but it is also quite possible that with solar generating costs dropping so low, it may be both cheaper and less disruptive to supply electricity in the developing world with solar energy rather than hydropower. Certainly the financial risks are smaller.

Though it has recently begun to reconsider large dams in a more positive light, over the last decade more than 60 percent of World Bank lending for water power has been for small-scale projects, including run-of-the-river facilities that set a turbine in the stream to capture the energy from flowing water without creating a reservoir. They have the advantage over large dams of requiring only small amounts of investment capital. In addition, the engineering work is relatively simple and the environmental impact from reservoir creation and the direct displacement of communities are both avoided. In contributing to meeting daily electricity demand at the grassroots level, small-scale hydro can help to reduce poverty and advance economic development.

China has been the leader in developing small-scale hydro, having started working on this several decades ago. Its total installed hydroelectric capacity comes to 249,000 megawatts. Of this, over 65,000 megawatts of generating capacity comes from 45,000 relatively small hydropower generating facilities of 50 megawatts or less.

As more plans for adding turbines to generate power from rivers come to fruition, the impacts of small hydro will likely become clearer. The cumulative impact of many small dams can be substantial, causing some hydrologists to liken it to "death from a thousand cuts." In northern India, a cascade of small dams has been linked to worsened flooding, for instance. Klement Tockner of the Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin notes that "we are seeing huge numbers of small hydropower plants affecting lots of free-flowing rivers, but not delivering much power." Ultimately, small hydro still may be a powerful aid, particularly in the developing world, where there are 1.3 billion people without electricity and another billion with only erratic electricity supply, but only if it is done thoughtfully.

One question remaining is whether small-scale hydro development can minimize negative effects that dams often have downstream, which historically have exacerbated tensions among communities, particularly on rivers that cross national borders. China relies heavily on the Yangtze and Yellow Rivers and their tributaries for the bulk of its hydroelectric generation. But it also taps rivers that are important to other countries.

In November 2014, China completed the first phase of a hydroelectric project on the Brahmaputra River, which starts in Tibet. Despite assurances that the additional build-out will be run-of-the-river projects allowing for continuous river flow, the development raises concerns in downstream India and Bangladesh. India itself is looking at the possibility of adding several hundred new dams to its roster, largely in-stream projects in the Himalayan region, where most of the hydroelectric potential has yet to be developed. China also appears to be moving forward in developing hydropower on the Nu River (also known as the Salween). This river, which starts in Tibet and flows to Myanmar, is the largest remaining free-flowing river in China.

China's dam building on the upper reaches of the Mekong River, which ultimately flows through Myanmar, Laos, Thailand, Cambodia, and Viet Nam, stresses its relationships with its downstream neighbors, where some 60 million people depend on the river flow. In 2012, Vietnamese President Truong Tan Sang told Radio Free Asia that after some of the early dams were built, river water and underground aquifers "are seriously declining, while floods, sea level rises, high tides, coastal erosion...have been exacerbated." A decrease in water flow allows saline water to creep up the river, while the loss of sediment transport from dam blockages can shrink the Mekong Delta, one of the world's most productive rice-growing regions. The largest lake in Southeast Asia, Cambodia's Tonle Sap—a major source of protein in a country where people are highly dependent on fish—could shrink in size as more upstream dams are completed.

Not to be left out, however, Cambodia and Laos, with investment from Thailand, Malaysia, China, and Viet Nam, are also looking at adding a series of dams on the river. The bulk of the power generated would be exported to Thailand and Viet Nam, with only 10 percent designated for the host countries. Yet a study by the nongovernmental International Centre for Environmental Management indicates that development of other renewable sources of electricity, importantly solar, could well exceed the dams' potential power generation.

Another site of contentious water allocation is in the Nile River Basin, now home to 600 million people. Downstream Egypt staked its claim in a 1929 treaty with the then-British colonies of East Africa. In 1959, Egypt and Sudan signed the Nile Waters Agreement, which gave Egypt 75 percent of the Nile River's flow and gave Sudan 25 percent. Ethiopia, at the Nile's headwaters, was left out. Impounding the Nile River near where it crosses from

Sudan into Egypt is the well-known Aswan High Dam, which has a generating capacity of 2,100 megawatts.

This hydroelectric capacity could be reduced when the reservoir for the Grand Ethiopian Renaissance Dam on the Blue Nile, the Nile River's major source, is filled. Ethiopia—Africa's second most populous country, with many of its 94 million people still mired in poverty—has spent over $1 billion on the project that is projected to cost at least four times as much, sacrificing other public spending and risking a tremendous debt burden. Its goal is to triple the country's electrical generating capacity, allowing for electricity sales to neighboring countries. China has leant Ethiopia $1 billion for a transmission line, but most international lending for the project has been dissuaded by Egypt's concerns about losing water. Also competing for the Nile's water are countries acquiring land in the Nile Basin for farming, including South Korea, Saudi Arabia, and India.

Dam building, largely by upstream Turkey, has also exacerbated water scarcity in Iraq and Syria. As of 2014, Turkey housed 478 hydroelectric power plants. Another 160 were under construction, including the 443-foot high Ilisu Dam on the Tigris. The dam is part of the Southeastern Anatolia Project, which is intended to provide power and also irrigation water for some 6,500 square miles of land. Unfortunately its reservoir will flood an estimated 121 square miles—including Hasankeyf, a settlement that has been continuously inhabited for some 12,000 years—while leaving downstream areas with less water.

In North America, water allocation conversations between the United States and Mexico, which share the large Rio Grande and Colorado Rivers, date back to the late 1800s. In the hierarchy of water uses outlined in their 1944 Water Treaty, electric power generation ranks after domestic and municipal use and use for agriculture and livestock. Water for nature is omitted from the treaty obligations. Diversions and dams on the Colorado River have meant that in many years the flow is depleted before it reaches the sea. In 2014, for the first time, the two countries allotted an increased share of the flow for the environment, allowing the river to reach the Gulf of California. Scientists are monitoring the region to see if periodic water releases from dams can help restore riparian ecosystems.

The advantages of countries working together on energy projects can be seen quite clearly in Central America. Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama have recently completed the Central American Electrical Interconnection System—a 1,100-mile-long high-voltage line that ties their national grids into a single regional grid. It also allows for power trades with Colombia and Mexico. This market enlargement, which has facilitated exploitation of the wealth of falling water resources in the region, was funded in part by the Inter-American Development Bank.

Beyond rivers, other water-power operations involve capturing the energy in tidal currents and waves. Wave energy projects are still largely in the testing phases, with most activity in Europe and Asia. Many countries with coastlines have considered capturing the energy in ocean tides, but only two have thus far made serious headway in doing so. South Korea (with 254 megawatts of tidal generating capacity) and France (240 megawatts) together account for over 90 percent of the world's tidal-generated electricity. Canada, China, and the United Kingdom make up much of the remainder. Total world tidal power capacity at the start of 2014 was near 530 megawatts.

The German company Siemens estimates that some 250 million homes worldwide could eventually be powered by tidal currents. Scotland's proposal to harness tidal energy in the Pentland Firth is expected to supply 86 megawatts of generating capacity in the first phase, potentially growing to 398 megawatts. Canada and the U.S. Department of Energy are experimenting with a tidal turbine in the mouth of the Bay of Fundy off the coast of Maine. The Chinese government is setting up their largest tidal test project near Shanghai. Other water energy projects in the works in China include a 10-megawatt ocean thermal conversion power station to be built by global security and aerospace firm Lockheed Martin. This technology relies on the heat differential between warm surface waters and cooler deep waters to drive a turbine. In its early days, ocean thermal power is still costly, but it could eventually undercut offshore wind.

A more established water energy practice that has gained attention in recent years is pumped storage. This involves using excess electricity when demand is low to pump water uphill so that it can be used to generate electricity when needed. Facilities can be connected to existing hydroelectric generating plants or they can be stand-alone, closed-loop, off-river systems. Worldwide pumped storage capacity stands at more than 130,000 megawatts. More than 50,000 megawatts of capacity are in Europe, which is planning to add another 11,500 megawatts. Some of this will come from modifying older facilities and some from investing in new ones. Japan and China each have over 20,000 megawatts of pumped storage capacity, as does the United States. Proposed U.S. projects would more than double its capacity. One of the attractions of pumped storage is that it can be deployed nearly instantaneously to offset fluctuations in wind and solar energy. In doing so, it helps expand the amount of wind and solar that can be integrated into the grid.

In sum, hydropower supplies an impressive one sixth of the world's electricity. Yet rivers in countries that are fully industrialized are near dam saturation. For the low-income countries that have more untapped river power potential, other renewables may prove a more cost-effective bet. Many of the historical decisions regarding financing hydropower were made before low-cost solar and wind energy arrived on the scene. With solar, people can own and thus control their power source, giving them a direct hand in the development process. Hydropower will continue to be important, but most of the big dam building is in the past.

Data, endnotes, and additional resources can be found at Earth Policy Institute, www.earth-policy.org.