H.R. 6084 THE WATER POWER RESEARCH AND DEVELOPMENT ACT

PREPARED BY

POTENTIAL POWER TEAM

AUGUST 2020

WORKSHOP IN APPLIED EARTH SYSTEMS MANAGEMENT

COLUMBIA UNIVERSITY
SCHOOL OF INTERNATIONAL AND PUBLIC AFFAIRS

TEAM
Elizabeth Wilson (Manager), Colleen Neely (Deputy Manager),
Rachel Goodgal, Carol Hu, Jessica Kenny, Katherine Lin,
Anna Nikolova, Drew Poling, Sophie Tolomiczenko

FACULTY ADVISOR
Professor Howard Apsan

TABLE OF CONTENTS

COVER IMAGES

Top: Wave energy technology in Cork, Ireland. *OceanEnergy*

Bottom: Impoundment hydropower facility in Quebec, Canada. *Fred Lambert for LaPresse*

EXECUTIVE SUMMARY

The Water Power Research and Development Act, H.R. 6084, promotes research, development, demonstration, and commercial application of hydropower, pumped storage, and marine energy technologies. The bill seeks to expand water power as a viable source of renewable energy in the United States.

Due to the damaging impacts of fossil fuels, it is vital that the United States increase its renewable energy capacity. Currently, hydropower is the largest renewable contributor to U.S. electricity generation. However, its systems are aging and environmentally disruptive.

Therefore, the bill's funding allocations for hydropower and pumped storage focus primarily on infrastructure improvements and system upgrades, with the goal of increasing capacity and efficiency and reducing environmental impacts. Marine energy is not yet at commercial scale but has large potential energy generation capacity and can complement other renewables. Accordingly, the bill focuses on technology development and evaluation of parameters such as environmental impact, grid integration, and scalability.

Over five years, the bill allocates over $800 million to the improvement and advancement of water power technologies. Indicators of successful implementation include increased electricity generation within the industry, increased grid reliability, and reduced environmental impacts.

The investments outlined in the bill will result in increased electricity generation from water power technologies, thereby diversifying U.S. electricity sources. This will help to reduce reliance on fossil fuels and to minimize environmental and health effects incurred during electricity production. By expanding production of water power, the U.S. will build a stronger, less polluting, and more resilient electricity system.

INTRODUCTION TO THE BILL H.R. 6084

Water power, which includes hydropower and marine energy, is the largest source of renewable energy in the United States. The U.S. currently ranks third in the world for installed hydropower capacity, with a total of 102.8 gigawatts (GW), behind China with 356.4 GW and Brazil with 109.1 GW. However, the U.S. hydropower capacity has been stagnant over the last 20 years.[1] Marine energy technologies, which hold enormous renewable energy potential and are beginning to be developed worldwide, are not yet established at utility scale in the U.S.

To address this problem, Representative Suzanne Bonamici (D-OR-1) introduced the Water Power Research and Development Act, H.R. 6084, ("Water Power Act") to the 116th Congress on March 4, 2020. The original co-sponsors are Rep. Ted Deutch (D-FL-22), Rep. Don Young (R-AK-At Large), Rep. Eddie Bernice Johnson (D-TX-30), and Rep. David B. McKinley (R-WV-1). Rep. Bonamici views marine energy as a vital component of decarbonizing the United States' energy system, and one that requires federal investment to achieve its potential.[2,3]

The Water Power Act amends Subtitle C of Title VI of the Energy Independence and Security Act of 2007, which also supported research and development of marine and hydrokinetic energy. The bill expands on the goals and directives of Subtitle C, and it reinstates and increases appropriations that expired in 2012.[4] While Subtitle C supported marine energy, it did not include conventional hydropower from dams and diversion; the Water Power Act supports both, though funding is primarily directed towards marine energy.

Hydrokinetic energy refers to energy generated from moving water, such as wave, tidal, and in-stream hydropower.

The bill states four main purposes: to promote the research, development, demonstration, and commercial application of water power to increase capacity and reduce costs; to support research and development aimed at improving the environmental impacts of these technologies; to improve grid reliability and resilience; and to promote the development of water power to spur economic growth in the sector. Two main sections of the bill detail program priorities for hydropower and marine energy. The bill also directs grants to institutions of higher education to continue and expand activities at National Marine Energy Centers, and to establish new Centers.

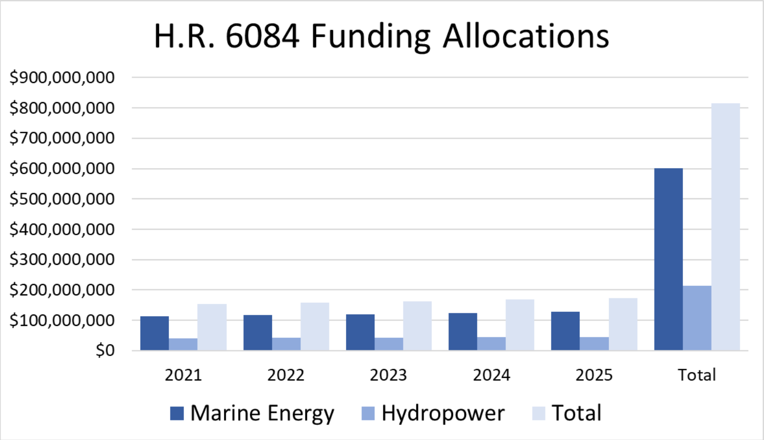

Figure 1: Breakdown of funding allocations in H.R. 6084

Funding is allocated to the bill's programs each year from 2021 to 2025. Marine energy funding is approximately $602 million and hydropower funding is approximately $213 million, for a total of about $815 million over the five-year period.

PROBLEMS THE BILL ADDRESSES

The United States is heavily dependent on fossil fuels for electricity generation.[5] Fossil fuels are inexpensive and abundant. However, the extraction and combustion of fossil fuels harm human health, impact local ecosystems, and fuel global climate change.

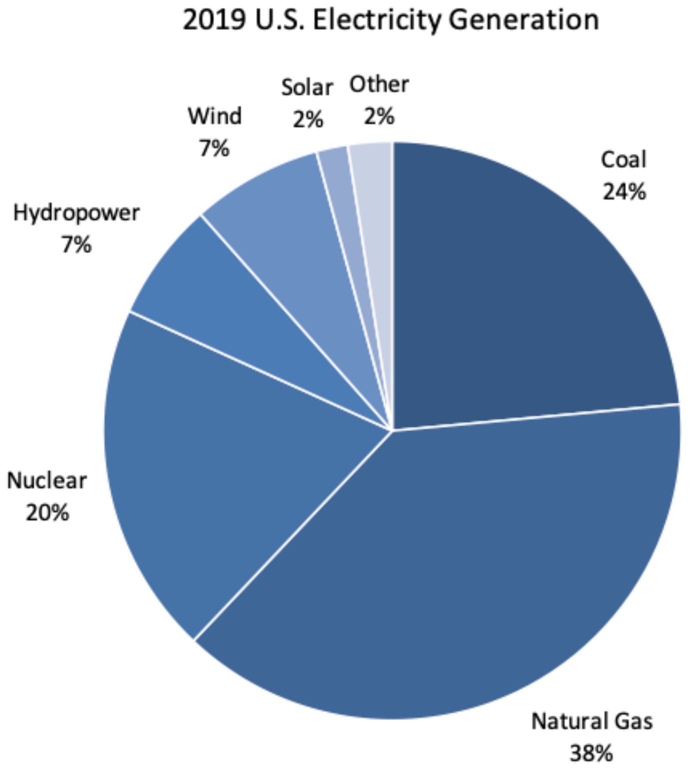

Figure 2: 2019 U.S. electricity generation by source. Data source: eia.gov[6]

In 2019, coal was responsible for 24% of energy generation in the U.S., and natural gas was responsible for 38%. While the use of coal has declined, electricity generation from natural gas has doubled since 2000. This is largely due to developments in hydraulic fracturing ("fracking") technology, which has enabled the extraction of previously inaccessible natural gas reserves, increasing production and decreasing cost.[7]

Coal production impacts land, air, and water from extraction to combustion. The method of extraction known as surface or "strip" mining removes topsoil and rock near the surface to access coal deposits below. Mountain top removal and valley fill practices radically alter the topography and hydrology of an area by removing hill tops and filling in surrounding valleys with removed material.[8] These practices cause extensive harm to local ecosystems.

Coal extraction also impacts air quality by releasing particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and heavy metals.[9] SO_2 causes damaging acid rain, and PM, NO_2, and heavy metals are linked to respiratory, neurological, and developmental human health effects.[10] Combustion of coal emits additional quantities of these pollutants as well as climate-change-causing carbon dioxide.[11]

The largest local concern about fracking is water pollution. Huge volumes of wastewater created during fracking pose contamination risks to local water sources. Wastewater often includes bromine, heavy metals, and radionuclides, all of which pose human health risks, including increased risk of cancer. In addition, leaks of natural gas at many points in the production cycle emit methane, a potent greenhouse gas.[12,13,14] Natural gas combustion also emits NO_2, which contributes to respiratory illness, as well as carbon dioxide.[15]

Case Study – Refinery at Grays Ferry, Philadelphia

A 150-year-old refinery in Grays Ferry, PA, is the largest fossil fuel processing plant on the east coast of the United States. The refinery is located in a low-income, predominantly Black community, which has high occurrences of cancer, lung disease, heart disease, and asthma. The E.P.A. discovered that the refinery at Grays Ferry had failed to comply with standards set by the Clean Air Act on multiple occasions.[17] One of the pollutants released by the refinery is particulate matter, which has been linked to increased death rates from COVID-19.[18] Additionally, in 2019, an explosion at the refinery released 5,000 lbs. of hydrofluoric acid, a pollutant which can cause heart and lung complications, into the air.[19]

Figure 3: Flames and smoke rise after an explosion at the Philadelphia Energy Solutions Refining Complex in Grays Ferry on June 21, 2019. Photo by Matt Rourke for AP file.[20]

Frequently, fossil fuel combustion plants are located in low income communities and communities of color. A study from the Environmental Protection Agency (E.P.A.) found that Black Americans are exposed to 1.5 times more air pollution from fossil fuel combustion than the rest of the population.[16] Reducing the nation's dependence on fossil fuels for electricity generation would alleviate the environmental and human health burdens experienced in these communities.

Why is Marine Energy Needed to Address Fossil Fuel Dependence?

Electricity generation from renewable energy sources has increased by approximately 88% since 2000.[21] Wind and solar energy, which have been responsible for much of this growth, provide intermittent power dependent on location, time of day, season, and weather conditions, which makes it challenging to meet peak electricity demands.[22] Hydropower and marine energy provide less variable and more flexible electricity generation and so can be used to help balance the electric grid and meet periods of high electricity demand.

Current State of Water Power in the United States

To understand the significance of the Water Power Act, this section will address the current state of water power in the United States, including existing capacity, technology, and challenges.

Hydropower and Pumped Storage Sector Overview

Hydropower and pumped storage plants currently have a combined installed capacity of 103 GW: 80 GW from hydropower plants and 23 GW from pumped storage plants.[23] Together, these sources comprise 38% of the renewable energy mix and 7% of total U.S. electricity generation.[24]

The majority of hydropower and pumped storage facilities in operation today were built between 1940 and 1970.[25] During this 30-year period, hydropower generation in the U.S. increased by 175%, from 100 terawatt-hours (TWh) to 275 TWh.[26]

However, hydropower has remained stagnant at 275 TWh per year since 1970s, as shown in **Figure 4**.[27] In addition, plants are beginning to reach the end of their 50-year lifespans. Without new investment, hydropower generation capacity will remain plateaued and even begin to decline as aging infrastructure reduces efficiency and requires plants and equipment to be decommissioned.

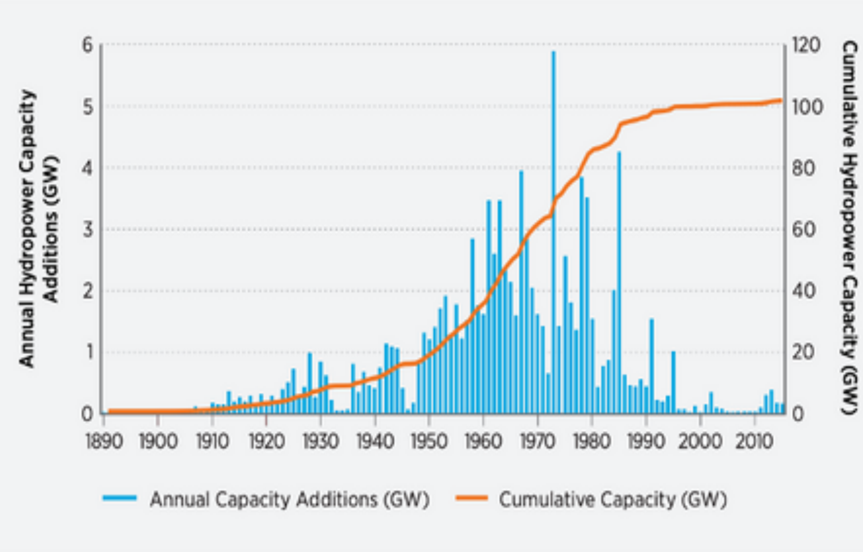

Figure 4: U.S. hydropower and pumped storage annual capacity additions and cumulative capacity from 1890 to 2015.[28]

According to research by the Oak Ridge National Laboratory for the Department of Energy, hydropower is ideal for providing "black start" power. Black start is when, during an outage, electricity generation must be restarted without any grid power. Hydroelectric plants are ideal because they require minimal power to restart, can restart quickly, and are usually large enough to energize the transmission system to help stabilize the frequency of electricity. It is important to stabilize the electricity frequency to prevent further blackouts as the grid is restarted. Currently, about 40% of black start resources in the U.S. are hydropower, even though it accounts for less than 10% of the overall energy supply. Hydropower was used to restart the grid during the widespread blackout of 2003.[31]

Types of Hydropower Plants

There are three primary types of hydropower plants: impoundment, diversion, and pumped storage.[29] All use the same basic principle to generate electricity: energy from falling or flowing water spins a turbine that drives a generator to convert kinetic energy to electrical energy.

Each generation method plays a distinct role in the electric grid. Impoundment and diversion plants excel at providing a steady supply of power to meet base load electrical demand, and impoundment offers some flexibility to adjust generation according to demand. Pumped storage is primarily used to meet peak demand. It is a critical part of the electric grid, providing 97% of the United States' energy storage capacity.[30]

Impoundment

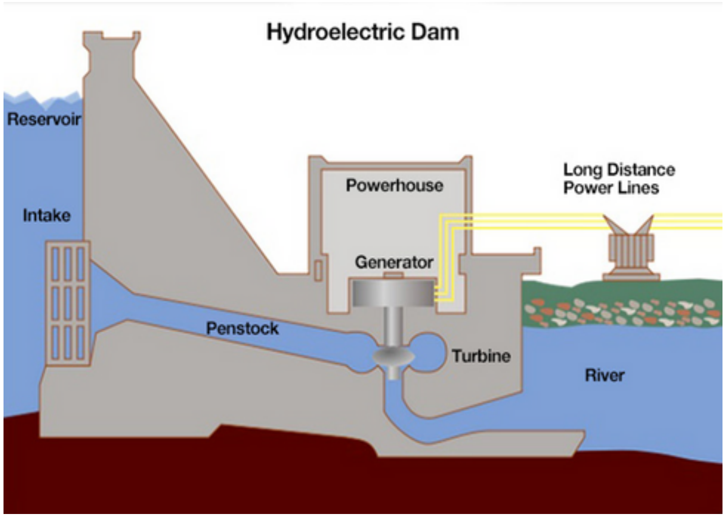

Figure 5: Schematic of impoundment hydroelectric facility. Image source: Department of Energy[32]

Figure 6: Kerr Dam, Montana. Image source: Missoulian[33]

In an impoundment system, water is held behind a dam in a reservoir. Water is released through a pipe in the dam called a penstock. The falling water activates and spins a turbine, a water wheel that converts water energy into mechanical power, which located at the end of the penstock. As the turbine spins, it turns a metal shaft that connects to an electrical generator. This movement causes the generator to rotate and produce electric power.[34]

Diversion

Diversion hydropower, also known as run-of-river, channels portions of a river's flow through a canal or penstock to a generating house to provide baseload electricity into an electric power grid. In this system, the kinetic force of moving water spins a turbine which then drives a generator that produces electricity.

Figure 7: The image shows an example of a diversion hydropower system in British Columbia, Canada. Image source: Energy BC[35]

Case Study: Diversion Hydropower in the Welsh Hills

There is growing popularity for "micro-hydro" systems among people who live in rural locations. 72-year old Howell Williams takes advantage of the small mountain stream on his farmland by generating electricity from a small (6-inch pipe) diversion. The water is diverted to the system pictured here, spinning a turbine and generating up to 18 kW. What he doesn't use on the farm gets sold back to the grid, earning him upwards of $15,000 per year.[38]

Figure 8: Howell Williams checks on his small diversion hydropower system. Source: The Guardian[39]

Once water has flowed through this system, the water then feeds back into the main river further downstream. Compared to impoundment systems, run-of-river has little or no storage reservoir which means that it has less flexibility to respond to changing grid demand.[37] Some run-of-river systems ensure there is sufficient water flow by using a weir, or small barrier, to control the upstream water level. Diversion systems can range from micro to utility scale.

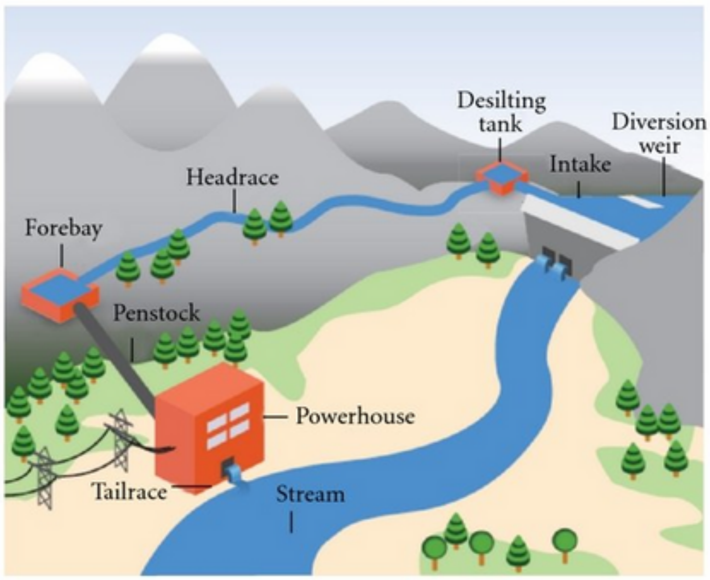

Figure 9: Diagram of diversion hydroelectric facility. As the river runs downstream, a diversion weir creates an eddy where water is diverted to the intake. The water runs near the existing river at a higher elevation to be run through the penstock and generate electricity. Source: Kaunda et al[36]

Pumped Storage

During periods of high electricity production and resulting lower electrical cost, pumped storage facilities use electricity to pump water uphill to reservoirs at higher elevation. The water is stored and released when demand increases, flowing through a turbine to generate electricity. This is useful for balancing the grid and meeting variable electricity demand. These systems work well with variable energy sources, such a solar power.[42]

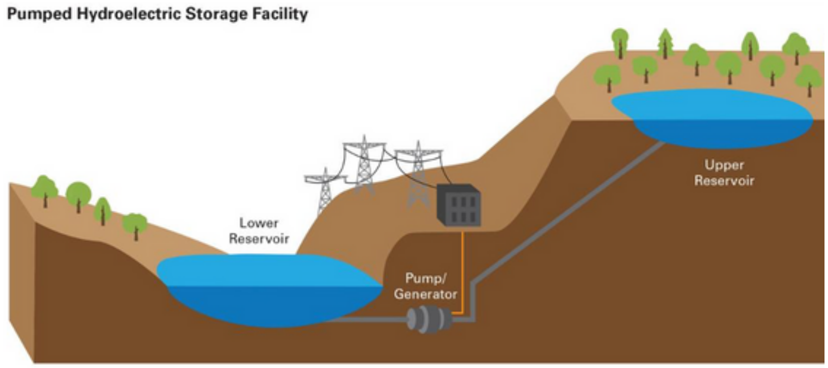

Figure 10: Schematic of a pumped storage system. Image source: Stephan Igo[40]

Challenges with the Current Hydropower Sector

While they provide a stable source of electricity, installed hydropower plants also pose serious environmental threats to rivers and aquatic life, including impeding fish migration and decreasing water quality.[43]

Hydropower infrastructure, primarily dams, can block fish migration. Dams prevent fish from reaching their breeding grounds, leading to declines in population sizes.[44] As well as impacting migratory fish populations, dams can also fragment non-migratory fish populations by creating challenges for locating new food sources and escaping predation.[45]

In addition to impeding aquatic movement, dams can slow rivers, impacting long-term viability of certain species. Some species of fish, such as salmon and river herring, require steady stream flow to guide their migration and spawning cycles. The interruption of the seasonal flow variations can cause disruptions in their reproductive cycles. Additionally, when migrating fish reach stagnant or slow flowing water bodies, they can become disoriented and suffer from longer migration periods.[46]

Figure 11: Pumped storage facility at Seneca, Pennsylvania. Image Source: RTO Insider[41]

Hydropower plants can also decrease water quality upstream by slowing or damming water supplies, as well as by suddenly releasing water during periods of peak electricity demand.[47] When water is slowed or dammed, the water temperature increases; temperature fluctuations can impact certain aquatic species. Downstream water quality can also be affected because dams often release water from the bottom of the reservoir, where dissolved oxygen content is low.[48] Low dissolved oxygen levels impede biological functions of aquatic life.

Marine Energy Overview

In contrast to the hydropower sector, marine energy generation is not yet at commercial scale, but rather in the research and development (R&D) phase. There are approximately 260 projects at various stages of R&D across the United States. The types of technologies being tested in these projects include energy generated from moving water, specifically from waves and tides, and energy generated through water salinity and temperature differentials. Of these four types, wave and tidal energy projects are relatively more advanced and are being actively piloted in the country.

While marine energy is still new, the conceivable growth of this sector is significant. The United States has long coastlines with an annual energy potential of 2.64 million gigawatt-hours (GWh), which is roughly the equivalent of two-thirds (64%) of the nation's electricity generation in 2018.[49] In addition to the generation potential, marine energy carries benefits related to its predictability: oceanographers have centuries of data to inform models of tide and ocean current fluctuations.[50]

PROPOSED SOLUTIONS

The Water Power Act provides the government intervention needed to promote water power as a widespread and commercially viable form of electricity. It aims to improve the current state of hydropower by developing technology to improve capacity and flexibility and reduce environmental impact. For marine energy, it promotes additional development and commercial demonstration.

Hydropower Improvements

Hydropower capabilities can be expanded by improving existing hydropower plants, converting non-powered dams, canals, and conduits into powered systems, and expanding pumped storage facilities.

Capacity

Restoring and upgrading existing hydropower facilities can improve their efficiency and flexibility, leading to increased generation potential. In 2014, the Department of Energy (D.O.E.) found that upgrades across all hydropower plants could result in an increase of at least 5 GW (or 13 TWh per year) of additional generation capacity.[51]

In addition to upgrading existing hydropower plants, installing turbines on existing non-powered dams would increase renewable power capacity. There are 54,000 non-powered dams in the U.S. eligible for conversion into hydropower facilities; if converted, these could increase hydropower capacity by 12 GW (31 TWh per year).[52] 8 GW (of the predicted 12 GW) could be produced from non-powered dams and locks on only the Ohio, Alabama, Mississippi and Arkansas Rivers.[53] Adding power to existing facilities can often be achieved at lower costs and in shorter timeframes than developing new dams.[54]

Just as non-powered dams can be converted to powered systems, new generating systems can be installed along existing diversions, which include existing irrigation canals and pressurized pipelines delivering water to municipalities. The DOE estimates that 1-2 GW of additional capacity exists in these diversions nationwide.[55]

Efficiency and Flexibility

Expanding the network and increasing the efficiency of pumped storage would improve grid flexibility, complementing increased generating capacity.

The DOE is investigating two possible methods of expansion: large, utility-scale pumped storage facilities ranging from 500-2000 MW capacity and smaller scale facilities generating 1-200 MW. The latter would reduce some of the permitting, financial, and environmental challenges of larger facilities.[56]

Retrofitting pumps and generators from fixed to variable speed can increase efficiency at pumped storage plants. All pumped storage facilities in the U.S. currently use fixed speed technologies.

Case Study: Le Cheylas Pumped Storage Project

Le Cheylas is a 480 MW pumped storage facility located in the French Alps. It was constructed in 1979 as a fixed speed facility.[60] In 2014, one of the plant's two 240 MW units was upgraded to replace the fixed speed generators and motors with variable speed technology.[61] The upgrade improved operational efficiency of the unit upgraded, increasing the generation output by 45 GWh per year.[62]

Figure 11: Le Cheylas pumped storage project. Source: Hydroreview[59]

Fixed speed systems only have two operating modes: running at full capacity or off, which can be inefficient. Variable speed pumps and generators allow the plant to better match energy generation or storage demands.[57] Additionally, variable speed motors and turbines are able to start-up more rapidly and respond to changing grid demands more quickly and efficiently.[58]

Environmental Impact

The environmental impacts of hydropower must be considered and improved in order to gain widespread public support. Solutions to reduce the impacts of hydropower include fish ladders that help fish migration, upgrades to the turbine systems to reduce injury to fish, and the implementation of water quality technology and monitoring.

Fish ladders allow migrating fish to detour around hydropower infrastructure.[63] While fish ladders are currently in use at dams across the United States, they are not always effective. Sometimes fish do not successfully enter the ladder, and long ladders may prevent fish from reaching the top of the dam.[64] In addition, fish ladders are designed to help fish migrate upstream to spawning grounds, but they fail to protect young fish moving downstream.[65]

The effectiveness of fish ladders also depends on the fish species' swimming performance and body size. R&D on improved fish ladders is underway and could be advanced by the Water Power Act.

Figure 12: A fish ladder near the south shore of Long Island, New York that assists with the Alewife migration over the infrastructure of the dam. Source: NOAA[66]

Furthermore, dam turbines can harm fish.[67] To combat this issue, sensors can be installed to measure and record water conditions caused by turbines. The variables measured include turbulence, rotation, pressure, and acceleration.[68] Better understanding of these variables and how they impact aquatic life can help in the development of more fish-friendly hydropower facilities. Although data acquired from fish sensors have already provided considerable insights, future improvements could include the addition of improved sensors, better accelerometers, and rate gyros that detect angular momentum to provide more accurate and time-sensitive data.

As previously discussed, impoundment dams often cause low dissolved oxygen levels downstream. This problem occurs because water is released from the reservoir floor, where there is less oxygen. Technology has been developed to aerate the water, adding oxygen to alleviate this problem before the water is released. Alternatively, multi-level water intakes can ensure that water released comes from all levels of the reservoir, allowing for normal dissolved oxygen content.[69] Further technology development could improve dissolved oxygen levels both up and downstream.

Marine Energy Research and Development Investments

In contrast to hydropower investments, which focus largely on upgrading existing systems (with some new pumped storage installation), marine energy allocations will focus on the research and development required to bring marine energy to a point of viable grid integration. In addition, the bill provides for expansion and continuing operation of National Marine Energy Centers, which perform critical testing work.

Types of Marine Energy Technology

Tidal Range

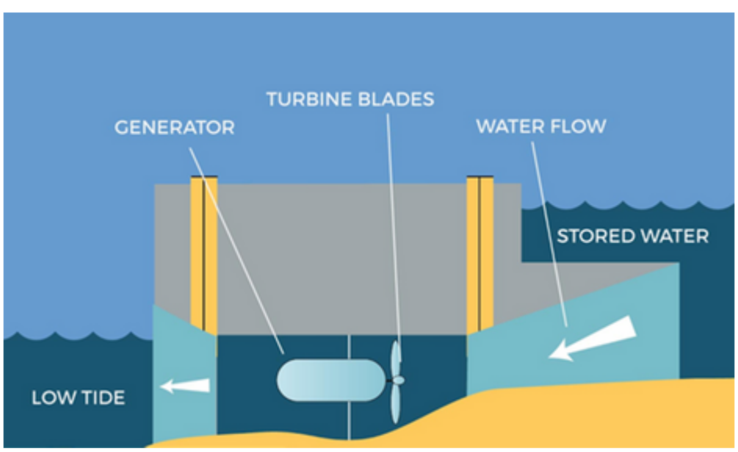

Figure 13: Schematic of a tidal range barrage system that stores water on one side of the barrage and slowly releases it, passing through a turbine generator, to the other side. Image source: The ASEAN Post[73]

Tidal technologies harness water level fluctuations caused by the rotation of the Earth and the gravitational pull of the moon and sun. Tidal influences can change coastal water levels by up to 13 meters, providing a great deal of potential energy.[70] Kinetic energy is usually harnessed near the shore, where land features such as straits, islands, and passes channel the water flow. While the United States does not currently have any large-scale tidal projects, countries such as Russia, France, South Korea and China are actively demonstrating this technology and generating electricity from tides. The two main types of tidal energy technologies are tidal range barrage and tidal stream.

Figure 14: In the photo above is the La Rance tidal barrage in France that generates electricity twice a day from incoming and retreating tides. Image source: Energy BC[74]

Tidal range barrages create electricity from both incoming and retreating tides. Tidal barrages use long walls, dams, sluice gates, or tidal locks to capture and store the potential energy of the ocean. These systems act similarly to dams in flowing water bodies. Producing tidal energy economically requires a tidal range of at least 3 meters.[75]

Tidal Stream

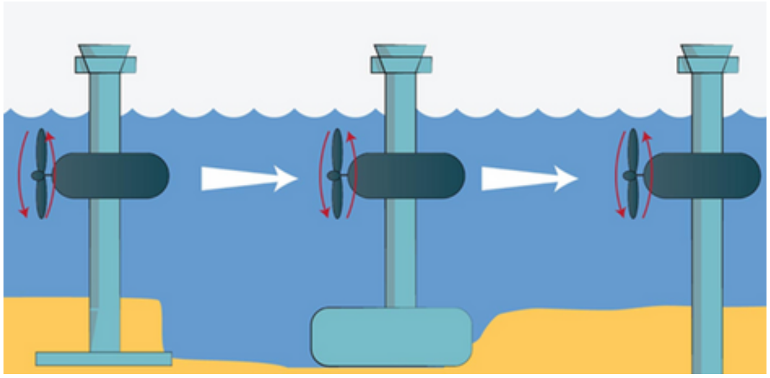

Figure 15: This schematic of a tidal stream system shows how streams of water in the ocean can spin turbine blades to create electricity. Image source: The ASEAN Post[76]

Tidal stream turbines harness the kinetic energy of fast-flowing currents to spin turbines that convert kinetic energy into electricity. As the tide moves in and out, it causes water to flow past the turbines. Similar to the way that moving air turns a wind turbine, the water flowing past the turbine spins the blades, powering a generator to produce electricity.[78]

Figure 16: This photo shows an example of tidal stream energy generation in the Bay of Fundy, Canada. A tugboat (in the upper right-hand corner) is used to position the turbine towards the incoming tidal water. Image source: The Philadelphia Inquirer[77]

Wave

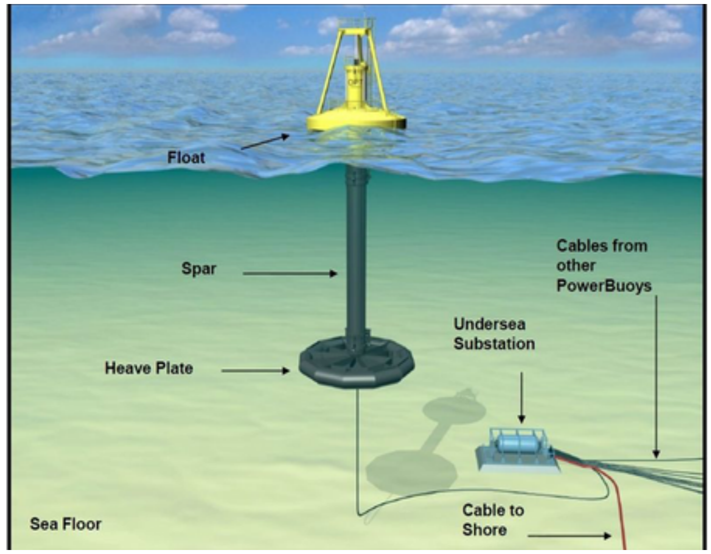

Figure 17: This figure shows a schematic of a floating power generating buoy. As the buoy float bobs up and down, a piston moves inside the spar (which is held down by the heave plate) creating electrical generation. The electricity moves to the undersea substation where it can be transferred to shore. Image source: Open EI [81]

Wave energy uses specifically designed buoys to capture kinetic energy.[79] Currently, there are two main types of this technology: power generating buoys and submerged buoys. Power generating buoys float on the surface of the water and capture energy from the continuous motion of waves. Underwater wave buoys operate completely underwater. One benefit of this design is increased resistance to storms, which can cause damage to power generating buoys. Wave energy has enormous potential, but the technical challenges and high upfront cost have caused a lag in development compared to other renewable technologies such as wind and solar.[80] However, as technologies advance and manufacturing processes improve, the cost will likely decrease, making these technologies more commercially viable.

Specially-designed, power-generating buoys can convert the kinetic energy of waves to electricity. When a wave encounters the buoy, the wave energy is captured by a device called a direct drive generator which is used to convert wave energy into electricity. The electricity is then delivered by an underwater cable to the shore. The electricity also continuously charges on-board battery packs in the buoys.[82]

Additional Marine Technologies

Salinity gradient and ocean thermal energy conversion (O.T.E.C.) are two of promising types of marine technologies in development, with a limited number of prototypes and demonstrations.

Salinity Gradient

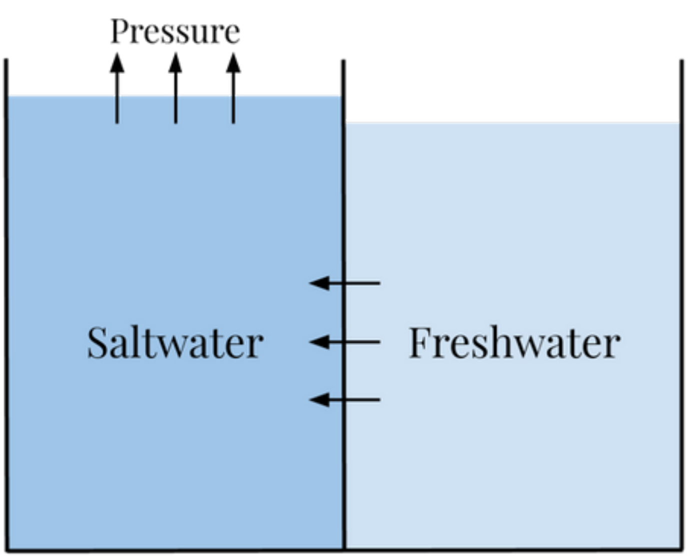

Figure 18. Schematic showing the principle behind pressure retarded osmosis, a salinity gradient technology.

Salinity gradient technologies generate electricity through chemical pressure differentials created between freshwater and saltwater.[83] There are two main techniques to capture energy from salinity gradients: pressure retarded osmosis and reverse electrodialysis.

Pressure retarded osmosis uses the difference in density between fresh and saltwater bodies. When separated by a special membrane, the water bodies equilibrate and generate pressure. It is this pressure that generates electricity. Reverse electrodialysis uses ionic exchange between fresh and saltwater, generating electricity through membranes that only allow anions and cations to cross through them.[84]

Ocean Thermal Energy Conversion

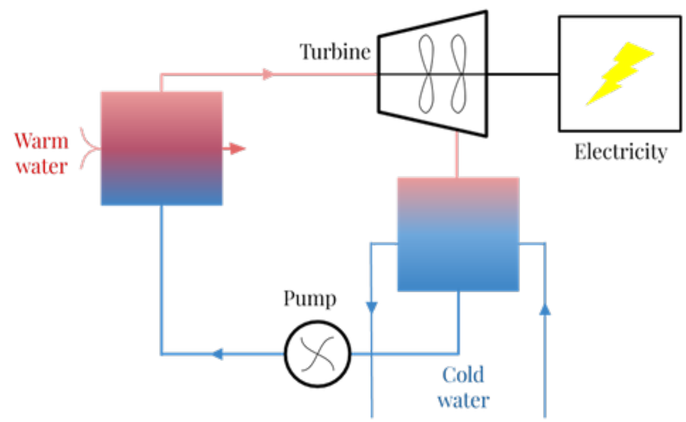

Figure 19. This schematic shows the workings of a thermal energy conversion system. Warm water from the ocean surface is used to create steam which drives a turbine. The turbine is connected to a generator, which generates electricity from the mechanical energy. The steam that powered the turbine is condensed by the cold water from the deep ocean, before being pumped back to the warm section to repeat the cycle.

Ocean thermal technology uses the temperature difference between warm and cold water to produce mechanical energy. Heat from the warm water is used to create steam, which is used to turn a turbine. The turbine is connected to a generator which produces electricity. The steam is then cooled by the cold water and condensed back into liquid water.[85,86] This liquid water can be a useful by-product of the process, as the salt content is removed through evaporation.

This means that O.T.E.C. technology can be combined with desalination technology to produce a source of freshwater as well as electricity.[87] The technology is most efficient when there is a large temperature difference between the warm surface water and the cold deep ocean water. This makes it ideal for tropical locations with access to deep ocean waters.[88]

Currently, the technology is limited by the size and cost of heat exchangers.[89] Heat exchangers are used to transfer heat from warm water to the water that is being evaporated. This heat is transferred by pumping the warm ocean water and the water that is being heated through adjacent pipes. As they flow past each other, the heat from the warm ocean water raises the temperature of the water that is being evaporated. By repeating this process, the heat is concentrated in the water that is being evaporated, and steam is created. Because this must be repeated over a large length of piping, heat exchangers can be physically very large.[90] Additionally, depending on the design they can be difficult to clean and maintain. Therefore, the heat exchanger is the limiting factor in making O.T.E.C. commercially viable.[91]

National Marine Energy Centers

National Marine Energy Centers are administered by institutions of higher education to advance research, development, demonstration, and commercial application of marine energy. The centers create and share best practices related to the development and management of marine energy systems.[92] Additionally, National Marine Energy Centers facilitate partnerships between the marine renewable energy industry, utility companies, N.G.O.s, engineering firms, environmental consultants, academia, and government agencies.[93]

The three current National Marine Energy Centers conduct wave, current, tidal, ocean thermal energy conversion, and in-river scientific and academic research.[94] These centers are the Pacific Marine Energy Center, the Southeast National Marine Renewable Energy Center, and the Hawaii National Marine Renewable Energy Center. The Pacific Marine Energy Center, managed by the University of Washington, Oregon State University, and the University of Alaska Fairbanks, focuses on the advancement of marine energy from wave, tidal, riverine, and offshore wind resources.[95] It operates several device testing sites, including a new grid-scale wave energy test site known as PacWave.[96] The Southeast National Marine Renewable Energy Center, managed by Florida Atlantic University, focuses on developing ocean current energy and ocean thermal energy conversion.[97] Finally, the Hawaii National Marine Renewable Energy Center, managed by the University of Hawaii and the U.S. Navy, studies wave energy and ocean thermal energy conversion and manages a wave energy test site.[98]

Case Study: Hawaii National Marine Renewable Energy Center

The Hawaii National Marine Renewable Energy Center facilitates testing and commercialization of wave energy conversion systems. The center's test site facilitates in-water testing of wave energy devices. The site features an array of devices with a capacity ranging from 10 to 1000 kW. The location in the Pacific Ocean allows the Center to test reliability under a variety of environmental conditions. The Center conducts studies to reduce permitting costs and delays. It develops testing infrastructure to connect marine energy to the grid.[99] Additionally, this work can help attract investors to the industry.[100]

Uncertainties of Marine Energy Technology

Due to the early stage of the marine energy technology industry, it is difficult to identify all potential barriers to implementation. One barrier is the lack of financial investment to date. The European Union (E.U.), the world leader in marine energy technology, has estimated that reaching its target of 1.9 GW generation within 10 years will cost $5-7 billion.[101] In contrast, the Water Power Act allocates approximately $815 million for marine technology development, less than 20% of the E.U.'s target. There is also limited data available to prove robustness and return on the high initial cost of marine energy deployment.[102]

There is great uncertainty about the impacts of marine energy systems on ecosystems. Although schematics and illustrations can suggest effects, there is limited experience with deployed systems worldwide. Proposed tidal infrastructure shows large rotor blades that have projected turning speeds of 10 miles per hour. These blades may pose threats to aquatic life through noise pollution, sedimentary pattern changes, and underwater vibrations.[103] There is particular concern about turbines in tidal range systems harming fish or impeding migration.[104] Moreover, the required anchoring of underwater infrastructure has potential to damage foraging habitats and poses collision threats to marine mammals such as whales.[105]

Wave energy buoys are challenging to design because they must withstand corrosive saltwater, constant movement, and extreme weather.[106] In addition, they require costly boats and crews with marine expertise to install and repair.

Marine energy technologies are sometimes opposed in coastal communities because they can reduce recreational and aesthetic value of the ocean environment.[107] However, they can also provide economic development and grid reliability in these communities, which are two aims of the bill.

Impacts of Climate Change

Climate simulation models indicate that climate change will continue to increase unpredictable weather patterns across the globe.[108] These changes will heavily influence water availability, including extreme weather events such as floods and droughts.

The United States' aging hydropower infrastructure is vulnerable to flooding. Floods can damage turbines, buildings, water retaining structures, and other components; if the damage is severe enough, the facility can collapse.[109] Dam collapse has devastating impacts on nearby communities and ecosystems and, of course, eliminates electricity generation.

Of the three main hydropower systems, diversion is most vulnerable to drought.[110] Because these systems have limited to no storage capacity, generating capacity is severely reduced by drought conditions.[111] The capacity of hydropower and pumped storage can also diminish in drought conditions, due to low water levels in the reservoirs.[112]

In order to maintain electricity generation in a changing climate, it will be necessary to adapt hydropower systems to new weather patterns.

Controversies of Environmental Impacts

As discussed above, large scale hydropower installations have significant impacts on the surrounding landscapes and ecosystems. The national opinion on dams has shifted significantly since 1950s and 1960s, when many of the country's dams were built. Now, there are multiple advocacy groups promoting the removal of dams as a way to restore the natural environment. Additionally, as many dams reach the end of their useful lives, there is an argument for large-scale dam removal across the country.[113] The Water Power Act funds research and development for retrofitting dams, aimed at both improvements of existing hydropower dams and the installation of hydropower generation to non-powered dams. Capacity improvements typically neither increase nor decrease the environmental impacts of dams.

Following the removal of dams, ecosystems begin to recover within several months.[114] This means there is a strong ecological case for removing dams. However, removing dams can create new problems. Frequently, dams are built to assist with flood control or water storage. Currently 17% of farmland uses water from dammed reservoirs for irrigation.[115] Flood control is an important benefit in many regions of the United States. In 2017, researchers estimated that dams in Central Valley, California and the Tennessee Valley had prevented $5 billion in lifetime flood damage in each region.[116]

The removal of dams also allows sediments that have built up behind the structure to flow downstream. In industrial regions, these sediments can contain pollutants or harmful chemicals, including polychlorinated biphenyls (PCBs).[117] Dam removal can allow these otherwise contained sediments to permeate through the environment.

Case Study: Fort Edward Dam Removal and PCB Exposure in the Hudson River

General Electric (G.E.) used PCBs at its facilities on the Hudson River from 1947-1977.[118] PCBs were intentionally discharged into the Hudson starting about 1951, with maximum inputs in the late 1960s and early 1970s. In 1973, the nearby, downstream Fort Edward Dam was removed. Subsequent flooding in 1974 and 1976 caused PCBs to be resuspended and transported down the Hudson, reaching New York Harbor, almost 200 miles away.[119] This event was one of the reasons the Hudson needed to be designated a Superfund site in 1984, and why PCB remediation was ongoing into the 2000s.[120]

MEASURING SUCCESS

Several specific outputs would indicate progress towards achieving the Water Power Act's goals. These include: improved capacity and cost; reduced environmental impacts; and increased grid reliability and resilience. Progress towards each output can be measured in distinct metrics.

Cost and Capacity

Two important measures of the bill's success will be whether and how much hydro and marine energy generation increase and whether and how much their costs decrease. Currently, hydropower provides 7% of the nation's power and is an affordable source of renewable electricity in the U.S. at $0.05/ kWh.[121] Marine energy has yet to be demonstrated on a commercial scale but is initially expected to cost $0.12-0.47/kWh for wave energy and $0.13–0.28/kWh for tidal energy.[122]

Capacity and cost both have metrics that allow progress to be monitored easily. Total GWh generated per year will be used to measure capacity. For hydropower, both increased generation at retrofitted hydropower plants and new generation at sites of formerly non-powered dams can be measured. For marine energy, the baseline is essentially zero since there are no current utility scale projects. Five years is a short timeframe in terms of developing and fully installing renewable energy technology, so the demonstration of any commercial-scale project spurred by the bill's programs will indicate success.

Cost can be measured easily in cents per kWh. A decrease in hydropower cost or an achievement of lower than projected marine energy cost would represent success.

Environmental Impacts

As discussed above, hydropower systems, especially impoundments, impact their surrounding environments. Low dissolved oxygen levels are a challenge both upstream and downstream.[123] Progress on this issue can be measured by testing dissolved oxygen levels in water released by major dams and monitoring water quality around them. Levels before and after infrastructure improvements are made can be compared to assess progress. Alleviation of impacts on fish populations can likewise be quantified by tracking the size of upstream breeding populations before and after technology improvements are installed.

As previously mentioned, the environmental impacts of marine energy technology are not yet clear. Monitoring procedures and environmental standards would need to be developed in order to measure progress.

Grid Reliability

In the United States, the electric grid is largely reliable; in 2018, the average customer experienced less than six hours of electricity outage.[124] However, any prolonged interruption in service has significant effects on customers, so improved grid reliability is vital, especially in the face of increasing extreme weather events. Hydropower is particularly effective at restarting the electric grid after an outage - making it an important source of reliability.

Two important metrics for grid reliability are the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). The SAIDI describes average lengths of outages over the course of a year. The SAIFI describes the average number of outages. These metrics can be reported with and without "major events" — without major events shows what happens when the electricity system is running normally, and with major events shows the impact of extreme weather.[125]

Lower SAIDI and SAIFI scores, especially in states that get a large share of electricity from hydropower, would indicate grid reliability success. As of 2017, the top source of electricity in Washington, Oregon, Idaho, South Dakota, Maine, and Vermont was hydropower.

Notably, Maine and Vermont were also in the top five states for both SAIDI and SAIFI interruptions, partially due to their propensity for winter storms. A decrease in those states' interruptions, along with those in other hydropower-reliant states, would indicate success in improving grid reliability through investment in water power. However, properly attributing improvements in SAIDI and SAIFI scores to water power, versus other advancements in grid reliability and signals, may be challenging.

Measuring capacity and cost, environmental impact, and grid reliability provides indicators of the bill's success. However, they do not guarantee progress on the larger problem of fossil fuel dependence for electricity. In order to truly assess success, quantifiable goals that pair improvements in the water power sector with reductions of fossil fuel electricity generation would be needed.

CONCLUSION

The Water Power Research and Development Act provides the necessary funding to increase the contribution of water power to the United States' electricity generation mix. This bill will invest in hydropower to improve efficiency, increase capacity, and reduce environmental impacts. The investments in marine energy will provide necessary support to accelerate this emerging industry towards commercialization.

The bill's investments will expand the United States' water power sector beyond conventional hydropower. Moving the focus towards marine power will help to reduce opposition to water power in the U.S. However, it will be important to investigate and address any concerns arising from this new sector if it is to ultimately meet a significant portion of the nation's electricity needs.

This bill also addresses deeper flaws in our energy industry — the disproportionate impact of fossil fuel extraction and combustion on low-income and communities of color. The Water Power Research and Development Act is a step towards alleviating the burden fossil fuels have on public and environmental health and safety. This bill has the potential to advance the energy sector towards a more equitable and sustainable future.

Below: Wave energy technology in Alaska. *Alaska Energy Wiki*

REFERENCES

[1] "U.S. Energy Information Administration (EIA) - Data," accessed August 6, 2020, https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T07.02A#/?f=A&start=1949&end=2019&charted=1-3-15.
[2] "Bonamici, Young, Deutch Introduce Bill to Strengthen Investments in Marine Energy," Congresswoman Suzanne Bonamici, March 5, 2020, https://bonamici.house.gov/media/press-releases/bonamici-young-deutch-introduce-bill-strengthen-investments-marine-energy.
[3] Theodore E. Deutch, "H.R. 3203 - Marine Energy Research and Development Act of 2019," Pub. L. No. H.R. 3203 (2019), https://www.congress.gov/bill/116th-congress/house-bill/3203?q=%7B%22search%22%3A%5B%22marine+energy+research+and+development%22%5D%7D&r=1&s=1.
[4] Nick J. Rahall, "Energy Independence and Security Act of 2007," Pub. L. No. H.R. 6 (2007), https://www.congress.gov/bill/110th-congress/house-bill/6.
[5] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)," accessed July 29, 2020, https://www.eia.gov/tools/faqs/faq.php.
[6] "U.S. Energy Information Administration (EIA) - Data."
[7] "U.S. Energy Information Administration (EIA) - Data."
[8] Mritunjoy Sengupta, *Environmental Impacts of Mining Monitoring, Restoration, and Control* (Routledge, 2018), https://doi.org/10.1201/9780203757062.
[9] Bhanu Pandey, Madhoolika Agrawal, and Siddharth Singh, "Assessment of Air Pollution around Coal Mining Area: Emphasizing on Spatial Distributions, Seasonal Variations and Heavy Metals, Using Cluster and Principal Component Analysis," *Atmospheric Pollution Research* 5, no. 1 (2014): 79–86.
[10] "Coal and the Environment - U.S. Energy Information Administration (EIA)," accessed August 4, 2020, https://www.eia.gov/energyexplained/coal/coal-and-the-environment.php.
[11] "Coal and the Environment - U.S. Energy Information Administration (EIA)."
[12] Lindsey Konkel, *Salting the Earth: The Environmental Impact of Oil and Gas Wastewater Spills* (National Institute of Environmental Health Sciences, 2016).
[13] Thomas F. Stocker et al., "Climate Change 2013: The Physical Science Basis," *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* 1535 (2013).
[14] Tanya J. Gallegos et al., "Hydraulic Fracturing Water Use Variability in the U Nited S Tates and Potential Environmental Implications," *Water Resources Research* 51, no. 7 (2015): 5839–5845.
[15] Dieter Lüthi et al., "High-Resolution Carbon Dioxide Concentration Record 650,000–800,000 Years before Present," *Nature* 453, no. 7193 (May 2008): 379–82, https://doi.org/10.1038/nature06949.
[16] "Pollution Is Killing Black Americans. This Community Fought Back. - The New York Times," accessed August 4, 2020, https://www.nytimes.com/2020/07/28/magazine/pollution-philadelphia-black-americans.html.
[17] "Pollution Is Killing Black Americans. This Community Fought Back. - The New York Times."
[18] "Pollution Is Killing Black Americans. This Community Fought Back. - The New York Times."
[19] Pandey, Agrawal, and Singh, "Assessment of Air Pollution around Coal Mining Area."
[20] "Huge Oil Refinery Leaks Toxic Chemical in South Philadelphia," NBC News, accessed August 4, 2020, https://www.nbcnews.com/science/environment/massive-oil-refinery-leaks-toxic-chemical-middle-philadelphia-n1115336.
[21] "U.S. Energy Information Administration (EIA) - Data."
[22] "Solar Explained - U.S. Energy Information Administration (EIA)," accessed July 30, 2020, https://www.eia.gov/energyexplained/solar/.
[23] "Electricity Explained: Electricity in the United States," U.S. Energy Information Administration (EIA), March 20, 2020, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php. "EIA."
[24] "EIA." "EIA."
[26] U.S. Department of Energy, "Chapter 2: State of Hydropower in the United States," in *Hydropower Vision A New Chapter for America's 1st Renewable Electricity Source* (United States: U.S. Department of Energy, 2016), 2, https://www.energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-Chapter-2-10212016.pdf. U.S. Department of Energy, 2.
[27] U.S. Department of Energy, "Chapter 2: State of Hydropower in the United States," 2. U.S. Department of Energy, 2.

REFERENCES

[27] U.S. Department of Energy, "Chapter 2: State of Hydropower in the United States." U.S. Department of Energy.
[28] U.S. Department of Energy, "Chapter 2: State of Hydropower in the United States," 2. U.S. Department of Energy, 2.
[29] National Hydropower Association, "Hydropower Vision: Hydropower and The Grid," National Hydropower Association, n.d., https://www.hydro.org/waterpower/why-hydro/hydropower-vision/.
[30] National Hydropower Association, "2018 Pumped Storage Report" (National Hydropower Association, 2018), https://www.hydro.org/wp-content/uploads/2018/04/2018-NHA-Pumped-Storage-Report.pdf.
[31] Jose R. Gracia et al., "Hydropower Plants as Black Start Resources," May 2019, 75.
[32] "Types of Hydropower Plants," Energy.gov, accessed July 31, 2020, https://www.energy.gov/eere/water/types-hydropower-plants.
[33] "Government Asks Judge to Dismiss Case against Kerr Dam Transfer | Local News | Missoulian.Com," accessed August 4, 2020, https://missoulian.com/news/local/government-asks-judge-to-dismiss-case-against-kerr-dam-transfer/article_01dd365c-745b-5816-9907-33fe61e375f3.html.
[34] "Types of Hydropower Plants."
[35] "Run of River Generators in British Columbia," EnergyBC.ca, accessed August 2, 2020, https://www.google.com/maps/d/viewer?mid=1Y7W09_eof_8PNBpJYnaj0dZdHS4.
[36] Chiyembekezo S. Kaunda, Cuthbert Z. Kimambo, and Torbjorn K. Nielsen, "Hydropower in the Context of Sustainable Energy Supply: A Review of Technologies and Challenges," *ISRN Renewable Energy* 2012 (2012): 1–15, https://doi.org/10.5402/2012/730631.
[37] "Conventional Hydroelectric Dams | EARTH 104: Earth and the Environment (Development)," accessed July 31, 2020, https://www.e-education.psu.edu/earth104/node/1067.
[38] John Vidal, 'Harvesting Hill Streams of Wales for Hydropower', *The Guardian*, 12 June 2015, sec. Environment, https://www.theguardian.com/environment/2015/jun/12/harvesting-hill-streams-of-wales-for-hydropower.
[39] Vidal.
[40] Stephen Igo, "Griffith's Pumped Storage Hydropower Bill Advances," timesnews.net, accessed July 31, 2020, https://www.timesnews.net/news/local-news/griffiths-pumped-storage-hydropower-bill-advances/article_2aa400a9-9ccf-5910-9246-b3deb2cda1a8.html.
[41] "RTO Insider: Company Briefs - Week of 9/10/2013," *RTO Insider* (blog), September 10, 2013, https://rtoinsider.com/company-briefs-3/.
[42] Omid Bozorg Haddad et al., "Optimization Model for Design-Operation of Pumped-Storage and Hydropower Systems," *Journal of Energy Engineering* 140, no. 2 (June 2014): 04013016, https://doi.org/10.1061/(ASCE)EY.1943-7897.0000169.
[43] "How Dams Damage Rivers," *American Rivers* (blog), accessed August 6, 2020, https://www.americanrivers.org/threats-solutions/restoring-damaged-rivers/how-dams-damage-rivers/.
[44] American Rivers, "How Dams Damage Rivers," American Rivers River Connect Us, n.d., https://www.americanrivers.org/threats-solutions/restoring-damaged-rivers/how-dams-damage-rivers/.
[45] American Rivers.
[46] "How Dams Damage Rivers."
[47] Gary Bilotta et al., "The Effects of Run-of-River Hydroelectric Power Schemes on Community Composition in Temperate Streams and Rivers" 11 (May 18, 2016), https://doi.org/10.1371/jounrla.pone.0154271.
[48] "Environmental Impacts of Hydroelectric Power | Union of Concerned Scientists," accessed July 28, 2020, https://www.ucsusa.org/resources/environmental-impacts-hydroelectric-power.
[49] U.S. Energy Information Administration, "Hydropower Explained Water Power," EIA U.S. Energy Information Administration, October 4, 2019, https://www.eia.gov/energyexplained/hydropower/wave-power.php.
[50] A. LiVecchi et al., "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets" (Washington, D.C.: U.S. Department of Energy, Office of Energy Efficency and Renewable Energy., April 2019), https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf.
[51] "Hydropower-Vision-021518.Pdf," accessed August 7, 2020, https://www.energy.gov/sites/prod/files/2018/02/f49/Hydropower-Vision-021518.pdf.
[52] "Reliability of Renewable Energy: Hydro," Strata.org, November 2015, https://www.strata.org/reliability-of-renewable-energy/hydro/.

[53] "Hydropower-Vision-021518.Pdf."
[54] "US Hydropower: The Potential for Converting Non-Powered Dams," Power Technology | Energy News and Market Analysis, September 19, 2016, https://www.power-technology.com/features/featureus-hydropower-the-potential-for-converting-non-powered-dams-4989938/.
[55] "Hydropower-Vision-021518.Pdf."
[56] "Hydropower-Vision-021518.Pdf."
[57] "Variable Speed Pumped Hydroelectric Tech," *Energy Storage Association* (blog), accessed August 7, 2020, https://energystorage.org/why-energy-storage/technologies/variable-speed-pumped-hydroelectric-storage/.
[58] "Variable Speed Pumped Hydroelectric Tech."
[59] Sylvain Antheaume et al., "Upgrading Two Pumped Storage Plants to Variable Speed," Hydro Review, accessed July 30, 2020, https://www.hydroreview.com/2015/02/17/upgrading-two-pumped-storage-plants-to-variable-speed/#gref.
[60] Audun Botterud, Todd Levin, and Vladimir Koritarov, "Pumped Storage Hydropower: Benefits for Grid Reliability and Integration of Variable Renewable Energy," August 1, 2014, https://doi.org/10.2172/1165460.
[61] Botterud, Levin, and Koritarov.
[62] Botterud, Levin, and Koritarov.
[63] Molly Edmonds, "What Are Fish Ladders?," HowStuffWorks, accessed August 5, 2020, https://adventure.howstuffworks.com/outdoor-activities/fishing/fish-conservation/fish-populations/fish-ladder.htm.
[64] Molly Edmonds.
[65] Molly Edmonds.
[66] NOAA, "What Is a Fish Ladder?," National Ocean Service, accessed August 5, 2020, https://oceanservice.noaa.gov/facts/fish-ladder.html.
[67] Thomas J. Carlson and Joanne P. Duncan, "Evolution of the Sensor Fish Device for Measuring Physical Conditions in Severe Hydraulic Environments," February 28, 2003, https://doi.org/10.2172/878148.
[68] Zhiqun Deng et al., "Applications of the Sensor Fish Technology," *Hydro Review* 26 (August 27, 2007): 10–14.
[69] "Environmental Impacts of Hydroelectric Power | Union of Concerned Scientists."
[70] "Tidal Power - U.S. Energy Information Administration (EIA)," accessed July 30, 2020, https://www.eia.gov/energyexplained/hydropower/tidal-power.php.
[71] "Technology_Information_Sheet_Ocean_Energy.Pdf," accessed July 30, 2020, https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Ocean_Energy.pdf.
[72] "Tidal Energy," accessed July 30, 2020, https://www.arcgis.com/apps/Cascade/index.html?appid=5a5131db118243c5afd1498f294bb0c2.
[73] "The Rising Wave of Tidal Energy in Southeast Asia | The ASEAN Post," accessed August 7, 2020, https://theaseanpost.com/article/rising-wave-tidal-energy-southeast-asia.
[74] Andrew Farris and Charlotte Helston, "Tidal Power," EnergyBC.ca, n.d., http://www.energybc.ca/tidal.html.
[75] "Tidal Barrage and Tidal Barrage Energy Devices," Alternative Energy Tutorials, accessed July 31, 2020, https://www.alternative-energy-tutorials.com/tidal-energy/tidal-barrage.html.
[76] "The Rising Wave of Tidal Energy in Southeast Asia | The ASEAN Post."
[77] Andrew Maykuth, "Can This Giant Turbine Turn the Tide for Ocean Energy?," https://www.inquirer.com, accessed August 4, 2020, https://www.inquirer.com/philly/business/energy/can-this-giant-turbine-turn-the-tide-for-ocean-energy-20170901.html.
[78] "Tidal Stream Energy, Tidal Energy | Renewable Energy," accessed August 7, 2020, http://www.greenrhinoenergy.com/renewable/marine/tidal_stream.php.
[79] "Hydropower Explained: Wave Power," U.S. Energy Information Administration (EIA), October 4, 2019, https://www.eia.gov/energyexplained/hydropower/wave-power.php.
[80] Dave Levitan, "Why Wave Power Has Lagged Far Behind as Energy Source," Yale E360, April 28, 2014, https://e360.yale.edu/features/why_wave_power_has_lagged_far_behind_as_energy_source.
[81] "Wave Energy | Open Energy Information," accessed July 31, 2020, https://openei.org/wiki/Wave_Energy.
[82] "PB3 PowerBuoy®," Ocean Power Technologies, 3, accessed July 31, 2020, https://oceanpowertechnologies.com/pb3-powerbuoy/.

REFERENCES

[83] "MARINE POWER GENERATION TECHNOLOGIES:SALINITY GRADIENT POWER GENERATION," *Electrical Power Generation* (blog), February 17, 2016, http://machineryequipmentonline.com/electrical-power-generation/marine-power-generation-technologiessalinity-gradient-power-generation/.

[84] "What Is Salinity Gradient Power?," Integrated Network for Energy from Salinity Gradient Power, accessed August 6, 2020, http://salinitygradientpower.eu/project/.

[85] "DOW: Deep Ocean Water as Our Next Natural Resource," accessed August 8, 2020, http://www.terrapub.co.jp/e-library/dow/index.html.

[86] "Heat Engines and the Second Law," accessed August 8, 2020, http://physics.bu.edu/~duffy/py105/Heatengines.html.

[87] Mariette DiChristina, "Sea Power," *Popular Science*, May 1995.

[88] DiChristina.

[89] "Makai Ocean Engineering's Heat Exchanger Test Facility Opened - OTEC NewsOTEC News," accessed August 8, 2020, http://www.otecnews.org/2011/11/makai-ocean-engineerings-heat-exchanger-test-facility-opened/.

[90] Jerry Taborek, "Industrial Heat Exchangers: A Basic Guide By G. Walker, Hemisphere Pub L. Corp. Washington Dc, 1982,$41.50, 408 Pg.," *AIChE Journal* 29, no. 2 (March 1983): 349–50, https://doi.org/10.1002/aic.690290228.

[91] "Makai Ocean Engineering's Heat Exchanger Test Facility Opened - OTEC NewsOTEC News."

[92] Luis Vega, "Hawaii National Marine Renewable Energy Center," Hawaii National Marine Renewable Energy Center, 2020, http://hinmrec.hnei.hawaii.edu/nmrec-test-sites/wave-energy-test-site/.

[93] Vega.

[94] LiVecchi et al., "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets."

[95] "20110429_NMREC_pres_Testing.Pdf," accessed August 7, 2020, http://depts.washington.edu/pmec/docs/20110429_NMREC_pres_Testing.pdf.

[96] LiVecchi et al., "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets."

[97] LiVecchi et al.

[98] LiVecchi et al.

[99] Ocean Renewable Energy Coalition, "National Marine Renewable Energy Centers Sustaining and Securing National Energy Needs with Water Power," http://depts.washington.edu/pmec/docs/20110429_NMREC_pres_Testing.pdf.

[100] Vega, "Hawaii National Marine Renewable Energy Center."

[101] Gema San Bruno, "Strategic Initative for Ocean Energy (SI Ocean)," European Commission, July 30, 2020, https://ec.europa.eu/energy/intelligent/projects/en/projects/si-ocean.

[102] Andreas Uihlein and Davide Magagna, "Wave and Tidal Current Energy – A Review of the Current State of Research beyond Technology," *Renewable and Sustainable Energy Reviews* 58 (May 2016): 1070–81, https://doi.org/10.1016/j.rser.2015.12.284.

[103] Anthony Lewis et al., "Chapter 6 Ocean Energy," in *Renenwable Energy Sources and Climate Change Mitigation*, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (Cambridge, United Kingdon and New York, NY, USA.: Cambridge University Press, 2011), 497–530, https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-6-Ocean-Energy-1.pdf.

[104] William Harris, "Concerns about Ocean Power," HowStuffWorks, accessed July 27, 2020, https://science.howstuffworks.com/environmental/green-tech/energy-production/ocean-power4.htm.

[105] "Hydrokinetic Energy," U.S. Fish and Wildlife Service Energy Development, May 2, 2018, https://www.fws.gov/ecological-services/energy-development/hydrokinetic.htmlh.

[106] Developing Wave Energy Has Its Challenges | Vincent Jelani," accessed July 30, 2020, https://scholar.harvard.edu/vincentjelani/publications/developing-wave-energy-has-its-challenges.

[107] "Technology_Information_Sheet_Ocean_Energy.Pdf."

[108] Russell Vose et al., "Monitoring and Understanding Changes in Extremes: Extratropical Storms, Winds and Waves," *Bulletin of the American Meteorological Society* 93 (March 1, 2014), https://doi.org/10.1175/BAMS-D-12-00162.1.

REFERENCES

[109] U.S. Department of Energy, "Effects of Climate Change on Federal Hydropower," Government (U.S. Department of Energy, January 2017), https://www.energy.gov/sites/prod/files/2017/01/f34/Effects-Climate-Change-Federal-Hydropower-Program.pdf.
[110] U.S. Department of Energy.
[111] Ottmar Edenhofer, Ramon Pichs Madruga, and Youba Sokona, *Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change* (Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi, Tokyo, Mexico City: CAMBRIDGE UNIVERSITY PRESS, 2012), https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_Full_Report-1.pdf.
[112] U.S. Department of Energy, "Chapter 2: State of Hydropower in the United States," in *Hydropower Vision A New Chapter for America's 1st Renewable Electricity Source* (United States: U.S. Department of Energy, 2016), 2, https://www.energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-Chapter-2-10212016.pdf.
[113] "The Undamming of America," accessed August 2, 2020, https://www.pbs.org/wgbh/nova/article/dam-removals/.
[114] "Frequently Asked Questions About River Restoration," *American Rivers* (blog), accessed August 2, 2020, https://www.americanrivers.org/conservation-resources/rrformer/removing-dams-faqs/.
[115] Michelle Ho et al., "The Future Role of Dams in the United States of America," *Water Resources Research* 53, no. 2 (2017): 982–98, https://doi.org/10.1002/2016WR019905. Ho et al.
[116] Ho et al., "The Future Role of Dams in the United States of America." Ho et al.
[117] "Frequently Asked Questions About River Restoration."
[118] "Hudson River PCBs: Actions Prior to EPA's February 2002 Record of Decision," EPA, February 23, 2016, https://www3.epa.gov/hudson/actions.htm.
[120] Steven Norris Chillrud, "Transport and Fate of Particle Associated Contaminants in the Hudson River Basin" (Columbia University, 1996).
[121] "Hudson River PCBs."
[122] "Renewable Energy Costs Take Another Tumble, Making Fossil Fuels Look More Expensive Than Ever," accessed July 28, 2020, https://www.forbes.com/sites/dominicdudley/2019/05/29/renewable-energy-costs-tumble/#464726e3e8ce. "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets," *U.S. Department of Energy*, April 2019, 207.
[123] "Environmental Impacts of Hydroelectric Power | Union of Concerned Scientists."
[124] "U.S. Customers Experienced an Average of Nearly Six Hours of Power Interruptions in 2018 - Today in Energy," U.S. Energy Information Administration (EIA), June 1, 2020, https://www.eia.gov/todayinenergy/detail.php?id=43915.
[125] "Average U.S. Electricity Customer Interruptions Totaled Nearly 8 Hours in 2017 - Today in Energy," U.S. Energy Information Administration (EIA), November 30, 2018, https://www.eia.gov/todayinenergy/detail.php?id=37652.