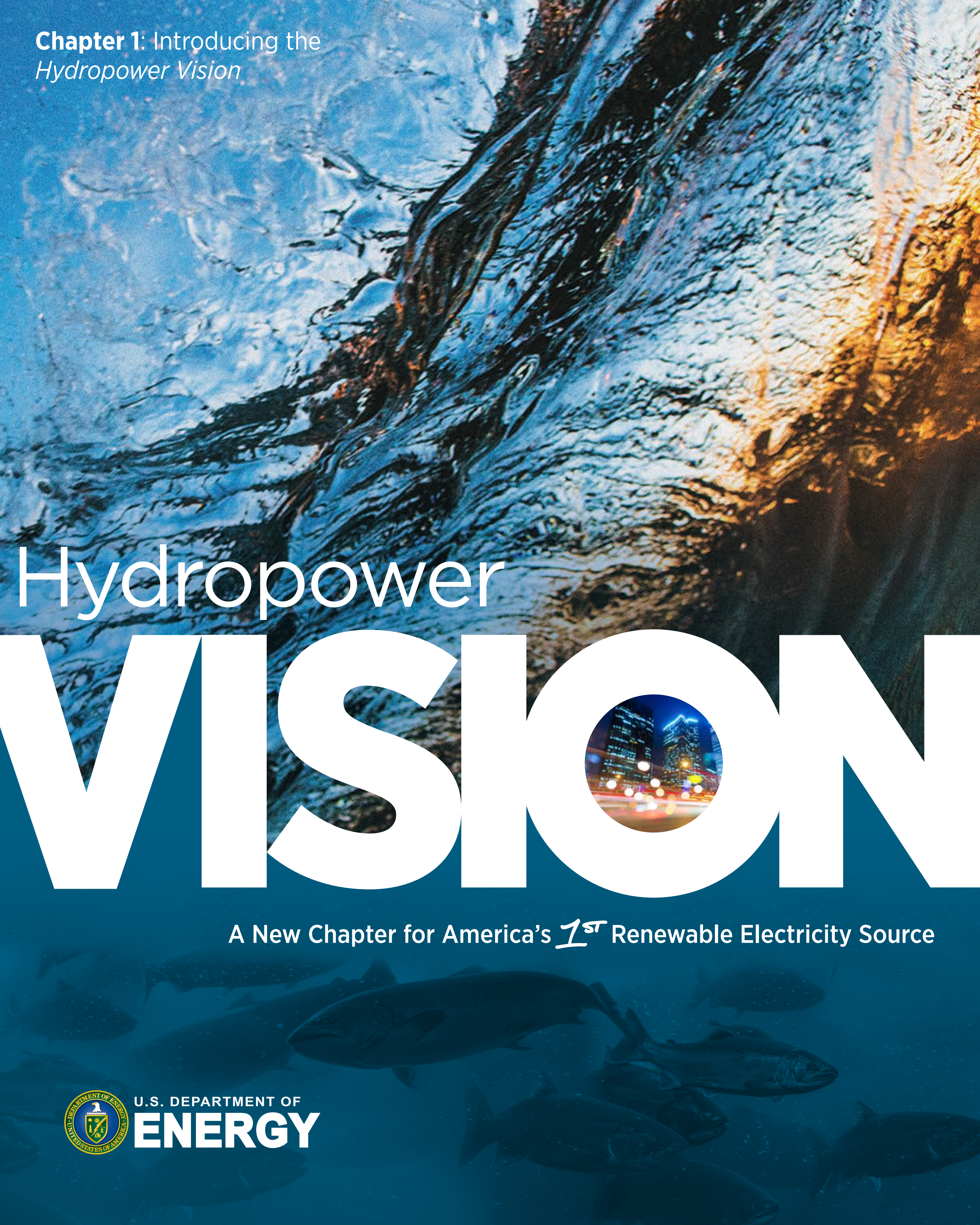
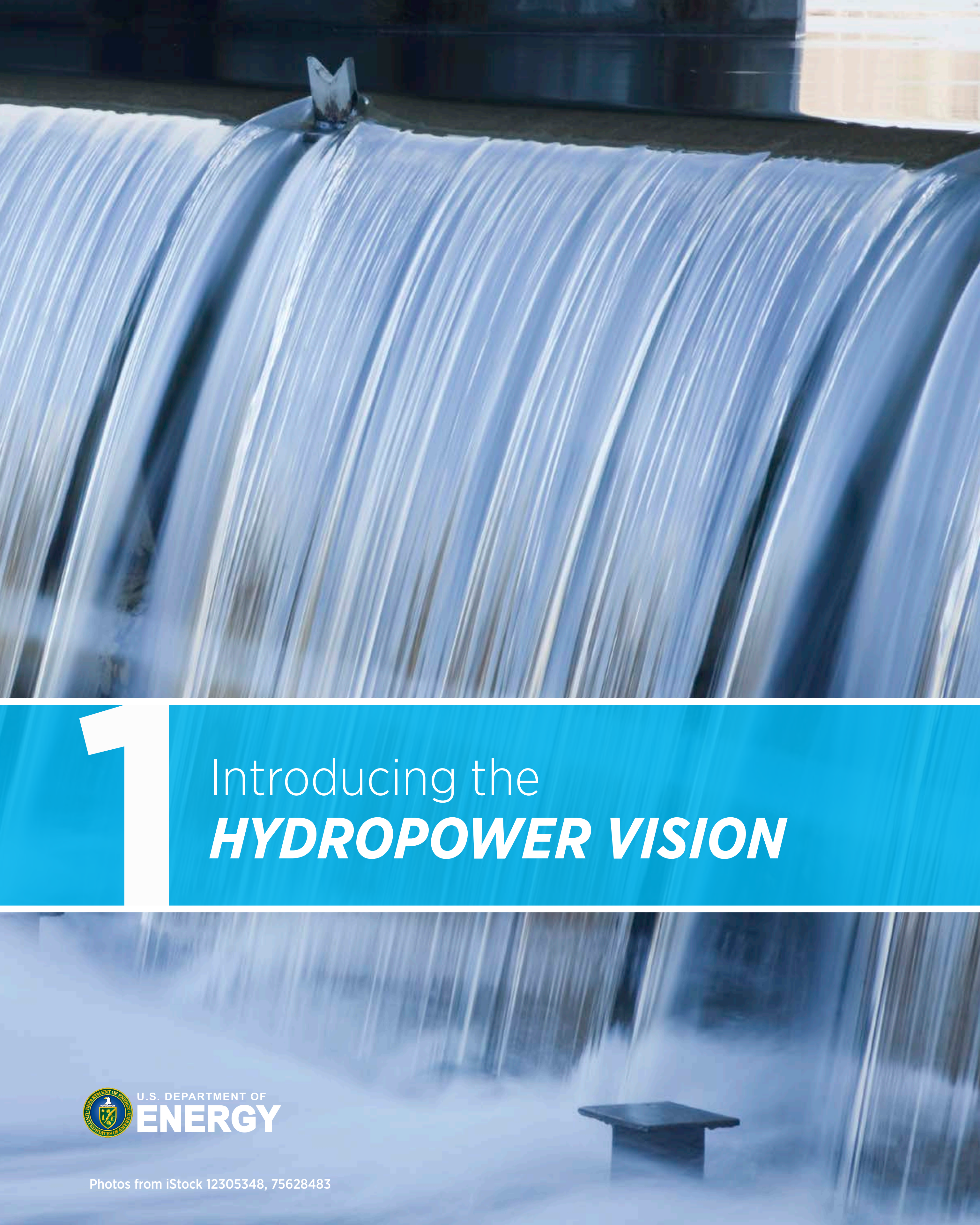
Chapter 1: Introducing the *Hydropower Vision*



Hydropower VISION

A New Chapter for America's 1st Renewable Electricity Source

U.S. DEPARTMENT OF ENERGY

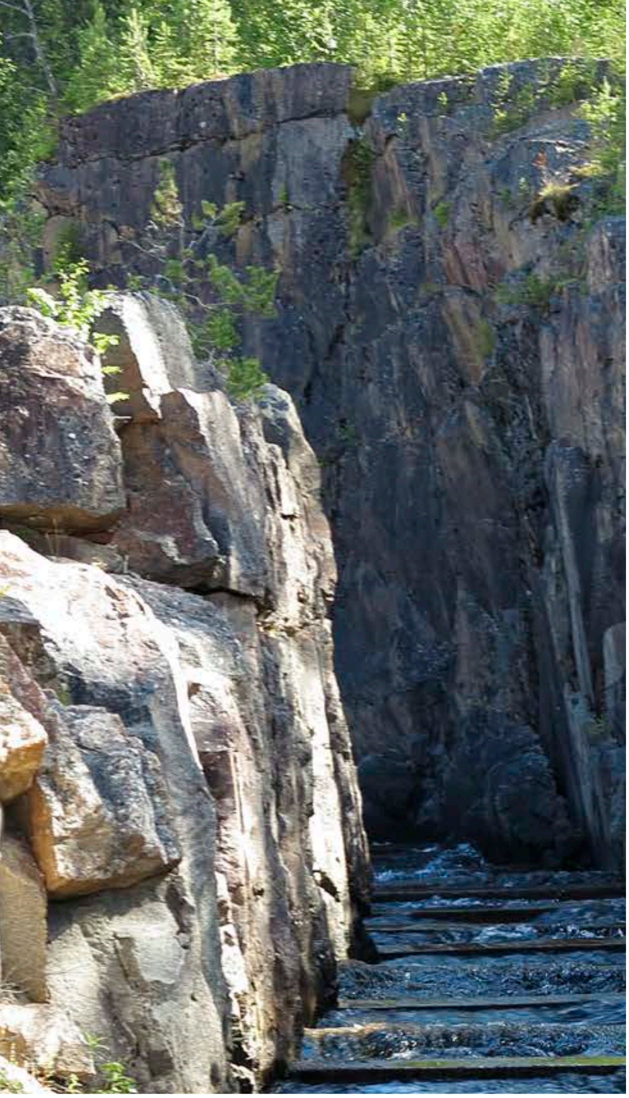


1

Introducing the *HYDROPOWER VISION*

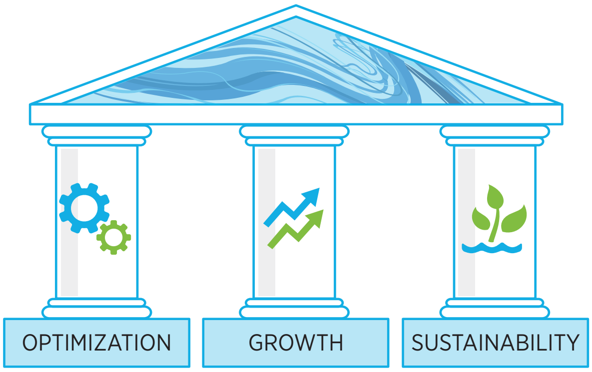
U.S. DEPARTMENT OF
ENERGY

Photos from iStock 12305348, 75628483



Overview

Hydropower has provided clean, affordable, reliable, and renewable electricity in the United States and supported development of the U.S. power grid and the nation's industrial growth for more than a century. In addition to providing a stable and consistently low-cost energy source throughout decades of fluctuations and fundamental shifts in the electric sector, hydropower is a scalable, reliable generation technology that offers operational flexibility to maintain grid reliability and support integration of variable generation resources.



The *Hydropower Vision* report is grounded on three equally important foundational pillars arrived at through extensive stakeholder input.

A range of cost-effective, low-carbon generation options—including hydropower—are required to reduce and avoid the power-sector emissions that contribute to climate change and human health impacts. As such, the U.S. Department of Energy's (DOE's) Wind and Water Power Technologies Office has led a broad-based collaborative effort to develop a first-of-its-kind comprehensive analysis identifying a set of potential pathways for the environmentally sustainable expansion of hydropower in the United States.

Developing a Hydropower Vision

Developed through DOE's collaboration with more than 300 experts from over 150 hydropower industry companies, environmental organizations, state and federal governmental agencies, academic institutions, electric power system operators, research institutions, and other stakeholder groups, the *Hydropower Vision* report documents a set of pathways to responsibly manage, optimize, and develop the hydropower sector in a manner that maximizes opportunities for low-cost, low-carbon renewable energy production, economic stimulation, and environmental stewardship to provide long-term benefits for the nation.

The *Hydropower Vision* is grounded in three foundational principles, or "pillars"—optimization, growth, and sustainability—arrived at through extensive stakeholder input and identified as critical to ensuring the integrity of the research, modeling, and analysis conducted during the *Hydropower Vision* collaborative process. These pillars are defined as follows:

- **Optimization**: Optimize the value and the power generation contribution of the existing hydropower fleet within the nation's energy mix to benefit national and regional economies; maintain critical national infrastructure; and improve energy security.
- **Growth**: Explore the feasibility of credible long-term deployment scenarios for responsible growth of hydropower capacity and energy production.
- **Sustainability**: Ensure that hydropower's contributions toward meeting the nation's energy needs are consistent with the equally important objectives of environmental stewardship and responsible water use management.

Several key insights of the *Hydropower Vision* collaborative effort that characterize the role hydropower has and can play in the U.S. power sector are discussed throughout Chapter 1.

Understanding the Role of U.S. Hydropower

Hydropower is a cornerstone of the U.S. electric grid, providing low-cost, low-carbon, renewable, and flexible energy services. As of 2015 year-end, the U.S. had a total installed hydropower capacity of 101 gigawatts (GW), consisting of 79.6 GW of hydropower generation plants and 21.6 GW of pumped storage hydropower (PSH). As of the beginning of 2014, hydropower supported approximately 143,000 jobs in the United States, with 2013 hydropower-related expenditures supporting $17.1 billion in capital investment and $5.9 billion in wages paid to workers.

Existing hydropower facilities have high value based on their ability to provide flexible generation and energy services; ancillary grid services; multi-purpose water management; and social and economic benefits, including avoidance of criteria air pollutants[1] and greenhouse gas (GHG) emissions. Hydropower is the largest U.S. renewable power source, providing approximately half (48%) of all U.S. renewable power in 2015.

Key Factors and Trends Motivating the Hydropower Vision

Trends specific to the U.S. electric sector, as well as broader national and global factors, motivated the development of the *Hydropower Vision.* A range of cost-effective, low-carbon generation options—including hydropower—are needed to reduce the power-sector emissions that contribute to climate change. A secure and stable domestic energy sector, including critical energy and water management infrastructure, is needed to support national energy and climate security.

Because hydropower is a stable renewable resource with long-lived infrastructure, it can provide a hedge against the future volatility of electricity prices in a changing market. While increases in U.S. natural gas resources and declines in natural gas cost from 2009 through 2015 have contributed to an increased share of natural-gas-fired electric generation capacity in the U.S. electric generation mix, several existing coal and nuclear plants have retired or announced pending retirement due to market competition, safety, or other reasons. This has allowed new markets for generation, including for renewable generation, to open up. Hydropower is complementary to increased integration of variable generation resources, such as wind and solar, into the power system, since hydropower can reduce curtailment of excess generation by providing load management and energy storage.

---

[1] The Clean Air Act requires EPA to set National Ambient Air Quality Standards for six common air pollutants (criteria pollutants) based on the human health-based and/or environmentally-based criteria. *https://www.epa.gov/criteria-air-pollutants*

Opportunities and Challenges for Hydropower

While hydropower's system-wide benefits are large and have historically underpinned the nation's electric systems, hydropower's future growth is coupled with the ability of innovation to enable hydropower resource opportunities to be economically competitive and environmentally sustainable. Keys to improved competitiveness are continued technical innovation to reduce capital and operating expenses; improved understanding and market valuation of system-wide grid reliability and stability services; and recognition and valuation of societal benefits from avoided power-sector air pollution and GHG emissions. Equally important to increasing hydropower's competitiveness is continued improvement in mitigating adverse effects, such as impacts on fish and wildlife, and increased public awareness of progress made in this regard.

Future hydropower development will require close coordination among developers, regulators, and affected stakeholders to reduce potential conflicts and meet multiple objectives pertaining to the use of water resources. There is increasing interest in these types of planning processes being carried out at the scale of entire river basins to better address potential system effects and the diverse set of interests that may be affected by a given project.

Modeling Hydropower's Contributions and Future Potential

Hydropower has the potential to grow and contribute to additional electricity production in the future generation portfolio. In the near term, there is significant potential for economically and environmentally sustainable growth by optimizing existing infrastructure through facility upgrades, and adding generation capabilities to non-powered dams (NPD) and water conveyances such as irrigation canals. In the longer term, capacity may be added through new stream-reach development (NSD). Additionally, the United States has resource potential for new pumped storage hydropower (PSH) development as a storage technology, which can enable grid flexibility and greater integration of variable generation resources.

Hydropower Vision uses the best available resource assessments to explore hydropower's market potential. Chapter 1 explains the process for interpreting hydropower's future market potential from technical resource assessments, using computational economic and dispatch models. These models provided the foundation to carry out comprehensive analyses of the existing and future role of hydropower within the electric sector on a national scale, and were used to evaluate a range of possible future outcomes for hydropower deployment. Actual deployment will be influenced by additional factors, including macroeconomic conditions, social and environmental considerations, policy, and others that are beyond the scope of the *Hydropower Vision* analysis.

Future Hydropower Technologies

Long-term hydropower growth potential, particularly at undeveloped sites (new stream-reaches), will be influenced by the extent to which new hydropower technologies and projects are able to be developed at lowered costs and with improved environmental performance. Chapter 1 describes innovations and non-traditional approaches in project development and applications of advanced technologies that could transform development of new hydropower projects in the decades to come. Integrated planning methods may allow advanced modeling, manufacturing, installation, operation, and maintenance innovations to reduce costs and improve generation and environmental performance simultaneously. Advanced technology approaches include cost-conscious design and manufacturing processes, modular systems, compact turbine/generator designs, and innovative passage technologies.

The Hydropower Vision Roadmap

Technical design innovation, implementation of advanced project strategies, optimization of regulatory processes, and application of the principles of sustainability will all be important to determining hydropower's future. The *Hydropower Vision* roadmap (Chapter 4) outlines a non-prescriptive set of actions for consideration by all stakeholder sectors to address many of the challenges that have affected hydropower projects. Addressing these challenges can facilitate the optimization, growth, and sustainability of the nation's hydropower sector. Chapter 1 details several key insights from the roadmap.

Opportunity, Risk of Inaction, and the Way Forward

The *Hydropower Vision* analysis (Chapter 3) found that hydropower's economic and societal benefits are significant and include cost savings in avoided mortality, morbidity, and economic damages from power-sector emissions of criteria air pollutants and avoided global damages from GHG emissions. Hydropower has been, and can continue to be, a substantial part of addressing the challenge of producing and making available clean, affordable, and secure energy for the nation.

The analysis modeled a credible future scenario combining assumptions on advanced technology, low-cost finance, and a combination of environmental considerations. The results indicate that U.S. hydropower could grow from 101 GW of combined generating and storage capacity in 2015 to nearly 150 GW by 2050, with more than 50% of this growth realized by 2030. However, while the industry is mature, many future actions and efforts remain critical to further advancement of domestic hydropower as a key energy source of the future. As previously noted, the *Hydropower Vision* roadmap identifies a high-level portfolio of new and continued actions and collaborations across many fronts to help the United States realize the long-term benefits of hydropower, while protecting the nation's energy, environmental, and economic interests.

1.0 Introduction

Hydropower has provided clean, affordable, reliable, and renewable electricity in the United States for more than a century. As of 2016, hydropower accounted for more than 6% of net U.S. power-sector electricity generation, nearly 9% of U.S. electric generating capacity, and 97% of U.S. utility-scale electrical storage capacity [1, 2, 3]. Because a range of cost-effective low-carbon generation options—including hydropower—are required to reduce and avoid the power-sector emissions that contribute to climate change and human health impacts, the U.S. Department of Energy's (DOE's) Wind and Water Power Technologies Office has led a first-of-its-kind comprehensive analysis to identify a set of potential pathways for the environmentally sustainable expansion of hydropower in the United States.

Hydropower has supported development of the U.S. power grid and the nation's industrial growth through the 20th century and into the 21st century. In addition to providing a stable and consistently low-cost energy source throughout decades of fluctuations and fundamental shifts in the electric sector, hydropower is a scalable, reliable generation technology that offers operational flexibility to maintain grid reliability and support integration of variable generation resources. Hydropower infrastructure is long-lived, and the resource is generally stable and predictable over long time periods.

Formulated through a broad-based collaborative effort, the *Hydropower Vision* initiative was undertaken to realize four primary objectives:

- Document the history and existing state of hydropower—consisting of both hydropower generation and pumped storage hydropower (PSH)—in the United States, including key technical advancements, societal benefits, and areas that must be addressed to facilitate future opportunities for sustainable hydropower development and operations;[2]
- Identify potential pathways for hydropower to expand its contribution to the electricity and water management needs of the nation from 2017 through 2030 and 2050, including supporting the growth of other renewable energy technologies, reducing carbon emissions, improving air quality, reducing water used for thermal cooling in the power sector, and fostering economic development and job growth;
- Examine critical environmental and social factors to assess how existing hydropower operations and potential new projects can be operated and delivered to minimize adverse effects and realize highest overall benefit; and
- Develop a roadmap identifying sets of stakeholder actions that could support continued responsible planning, operations, and expansion of new and existing hydropower facilities.

---

[2] Hydropower, as assessed in this report, includes new or conventional technologies that use diverted or impounded water to create hydraulic head to power turbines, and pumped storage hydropower facilities in which stored water is released to generate electricity and then pumped to replenish a reservoir. Throughout this report, the term "hydropower" generally encompasses all categories of hydropower. If a distinction needs to be made, the term "hydropower generation" distinguishes other types of projects from "pumped storage hydropower," or PSH.

1.1 Developing a *Hydropower Vision*

The *Hydropower Vision* report was developed with extensive stakeholder engagement, including input from multiple federal agencies involved in water resource issues. The *Hydropower Vision* establishes principles of optimization, growth, and sustainability for the nation's hydropower sector, and provides insights highlighting hydropower's importance to the nation.

The *Hydropower Vision* was developed with extensive stakeholder engagement.

The *Hydropower Vision* report resulted from DOE's collaboration with more than 300 experts from over 150 hydropower industry companies, environmental organizations, state and federal governmental agencies, academic institutions, electric power system operators, research institutions, and other stakeholder groups. Collectively, these participants were instrumental in documenting the state of the industry and identifying future opportunities for growth, as well as pinpointing challenges that need to be addressed to assure hydropower continues to evolve and contribute value to the nation for decades to come.

Individual expert opinion was provided at regular intervals throughout the project by a Senior Peer Review Group comprising 17 senior executives who are intimately aware of hydropower deployment and market issues. The group included broad representation of the hydropower industry, electric power sector, non-governmental organizations, developers, and federal agencies. The Senior Peer Review Group individually provided their review of the report and did not function as a consensus-building body. All decisions regarding final report content were made by DOE. The Senior Peer Review Group and DOE adhered to the requirements of the Information Quality Act, including DOE's associated guidelines and the Office of Management and Budget's peer review bulletin.[3,4]

Ten topical task forces conducted analyses, provided information, and generated draft text for consideration in this report. The task force topics were: technology; project development; sustainability, environmental, and regulatory considerations; grid integration and transmission; operations, maintenance, and performance optimization; markets; pumped storage; economic development; modeling and analysis; and communications.

Representatives from four DOE national laboratories—Argonne National Laboratory, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory—provided the leadership and technical expertise for each of the task forces. Other task force members included representatives from the hydropower industry (domestic and international), academia, the electric power sector, non-governmental organizations, and governmental organizations with regulatory, ownership, and other interests. In addition to the task forces and Senior Peer Review Group, external peer reviewers who were not otherwise involved in the preparation of the report reviewed the draft report content for accuracy and objectivity.

The *Hydropower Vision* engaged multiple federal agencies.

Cooperation with other federal agencies has been a consistent part of the DOE's hydropower research, development, deployment, and demonstration efforts, as has scientific leadership and technical expertise provided by DOE's national laboratories. Given the role of federal agencies in hydropower ownership and regulation, this interagency cooperation was critical during fact-finding and analysis carried out for the *Hydropower Vision.*

A 2010 multiagency memorandum of understanding (MOU) established a framework for federal collaboration specifically targeting sustainable hydropower. The MOU was signed by the DOE, the Department of the Interior, and the U.S. Army Corps of Engineers (Corps) in 2010 and extended in 2015. It established a Federal Inland Hydropower Working Group, with 15 federal

---

[3] The Department of Energy's Information Quality Guidelines are developed in accordance with Section 515, Treasury and General Government Appropriations Act (Information Quality Act) Public Law 106-554. *http://energy.gov/cio/department-energy-information-quality-guidelines*

[4] The Office of Management and Budget's "Final Information Quality Bulletin" provides guidelines for properly managing peer review at federal agencies in compliance with section 515(a) of the Information Quality Act (Pub. L. No. 106-554). The *Hydropower Vision* assessment followed these guidelines.

entities as members.[5] Thirteen overarching goals are established by the MOU, with specific collaborative activities delineated for each. DOE reports created under the MOU umbrella provided citable data that are incorporated into the *Hydropower Vision.*

The *Hydropower Vision* establishes principles of optimization, growth, and sustainability.

For purposes of the *Hydropower Vision*, sustainable hydropower projects are those that are sited, designed, constructed, and operated to balance social, environmental, and economic objectives at multiple geographic scales (i.e., national, regional, basin, site). While hydropower development has, in some cases, had adverse effects on river systems and the species that depend upon them, hydropower offers many benefits continues to make advances in environmental performance. Accordingly, *Hydropower Vision* sets increasing expectations for hydropower development under which gains are maintained and the trend of improvement continues. Sustainable hydropower fits into the water-energy system by ensuring that the ability to meet energy needs is balanced with the functions and co-objectives of other water management missions in the present, as well as into the years ahead. In some cases, dam removal and site restoration may be part of meeting the sustainability objective.

Hydropower Vision is grounded in three foundational principles or "pillars"—optimization, growth, and sustainability—arrived at through extensive stakeholder input and identified as critical to ensuring the integrity of the research, modeling, and analysis conducted during the *Hydropower Vision* collaborative process. These pillars are defined as follows:

- **Optimization:** Optimize the value and the power generation contribution of the existing hydropower fleet within the nation's energy mix to benefit national and regional economies; maintain critical national infrastructure; and improve energy security.
- **Growth**: Explore the feasibility of credible long-term deployment scenarios for responsible growth of hydropower capacity and energy production.
- **Sustainability**: Ensure that hydropower's contributions toward meeting the nation's energy needs are consistent with the equally important objectives of environmental stewardship and responsible water use management.

Insights from the *Hydropower Vision* highlight hydropower's importance.

Several key insights of this *Hydropower Vision* collaborative effort characterize the role that hydropower has and can play in the U.S. power sector:

1. Hydropower has been a cornerstone of the U.S. electric grid, providing low-cost, low-carbon, renewable, and flexible energy services for more than a century;
2. Existing hydropower facilities have high value based on their ability to provide flexible generation and energy services; ancillary grid services; multi-purpose water management; and social and economic benefits, including avoidance of criteria air pollutants[6] and greenhouse gas (GHG) emissions;
3. Hydropower has the potential to grow and contribute to additional electricity production in the future generation portfolio. In the near term, there is significant potential for economically and environmentally sustainable growth by optimizing existing infrastructure through facility upgrades, and adding generation capabilities to non-powered dams (NPDs) and water conveyances such as irrigation canals;
4. Long-term hydropower growth potential, particularly at undeveloped sites (new stream-reaches, or NSDs), will be influenced by the extent to which new hydropower technologies and projects are developed at lowered costs and with improved environmental performance;
5. The United States has resource potential for new pumped storage hydropower (PSH) development as a storage technology, which can enable grid flexibility and greater integration of variable generation resources, such as wind and solar;

---

[5] The members of Federal Inland Hydropower Working Group are the Corps, Bonneville Power Administration, the Bureau of Indian Affairs, the U.S. Bureau of Reclamation, DOE, the U.S. Environmental Protection Agency, the Federal Energy Regulatory Commission, the U.S. Fish and Wildlife Service, the U.S. Forest Service, the National Oceanic and Atmospheric Administration, the National Park Service, Southeastern Power Administration, Southwestern Power Administration, the U.S. Geological Survey, and the Western Area Power Administration. For more information see: *http://en.openei.org/wiki/Federal_Memorandum_of_Understanding_for_Hydropower/Federal_Inland_Hydropower_Working_Group*.

[6] The Clean Air Act requires EPA to set National Ambient Air Quality Standards for six common air pollutants (criteria pollutants) based on the human health-based and/or environmentally-based criteria. *https://www.epa.gov/criteria-air-pollutants*

6. Technical design innovation, implementation of advanced project strategies, optimization of regulatory processes, and application of the principles of sustainability will all be important to determining hydropower's future; and
7. Hydropower's economic and societal benefits are significant and include cost savings in avoided mortality, morbidity, and economic damages from power-sector emissions of criteria air pollutants and avoided global damages from GHG emissions.

The *Hydropower Vision* does not define numeric goals or targets for hydropower development, and it does not specifically evaluate nor recommend new policy actions. The *Hydropower Vision* instead analyzes the feasibility and potential benefits of varied hydropower deployment scenarios, all of which could inform policy decisions at the federal, state, tribal, and local levels.

1.2 Understanding the Role of U.S. Hydropower

By the end of 2015, the U.S. hydropower[7] generation fleet included 2,198 active power plants with a total capacity of 79.6 gigawatts (GW) and 42 PSH plants totaling 21.6 GW, for a total installed hydropower capacity of 101 GW [3]. Hydropower is currently the largest U.S. renewable power source, providing nearly half (48%) of all U.S. renewable power in 2015. Forty-eight states have hydropower facilities, and ten of these states generated more than 10% of their electricity from hydropower in 2015 [4].

Hydropower has been the cornerstone of low-cost, low-carbon, renewable, and flexible contributions to the U.S. electric grid.

Hydropower has played an important role in U.S. industrial development. Hydropower supported rapid expansion of the nation's production of aluminum for aircraft during World War II, and helped support developing post-war industries, including automobile and durable goods manufacturing [5]. Hydropower has also played an major role in U.S. clean power generation, providing on average 10% of U.S. electricity generation over the past 65 years (1950–2015), and 85% of cumulative U.S. renewable power generation over the same time period (Figure 1-1) [1].

Hydropower has provided a cumulative 10% of U.S. electricity generation and more than 85% of cumulative U.S. renewable power generation between 1950 and 2015.

Hydropower supports jobs and provides economic value.

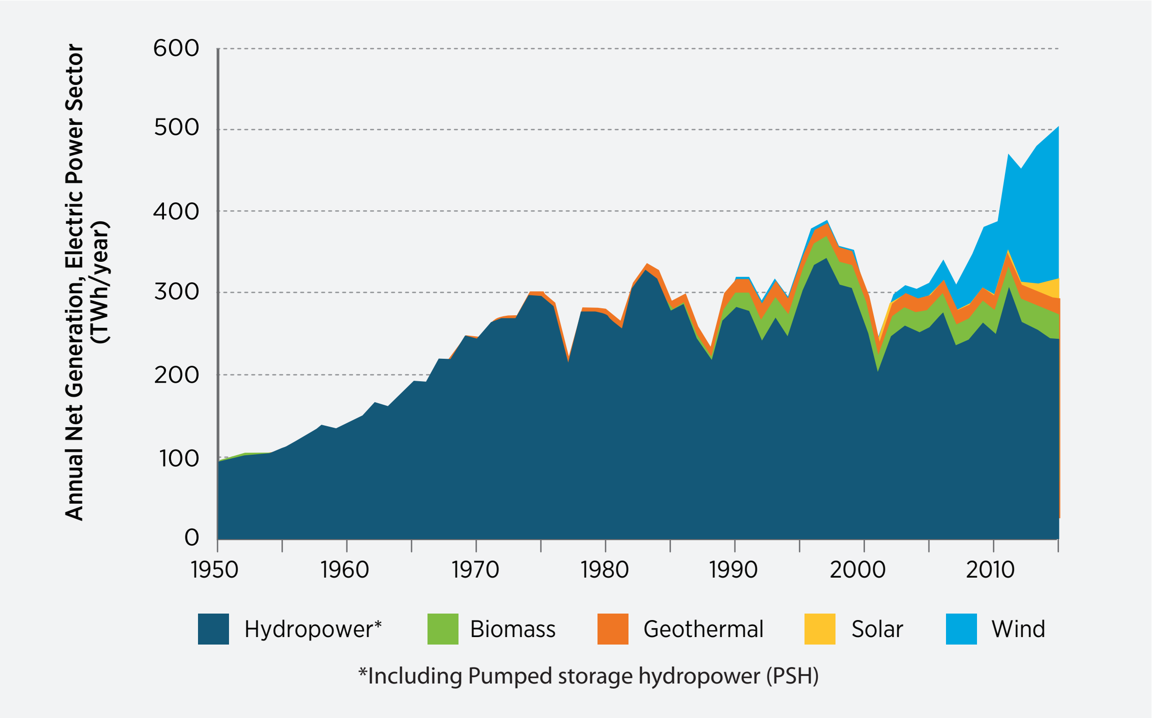
As of the beginning of 2014, hydropower supported approximately 143,000 jobs in the United States, comprising 118,000 total ongoing full-time equivalent jobs in operations and maintenance and 25,000 temporary jobs in construction and upgrades [6]. Navigant Consulting Services estimates that the full-time jobs include 23,000 direct jobs at operating sites, with jobs such as plant operators, mechanical maintenance workers, and hydropower engineers; 54,000 direct jobs in the supply chain; and 41,000 induced jobs from the resulting economic activity [6]. In 2013, expenditures related to hydropower supported roughly $17.1 billion in economic output (capital investment) and $5.9 billion in earnings (wages paid to workers) [6].

Hydropower provides flexibility and essential grid services.

Hydropower provides many ancillary and essential reliability services that ensure national grid stability and flexibility. Grid services, including regulation and frequency response, load-following and flexibility

---

[7] This report does not address marine (wave, current, and tidal) and river hydrokinetic technologies, as marine and hydrokinetic technologies are defined by Congress as separate and distinct from hydropower [58].



Source: EIA 2016 [1]

Figure 1-1. Annual U.S. renewable electricity net generation (terawatt-hours per year), electric power sector, 1950–2015

reserve, energy imbalance service, spinning reserve, supplemental (non-spinning) reserve, reactive power and voltage support, and black start (restoration) service, are discussed in Chapter 2 (see Text Box 2-2a). These services contribute to maintenance of power system balance on time scales ranging from sub-seconds to hours.

Existing hydropower facilities have high value due to flexibility, grid support services, and social and economic benefits, including avoidance of GHGs and criteria air pollutants.

Certain grid services, known as essential reliability services, are considered critical to maintaining the operations and stability of the national grid. These services are identified by the North American Electric Reliability Corporation as frequency response, ramping, and voltage support, and are discussed in Chapter 2 (see Text Box 2-2b). Hydropower facilities, with storage and fast ramping ability, can react quickly to system disturbances and contribute to greater flexibility and reliability of power system operation [7].

Pumped storage hydropower—where water is pumped to an upper reservoir when demand and market price is low, and then released back through turbines to generate electricity as needed—also has the capability to absorb large amounts of generation, providing grid operators with an important tool to avoid operational and reliability problems associated with over-generation conditions. Hydropower also provides short- and long-term energy storage in the form of the energy potential of impounded water.

Hydropower's ability to rapidly absorb load or supply power to serve load as needed is critical for grid stability and voltage support. The ancillary and essential reliability services provided by hydropower are particularly important in compensating for unexpected voltage sags from thermal or nuclear plants going offline, transmission line outages, and providing system restoration. These services also provide quick response in regions with high penetrations of variable generation sources, such as wind and solar.

Hydropower supports integration of variable generation resources.
Hydropower's ability to provide grid ancillary services and essential reliability services makes the technology suited to cost effectively support increased integration of variable generation resources into the power grid and balance the variable generation of such changes over time due to factors outside the direct control of the operator, e.g., wind or solar resource. PSH in particular is complementary to integration of variable generation resources, as PSH can reduce curtailment of excess generation by providing load management and energy storage. *Hydropower Vision* analysis presented in Chapter 3 indicates there is a positive correlation between PSH and variable generation deployment.

Hydropower produces low carbon and criteria pollutant air emissions.
Because its fuel (water) is renewable, the hydropower electricity generation process has very low life cycle GHG and criteria air pollutant emissions [8]. The potential for biogenic GHG emissions (mainly methane) from bodies of impounded water, independent of whether such an impoundment is equipped with hydropower, is a complex issue and subject to ongoing research [9]. Given the state of scientific understanding and discourse, including persistent uncertainties, the *Hydropower Vision* does not attempt to address hydropower-related biogenic GHG emissions. Instead, Chapter 3 provides an introduction to the subject and a review of the literature. It is unlikely that powering existing NPDs would result in methane production higher than that caused by natural conditions in rivers and lakes.

Hydropower is integrated with multiple water uses.
The existing role and emerging future of hydropower is complex. Dams and reservoirs serve many functions, including flood management and control, irrigation, recreation, navigation, and drinking water supply. The vast majority of the more than 87,000 existing dams in the United States do not include hydropower generation plants. Those that do generate electricity (less than 2,200) must meet both the ongoing power and non-power needs of multiple and varied interests and stakeholders within the context of complex and sometimes redundant regulatory frameworks. In terms of number of sites, the top three uses of federally owned hydropower reservoirs—approximately 50% of installed capacity—are recreation, flood control, and irrigation [10].

The complex interplay among hydropower facilities, the geographic areas in which they are located, the ecosystems and aquatic life that are affected, relevant power-producing operations, and the roles that water impoundments of varying scales all play in water management highlight the need for a coordinated and balanced approach to prioritization, planning, and facility design and management among a multitude of stakeholders.

Hydropower has direct interaction with the riverine environment.
Because hydropower interacts directly with water and the related riverine environment, hydropower generation facilities can directly influence riverine ecosystem health above and below a facility. Potential environmental impacts include: timing of release and amount of stream flows; water quality effects, including water temperature, turbidity, and oxygen content; fragmentation of riverine habitat; alteration of fish migration patterns; alteration or destruction of fish habitat; fish injury or mortality from turbine passage; possible damage to or inundation of archaeological, cultural, or historic sites; changes in visual quality; and increase in the potential for stream-bank erosion. Mitigation of these potential adverse environmental or fish and wildlife impacts is required (see Chapter 2).

Public and private funding has been allocated to improving conditions for fish affected by hydropower projects, primarily diadromous migratory species.[8] For example, the National Oceanic and Atmospheric Administration (NOAA) partners with conservation organizations, energy companies, states, tribes and citizens to evaluate barriers—big and small—to improve fish passage. NOAA opens fish passage and conducts dam removals by providing grant funding, providing technical assistance to partners, and participating in the hydropower project relicensing process. Since 1996, NOAA with its partners has invested more than half a billion dollars to restore access for migratory fish to approximately 16,000 miles of rivers and streams.

---

[8] There are two categories of diadromous fishes (species that spend part of their lives in fresh water and part in salt water). An anadromous species, born in fresh water, spends most of its life in the sea and, when mature, returns to fresh water to spawn. This freshwater/saltwater cycle is essential to survival for these fishes. Salmon, smelt, shad, striped bass, and sturgeon are common examples. Catadromous species, such as the American eel, hatch or are born in marine habitats, migrate to freshwater areas where they spend the majority of their lives, and then return to the sea to spawn.

Researchers have developed innovative upstream and downstream passage facilities, innovations in combining temperature control structures with passage facilities, and design tools that allow manufacturers to build turbines that reduce fish injury and mortality associated with turbine passage. DOE- and industry-funded projects for features such as advanced turbines and biologically based design and evaluation tools help enable improvements in turbine environmental performance. Additional work has focused on mitigation of environmental impacts that affect aquatic organisms, such as degraded water quality associated with hydropower facilities and elevated levels of total dissolved gases at Columbia River projects.

Hydropower infrastructure has a long lifetime. Hydropower facilities have a long capital lifetime as compared to other generating technologies, with an average operational lifespan on the order of 100 years [11]. In the United States, more than 1,500 facilities installed prior to World War II are still operational, with 10.2 GW of combined capacity [12]. Although the lifetime of the impoundment is generally greater than that of the power plant, the turbines, buildings, water retaining structures, and other components of the facility are regularly serviced and often replaced or rehabilitated during these long operating periods. Therefore, it is expected that much of the existing hydropower infrastructure will continue to function for many more decades if properly maintained, operated, and upgraded.

1.3 Key Factors and Trends Motivating the *Hydropower Vision*

Changes and trends specific to the U.S. electric sector, as well as broader national and global factors, have motivated the development of the *Hydropower Vision* to evaluate the potential for optimization, growth, and sustainability of U.S. hydropower. As discussed in this section, requirements for electric generation capacity and the choices of fuel mix are influenced by many factors, including national priorities, social and environmental concerns, policy and regulation, energy markets, and advances in technology and operations.

Hydropower can reduce carbon emissions. A range of cost-effective low-carbon generation options, including hydropower, are needed to reduce the power-sector emissions that contribute to climate change. President Barack Obama's 2013 Climate Action Plan calls for the deployment of clean energy[9] to support reduced carbon pollution from power plants; American leadership in renewable energy; and long-term investment in clean energy innovation [13]. The National Security Strategy, issued by the U.S. Department of Defense in February 2015, specifies that climate change is an urgent and growing threat to national security. The DOD report states that climate change impacts are already occurring, and that their scope, scale, and intensity are projected to increase over time [14].

State and local governments have enacted policies to encourage GHG emission reductions for many years. Examples include the California Global Warming Solutions Act of 2006 [15], and the Regional Greenhouse Gas Initiative—a cooperative GHG cap-and-trade agreement that became effective on January 1, 2009 in the northeastern United States and Eastern Canada. Increasing concern about the effects of carbon emissions on climate change led the U.S. Environmental Protection Agency to issue the Clean Power Plan in August 2015 to adopt carbon pollution standards for existing power plants, and instruct states to begin making meaningful progress toward reductions by 2022 [16]. The Clean Power Plan establishes unique emission rate goals and mass equivalents for each state, and is projected to reduce power-sector carbon emissions 32% from 2005 levels by 2030 [17]. Hydropower can play a role in carbon emission avoidance and reduction into the future.

---

[9] The President's Climate Action Plan defines clean energy as renewable energy (wind, solar, geothermal, hydropower, biomass, and advanced biofuels), natural gas, nuclear power, and "clean coal."

Hydropower supports a broader definition of national security.
Power system stability and reliability, such as that provided by hydropower, is critical to national security. In releasing the first installment of the national Quadrennial Energy Review,[10] the U.S. Administration stated [18]:

> ***"The focus of U.S. energy-policy discussions has shifted from worries about rising oil and natural gas imports to debates about how much and what kinds of U.S. energy should be exported, concerns about safety and resilience, integrating renewable sources of energy, and the overriding question of what changes in patterns of U.S. energy supply and demand will be needed—and how they can be achieved—for the United States to do its part in meeting the global climate-change challenge."***
>
> White House Office of the Press Secretary, April 21, 2015.

According to the Quadrennial Energy Review, while the concept of "oil security" has come to serve as a proxy for "energy security," energy security needs to be more broadly defined to cover not only oil but all other sources of supply. Energy security should also be based not only on the ability to withstand shocks in price and availability, but also to be able to recover quickly from any volatility. In the electric sector, this means the ability to operate a reliable and secure grid as well as the flexibility to avoid and recover quickly from any widespread outages. Hydropower is one of the few electricity sources that can provide these critical flexibility functions, including black-start capability[11] and the ability to ramp up power production quickly.

The International Energy Agency (IEA) is a 29-member autonomous organization made up of countries and founded in 1974. The organization was initially designed to help countries coordinate a collective response to major disruptions in the supply of oil. IEA defines energy security in a broad manner, similar to the Quadrennial Energy Review:

> ***"IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance"*** *[60].*

As defined by the IEA, lack of energy security is linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile. Hydropower and most renewable energy sources have relatively stable operational costs over time, since they are not subject to market-driven fuel price fluctuations. Concerns about physical unavailability of supply are more prevalent in energy markets where transmission systems must be kept in constant balance, such as electricity and, to some extent, natural gas. Hydropower, through large impoundments and PSH, can provide long-term electricity storage services. The long-term aspect of energy security was also included in the IEA's founding objectives, which called for promoting alternative energy sources in order to reduce oil import dependency [19].

Hydropower is part of the nation's critical infrastructure.
Reliable electricity delivery is increasingly important in the global flow of information and commerce, and the cost of power interruptions—whether accidental or intentional—makes power system stability and reliability ever more critical to national security. The energy and dams sectors are two of the 16 critical infrastructure sectors listed by the U.S. Department of Homeland Security under Presidential Policy Directive 21 [20]. The directive defines critical infrastructure as assets, systems, and networks—whether physical or virtual—that are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof [21]. The Department of Homeland

---

[10] In response to a 2010 recommendation by the President's Council of Advisors on Science and Technology , the Administration initiated a quadrennial cycle of energy reviews to provide a multiyear roadmap for U.S. energy policy. More information on the Quadrennial Energy Review is available at: *http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report*

[11] A black start is the process of restoring a power station to operation without relying on the external electric power transmission network. It is not economical to provide a large standby generation capacity at each station, so black-start power must be provided over designated power lines from another station. Hydroelectric power plants are often designated as the black-start sources to restore network interconnections.

Security provides strategic guidance and coordinates the overall federal effort to promote the security and resilience of the nation's critical infrastructure, including hydropower.

Public policy influences renewable energy deployment.
Public policy has supported deployment of renewable energy at state and regional levels through policies such as renewable portfolio standards (RPS) and other initiatives. Hydropower is characterized as renewable and "clean" because its energy source is not depleted during use and carbon-based fuels are not burned as part of energy production. Some state RPS and federal policies, however, exclude hydropower from consideration or give hydropower reduced credit compared to other renewable sources of generation. In addition to state and regional initiatives, the federal government has supported development of clean, renewable energy through a variety of mechanisms, including federal funding for research, development, demonstration, and deployment.

As of April 2016, mandatory RPS policies exist in 29 states [22], the District of Columbia, and Puerto Rico and voluntary renewable targets in eight states. Hydropower is an eligible technology in most of the states' RPS policies, but there are generally restrictions on which hydropower projects can be included. Of the 30 states (including the District of Columbia) in which hydropower is eligible for the RPS, 23 allow new hydropower development and five others explicitly prohibit new dams [23]. Two of the states prohibiting new dams allow new run-of-river facilities to qualify for the RPS. Because of concern over the ecological impacts of large dams, large hydropower—most frequently defined as greater than 30 megawatts (MW)—is limited in inclusion in state RPS policies. In contrast, 25 states allow small hydro, generally defined between 3 and 60 MW (depending on the state).

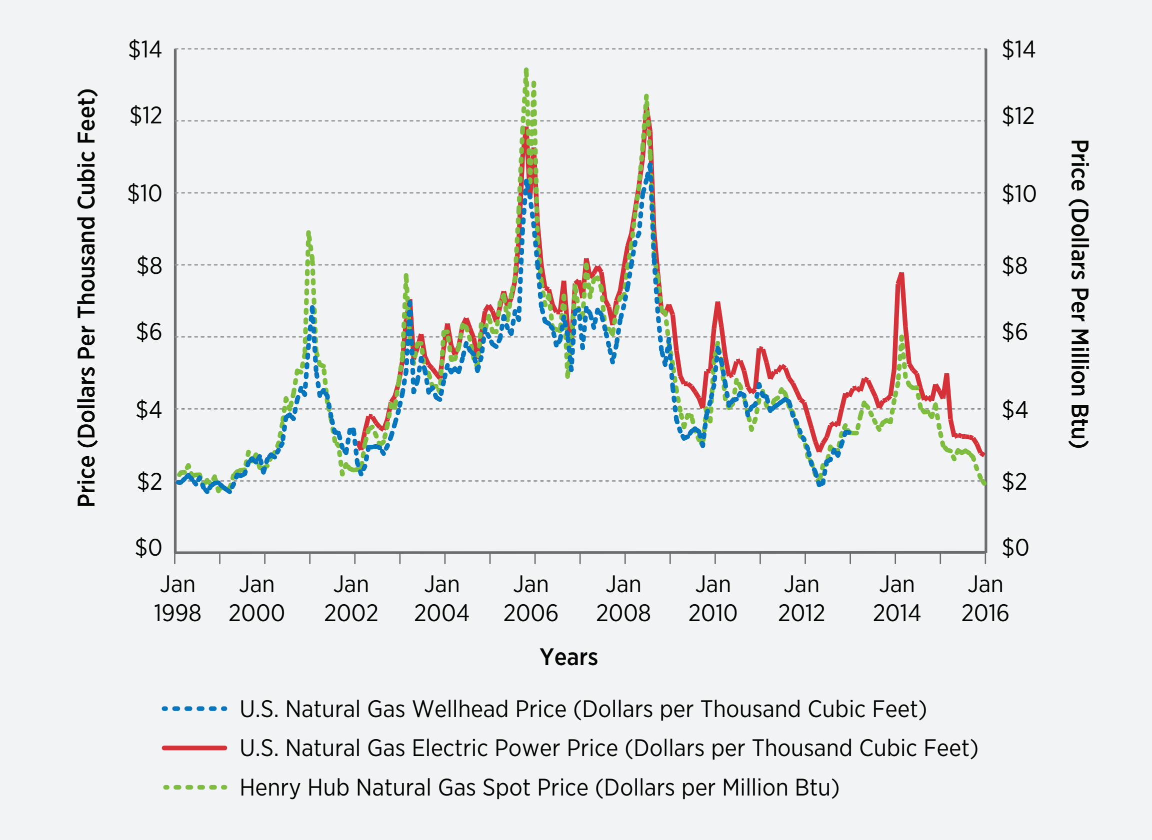
As other renewables become more mature (e.g., wind power approached 5% of total electricity generation in 2015), state programs may reassess the value of distinguishing hydropower from "non-hydro" renewables. Whether or not hydropower (either new or existing) should be included or excluded from renewable energy incentive programs or market compensation mechanisms is ultimately dependent upon the goals of specific policies and their related implementation approaches.

Hydropower provides a hedge against electric price volatility.
As a stable renewable resource with long infrastructure life, hydropower provides a direct hedge against the volatility of electricity prices. Hydropower additionally provides an indirect hedge against price volatility, through grid support for increased integration of variable generation resources such as wind and solar—which, as fuel-free power sources, also have stable long-term pricing.

While hydraulic fracturing for oil and natural gas extraction has been used for more than a century, technological improvements in the early 2000s allowed the technology to be successfully applied to U.S. oil shales bearing natural gas deposits and other unconventional natural gas resources. Between 2005 and 2010, the shale gas industry in the United States grew 45% per year. As a proportion of the country's overall gas production, shale gas increased from 4% in 2005 to 24% in 2012 [24]. As illustrated in Figure 1-2, this increase in supply coincided with a measurable decrease in U.S. natural gas prices from 2009 through 2015. Prices for natural gas used to generate electricity (solid red line in Figure 1-2) can affect the value of electricity sales in power markets.

Coal and nuclear retirements create markets for new generation.
According to the Energy Information Administration (EIA) and other market analysts, the role of coal and nuclear technologies in the U.S. generation mix has been changing since 2009. Low natural gas prices and slower growth of electricity demand have both altered the competitiveness of these technologies relative to other fuels [27]. Coal-fired plants also must comply with requirements of the Mercury and Air Toxics Standards and other environmental regulations, and some nuclear plants are experiencing increasing operations and maintenance costs or capital addition costs. As existing coal and nuclear plants retire—whether due to market competition, safety, or other reasons—new markets for generation, including hydropower, open up.

To estimate future national energy needs, EIA publishes an Annual Energy Outlook (AEO) presenting long-term (25-year) annual projections of U.S. energy supply, demand, and prices. A *Reference Case* is established by EIA to provide a business-as-usual



Source: EIA Natural Gas Monthly [25]

Figure 1-2. Trends in U.S. natural gas prices, 1998–2015

trend estimate, given known technology, technological and demographic trends, as well as federal, state, and local laws and regulations in effect at the time.

Under EIA's AEO 2015 *Reference Case* [27], 40.1 GW of coal-fired capacity would be retired from 2013–2040, with more than 90% (37.4 GW) of this capacity being retired by 2020. Under EIA's AEO 2014 *Accelerated Coal Retirements Case*, 110 GW of capacity out of the total installed 310 GW of coal-fired generating capacity available at the end of 2012 would be retired by 2040 [26]. By contrast, natural gas combined cycle capacity would increase by 93 GW from 2013–2040 under the AEO 2015 *Reference Case.*

From 2010 through June 2016, fourteen U.S. nuclear reactors totaling 11.9 gigawatts of electric capacity were or had closures accounted by their owners [28]. According to the Natural Resources Defense Council, three of the reactors closed for primarily mechanical or safety reasons, whereas 11 reactors closed or will close primarily because of an inability to compete in existing market conditions [28]. Under EIA's AEO 2015 *Reference Case,* nuclear capacity would experience net growth of 5.9 GW (6%) from 2013–2040. Under the AEO 2014 *Accelerated Nuclear Retirements Case,*[12] 42 GW of nuclear capacity would be retired through 2040.[13]

---

[12] Because EIA now publishes shorter and longer editions of the AEO in alternating years, AEO 2015 does not include all of the alternative cases presented in AEO 2014.

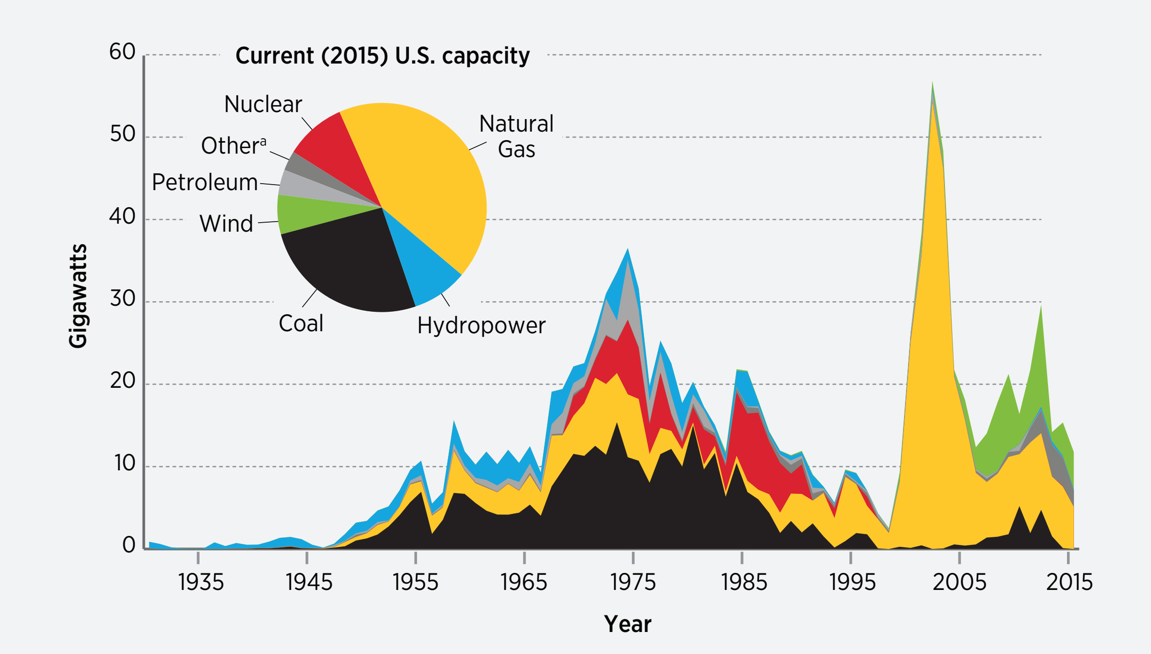
[13] In a 2015 National Renewable Energy Laboratory report using different retirement assumptions than EIA, and under a modeled "central scenario," roughly half of the existing (as of 2012) coal capacity and nearly all of the existing oil and gas steam turbines and existing nuclear units are retired by 2050 [32].

The loss of generating capacity due to ongoing retirement of coal-fired plants is largely being replaced by the addition of gas-fired and variable generation resources [29]. Increases in natural gas resources and declines in gas cost from 2009 through 2015 have contributed to an increased share of natural-gas fired electric generation capacity added to the U.S. electric generation mix (Figure 1-3), with natural gas generation roughly doubling between 2000 (518 terawatt-hours [TWh]) and 2014 (1,029 TWh) [1]. As can also be seen in Figure 1-3, wind power capacity additions have increased since about 2010, due to technological advances, lower cost, favorable markets, and ease in siting and permitting. These developments in the national energy mix imply a growing opportunity for hydropower, not only for generation but for maintaining grid system efficiency and stability.

Hydropower can support an increasing need to integrate variable generation.

Deployment of variable generation resources is increasing over time, making balancing of the U.S. electric power system all the more critical. In the future, electric vehicles, distributed generation, smart grid functions, and other changes could further affect grid operations. While the electric power system has provided reliable electricity for more than a century, much of the existing electric grid was designed and built decades ago using system design models and concepts that may require restructuring to meet the needs of a low-carbon economy (as discussed previously).

Hydropower can be an integral part of this future energy mix because of its ability to provide ancillary and essential reliability grid services. As the electric power system evolves, power system flexibility will be needed at time scales that range from sub-second for inertial/frequency response, to minutes or hours, during which there will be an increase in the need for regulating and ramping capability. Transmission system operators require tools and resources to realize this increased level of flexibility, which will also require new strategies for managing grid operations. Some of the new tools and methods include expanding balancing areas,[14] increasing the ramping capability of the generation fleet, using dispatchable



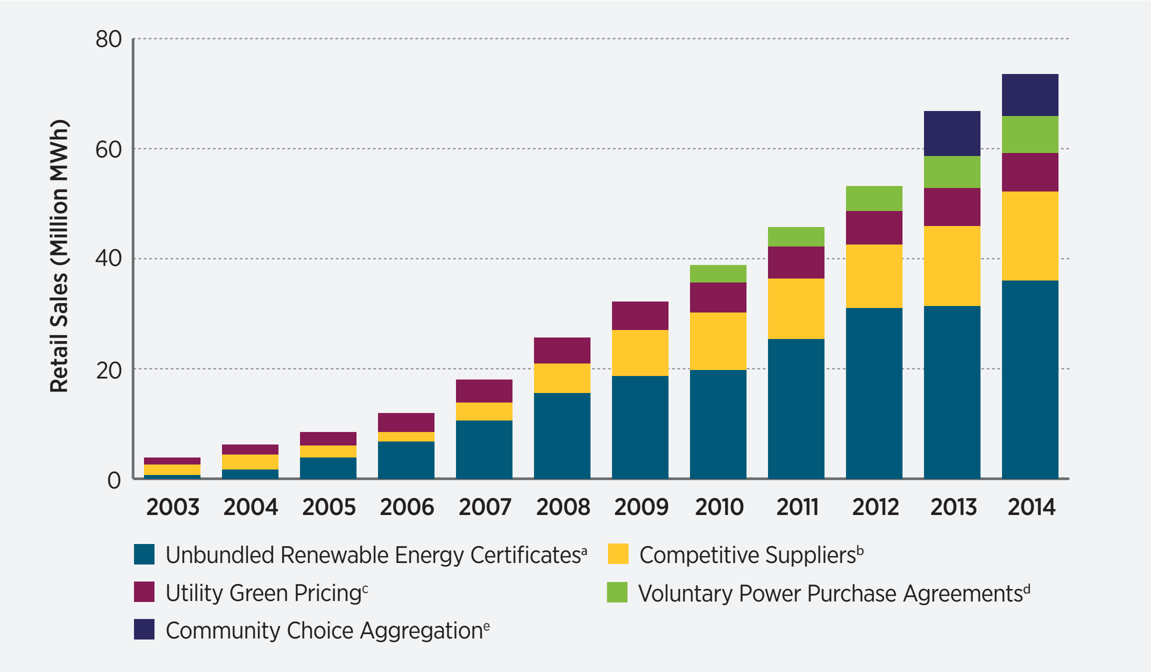
Source: EIA [30], Federal Energy Regulatory Commission Energy Infrastructure Updates 2011-2015 [31]

a. Other" includes biomass, geothermal steam, solar, waste heat, tires, and miscellaneous technology such as batteries, fuel cells, energy storage, and fly wheel.

Figure 1-3. Cumulative U.S. electric generating capacity by fuel type, 1930–2015 (EIA, FERC)

---

[14] Large transmission grids can be broken into smaller transmission "balancing authority areas," where reliability requirements can be met while balancing load with generation and interchanges of neighboring regions.



Notes: The unbundled renewable energy certificate market allows consumers to purchase RECs separate from power. Competitive supply allows customers to purchase renewable electricity directly from alternate suppliers. Utility green pricing bundles renewable energy certificates with electricity sales. Voluntary power purchase agreements allow negotiated long-term purchases of renewable energy. Community choice aggregation allows communities aggregate their load and purchase electricity from an alternate electricity supplier, while still receiving transmission and distribution service from their existing utility.

Sources: Bird and Swezey [35], Heeter and Nicholas [36], and Heeter et al [37]

Figure 1-4. Estimated voluntary U.S. sales of renewable energy, 2003–2014

demand resources, adding power flow controllers, and increasing energy storage to maintain reliability [33]. Corresponding to these new tools and approaches is the need for financial incentives to support their development and deployment, in order to meet required levels of system flexibility.

Market drivers for utility-scale grid storage are increasing.

Key market drivers of energy storage for grid support services, such as PSH, include: (1) growth in renewable energy deployment; (2) governmental focus on initiatives to reduce carbon emissions; (3) the need for modernization of grid infrastructure; and (4) the need to improve the resilience of the electrical grid to unforeseen interruptions [34]. PSH is a low-risk technology with a proven track record and high efficiency in providing load management, energy storage, and grid services. Additionally, PSH is more flexible and has longer facility lifetimes and lower cost compared to other technologies that can provide these services in facilitating the integration of variable generation resources into the grid. A detailed discussion of PSH is found in Chapter 2, Section 2.7 of the *Hydropower Vision* report.

There is increased public and private interest in renewable energy.

As shown by increases in voluntary purchases of renewable energy, public and private interest in and understanding of the role and value of renewable energy continues to increase. In 2014, voluntary retail sales of renewable energy totaled 74 TWh, representing 2.0% of total U.S. electricity sales and four times the voluntary green power sales of 18 TWh in 2007 (Figure 1-4) [35, 36, 37]. One of many examples of private sector investment in renewable energy is the U.S. Environmental Protection Agency's Green Power Partnership. Nearly 25 TWh in combined green power usage was reported in 2015 for the Top 100 Green Power Partners, enough to power nearly 2.3 million homes. This includes 14 TWh used by the 76 Fortune 500 Green Power Partners [38].

Private and public owners are investing in hydropower generation.
Hydropower growth occurs in three different ways: unit additions and upgrades at existing facilities; adding hydropower generating equipment to existing NPDs and conduit projects; and NSD. Installed hydropower capacity in the United States experienced a net increase of 1.48 GW from 2005 to 2013, with capacity additions to existing projects accounting for 86% of the increase. Capital investment toward modernizing and upgrading the existing fleet continues, with private and public owners investing more than $6 billion in refurbishments, replacements, and upgrades to hydropower plants from 2005-2014 [3].

Technology innovation enables low-cost, sustainable hydropower development.
Development of hydropower technologies and operations with reduced adverse impacts is vital if hydropower is to be deployed in an environmentally sustainable manner and at lower cost. Some of the innovations emerging for low-head hydropower include concepts such as mechanically unregulated turbines that vary speed with head or flow, and permanent magnet-type generators that produce an output voltage that varies with head and flow. Other technologies are being developed for very low-head turbines, such as a direct-drive variable speed permanent magnet-type generator that can be placed directly in a flow channel with approximately 4–8 feet of head. This concept can reduce civil works required for intake structures or water conveyance, and the associated cost of those works. Innovative technologies are being developed for safe and effective fish passage at dams, including high head dams and dams with a large range of reservoir levels [39]. Such innovations and improvements are being integrated into both the existing fleet and new projects, and this trend of improved environmental performance is expected to continue. Future hydropower technologies are discussed further in Section 1.7.

1.4 Opportunities and Challenges for Hydropower

The *Hydropower Vision* identifies opportunities and challenges for hydropower through its documentation, modeling and analysis, and stakeholder roadmap. Hydropower's system-wide benefits are large and have historically underpinned the nation's electric systems. Hydropower's growth is critically coupled with the ability of innovation to enable hydropower resource opportunities to be economically competitive and environmentally sustainable.

Keys to improved competitiveness include continued technical innovation to reduce capital and operating expenses, improved understanding and market valuation of system-wide grid reliability and stability services, and recognition and valuation of societal benefits from avoided power-sector air pollution and GHG emissions. Equally important to increasing hydropower's competitiveness is continued improvement in mitigating adverse effects, such as impacts on fish and wildlife, and increased public awareness of progress made in this regard. Addressing these objectives is likely to require continued technical innovation, actionable and measurable environmental sustainability metrics and practices, planning at the basin or watershed scale, and access to new science and assessment tools.

The degree to which such challenges can be effectively addressed will influence the levels of future hydropower growth and reinvestment in existing facilities. In turn, it will affect realization of the opportunities and benefits provided by low-cost hydropower generation, grid support, and long project operating life. Chapter 2 provides detailed discussion of the state of the hydropower industry and its trends, opportunities, and challenges.

Hydropower services could benefit from improved valuation.
Inherent market and regulatory challenges must be overcome to realize hydropower's potential to improve grid flexibility and facilitate integration of variable generation resources. The full accounting, optimization, and compensation for hydropower

generation, grid ancillary services and essential grid reliability services in power markets is difficult, and not all benefits and services provided by hydropower facilities are readily quantifiable or financially compensated in today's market framework. In both traditional and restructured market environments, many hydropower services and contributions are not explicitly monetized, and, in some cases, market rules undervalue operational flexibility.

With regard to PSH, in April 2016, the Federal Energy Regulatory Commission (FERC) initiated a proceeding (Docket No. AD16-20-000)—to examine whether barriers exist to the participation of electric storage resources in the capacity, energy, and ancillary service markets potentially leading to unjust and unreasonable wholesale rates [40]. This action was motivated in part by trends of increasing exploration of the value electric storage resources may offer the grid when providing transmission services and acting as both generation and load.

Hydropower must account for potential impacts of climate change.
Climate change creates uncertainty around water availability for hydropower generation, and this uncertainty can affect the long-term outlook of the hydropower industry. Water availability—including more water in some areas and less in others—affects the energy production potential of hydropower resources, which, in turn, influences their economic attractiveness in the electric sector. A changing climate may also impact the availability of water for thermal power plant cooling; electricity demand; and aquatic systems, such as warmer streams influencing the health of fish and other species.

Hydropower development can benefit from improved planning and reduced regulatory uncertainty.
Uncertainty in licensing processes and outcomes can adversely affect development costs, timelines, and financing options. Existing regulatory statutes and related regulatory processes governing hydropower ensure that project development and operations are carried out responsibly and consistently. However, there is concern that regulatory process inefficiencies, overlaps, and interpretations can result in delays and costs that cause long-term business risks to hydropower owners, operators, and developers.

Modernizing future regulations and enhancing communication and coordination among commercial entities and federal, state, and local regulatory bodies could help ensure mutually beneficial improvements in process efficiency and potentially reduce individual project development costs and timeframes, while maintaining or improving environmental protection. In addition, given the interrelated nature of watersheds and related ecosystems within a given drainage basin, applying comprehensive basin-wide planning methodologies may provide an opportunity to preserve or rehabilitate the health of river systems, while promoting efficient use of water resources for power production and other purposes.

Opportunities exist for collaboration among federal agencies.
There are opportunities for coordination and collaboration among federal agencies to meet mutual objectives with regard to sustainable hydropower development and operations, as well as broader water resource use, planning, and protection needs. Increased efficiencies in regulatory compliance and water resource planning processes that lead to lowered costs, reduced uncertainties, and better coordination among affected stakeholders can facilitate refinement and broad adaptation of future advanced technologies for sustainable development.

Federal agencies have worked together on several initiatives to help continually improve regulatory and water resource planning processes. These actions serve as examples of how collaboration and coordination may help further cost-effective, sustainable hydropower development in the future. Examples of this are discussed here and include:

- An agreement between the Corps and FERC to synchronize NPD approvals;
- DOE's Basin Scale Opportunity Assessment Initiative; and
- Release of DOE's Regulatory and Permitting Information Desktop, or RAPID, Toolkit.

While there is abundant potential to add power at NPDs, particularly those controlled by the Corps, development of such sites can be delayed by overlapping Corps and FERC licensing and permitting processes. Through an existing MOU and facilitated by DOE, the Corps and FERC agreed within a collaborative framework to enable permitting reviews to occur in a more coordinated manner [41]. As the result of this agreement and input from affected stakeholders, a coordinated set of processes has been identified to reduce cost, timeframes, uncertainties, and risks for developers. These process improvements include simultaneous FERC and Corps environmental reviews; single rather than redundant National Environmental Policy Act documentation; and one Water Quality Certification application rather than two.

Future hydropower development will require close coordination among developers, regulators, and affected stakeholders to reduce potential conflicts and meet multiple objectives pertaining to the use of water resources. There is increasing interest in these types of planning processes being carried out at the scale of entire river basins to better address potential system effects and the diverse set of interests that may be affected by a given project. As part of the MOU between the DOE, Corps, and the U.S. Bureau of Reclamation [42], the DOE initiated the Basin Scale Opportunity Assessment Initiative to develop multidisciplinary approaches and tools aimed at facilitating basin-scale water resource planning processes [43]. The project has implemented various tools and techniques in four river basins throughout the United States (Bighorn, Connecticut, Deschutes, and Roanoke). The primary focus is on applying Geographic Information Systems to rapidly assimilate and evaluate planning data in a multi-scale, hydrologic context. These methods are being integrated into interactive, web-based tools to demonstrate possible means of deployment to the hydropower community.

Navigating the complex system of federal and state regulations to secure project approvals can be creates hurdles for renewable energy developers. Uncertainty regarding the duration and outcome of the permitting process can be a deterrent for investment in clean energy and can delay construction of renewable energy and related transmission projects. DOE's Hydropower Regulatory and Permitting Information Desktop Toolkit was developed to make permitting information rapidly accessible from one location, by providing links to permit applications, processes, manuals, and related information for both state and federal levels (Text Box 1-1).

Existing hydropower facility economic performance should be maintained.
Existing hydropower facilities, the backbone of any future hydropower expansion, require maintenance to avoid potential degradation of capacity or generation. Maintaining this capacity is important because a large proportion of future electricity generation and other hydropower benefits will derive from the existing fleet.

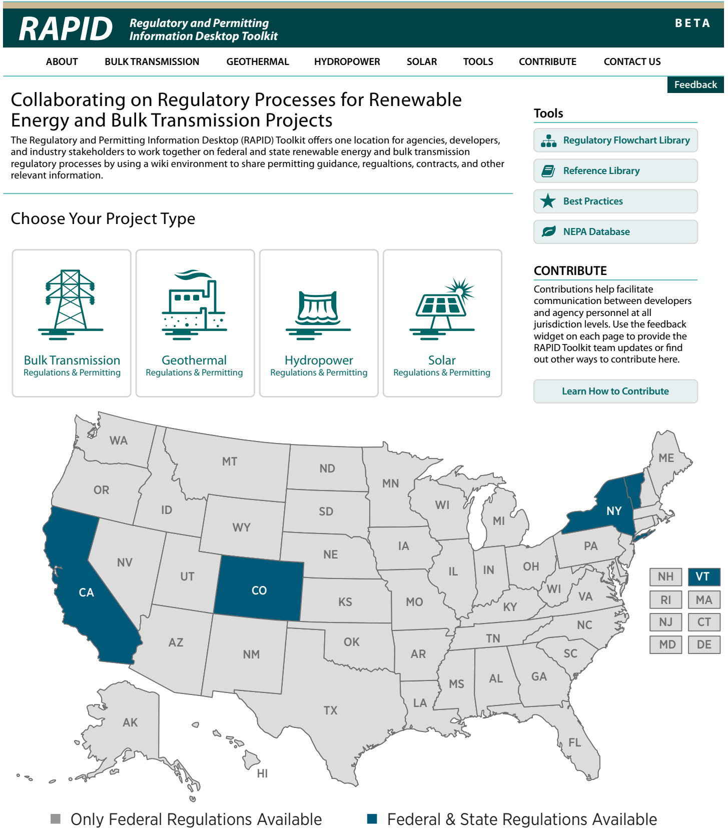
Some hydropower stakeholders have raised concerns that generation at Corps facilities—which account for approximately 24% of total U.S. hydropower generation—may be declining due to aging infrastructure, and many of its hydropower assets have fallen below the generally accepted hydropower industry goal of 95% unit availability [44]. While the exact effects of aging infrastructure on Corps facilities have not been documented on a nationwide basis and, as such, remain uncertain [44], the Corps reports that forced outages (generating units unavailable to produce power due to unanticipated breakdown) increased from 4%to 5.5% during the 2008–2014 period [45]. Efforts are underway in the Federal Columbia River Power System to systematically replace turbine units at main stem Corps facilities.

Net generation from Bureau of Reclamation facilities has remained relatively constant from 2004 to 2014, and Reclamation has stated that its project performance is generally favorable compared with most industry benchmarks [44]. The Tennessee Valley Authority hydropower modernization program began in 1992 to address the reliability issues of an aging fleet and increase the Authority's hydroelectric capacity and efficiency over the long term. The program increased hydropower capacity by 560 MW (9.48% increase) and realized an average efficiency gain of 4.8% from 1992–2010 [46]. Similar opportunities for optimization exist in the non-federal fleet.

Text Box 1-1.

Hydropower Regulatory and Permitting Information Desktop Toolkit

The DOE's Hydropower Regulatory and Permitting Information Desktop (RAPID) Toolkit development effort, which began in 2014, documents and presents easily navigable information on federal and state permitting processes and regulatory approvals required for the development of hydropower projects. In addition, the RAPID Toolkit allows users to document best practices for complying with the range of regulatory processes. RAPID facilitates collaboration among federal and state regulatory agencies, as well as other industry stakeholders, in reviewing and coordinating the permitting process for both small and large conventional hydropower, run-of-river hydropower, in-conduit, and pumped storage projects. The RAPID Toolkit seeks to help both developers and regulatory agencies by increasing clarity of and efficiency in the regulatory process.



Collaborating on Regulatory Processes for Renewable Energy and Bulk Transmission Projects

The Regulatory and Permitting Information Desktop (RAPID) Toolkit offers one location for agencies, developers, and industry stakeholders to work together on federal and state renewable energy and bulk transmission regulatory processes by using a wiki environment to share permitting guidance, regualtions, contracts, and other relevant information.

Choose Your Project Type

CONTRIBUTE

Contributions help facilitate communication between developers and agency personnel at all jurisdiction levels. Use the feedback widget on each page to provide the RAPID Toolkit team updates or find out other ways to contribute here.

■ Only Federal Regulations Available ■ Federal & State Regulations Available

RAPID screen shot with example data map

Source: RAPID website, *http://en.openei.org/wiki/RAPID/Hydropower*

Federally owned facilities face unique challenges. Multipurpose federally owned and operated dams—roughly half of existing national hydropower capacity—have limited operational flexibility and face financing constraints that other public and privately owned facilities do not. As with expansions and upgrades, new federal developments are dependent upon Congressional actions. Federal facilities face limited operational flexibility (i.e., due to limits derived from Congressional authorization and negotiated operating guidelines to balance multiple uses of water resources and dam/reservoir infrastructure); and demand for water by competing uses (e.g., municipal water supply, navigation, and recreation) [44].

1.5 Modeling Hydropower's Contributions and Future Potential

For the *Hydropower Vision,* computational economic and dispatch models provided the foundation for comprehensive analyses of the existing and future role of hydropower within the electric sector on a national scale. These analytical modeling methods were used to evaluate a range of possible future outcomes for hydropower deployment based on potential technical innovation, economic factors, national priorities, stakeholder action or inaction, market forces, and requirements for environmental mitigation and environmental sensitivity. Because growth potential is tied to a set of complex and unpredictable variables, the modeling results presented in Chapter 3 serve primarily as a basis to identify key factors and drivers that are likely to influence future pathways. Modeling results presented in *Hydropower Vision* should not be interpreted as DOE predictions or targets.

The primary tool used to assess potential growth trajectories and the basis to evaluate resulting cost and benefit impacts is the National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) model [47]. ReEDS is an electric sector capacity expansion model that simulates the cost of construction and operation of generation and transmission capacity to meet electricity demand and other power system requirements on a competitive basis over discrete study periods—in 2017, through 2030, and through 2050. Results from ReEDS include estimated electricity generation, geographic distribution of new electricity infrastructure additions, transmission requirements, and capacity additions of power generation technologies built and operated during the study period.

The modeling analysis assumes policy as effective on December 31, 2015, including the U.S. Environmental Protection Agency's *Carbon Pollution Standards for Existing Power Plants* (Clean Power Plan [16]).[15]

This analysis cannot comprehensively represent all of the costs or benefits of hydropower—it only represents factors that DOE can objectively quantify. This analysis also does not attempt to assess the costs for past, present, or future environmental impacts and solutions, such as resource protections needed to mitigate potential effects on fish and wildlife.

Both the existing hydropower fleet and the potential for new development are included in the quantitative modeling. Although deployment of existing hydropower facilities occurred over more than a century, modeling results indicate that important growth opportunities remain. Hydropower resource opportunities for potential growth fall into four distinct categories:

1. **Existing power plants and dams** that must be maintained and can be upgraded and optimized for increased production and environmental performance;
2. **New power plants at existing NPDs and water conveyances such as canals and conduits** that are not powered, but could be cost-effectively leveraged to support hydroelectric facilities;
3. **New and existing PSH** facilities and upgrades, including reservoirs and pumping/generating plants; and
4. **NSD,** including diversionary methods, new multi-purpose impoundments, or instream approaches.

Capacity additions from canals and conduits, resource potential in Alaska and Hawaii, and the potential for upgrades to existing PSH facilities are not available within the ReEDS quantitative modeling framework, and are therefore not part of the modeled results. Instead, these resources are discussed qualitatively throughout the *Hydropower Vision* report.

---

[15] The U.S. Supreme Court stayed implementation of the Clean Power Plan on February 9, 2016. For the purposes of this report, DOE is assuming full implementation of the Clean Power Plan as described in the October 23, 2015, Federal Register notice at 80 Fed. Reg. 64661.

1.5.1 Resource Estimates and Modeling Scenarios

The *Hydropower Vision* uses the best available resource assessments to explore hydropower's market potential. The process of converting existing estimates of total physical or technical resource potential[16] to a modeling result of realistically potential deployment requires making technical, economic, physical, and geographic assumptions and corrections. These assumptions and corrections reduce the size of the resource base from total technical potential to that resource which will be available to the model.

The process flow for interpreting hydropower's future market potential from technical resource assessments is represented by Figure 1-5. The initial resource base considered is denoted in the figure by the "Technical Resource Potential." This resource potential is then reduced to the resource potential available to a capacity expansion model by applying economic and other assumptions and corrections, resulting in the "Modeled Resource Potential." The potential for market deployment is then calculated for future scenarios, denoted in the figure by "Modeling Results."

Parameters and assumptions for modeling of future deployment scenarios include cost reduction through technology advancement, cost reduction though innovative financial mechanisms, consideration of social and environmental objectives, changes in fossil fuel costs over time, future market penetration of variable generation resources, potential effects of climate change, and others. See Chapter 3 for detailed discussion of resource assessments, the *Hydropower Vision* modeling methodology, and modeling results.

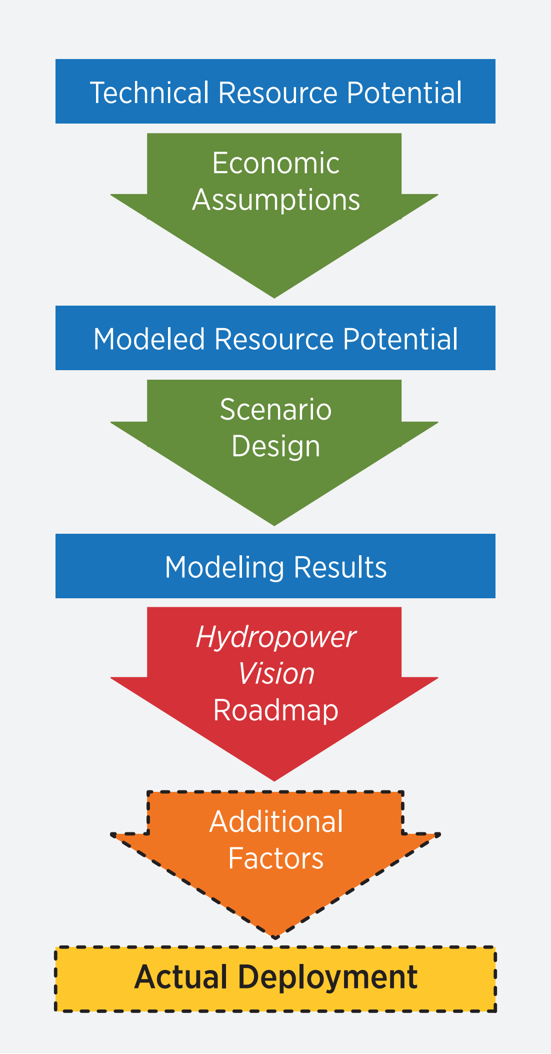


Figure 1-5. Process flow for interpreting hydropower's future market potential from technical resource assessments

While modeling results provided in Chapter 3 identify potential deployment pathways and the influence of key parameters, they do not—and cannot—indicate what actual future deployment may be. As indicated by Figure 1-5, actual deployment will be influenced by additional factors, including macroeconomic conditions, social and environmental considerations, policy, and others that are beyond the scope of the *Hydropower Vision* analysis. The *Hydropower Vision* roadmap (Chapter 4) provides a broad set of actions stakeholders may take to pursue opportunities for potential deployment identified in the modeling results.

---

[16] The technical potential of a specific renewable electricity generation technology estimates energy generation potential based on renewable resource availability and quality, technical system performance, topographic limitations, and environmental and land-use constraints only. The estimates do not consider (in most cases) economic or market constraints, and therefore do not represent a level of renewable generation that might actually be deployed [48].

1.5.2 Characterizing the Potential for Hydropower Growth

Although future economic and societal needs and priorities can be anticipated, they are not fully predictable. Ongoing and sometimes rapid developments in information, manufacturing, and grid management technologies illustrate that—within the time frame of the *Hydropower Vision*—important and unanticipated changes in the needs for and uses of the key attributes of hydropower may lead to new and potentially sizable market opportunities. Through pursuit of actions laid out in the *Hydropower Vision* roadmap, the hydropower industry can build on its inherent operational flexibility and position itself to adapt to alternative market structures in the future. Regular and increasingly refined analysis of potential growth scenarios will help inform industry responsiveness.

Hydropower Vision takes into account several considerations regarding the potential and value of hydropower growth:

- As with existing hydropower infrastructure, better understanding of the market value for ancillary services provided by new hydropower facilities and those historically uncompensated or undercompensated from existing hydropower facilities can better inform market investment and policy decisions.
- PSH plants reduce overall system generation costs by helping to balance the complex operation of the electrical grid and provide a number of valuable grid services, such as operating reserves and voltage support, which are ancillary to power production. While there is significant resource potential for new PSH development in the United States, accessing this resource will require coordinated effort to address existing cost, market, environmental, and regulatory challenges.
- A variety of small hydropower projects may be able to be placed throughout the grid, particularly on distribution systems (distributed generation). For example, development of new technologies that enable cost-effective integration of small-scale, modular power generation into existing water infrastructure (such as conduits and pipelines) and conveyances may open up new markets using existing local distribution grids.
- Because hydropower depends on water availability, regional water management adaptations in response to climatic fluctuation may impact the potential for long-term growth in hydropower generation.
- Canadian and U.S. hydropower both serve the North American transmission grid. Therefore, long-term planning for and investment in operation of U.S. hydropower may need to consider potential regional and national grid and power market impacts of any increasing Canadian capacity.

The *Hydropower Vision* analysis of potential for growth takes into account several resource assessments examining opportunities for increased U.S. hydropower generation (Text Box 1-2) and untapped hydropower potential. Existing hydropower facilities may increase generation and environmental performance through technology upgrades and deployment of additional generating units. Suitable NPDs, as well as existing conduits and canals, may be retrofitted for power production. Suitable undeveloped streamreaches have power production potential; developing this resource will involve working with resource agencies and river stakeholders on protection, mitigation, and enhancement measures to alleviate any adverse project effects. Such collaboration can provide an opportunity to identify win-win scenarios and meet multiple objectives for the use of rivers, e.g., basin-scale planning approaches and innovative hydropower technology and civil works with lower costs and reduced environmental footprints. Existing PSH facilities may be retrofitted with more efficient variable-speed turbines and higher capacity generating equipment, and new PSH facilities may be developed at suitable sites.

Text Box 1-2.

Hydropower Resource Potential in the United States

Upgrades and Optimization of Existing Hydropower Plants: Improvements to existing hydropower facilities can make them more efficient and flexible, reduce adverse impacts to fish, and aerate to improve water quality. A 2014 analysis of a sample of existing facilities found an annual generation-weighted upgrade potential of 7.1% [49]. Extrapolating this to the existing base of hydropower generating capacity in the United States yields a fleet-wide upgrade estimate of at least 5 GW (approximately 13 TWh per year) of additional capacity that may be obtained through restoring and upgrading existing hydropower facilities [50]. In some cases, even greater gains are possible—seven hydropower modernization projects funded through the American Recovery and Reinvestment Act of 2009 resulted in generation increases averaging 35% at existing project facilities [49].

Powering of Non-Powered Dams: Existing NPDs can be retrofitted for hydropower generation without the costs and impacts of additional dam construction and operation, and with reduced environmental impact (e.g., no new impoundment). A 2012 study found that the nation has more than 50,000 suitable NPDs with the technical potential to add about 12 GW (31 TWh/year) of hydropower capacity [51]. The 100 largest capacity facilities—primarily locks and dams on the Ohio, Mississippi, Alabama, and Arkansas Rivers, operated by the Corps—could provide 8 GW of power combined.

Powering of Existing Canals and Conduits: Although water conveyance infrastructures such as irrigation canals or pressurized pipelines that deliver water to municipalities, industry, or agricultural water users are not usually designed for energy purposes, renewable energy can be captured from them without the need to construct new dams or diversions. While the potential is not well quantified, it is estimated that perhaps 1–2GW of generating potential in this form exists nationwide. Legislation has reduced some of the regulatory barriers that may have hindered full development of this energy resource [52].

Low-Impact New Stream-Reach Development: A 2014 national study found that a portion of the more than 3,000,000 million stream-reaches in the United States may offer new hydropower development opportunities [53]. The study concluded that the technical resource potential is over 65 GW (347 TWh/year) after exclusion of federally protected lands—i.e., designated National Parks, national Wild and Scenic Rivers, and Wilderness areas. Each stream-reach was assigned key social, economic, and environmental attributes. A given portion of these undeveloped stream-reaches may be economically feasible to develop for hydropower only after taking into account other uses and environmental considerations. More than 60% of the undeveloped stream resource potential would operate at less than 25 feet of head.

New Pumped Storage Hydropower: Facing a future with growing levels of variable generation, many developers and utilities are investigating the construction of new PSH to provide additional grid flexibility. These projects are typically large (500–2,000 MW), utility-scale facilities. Some would be “closed-loop” designs not connected to natural water bodies, thereby avoiding many of the environmental considerations associated with hydropower development. Additionally, DOE is investigating the feasibility of developing small (1–200 MW), modular PSH technologies that could reduce the permitting, financing, and environmental “footprint” challenges faced by larger, traditional PSH systems [54].

See Chapter 3, Table O3-3, for discussion of how these technical resource potential estimates are used to inform the modeled resource potential of the *Hydropower Vision* analysis.

1.6 Future Hydropower Technologies

The results of the forward-looking analysis presented in *Hydropower Vision* imply that future development of projects at previously undeveloped sites and waterways is likely to remain limited without innovative—even transformational—advances in technologies and project development methods to meet sustainability objectives. While facility upgrades and expansions as well as NPD projects will also benefit from these innovations, development of NSD projects are the most dependent on them. It is difficult to predict how these advances will take shape in the coming decades, but innovation trends offer indications of how non-traditional approaches could transform development of hydropower projects.

The innovations in project development and applications of advanced technologies described in this section are examples of non-traditional approaches that could transform development of new hydropower projects. Information characterizing the predominant existing technologies and design trends are in Chapter 2.

1.6.1 Advances in Sustainable Project Evaluation and Design

Innovative approaches that achieve multiple objectives require integrated planning methods. Figure 1-6 illustrates an integrated approach under which natural stream functionality is taken into account in establishing primary design objectives, design constraints, and functional requirements during the project planning and design process. If environmental objectives are integrated fully into the design paradigm for system components and facilities from the outset, there will be opportunities for advanced modeling, manufacturing, installation, operation, and maintenance innovations to reduce costs and improve generation and environmental performance simultaneously.

Environmentally sustainable hydropower projects should be sited, built, and operated to strike a balance between ecological considerations—such as species diversity, water quality, recreation, and physical processes within the ecosystem—and the needs of hydropower developers and operators to generate and sell power. Jager et al. [55] state, "making spatial decisions about hydropower development at the extent of large river basins and the resolution of smaller watersheds as planning units will produce solutions with higher ecological value that accommodate sustainable hydropower development." The process of making decisions that result in higher value solutions can be enhanced through identification of specific environmental metrics and based on scientific data to model, evaluate, and refine the performance of proposed hydropower system designs within the context of a specific site and watershed.

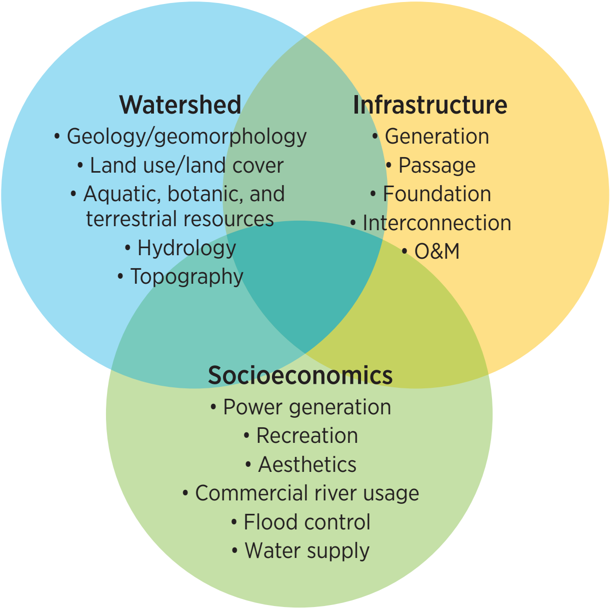


Figure 1-6. Primary linkage relations and indices for an integrated approach to hydropower development

The DOE project, *Environmental Metrics for Hydropower,*[17] is intended to help enhance the scientific basis for assessing environmental effects of next-generation hydropower developments in new stream-reaches. The outcome of this initiative will be a suite of scientifically rigorous metrics and related data from which hydropower developers, policy makers, and other stakeholders can select to evaluate design and performance of new, low-impact hydropower. Specific metrics may pertain, for instance, to geomorphology or to the function of streams in supporting successful reproduction of species.

The objective of DOE's *Biologically-Based Design and Evaluation Initiative for Hydropower* effort is to further biologically-based design, evaluation, and operation of hydropower turbines to limit the impacts on fish when they pass through turbines [56]. Applied research will be used to develop (1) tools that predict biological performance and (2) tools to evaluate empirical field measurements, and (3) methods to interpret population-level effects of given designs on fish injury and mortality.

The examples of new technologies presented in this section illustrate that there is ongoing research and development activity that can lead to measurable changes in the cost, configuration, and function of hydropower facilities in the decades to come. The *Hydropower Vision,* however, does not attempt to predict which technologies and design approaches will be implemented in the marketplace. Innovative approaches that have not yet been developed are likely to also impact how future projects are configured and operated.

1.6.2 Cost-Conscious Design and Manufacturing Processes

Potential hydropower cost reductions can be realized through standardization, consistency of implementation, and data-driven process improvements in project design, equipment procurement and fabrication, installation, and lifecycle management. Improved design approaches and commonality of equipment configurations can reduce typical maintenance requirements, increase predictability in operations planning, and reduce the need for site-specific environmental assessment or customized technical solutions. Simplification strategies are emerging to reduce life cycle costs, including integrated turbine/generator units, and eliminating the traditional penstock and powerhouse.

New materials and additive manufacturing, or the three-dimensional printing of components in layers, enables fabrication of components with fewer bolted connections, decreased manufacturing labor costs, and higher factory throughput. These features have already led to cost reductions of mass-produced components in other industrial sectors, e.g., pumps and pump impellers. Applied research has shown a systematic assembly of composite hydropower turbines could lead to reduced labor costs and substantial weight reductions [57]. A DOE project is assessing alternative materials to build stronger, lighter, less expensive components, by combining dissimilar materials to adhere metallic microparticles to turbine blades in order to address cavitation problems.

---

[17] The *Environmental Metrics for Hydropower* initiative is a multiyear project started in FY 2016 at Oak Ridge National Laboratory. See *http://hydropower.ornl.gov for more information*.

1.6.3 Modular Systems

The DOE Standard Modular Hydropower project (Text Box 1-3) is intended to catalyze development of a suite of standardized components that preserve the functionality of natural streams in conjunction with electricity production. The project will also explore systemic analyses of undeveloped stream sites to establish broad classes for which standardized component modules would be most successful in preserving natural functions.

1.6.4 Compact Turbine/Generator Designs

Potential sites for NSD are predominantly low head, with variable flow rates. Several new turbine/generator configurations illustrate how compact and modular designs can simplify facility design, limit the need for civil works, and reduce lifetime maintenance requirements at sites with these characteristics.

Two compact turbines with bulb-enclosed permanent magnet generators are shown in Figure 1-7.

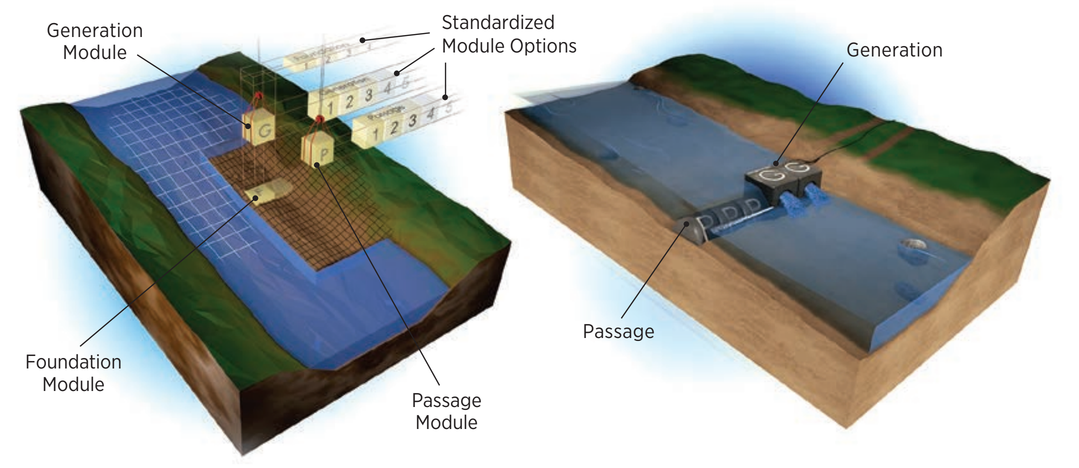
Text Box 1-3.

Standard Modular Hydropower Approach

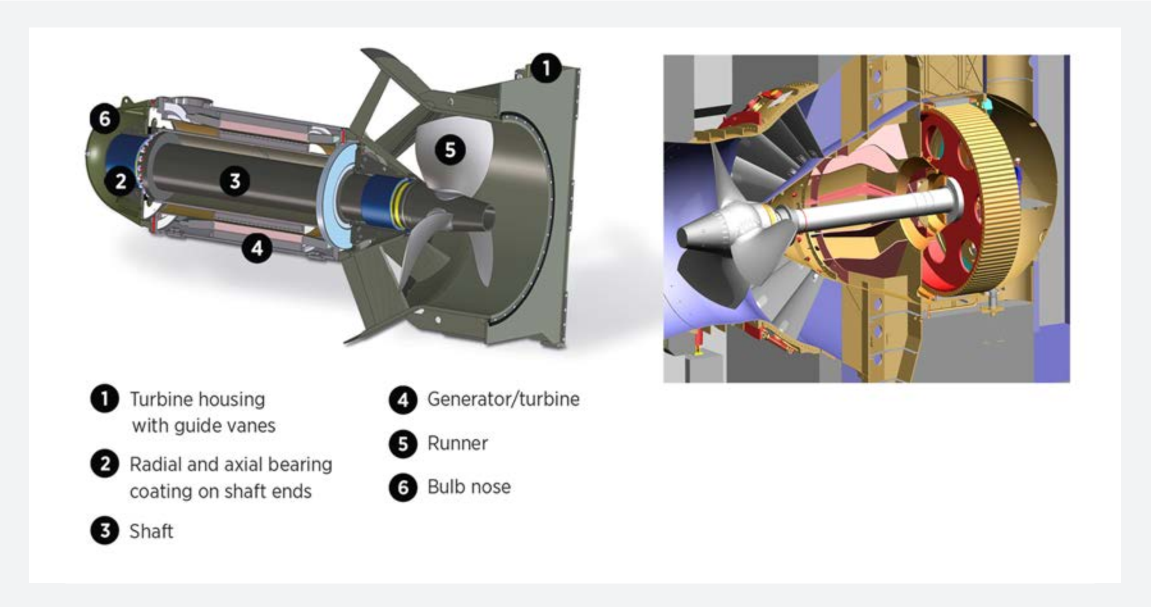
DOE is laying the groundwork for enhanced understanding of how low-impact and low-cost hydropower generation can be compatible with and even enhance the existing uses and functions of natural streams. The Standard Modular Hydropower project considers future hydropower facilities as integrated combinations of standard and validated modules, each with a primary objective, multiple functional requirements, and multiple design constraints. Research will focus on modules specific to power generation, fish and vessel passage, and stream connectivity, water quality improvement, streambed interface, installation, and grid interconnection. Initial categories of design constraints and specifications include aesthetics, public health and safety, environmental disturbance, operability, reliability and maintainability, security, module interoperability, and manufacturability.

Modules will be defined and validated by their adherence to these types of specifications, developed through research and development phases and drawing collaboratively on the expertise of industry, academia, national laboratories, non-governmental organizations, and agencies. The specification phases will be followed by cost modeling, supply chain, and manufacturing optimization, and technology transfer activities to enable physical modules to be demonstrated and deployed.

The conceptual rendering of Standard Modular Hydropower illustrates how different modules for foundation, generation, and stream passage may be considered and fit together to meet site-specific parameters, as well as environmental and power generation objectives.



Conceptual illustration of modular approach to new in-stream hydropower facility

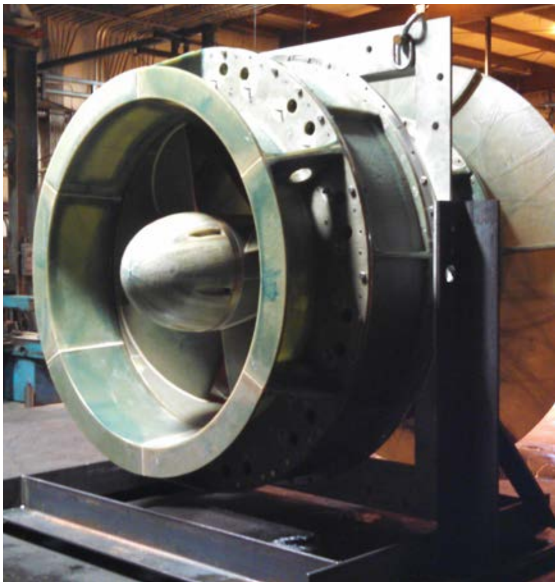


Sources: Voith, Andritz

Figure 1-7. Examples of compact turbine and permanent magnet generator designs: Voith StreamDiver turbine module encased in a bulb (left); Andritz bulb-type turbine (right)

Source: The New England Hydropower Company

Figure 1-8. Archimedes screw for hydropower generation

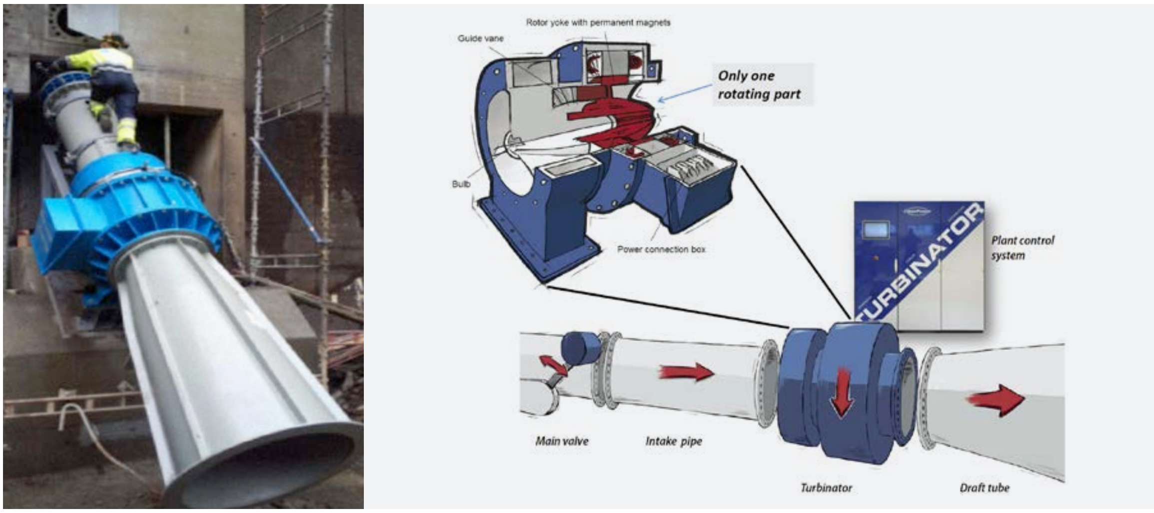


Source: Amjet

Figure 1-9. Composite housing with combined turbine/ generator assembly

Source: Andritz Hydro

Figure 1-10. Modular application of standard turbine runners to an existing dam

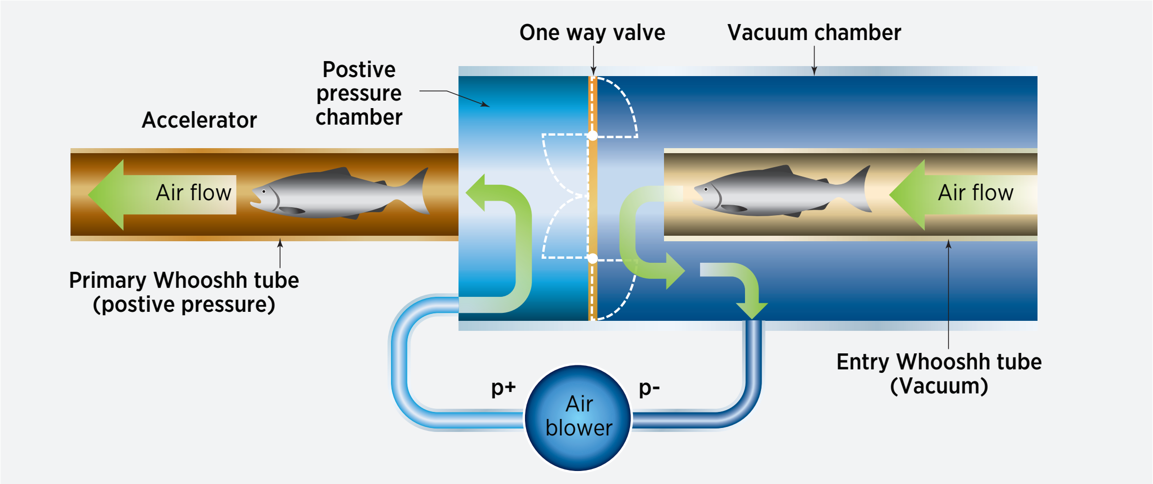


Source: Opsahl 2013

Figure 1-11. Inclined (left) and horizontal (right) integrated turbine-generator technology installed without a powerhouse

Sources: MKEC Engineering; Alicia Pimental

Figure 1-12. Combined fish and recreational boating passage, Wichita, KS (left);“nature-like” Acushnet Fishway, New Bedford, MA (right)



Source: Whooshh Innovations, LLC

Figure 1-13. Whooshh Fish Transport System

Permanent magnet generators eliminate the need for external excitation, allowing simplification of the mechanical design and improved system efficiency and reliability.

The Archimedes screw, historically used as a water pump, has emerged as another potential solution for high-flow, low-head sites. Water that enters the top of the screw is slowly pulled down by gravity, rotating the blades (Figure 1-8). This type of turbine is generally considered fish-friendly due to slow operating speeds and large blade spacing.

Figure 1-9 illustrates another example of an innovative compact turbine/generator combination. In this case, the permanent magnets are mounted directly to the blades of the turbine in a lightweight composite turbine housing that reduces overall weight. Variable-speed technology eliminates the need for mechanical controls.

Most innovative compact turbine generator units can be installed in existing infrastructure—including NPDs, irrigation canals, and other types of water conveyances—often in a standardized modular fashion. Figure 1-10 shows multiple units installed on an existing dam.

A key factor at low-head sites is the volume of concrete necessary for a powerhouse. Low-head turbines have larger diameters to accommodate higher discharges, which increases the structural stability requirements. Compact turbine technologies that incorporate the generator and turbine runner into a single rotating unit, however, may eliminate the need for a conventional powerhouse (Figure 1-11).

1.6.5 Passage Technologies

The use of a dam, weir, or diversion structure is common for most hydropower projects. These structures allow water flow while creating hydraulic head to drive the turbine. However, they also typically create disruptions in the complex interplay between water, organisms, sediment, nutrient cycles, and other elements of an aquatic ecosystem. During the project design phase, technical solutions must consider passage requirements for (at the least) water, fish, sediment, and recreation.

The need for inexpensive, effective, and standardized passage facilities has led to the investigation and demonstration of innovative approaches. An emerging trend in downstream passage is the use of nature-like fish channels, which incorporate natural riverine features into complex bathymetries with space for internal habitat development. Figure 1-12 illustrates a natural fish passage facility designed in collaboration with the Massachusetts Division of Marine Fisheries, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service to restore river herring and American eel populations; and a novel design combining fish and recreational vessel passage around a dam in Wichita, KS.

A novel approach to moving migrating fish upstream past hydropower facilities is the Whooshh Fish Transport System. This transport system uses a flexible tube and pressure (Figure 1-13) to guide fish over and around structures. The system has the potential to facilitate fish passage more quickly and safely, and at lower cost, with passage results at least comparable to traditional trap and haul fish transport methods (Geist et al., In Press).

1.7 The *Hydropower Vision* Roadmap

The *Hydropower Vision* roadmap for national action was developed through extensive collaboration, contributions, and rigorous peer review from industry, the electric power sector, non-governmental organizations, academia, national laboratories, and representatives of government agencies. The roadmap (Chapter 4) outlines, in a non-prescriptive manner, five topical areas, 21 topical sub-categories, and 64 actions for consideration by all stakeholder sectors to address many of the challenges that have affected hydropower. These roadmap actions are intended to leverage the existing hydropower fleet and potential for sustainable hydropower growth to increase and support the nation's renewable energy portfolio, economic development, environmental stewardship, and effective use of resources through specific technical, environmental, economic, and institutional stakeholder actions. It is beyond the scope and purview of the *Hydropower Vision* to suggest policy preferences or recommendations, and no attempt is made to do so.

Key insights from the roadmap include:

- The hydropower industry and research community will need to take an innovative approach to designing a suite of technologies and civil structures that can successfully balance multiple objectives, including cost-effective energy production, penetration of variable generation from renewable energy resources, water management, and environmental protection;
- Collaboration is critical across all roadmap action areas, including within the industry to develop the next generation of technologies; among stakeholders to improve regulatory efficiency; or between industry and academia to prepare the incoming workforce;
- Improving the environmental performance of hydropower technologies can help achieve sustainability objectives, and developing a comprehensive set of science-based environmental performance metrics will further the design and sustainable operation of hydropower projects;
- Undertaking actions such as establishing better mechanisms for collaboration and disseminating successful practices can improve regulatory process implementation; and
- Outreach actions cut across all roadmap areas.

Articulating and disseminating objective information regarding hydropower's role as an established and cost-effective renewable energy source, its importance to grid stability and reliability, and its ability to support variable generation can help increase hydropower's acceptance and lead to: (a) increased investor confidence, (b) improved understanding among stakeholders of environmental, social, and regulatory objectives, (c) improved compensation for grid services, and (d) enhanced eligibility in renewable and clean energy markets.

While the roadmap includes collective steps that can be taken by many parties working in concert, it cannot and does not represent federal agency obligations or commitments.

1.7.1 Opportunity, Risk of Inaction, and the Way Forward

One of the greatest challenges for the United States in the 21st century is producing and making available clean, affordable, and secure energy. Hydropower has been, and can continue to be a substantial part of addressing that challenge. Although the hydropower industry has adopted improved technology and exhibited significant growth over the past century, the path that led to its historical growth rates is different under modern conditions, and continued evolution of that path—including transformative innovation—is needed.

The *Hydropower Vision* report highlights the national opportunity to capture additional domestic low-carbon energy with responsible development of advanced hydropower technologies across all U.S. market sectors and regions. Where objectively possible, the analysis quantifies the associated costs and benefits of this deployment and provides a roadmap for the collaboration needed for successful implementation.

1.7.2 The Opportunity

The *Hydropower Vision* analysis (Chapter 3) modeled a credible future scenario combining *Advanced Technology, Low Cost Finance* and *Combined Environmental Considerations,* finding that U.S. hydropower could grow from 101 GW of combined generating and storage capacity in 2015 to nearly 150 GW by 2050, realizing over 50% of this growth by 2030. NSD beyond this scenario could conceivably become economically viable in the future if significant and transformative innovation is achieved that can address a range of environmental considerations. Increasing hydropower can simultaneously deliver an array of benefits to the nation that address issues of national concern, including climate change, air quality, public health, economic development, energy diversity, and water security. Additionally, new PSH technology can further facilitate integration of variable generation resources—such as wind and solar—into the national power grid due to its ability to provide grid flexibility, reserve capacity, and system inertia.

1.7.3 The Risks of Inaction

While the industry is mature, many future actions and efforts remain critical to further advancement of domestic hydropower as a key energy source of the future. This includes continued technology development to increase efficiency, further sustainability, and drive down costs; as well as the availability of market mechanisms that take into account the value of grid reliability services, air quality and reduced emissions, and long asset lifetimes. A lack of well-informed, coordinated actions to meet these challenges reduces the likelihood that potential benefits to the nation will be realized. Failure to address business risks associated with hydropower development costs and development timelines—including uncertainties related to negotiation of interconnect fees and power sales contracts, regulatory process inefficiencies, environmental compliance, financing terms, and revenue sources— could mean that opportunities for new deployment will not be realized. Engagement with the public, regulators, and other stakeholders is needed to enable environmental considerations to be effectively addressed. Continued research and analysis on energy policy and hydropower costs, benefits, and effects is important to provide accurate information to policy makers and for the public discourse. Finally, a commitment to regularly revisit the *Hydropower Vision* roadmap and update priorities across stakeholder groups and disciplines is essential to ensuring coordinated pathways toward a robust and sustainable hydropower future.

1.7.4 The Way Forward

The *Hydropower Vision* roadmap identifies a high-level portfolio of new and continued actions and collaborations across many fronts to help the United States realize the long-term benefits of hydropower, while protecting the nation's energy, environmental, and economic interests. Stakeholders and other interested parties must take the next steps in refining, expanding, operationalizing, and implementing a credible hydropower future. These steps could be developed in formal working groups or informal collaborations, and will be critical in overcoming the challenges, capitalizing on the opportunities, and realizing the national benefits detailed within the *Hydropower Vision.*

Chapter 1 References

[1] U.S. Energy Information Administration. Monthly Energy Review. U.S. Department of Energy. Accessed July 1, 2016. *http://www.eia.gov/totalenergy/data/monthly/.*

[2] Federal Energy Regulatory Commission, Energy Infrastructure Updates (2011-2015). Accessed July 1, 2016. *http://www.ferc.gov/legal/staff-reports.asp*/.

[3] Uria-Martinez, R., P. O'Connor, M. Johnson. 2015. "2014 Hydropower Market Report". Prepared by Oak Ridge National Laboratory for the U.S. Department of Energy. DOE/EE 1195. April 2015. *http://energy.gov/eere/water/downloads/2014-hydropower-market-report.*

[4] U.S. Energy Information Administration. Electricity Data Browser. Accessed July 12, 2016. *http://www.eia.gov/electricity/data/browser/*.

[5] "The History of Hydropower Development in the United States." c2015. U.S. Bureau of Reclamation. *http://www.usbr.gov/power/edu/history.html*.

[6] U.S. Department of Energy. Prepared by Navigant Consulting, Inc. DOE/EE-1400. Forthcoming (2016). "United States Hydropower Workforce Assessment and Future Scenarios".

[7] Koritarov, V.; T. Veselka; J. Gasper; B. Bethke; A. Botterud; J. Wang; M. Mahalik; Z. Zhou; C. Milostan; J. Feltes; Y. Kazachkov; T. Guo; G. Liu; B. Trouille; P. Donalek; K. King; E. Ela; B. Kirby; I. Krad; and V. Gevorgian. 2014. Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the United States. Technical Report, ANL/DIS-14/7. Argonne National Laboratory, Argonne, IL, June 2014. Accessed July 12, 2016: *http://www.ipd.anl.gov/anlpubs/2014/07/105786.pdf*

[8] Kumar, A.; T. Schei; A. Ahenkorah; R. Caceres Rodriguez; J.-M.; Devernay; M. Freitas; D. Hall; Å. Killingtveit; and Z. Liu. 2011. "Hydropower." In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation; Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA. Accessed July 12, 2016. *http://www.ipcc.ch/report/srren/*.

[9] United Nations Educational, Scientific and Cultural Organization and the International Hydropower Association (UNESCO). Research project on the greenhouse gas status of freshwater reservoirs. 2015 World Hydropower Congress, Beijing, China. May 20, 2015.

[10] Bonnet, M.; A. Witt; K. Stewart; B. Hadjerioua; and M. Mobley. The Economic Benefits of Multipurpose Reservoirs in the United States-Federal Hydropower Fleet. September 2015. ORNL/TM-2015/550. Accessed July 12, 2016. *http://info.ornl.gov/sites/publications/files/Pub59281.pdf*.

[11] Cada, G.F.; T.J. Carlson; D.D. Dauble; R.T. Hunt; M.J. Sale; and G.L. Sommers. "Hydropower: Setting a Course for Our Energy Future." Wind and Hydropower Technologies Program (Brochure). National Renewable Energy Laboratory for the U. S. Department of Energy. DOE/GO-102004-1981; NREL/BR-500-34916. July 2004. Accessed July 12, 2016. *http://www.nrel.gov/docs/fy04osti/34916.pdf*.

[12] U.S. Energy Information Administration. Form 860_US Capacity by Generator Unit_Y1891-Y2014. U.S. Department of Energy. October 21, 2015 Accessed July 12, 2016. *http://www.eia.gov/electricity/data/eia860/index.html.*

[13] Executive Office of the President, "The President's Climate Action Plan." June 2013. Accessed July 12, 2016. *https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.*

[14] U.S. Department of Defense. Report on National Security Implications of Climate-Related Risks and a Changing Climate. July 2015. Accessed July 12, 2016. *http://archive.defense.gov/pubs/150724-congressional-report-on-national-implications-of-climate-change.pdf.*

[15] California Air Resources Board. Assembly Bill 32 Overview. Accessed July 12, 2016. *http://www.arb.ca.gov/cc/ab32/ab32.htm.*

[16] U.S. Environmental Protection Agency. Clean Power Plan for Existing Power Plants. Accessed July 12, 2016: *https://www.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.*

[17] U.S. Environmental Protection Agency. Regulatory Impact Analysis for the Clean Power Plan Final Rule. Docket ID EPA-452-R-15-003. 2015. Research Triangle Park, NC: U.S. Environmental Protection Agency. Accessed July 12, 2016: *http://nepis.epa.gov/Simple.html*.

[18] The White House. Fact Sheet: Administration Announces New Agenda to Modernize Energy Infrastructure, Releases Quadrennial Energy Review. Office of the Press Secretary. April 2015. Accessed July 12, 2016. *https://www.whitehouse.gov/the-press-office/2015/04/21/fact-sheet-administration-announces-new-agenda-modernize-energy-infrastr*.

[19] "What is energy security?" ©2016. International Energy Agency. Accessed July 12, 2016. *http://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/*

[20] The White House. Office of the Press Secretary. Presidential Policy Directive—Critical Infrastructure Security and Resilience (PPD-21). February 2013. Accessed July 12, 2016: *https://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.*

[21] "Critical Infrastructure Sectors," October 27, 2015. U.S. Department of Homeland Security. Accessed July 12, 2016. *http://www.dhs.gov/critical-infrastructure-sectors.*

[22] Barbose, G. U.S. Renewables Portfolio Standards 2016 Annual Status Report. Lawrence Berkeley National Laboratory. LBNL-1005057. April 2016. Accessed July 12, 2016. *https://emp.lbl.gov/projects/renewables-portfolio.*

[23] Stori, V. Environmental Rules for Hydropower in State Renewable Portfolio Standards. Clean Energy States Alliance. April 2013. Accessed July 12, 2016. *http://www.cesa.org/resource-library/resource/environmental-rules-for-hydropower-in-state-renewable-portfolio-standards*.

[24] *The Economist.* "Natural gas: Shale of the century." June 2, 2012. Accessed July 12, 2015. *http://www.economist.com/node/21556242.*

[25] U.S. Energy Information Administration. Selected national average natural gas prices, 2010-2015. Natural Gas Monthly. Accessed July 12, 2016. *http://www.eia.gov/naturalgas/monthly/.*

[26] U.S. Energy Information Administration. Issues in Focus - Implications of accelerated power plant retirements. Annual Energy Outlook 2014. DOE/EIA-0383(2014). April 2014. Accessed July 12, 2016. *http://www.eia.gov/forecasts/archive/aeo14/section_issues.cfm#power_plant.*

[27] U.S. Energy Information Administration. April 2015. Annual Energy Outlook 2015. Accessed July 12, 2016: *http://www.eia.gov/forecasts/aeo/.*

[28] "Diablo Canyon Nuclear Closure Plan: An Important Model." June 22, 2016. McKinzie, M. Natural Resources Defense Council. Accessed July 12, 2016: *https://www.nrdc.org/experts/matthew-mckinzie/diablo-canyon-nuclear-closure-plan-important-model.*

[29] Nuclear Energy Regulatory Commission. 2015 Summer Reliability Report. May 2015. Accessed July 12, 2016. *http://www.nerc.com/pa/RAPA/ra/Pages/default.aspx*.

[30] U.S. Energy Information Administration, Form EIA-860 Annual Electric Generator Report, and Form EIA-860M. Hydropower has a long history in the United States. July 2011. Accessed July 12, 2016. *http://www.eia.gov/todayinenergy/detail.cfm?id=2130*.

[31] Federal Energy Regulatory Commission, Energy Infrastructure Updates (2011-2015). Accessed July 12, 2016. *http://www.ferc.gov/legal/staff-reports.asp.* For December 2015, *http://www.ferc.gov/legal/staff-reports/2015/dec-infrastructure.pdf.*

[32] Sullivan, P., W. Cole, N. Blair, E. Lantz, V. Krishnan, T. Mai, D. Mulcahy, and G. Porro. 2015 Standard Scenarios Annual Report: U.S. Electric Sector Scenario Exploration. NREL/TP-6A20-64072. Golden, CO: National Renewable Energy Laboratory, 2015. Accessed July 12, 2016. *http://primo-pmtna01.hosted.exlibrisgroup.com/Pubs:PUBS:NREL_HORIZON99724*.

[33] U.S. Department of Energy. Quadrennial Technology Review - An Assessment of Energy Technologies and Research Opportunities. September 2015. Accessed July 12, 2016. *http://energy.gov/qtr.*

[34] Eller, A., and A. Dehamna. Energy Storage for the Grid and Ancillary Services. Navigant Consulting, Inc. May 2016. Accessed July 12, 2016. *https://www.navigantresearch.com/research/energy-storage-for-the-grid-and-ancillary-services* .

[35] Bird, L. and B. Swezey. Green Power Marketing in the United States: A Status Report (Ninth Edition). National Renewable Energy Laboratory. NREL/TP-640-40904. November 2006. Accessed July 12, 2016. *http://apps3.eere.energy.gov/greenpower/resources/pub_alpha.shtml?alpha_char=B.*

[36] Heeter, J. and T. Nicholas. October 2013. Status and Trends in the U.S. Voluntary Green Power Market (2012 Data). National Renewable Energy Laboratory. NREL/TP-6A20-60210. Accessed July 12, 2016. *http://primo-pmtna01.hosted.exlibrisgroup.com/Pubs:PUBS:NREL_HORIZON81700*.

[37] Heeter, J.; K. Belyeu; and K. Kuskova-Burns. Status and Trends in the U.S. Voluntary Green Power Market. National Renewable Energy Laboratory. NREL/TP-6A20-63052. November 2014. Accessed July 12, 2016. *http://primo-pmtna01.hosted.exlibrisgroup.com/Pubs:PUBS:NREL_HORIZON98848.*

[38] U.S. Environmental Protection Agency. National Top 100. EPA Green Power Partnership. October 2015. Accessed July 12, 2016. *http://www3.epa.gov/greenpower/toplists/top100.htm.*

[39] "Making Way for Fish Migration: Celebrating World Fish Migration Day (May 21, 2016)." May 16, 2016. National Oceanic and Atmospheric Administration Fisheries. Accessed July 13, 2016. *http://www.fisheries.noaa.gov/stories/2016/05/05-world-fish-migration-day-2016.html.*

[40] Federal Energy Regulatory Commission. Open Commission Meeting. Staff Presentation Item A-4. April 21, 2016. Accessed July 12, 2016. *http://www.ferc.gov/CalendarFiles/20160421110616-A-4-Presentation.pdf.*

[41] U.S. Army Corps and FERC, 2011. MOU on Non-Federal Hydropower Projects - Memorandum of Understanding between United States Army Corps of Engineers and the Federal Energy Regulatory Commission on Non-federal Hydropower Projects. Accessed July 12, 2016. *http://www.ferc.gov/legal/mou.asp*.

[42] U.S. Department of Energy, U.S. Department of the Interior, U.S. Army Corps of Engineers, 2010. Hydropower Memorandum of Understanding for Hydropower. Accessed July 12, 2016. *http://energy.gov/eere/water/downloads/hydropower-memorandum-understanding.*

[43] Basin Scale Opportunity Assessment. Pacific Northwest National Laboratory. Accessed July 13, 2016. *http://basin.pnnl.gov/.*

[44] Bracmort, K.; A. Vann; and C.V. Stern. Hydropower: Federal and Nonfederal Investment. Congressional Research Service. CRS Report R42579. July 12, 2015. Accessed July 12, 2016. *https://www.fas.org/sgp/crs/misc/R42579.pdf.*

[45] Personal communication with E. Hansen, Office of the Assistant Secretary of the Army (Civil Works), June 29, 2016. Data cited based on Corps annual performance reports.

[46] Tennessee Valley Authority. Strategic Sustainability Performance Plan. Accessed July 12, 2014. *https://www.tva.gov/About-TVA/Guidelines-and-Reports/Sustainability-Plans-and-Performance*.

[47] Short, W., P. Sullivan, T. Mai, M. Mowers, C. Uriarte, N. Blair, D. Heimiller, A. Martinez, Regional Energy Deployment System (ReEDS). NREL/TP-6A20-46534. Golden, CO: National Renewable Energy Laboratory, December 2011; 94 pp. Accessed July 12, 2016. *http://www.nrel.gov/analysis/reeds/documentation.html*.

[48] Lopez, A., B. Roberts; D. Heimiller; N. Blair; and G. Porro. U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. National Renewable Energy Laboratory. July 2012. NREL/TP-6A20-51946. Accessed July 12, 2016. *http://www.nrel.gov/docs/fy12osti/51946.pdf.*

[49] U.S. Department of Energy. 2014 Water Power Program Peer Review Compiled Presentations—Hydropower Technologies. Accessed July 12, 2016. *http://energy.gov/eere/water/downloads/2014-water-power-program-peer-review-compiled-presentations-hydropower.*

[50] Smith, B. T.; Zhang, Q. 2015. Final report for aggregated baseline assessments of aging hydropower facilities. ORNL/TM-2015/698. Oak Ridge, TN: Oak Ridge National Laboratory. Accessed July 12, 2016: *http://hydropower.ornl.gov/research/hydropower/.*

[51] Hadjerioua, B.; Y. Wei; and S.C. Kao. An Assessment of Energy Potential at Non-powered Dams in the United States. April 2012. GPO DOE/EE-0711, Washington, DC. Accessed July 12, 2016. *http://nhaap.ornl.gov/sites/default/files/NHAAP_NPD_FY11_Final_Report.pdf.*

[52] Sale, M. J., N.A. Bishop, Jr., S.L. Reiser, K. Johnson, A.C. Bailey, A. Frank, and B.T. Smith. 2014. Opportunities for Energy Development in Water Conduits: A Report Prepared in Response to Section 7 of the Hydropower Regulatory Efficiency Act of 2013. ORNL/TM-2014/272. Prepared for the U.S. Department of Energy by the Oak Ridge National Laboratory Water Power Technologies Team.

[53] Kao, S. C.; R. M. McManamay; K. M. Stewart; N. M. Samu; B. Hadjerioua; S. T. DeNeale; D. Yeasmin; M. F. K.; Pasha; A.Oubeidillah; and B.T. Smith. 2014. New Stream-Reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States. GPO DOE/EE-1063. Washington, DC. Accessed July 12, 2016. *http://nhaap.ornl.gov/sites/default/files/ORNL_NSD_FY14_Final_Report.pdf.*

[54] Hadjerioua, B.; R. Uria-Martinez; A. Witt; and N. Bishop. 2014. Evaluation of the Feasibility and Viability of Modular Pumped Storage Hydro (m-PSH) in the United States. ORNL/TM- 2015/559. Oak Ridge National Laboratory. Oak Ridge, Tennessee. Accessed July 12, 2016. *http://info.ornl.gov/sites/publications/files/Pub59307.pdf*.

[55] Jager, H.I.; R.A. Efroymson; J. Opperman; and M. Kelly. Spatial design principles for sustainable hydropower development in river basins. Renewable and Sustainable Energy Reviews 45: 808-816. Accessed July 12, 2016. *http://www.esd.ornl.gov/~zij/mypubs/Waterpower/Jager2015-RiverBasinDesign-Reviews Renewable.pdf.*

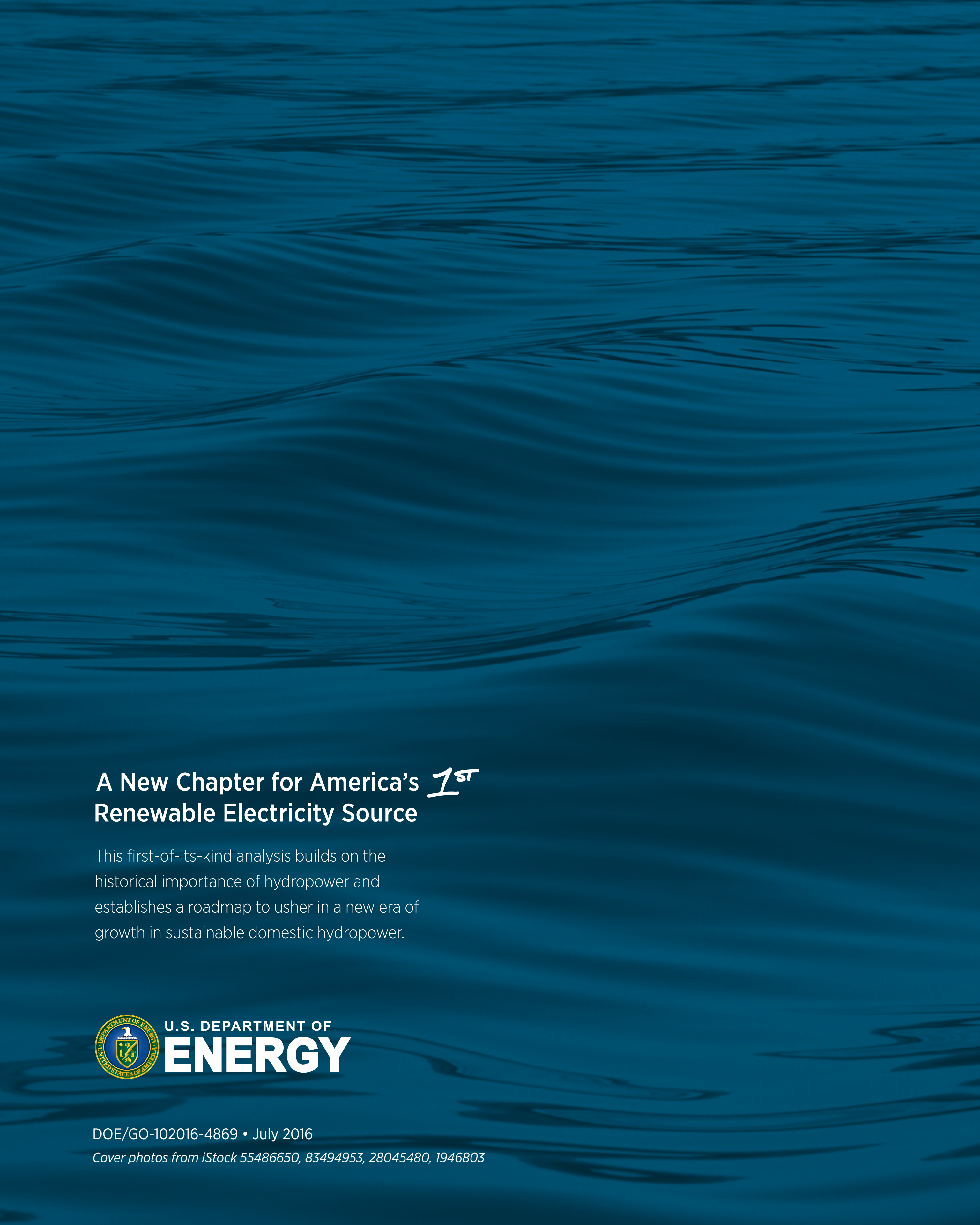
[56] U.S. Department of Energy. 2016. Biologically Based Design and Evaluation Initiative for Hydropower: Multi-Year Research Plan (2016–2018). Prepared by the Pacific Northwest and Oak Ridge National Laboratories for the U.S. Department of Energy, Water Power Program.

[57] Whitehead, M. and R. Albertani, "How Composite Materials Can be Used for Small Hydro Turbines," Hydro Review and HydroWorld.com, Vol. 34, No. 2, pp. 56-63, March 2015. Accessed July 12, 2016. *http://www.hydroworld.com/articles/hr/print/volume-34/issue-2/articles/how-composite-materials-can-be-used-for-small-hydro-turbines.html*.

[58] P.L. 109-58. Energy Policy Act of 2005. Public Law No: 109-58. 42 U.S.C. § 931 (a)(2)(D) Hydropower and 42 U.S.C. § 931 (a)(2)(E)(i) Miscellaneous Projects.) Accessed July 12, 2016. *https://www.gpo.gov/fdsys/pkg/PLAW-109publ58/content-detail.html*.

[59] Geist, D.R., Colotelo, A.H., Linley, T.J., Wagner, K.A., and Miracle, A.L. Forthcoming (2016). *Journal of Fisheries and Wildlife Management*. "Physical, physiological, and reproductive effects on adult fall Chinook salmon due to passage through a novel fish transport system."

[60] International Energy Agency. Energy security. International Energy Agency. Accessed November 15, 2015. *http://www.iea.org/topics/energysecurity/*.



A New Chapter for America's 1st Renewable Electricity Source

This first-of-its-kind analysis builds on the historical importance of hydropower and establishes a roadmap to usher in a new era of growth in sustainable domestic hydropower.

U.S. DEPARTMENT OF
ENERGY

DOE/GO-102016-4869 • July 2016

Cover photos from iStock 55486650, 83494953, 28045480, 1946803