Chapter 4: *The Hydropower Vision:* A Pathway Forward

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Hydropower VISION

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

U.S. DEPARTMENT OF ENERGY

4 THE *HYDROPOWER VISION* ROADMAP: A Pathway Forward

U.S. DEPARTMENT OF ENERGY

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Overview

This chapter provides a detailed roadmap of potential technical, economic, and institutional actions by the hydropower community to optimize hydropower's continued contribution to a clean, reliable, low-carbon, domestic energy generation portfolio, while also ensuring that the nation's natural resources are adequately protected or conserved. Each of the actions was formulated to address opportunities and challenges presented in Chapter 2.

5 ACTION AREAS

64 detailed actions

TECHNOLOGY ADVANCEMENT

ENHANCED REVENUE & MARKET STRUCTURES

SUSTAINABLE DEVELOPMENT & OPERATION

REGULATORY PROCESS OPTIMIZATION

ENHANCED COLLABORATION EDUCATION & OUTREACH

The proposed roadmap actions are intended to motivate committed stakeholders to consider specific activities that they are in a position to facilitate or carry out, whether alone or in concert with others.

Hydropower[1] has important attributes as a flexible, renewable energy source. Despite available generation potential, hydropower growth has lagged for a number of reasons, including the failure of markets to recognize hydropower's value, the long lead time for development, and stakeholder opposition based largely on environmental concerns. The roadmap actions are designed to address many of the challenges that have affected hydropower in recent decades. These actions are intended to stimulate a broadly inclusive multi-stakeholder dialogue that could result in new opportunities to upgrade existing hydropower facilities, utilize existing water infrastructure such as unpowered dams and water conveyances of different types, and stimulate sustainable development of low-impact projects at new sites. Realization of these opportunities will require collaborative efforts by various stakeholder groups, and will be impacted by national and regional policies and priorities as they evolve.

The analysis carried out in support of the *Hydropower Vision* has clearly shown that, of the types of development summarized above, new hydropower projects at previously undeveloped "new stream-reach" sites will continue to face substantial challenges. As such, this type of project will experience very limited growth without transformational changes in technologies and approaches that are able to successfully balance multiple co-objectives, including energy production, other water management requirements, and environmental protection. It is not possible to predict a timetable under which such major changes may be realized. However, the actions in this roadmap, taken as a cohesive body of work building on specific innovative efforts to date, will all contribute in incremental steps to realizing those co-objectives.

The roadmap is the result of a collaborative effort led by the U.S. Department of Energy (DOE), with significant contributions and rigorous peer review from industry, the electric power sector, non-governmental organizations, academia, national laboratories, and representatives of other government agencies. The roadmap is intended to be the beginning of an evolving, collaborative, and necessarily dynamic process. It would thus benefit from periodic reviews and adaptive updates at approximately three-year intervals, informed by its objective analysis activities. These reviews and related feedback loops will hopefully lead to the evolution of specific mechanisms for collaboration among stakeholders, and prioritization of individual and joint efforts.

Roadmap actions are identified in five topical areas, introduced below:

Technology Advancement

Cost reduction, improved performance, and environmental stewardship are critical to the optimization and growth of hydropower in the United States. Innovative technology and system design concepts, such as standardized powertrain components, biologically-based turbine design and evaluation, modular civil structures, and alternative closed-loop pumped storage hydropower (PSH) systems will be essential to attaining those objectives. Continued operation of existing facilities and deployment of new facilities will depend on demonstration and acceptance of environmental mitigation technologies for facilities of all sizes. Mechanisms to test and validate performance of hydropower and PSH innovations are critical for introducing nascent technologies into the market. With the growing integration of variable renewable generation technologies into the electric grid, hydropower and PSH technologies and systems will also need to accommodate demands for greater operational flexibility in the grid.

Sustainable Development and Operation

Increasing the amount of hydropower for meeting the nation's electricity needs will require a holistic approach to project development that incorporates sustainability principles by balancing environmental, social, and economic factors associated with hydropower. Development and operation at new and existing

1. 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" (PSH).

hydropower facilities must be compatible with social, environmental, and economic values that prepare the United States for a future in which climate change may influence water supply and other flow- or water-dependent resources, as demand for renewable energy increases. Extensive stakeholder collaboration will be necessary to address these challenges. Such collaboration should examine and consider interactions of a particular hydropower project with other hydropower projects and other water uses within and among basins or watersheds to achieve optimum delivery of power and non-power benefits. Additionally, reservoir operations and other basin/watershed factors or competing uses and demands should be evaluated during planning processes to ensure that new development is compatible with and supports multiple objectives under changing energy demands and hydrologic conditions, both in the near or longer term.

Enhanced Revenue and Market Structures

Hydropower plays a vital role in grid operation through its unique performance attributes and long-lasting facilities. In addition to providing energy production, capacity, and ancillary grid support services (as designated by the Federal Energy Regulatory Commission [FERC]), hydropower offers operational flexibility, energy storage, and other services essential to the continued reliability of the entire power system. Improved market structures and compensation mechanisms could more appropriately reward new and existing hydropower for the numerous services and benefits it provides. Important actions in this area include determining how much flexibility is provided by hydropower in existing grid operations, exploring opportunities to enhance market valuation of that flexibility, and examining how and at what time scale settlement of prices in energy markets could facilitate better use of hydropower flexibility to support integration of variable renewable generation resources. Additionally, improving the valuation and revenue of PSH services would help optimize PSH facility operation to benefit the entire electric system and stimulate new projects through improved economic performance.

Regulatory Process Optimization

The continued development of unified, well-established mechanisms for collaboration and dissemination of the best available scientific procedures and findings could allow participants and regulators to realize mutual benefits by increasing approval process efficiency. For example, costs, risks, and implementation timeframes may be reduced by providing hydropower stakeholders with an increased knowledge base, easier access to information relevant to their projects, and increased mechanisms for collaboration. Additionally, achieving the same outcomes more rapidly and predictably can reduce the risks and costs to developers and encourage investment in new projects by the financial community, without a reduction in environmental protection. Benefits in environmental and energy generation performance could also be realized if cutting edge science were better disseminated and integrated into fulfillment of regulatory processes, while greater consideration of scientific advances could inform policy decisions. Successfully addressing the actions outlined in this topic area could result in both better performance and increased environmental protection, and could contribute to improved cohesion within the regulatory framework for hydropower.

Enhanced Collaboration, Education, and Outreach

There are significant opportunities for improved communication and collaboration within the hydropower community, as well as with interested external stakeholders. Objective and verified information regarding hydropower as an established reliable, low-carbon, renewable energy source should be articulated and disseminated in order to increase the awareness of its benefits as well as its impacts. Hydropower facility owners and developers would also benefit from a national-scale effort to identify and regularly update best practices for maintaining, operating, and constructing hydropower facilities. These ongoing best practices and benchmarking programs will enable the industry to achieve its full potential as a reliable and low-cost renewable energy source. Finally, in order maintain the industry and have it grow to the potential levels of deployment analyzed in the *Hydropower Vision*, the United States will need to sustain and expand its highly qualified and well-trained workforce. Hydropower-specific curricula can be implemented within vocational and university programs for students interested in technical skills, engineering, and development of renewable energy to motivate new professionals to enter the hydropower field.

4.0 Introduction

This chapter provides a detailed roadmap consisting of potential actions necessary to optimize hydropower's economically and environmentally sustainable[2] contribution to a cleaner, more reliable domestic portfolio for energy generation and grid stability.

The roadmap is the result of a collaborative effort led by DOE, with significant contributions and rigorous peer review from industry, power generation owners/operators, non-governmental organizations, academia, national laboratories, and other government agencies.[3]

The proposed actions are intended to inform stakeholders to consider specific activities that they are in a position to facilitate or carry out, whether alone or in concert with others. However, the roadmap is not prescriptive; it does not detail how suggested actions are to be accomplished or by whom.

Further, while the roadmap provides a range of actions to inform the evaluation of policy options, it is beyond the scope of the *Hydropower Vision* to suggest policy preferences and no attempt is made to do so.

The *Hydropower Vision* modeling analysis of a range of potential scenarios (Chapter 3) supports the conclusion that, under certain assumed conditions, extensive industry growth between 2015 and 2050 is feasible. The analysis also indicates that new hydropower projects at previously undeveloped sites will continue to face significant challenges without transformational changes in technologies and approaches that are able to successfully balance multiple co-objectives including energy production, other water management requirements, and environmental protection. In aggregate, the roadmap actions are aimed at achieving the potential progress implied by these assumptions, though it is not possible to predict a timetable under which such major changes can be realized.

Growth is categorized into five technical areas, or "sectors of potential growth" (see Chapter 3, Section 3.1.4.1 for more details):

- Expanding, upgrading, and/or improving efficiency of existing hydropower facilities;
- Adding power generation capabilities at existing but non-powered dams;
- Installing hydropower in existing water conveyance infrastructure, such as canals and conduits;
- Developing new hydropower projects requiring new water diversions or impoundments; and
- Developing new PSH projects.

Although DOE supports research on marine and river hydrokinetic technologies[4] that convert the energy of waves, tides, and currents into electricity, those technologies are not addressed in this report, as explained in Chapter 1.

The Roadmap Approach

The *Hydropower Vision* roadmap outlines actions grounded in three distinct yet complementary objectives that link to the three foundational "pillars" of the *Hydropower Vision*. The three key roadmap objectives are:

1. **Optimization:** Advance the nation's hydropower fleet by maintaining its long-standing economic value, energy contribution, and critical water management infrastructure while modernizing and optimizing its facilities, operations, and environmental performance.
2. **Growth:** Expand hydropower through innovative technologies, utilization of existing infrastructure, enhanced value recognition in electricity and environmental markets, and improved efficiency in regulatory processes.
3. **Sustainability:** Maintain the overall value of hydropower to the nation through balancing economic, social, and energy-related factors with the co-objective of responsible environmental stewardship.

2. For purposes of the *Hydropower Vision,* sustainable hydropower is defined as a project or interrelated projects that are sited, designed, constructed, and operated to balance social, environmental, and economic objectives at multiple or applicable geographic scales (e.g., national, regional, basin, site).

3. The authors acknowledge other reports that outline potential actions related to future developments in hydropower, including: the Hydro Research Foundation's *Blue Gold: Building New Hydropower with Existing Infrastructure*; the New Hydropower Innovation Collaborative's *New Pathways for Hydropower: Getting Hydropower Built—What Does It Take?;* and the International Energy Agency's *Technology Roadmap: Hydropower*.

4. See the DOE website (*http://energy.gov/eere/water/marine-and-hydrokinetic-energy-research-development*) for more information.

The challenges and opportunities of realizing each of these objectives are separated into five Action Areas of the roadmap:

4.1: Technology Advancement

4.2: Sustainable Development and Operation

4.3: Enhanced Revenue and Market Structures

4.4: Regulatory Process Optimization

4.5: Enhanced Collaboration, Education, and Outreach

As noted, the actions outlined in the roadmap specifically and intentionally do not include policy recommendations. However, by addressing market barriers and process inefficiencies, roadmap actions have the potential to reduce the cost and timelines of complying with existing and future policies, and can help improve the market competitiveness of hydropower.

The *Hydropower Vision* roadmap is intended to be a living document that will be modified using an evolving and collaborative process. It thus suggests an approach of periodic reviews of progress toward the roadmap objectives approximately every three years, informed by analysis activities and resulting in regular updates. These reviews would assess impacts of and suggest adjustments to the outlined actions as necessary and appropriate through 2050 to optimize adaptation to changing technologies, markets, public priorities, and policy factors.

As feedback loops develop during the follow-up roadmap review process, it will likely become increasingly advantageous for stakeholder groups to collaborate in prioritizing actions to attain mutual objectives. For example, a national laboratory project to evaluate the potential for science-based metrics of environmental sustainability to be applied to hydropower development, as outlined in Action 4.2.4, was initiated by DOE in response to needs identified during formulation of the *Hydropower Vision*. This collaborative project provides an early example of stakeholders initiating roadmap actions that will be subsequently reviewed for progress and effectiveness in future years.

The linkages between key objectives and the action areas of the roadmap are summarized in Table 4-1, and activities included within each action area are presented in Text Box 4-1.

Table 4-1. *Hydropower Vision* Roadmap Strategic Position and Approach Summary

Core Challenge	**Facilitate and leverage the existing hydropower fleet and sustainable hydropower growth to increase and support the nation's renewable energy portfolio, economic development, environmental stewardship, and effective use of resources.**		
Key Objectives	**Optimization** Advance the nation's hydropower fleet by maintaining its long-standing economic value, energy contribution, and critical water management infrastructure, while modernizing and optimizing its facilities, operations, and environmental performance.	**Growth** Expand hydropower through innovative technologies, utilization of existing infrastructure, enhanced value recognition in electricity and environmental markets, and improved efficiency in regulatory processes.	**Sustainability** Maintain the overall value of hydropower to the nation through balancing economic, social, and energy-related factors with the co-objective of responsible environmental stewardship.
Intended Results	Investment in technology advancement, modernization, and environmental performance to ensure that the existing wide range of high-value, multi-use benefits of the hydropower fleet do not diminish.	Development of the next generation of hydropower facilities—and a trained workforce to support them—that leverage untapped infrastructure, technology advancement, plant modernization, improved environmental performance, and cost reduction pathways.	Capture and increase of the enduring economic and social value of hydropower through reduction of environmental impacts and continuous improvement of power systems and other project resources to ensure that sustainability objectives are incorporated throughout the full hydropower facility life cycle.

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Table 4-1. continued

Core Challenge	Facilitate and leverage the existing hydropower fleet and sustainable hydropower growth to increase and support the nation's renewable energy portfolio, economic development, environmental stewardship, and effective use of resources.
Linkage to *Hydropower Vision*	The modeling within the *Hydropower Vision* presents potential hydropower development scenarios based on varying assumptions about key factors influencing growth over a 35-year period and beyond. Activities undertaken within the five Action Areas listed below and designed to incorporate the Core Challenge, Key Objectives, and Intended Results, and can significantly affect which of those development scenarios will ultimately be realized.
Roadmap Action Areas	4.1 Technology Advancement 4.2 Sustainable Development and Operation 4.3 Enhanced Revenue and Market Structures 4.4 Regulatory Process Optimization 4.5 Enhanced Collaboration, Education, and Outreach
Sectors of Potential Growth	• Upgrades to existing hydropower facilities (Upgrades) • Powering of existing non-powered dams (NPD) • Installations in existing water conveyance infrastructure (Conduits) • New stream-reach development (NSD) • Pumped storage hydropower (PSH) *Each action in the roadmap indicates the specific growth sector(s) to which it applies.*

Risks of Inaction

The characterization of the state of hydropower in Chapter 2 of the *Hydropower Vision* and the analytical results detailed in Chapter 3 reveal potential benefits and ongoing challenges for the hydropower community. These challenges must be met in order to realize the benefits that both existing hydropower plants and new projects could contribute to meeting grid flexibility needs; stimulating job growth and economic stability; protecting public health and reducing greenhouse gas emissions; and meeting environmental and societal needs related to watershed protection and management. Lack of well-informed, coordinated actions to meet these challenges may reduce the likelihood of each of those potential contributions of hydropower being fully realized.

The "Business-as-Usual" scenario in the economic modeling analysis of Chapter 3 illustrates that, when looked at from within the energy sector as a whole, growth of hydropower could be very limited in the next decades without the types of changes that could be precipitated by actions in the roadmap. On a national scale, reduced economic growth and increased energy efficiency measures have slowed the growth of electricity demand and increased the competition among energy technologies to supply new generation capacity. To maintain its share of the energy market, or to compete successfully for a greater share, hydropower will need to become more economically competitive.

Increasing competitiveness will require greater value to be placed on hydropower's essential role within key areas (e.g., grid services and indirect power system-wide benefits) by electricity markets, concurrent with establishing appropriately linked revenue mechanisms and reducing costs. Increasing competitiveness also includes mitigating or avoiding negative environmental impacts, increasing public understanding of progress to date in mitigating those impacts, Regulatory Process Optimization, and having hydropower be consistently recognized as a renewable energy technology that offers multiple and varied benefits beyond power production. Otherwise, hydropower could continue to see limited growth—as in the decades leading up to the *Hydropower Vision*—and decreasing energy contribution as a percentage of national generation, with resulting negative impacts on electric grid reliability and efforts to reduce carbon emissions. Reinvestment in existing facilities could also decline over time, leading to a decrease in hydropower generation capacity.

Text Box 4-1.

Hydropower Vision Action Areas

4.1 Technology Advancement	
Action 4.1.1	Develop Next-Generation Hydropower Technologies
Action 4.1.2	Enhance Environmental Performance of New and Existing Hydropower Technologies
Action 4.1.3	Validate Performance and Reliability of New Hydropower and PSH Technologies
Action 4.1.4	Ensure Hydropower Technology Can Support Increased Use of Variable Renewable Generation Resources
4.2 Sustainable Development and Operation	
Action 4.2.1	Increase Hydropower's Resilience to Climate Change
Action 4.2.2	Improve Coordination among Hydropower Stakeholders
Action 4.2.3	Improve Integration of Water Use within Basins and Watersheds
Action 4.2.4	Evaluate Environmental Sustainability of New Hydropower Facilities
4.3 Enhanced Revenue and Market Structures	
Action 4.3.1	Improve Valuation and Compensation of Hydropower in Electricity Markets
Action 4.3.2	Improve Valuation and Compensation of PSH in Electricity Markets
Action 4.3.3	Remove Barriers to the Financing of Hydropower Projects
Action 4.3.4	Improve Understanding of and Eligibility/Participation in Renewable and Clean Energy Markets.
4.4 Regulatory Process Optimization	
Action 4.4.1	Provide Insights into Achieving Improved Regulatory Outcomes
Action 4.4.2	Accelerate Stakeholder Access to New Science and Innovation for Achieving Regulatory Objectives
Action 4.4.3	Analyze Policy Impact Scenarios
Action 4.4.4	Enhance Stakeholder Engagement and Understanding within the Regulatory Domain
4.5 Enhanced Collaboration, Education, and Outreach	
Action 4.5.1	Increase Acceptance of Hydropower as a Renewable Energy Source
Action 4.5.2	Compile, Disseminate, and Implement Best Practices and Benchmarking in Operations and Research and Development (R&D)
Action 4.5.3	Develop and Promote Professional and Trade-Level Training and Education Programs
Action 4.5.4	Leverage Existing Research and Analysis of the Federal Fleet in Investment Decisions
Action 4.5.5	Maintain the Roadmap in Order to Achieve the Objectives of the *Hydropower Vision*

With increasing penetration of variable renewable generation resources such as wind and solar on the grid, the demand for storage and grid support flexibility offered by both traditional hydropower and PSH projects will increase. 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—may mean that opportunities for renewed deployment of this technology will not be realized. Mitigating these risk factors would help in addressing high initial capital costs and long licensing and permitting timeframes that are often experienced before the benefits of low-cost hydropower generation, grid support, and long project operating life are realized.

As mentioned earlier, the analysis carried out in support of the *Hydropower Vision* has shown that hydropower projects at previously undeveloped sites could provide valuable renewable energy, storage, and grid reliability services, but that very limited growth can be expected without transformational changes in technologies and approaches. Such changes are only likely to come about via the types of actions that this roadmap prescribes.

4.1 Technology Advancement

The continued contribution and value of hydropower to the nation's energy portfolio can be furthered by improvements and advancements in technology. Aging infrastructure, untapped low-head hydropower potential, and changing operational demands highlight the need for cost-effective and unique solutions to maintain the existing fleet and assess new opportunities for hydropower energy production. Emerging technologies and other innovations should enhance performance of advanced hydropower and PSH designs at reduced costs, while minimizing environmental effects. To be most effective, these designs should also be responsive to emerging demands for balancing variable renewable generation resources and other requirements for flexibility and diversity within the energy portfolio.

Hydropower technology has progressed in terms of environmental monitoring, mitigation, and protection, with advancements such as fish-friendly turbines that reduce fish injury and mortality, fish passage structures to facilitate upstream and downstream fish movements, auto-venting turbines to ensure availability of adequate oxygen levels in outflows, and closed-loop PSH systems, which are located off-stream and therefore can provide energy storage without degrading aquatic habitats. Research and development (R&D) advancements and innovative technologies should continue to be applied at new and existing facilities to enhance environmental performance and water use efficiency. New hydropower technologies will need to be designed, assessed, and monitored to determine their environmental performance, with improvements adaptively implemented when needed. Developing the environmental and biological design objectives necessary to mitigate adverse effects requires assessing techniques and metrics to evaluate tradeoffs quantitatively and assure that new technologies accommodate both environmental and power generation requirements. These steps could help achieve broader acceptance and use of hydropower by industry and stakeholder groups.

New technologies represent risks to first adopters, making it difficult for equipment manufacturers to bring nascent technologies to market. Those risks can be reduced through validation activities, such as fleet benchmarking and the development of testing facilities, to confirm performance and reliability. Testing and validation of emerging technologies can ensure that biological, physical, and environmental requirements are met. Validation can also increase confidence on the part of investors and decision makers, which, in turn, helps accelerate deployment of new hydropower and PSH technologies.

With the growing integration of variable renewable generation technologies, hydropower technologies and operating systems will need to accommodate needs for greater operational flexibility in the power grid. This will allow hydropower and PSH to continue to support and respond to the increase in variability

and uncertainty associated with variable generation. Achieving this objective requires improved reliability and resiliency of new and existing hydropower equipment; operational strategies to accommodate these demands and challenges; and increased sophistication in power system scheduling to blend variable generation with new or existing hydropower, ultimately strengthening the
grid. Larger hydropower facilities and operators with robust monitoring systems are in a unique position to share lessons learned and best practices across the industry, benefitting smaller owners who cannot justify the high costs of such systems.

The actions outlined in this section seek to preserve and increase hydropower potential in the United States through advancements in technology that lead to cost reductions, optimized performance, and low environmental impact. Success in these actions will require increased collaboration across the hydropower industry (e.g., original equipment manufacturers, developers, researchers). The efforts will benefit from outreach to other sectors, including construction firms, additive manufacturing facilities, environmental groups, and other renewable energy and energy storage industries.

ACTION 4.1.1: *Develop Next-Generation Hydropower Technologies.*

ACTION 4.1.1: Develop Next-Generation Hydropower Technologies
The next generation of hydropower and PSH technologies must be able to realize high efficiencies and enhanced performance, while minimizing environmental footprint and lowering capital costs.

Deliverable: New designs and approaches that will allow developers to tap into previously unrealized potential, while making hydropower more competitive with other generation resources.

Impact: Reduced costs and higher reliability.

Key Objectives: Optimization, Growth

Growth Sectors Addressed: Upgrades, NPD, Conduits, NSD, PSH

Timeframe: All actions in this area could commence immediately and simultaneously. Research is already underway by DOE in standard and modular designs (4.1.1.1 and 4.1.1.2), and components manufactured using advanced techniques and materials (4.1.1.3) already exist, but additional applications should continue to be explored. Research and development efforts in new design philosophies (4.1.1.4) will be ongoing and evolving to adapt to new markets, regulatory actions, and unrealized potential. While closed-loop PSH plants already exist, there are opportunities to explore non-conventional designs at perhaps smaller scales.

Action	Deliverable	Impact
Action 4.1.1.1 Standardize equipment components.	Standard equipment components that can be mass produced and assembled in a variety of packaged designs.	Reduced costs, expanded manufacturing capabilities, increased industry collaboration.
Action 4.1.1.2 Develop scalable modular civil structure designs.	Modular civil structure designs, manufacturing and implementation plans, database describing performance characteristics of modular designs.	Reduced construction costs, reduced lead time on project construction.
Action 4.1.1.3 Implement additive manufacturing techniques and advanced materials.	Stronger and lighter hydropower components that are more resistant to corrosion and that can be manufactured and installed quickly.	Faster production of turbine components, lower project and maintenance costs.
Action 4.1.1.4 Explore alternative hydropower design philosophies.	Cost-benefit studies and technical reports documenting the feasibility of new design philosophies.	Reduced capital costs, potential deployment at previously unfeasible sites.
Action 4.1.1.5 Demonstrate potential and feasibility of innovative closed-loop PSH design concepts.	Reports and feasibility studies of innovative closed-loop PSH technologies, such as distributed closed-loop PSH systems.	Greater grid flexibility and storage capacity as a result of increased development of PSH.

Rationale for Actions

To promote hydropower growth and develop new hydropower capacity, the hydropower industry and research community will need to take an innovative approach to designing a suite of generating technologies and civil structures and techniques. This is particularly true with regard to potential new stream-reach facilities, which will require transformational innovation before significant development will occur. For hydropower to remain competitive with other renewable energy resources, next-generation technologies associated with upgrades, new site development (including low-head sites), powering of conduits/canals and non-powered dams, or new or advanced PSH should be designed to reduce equipment and construction costs, improve environmental stewardship, and attain high power efficiencies.

ACTION 4.1.1.1: Standardize equipment components.
Existing hydropower technologies are often designed and manufactured to meet the requirements at individual project sites. As such, the majority of total project costs are typically tied to site-specific designs. Developing and design-testing standardized components that can be purchased "off-the-shelf" and can operate in a variety of flows and heads would result in faster deployment of hydropower technologies. Part of the technology research within this action item would be to evaluate the tradeoffs between reduced efficiency and reduced costs of standardized equipment. Reduced costs may be achieved through innovative designs for mass production, economies of scale, and enhanced familiarity of investors and regulators. Standardized components could also drive down long term maintenance costs by making components more readily available and easily replacable.

ACTION 4.1.1.2: Develop scalable modular civil structure designs.
The term "modular" refers to precast, pre-assembled, and/or standardized civil structure components that would otherwise be site-customized in traditional hydropower design approaches. Development and implementation of innovative modular hydraulic structure and foundation concepts have the potential to transform existing designs and streamline construction to reduce overall costs. One goal of this action is to be able to initially develop projects under a least-cost methodology. After a project is on-line and generating revenue, the project owner could then further customize the equipment and operating features to suit their particular needs. For example, a developer may decide to install a turbine-generator unit at a non-powered dam that does not utilize the dam's full hydroelectric potential. Once the project begins generating revenue, the developer can, through a license amendment or during relicensing, add an additional unit and generate more electricity using modular civil structures with minimal infrastructure costs.

ACTION 4.1.1.3: Implement additive manufacturing[5] techniques and advanced materials.
Advancements in additive manufacturing techniques hold promise for fast and efficient production of hydropower components. When combined with standardized packages and modular civil structures (Actions 4.1.1.1 and 4.1.1.2), additive manufacturing can lead to accelerated production of off-the-shelf components that are easily deployed, resulting in lower installation time and project costs. Composite materials used in additive manufacturing can be combined to meet a wide variety of material properties. As such, these processes can be used to manufacture drivetrain components that are lighter, stronger, and more corrosion-resistant, therefore reducing maintenance costs.

ACTION 4.1.1.4: Explore alternative hydropower design philosophies.
Potential hydropower growth can be achieved by creatively developing technologies that lie outside of the existing design paradigms. Hydropower projects are designed for longevity, with many projects operating for more than 100 years. To the extent that electricity markets are focused on short-term gains, exploring the economic feasibility of and market potential for less expensive hydropower technologies with shorter lifecycles may lead to development of hydropower designs capable of competing under these short-term market drivers. Opportunities to develop modularized hydropower components that may have shorter life cycles—but are lower in cost and easy to replace—should be evaluated and assessed through a variety of tradeoff analyses. Another design philosophy worth examining is powerhouses with an optimal mix or family of turbine sizes to capture energy from variable flows and heads commonly found at low-head sites. The trend in existing projects is a few large machines, all of the same size. Having a

5. Additive manufacturing is a process by which three-dimensional, or 3D, products are built in a layer-by-layer process, i.e., "3D printing."

range of different machine sizes could generate more efficiently over a wide range of flow releases while also meeting environmental flow requirements.

ACTION 4.1.1.5: Demonstrate potential and feasibility of innovative closed-loop PSH design concepts.
Nearly all PSH development since the mid-1980s has occurred in Europe and Asia. While there is strong interest in the United States in constructing new plants, their development may be hindered by a variety of issues related to cost, limited market for grid services, and regulatory processes. Closed-loop PSH projects are located off-stream and therefore can provide energy storage without degrading aquatic habitats. Incorporating elements of modular design (e.g., using commercial off-the-shelf pumps, turbines, piping, tanks, and valves) may drive down investment cost, compensating the loss of economies of scale with cost reductions achieved through component standardization; reduce development risk; and increase the ease of implementation. Small, modular closed-loop PSH systems could be a competitive option for distributed energy storage applications. Development of this next generation of PSH technologies, and validation of the performance and reliability of these new technologies, would increase the prospects of developing PSH in the United States.

ACTION 4.1.2: *Enhance Environmental Performance of New and Existing Hydropower and PSH Technologies.*

Rationale for Actions

Environmental performance refers to the effects hydropower technologies may have on the physical, geological, chemical, biological, ecological, cultural, and social features of the environment. Environmental performance can include, but may not be limited to, flow regimes, water quality, sediment transport, habitat connectivity, fish passage and mortality, and culturally sensitive lands. Because deployment of hydropower technologies is subject to regulatory processes for environmental protection, it will be important to communicate and work with stakeholders to identify, prioritize, and design means to avoid or mitigate adverse environmental effects, and to enhance or promote favorable environmental effects. Doing so earlier in the development process can help minimize expensive redesigns and avoid surprises and unintended consequences of design changes later in the process. Evaluating and improving environmental performance of hydropower technologies, and deploying them within the context of regulatory requirements that ensure environmental performance, can help facilitate acceptance by stakeholders and support hydropower deployment.

ACTION 4.1.2.1: Develop metrics, monitoring, and measurement methodologies for environmental stressors.
Key environmental stressors at new or existing hydropower facilities (e.g., habitat connectivity, water quality, flow alterations, in-turbine pressures and shear stresses) can be identified and prioritized for avoidance or mitigation. Metrics and monitoring methodologies will need to be matched and applied to each stressor, or developed if not already available. As each individual circumstance dictates, developers and regulators can apply these metrics and monitoring technologies to the siting, design, and post-construction monitoring phases of new development. Monitoring results will be used to assess compliance with environmental commitments and achievement of environmental performance targets. This action will also produce a consistent and adaptive means to aid assessment of the environmental performance of hydropower facilities by measuring exposure to priority environmental stressors. These assessments can be used to ensure facilities are designed and evaluated with respect to environmental objectives of multiple stakeholders, including regulatory and resource management agencies.

ACTION 4.1.2.2: Develop biologically-based design and evaluation techniques for hydropower components and associated water control facilities.
There are concerns related to potential fish injury or mortality caused by hydropower facilities. Industry and regulators recognize these concerns and have made significant improvements in mitigating injury and mortality. To build on this progress, continued improvement is needed in biologically-based design and evaluation tools and information that can be applied during development, deployment, and post-construction by industry, regulators, and natural resource managers.

ACTION 4.1.2: Enhance Environmental Performance of New and Existing Hydropower Technologies Environmental performance (e.g., fish survival rates, water quality) of hydropower and PSH technologies is a significant concern of all parties and should thus be evaluated and, when necessary, modified to ensure continual improvement.	
Deliverables: Methodologies and metrics to measure environmental performance of hydropower components that are applied during development, deployment, and evaluation of hydropower technologies. **Impact:** Improved environmental performance due to adaptations of hydropower technology in response to environmental performance findings; acceptance and support from the stakeholder community for individual facilities or projects, resulting in increased deployment of new hydropower technologies. **Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH	**Timeframe:** Actions to assess environmental performance through the development of methodologies (4.1.2.1) and biologically-based designs and evaluation techniques (4.1.2.2) are underway. Findings from the assessments can sequentially be used to identify potential modifications for specific technologies to enhance their environmental performance (4.1.2.3). Baseline studies of environmental metrics (4.1.2.4) are already being performed, but these will be refined with the deliverables from 4.1.2.1 and 4.1.2.2. The existing fleet could be continuously modernized with the latest enhancement technologies to ensure environmental sustainability of hydropower projects (4.1.2.5).

Action	Deliverable	Impact
Action 4.1.2.1 Develop metrics, monitoring, and measurement methodologies for environmental stressors.	Metrics and testing methodologies for environmental stressors.	Improved characterization and quantification of environmental stressors.
Action 4.1.2.2 Develop and apply biologically-based design and evaluation techniques for hydropower components and associated water control facilities.	Biologically-based design and evaluation techniques for hydropower.	Greater prediction and evaluation of environmental performance of hydropower components and associated water control facilities.
Action 4.1.2.3 Apply environmental performance findings within an adaptive management process to prompt modifications to given hydropower technology.	Application of environmental performance findings to drive improvements in hydropower structures and operations.	Improved environmental performance of hydropower technologies.
Action 4.1.2.4 Compare environmental metrics before and after upgrades, new environmental requirements, or deployments at select example facilities to validate and communicate environmental performance improvements.	Comparisons of environmental performance for baseline and post-construction conditions.	Improved documentation and communication of environmental performance.
Action 4.1.2.5: Ensure that enhancing environmental performance is addressed within hydropower fleet modernization efforts.	Comparisons of environmental performance for baseline and post-construction conditions.	Improved documentation and communication of environmental performance.

The intent of such refinements is to reduce design and regulatory review time, and improve fish survival rates. Biologically-based technologies to predict and measure environmental performance relative to fish passage can apply to any hydraulic structure necessary for hydropower production, as well as operations. Establishing objectives and developing improved tools or methods to assess and improve expected environmental performance of new and rehabilitated facilities and components will build on a subset of the metrics and measurement methodologies developed under Action 4.1.2.1.

ACTION 4.1.2.3: Apply environmental performance findings within an adaptive management process to prompt modifications to given hydropower technology.

Focused steps to prompt changes based on the results from Actions 4.1.2.1 and 4.1.2.2 can improve environmental performance of hydropower components. It is not enough to measure performance; the results must be applied and integrated into actions to make new and existing facilities more sustainable and still capable of delivering energy to power system services at marketable prices. The application of environmental performance findings to drive improvements in hydropower structures and operations will improve overall environmental performance of hydropower technologies.

ACTION 4.1.2.4: Compare environmental metrics before and after upgrades, new environmental requirements, or deployments at select example facilities to validate and communicate environmental performance improvements.

Collecting baseline data would allow for before and after comparisons of the environmental performance of new hydropower facilities, existing facilities accommodating new environmental requirements or mitigation actions, or new technology deployments. Such studies can be an important communication mechanism in improving and promoting hydropower. This action would build directly from metrics, methodologies, and designs developed in Actions 4.1.2.1 and 4.1.2.2. Validation through comparison of before and after metrics would require baseline and post-modification data collection and assessment. Comparisons should occur at various scales both temporally (e.g., baseline vs. one year or five years) and spatially (e.g., turbine unit, powerhouse, reservoir). The comparisons will spur identification of acceptable mitigation and enhancement measures that stakeholders agree upon as beneficial. Results from such comparisions would spur identification of acceptable mitigation and enhancement measures that stakeholders agree upon be applied as appropriate to modify hydropower structures and operations, as described in Action 4.1.2.3.

ACTION 4.1.2.5: Ensure that enhancing environmental performance is addressed within hydropower fleet modernization efforts.

Hydropower industry and researchers regularly carry out R&D efforts to develop innovative technologies that meet environmental objectives. This research takes into account factors such as environmental regulations, changing operating modes, and the effects of climate change. As hydropower owners and operators modernize facilities, equipment, and components, they can help ensure continued environmental compliance and stewardship at existing hydropower facilities by implementing the best available technologies to monitor and mitigate environmental impacts. Even as they do so, owners and operators must also consider the costs of such technologies and the effect of those costs on the viability of hydropower production at the facility. This is particularly important for older facilities that are at or near their relicensing periods, or that may have been designed under less stringent environmental protection regimes.

ACTION 4.1.3: *Validate Performance and Reliability of New Hydropower Technologies.*

Rationale for Actions

New technologies represent risks to first adopters. These risks must be addressed with validation activities to confirm performance and reliability, such as fleet benchmarking and the development of component and system testing facilities and other mechanisms. Validation will increase confidence on the part of investors and decision makers, which can help accelerate hydropower and PSH deployment.

ACTION 4.1.3.1: Develop and apply broadly enhanced methodologies for benchmarking and performance assessment across the industry.

This action will focus on developing methodologies for measuring return on investment as a result of fleet maintenance and optimization. Aspects to be evaluated include hydropower generation, operational performance, equipment efficiency, water efficiencies, and environmental performance testing. Benchmarking can indicate ways to increase reliability and efficiency of the hydropower fleets throughout the industry, while also clarifying financial outlays and addressing future expenditures.

ACTION 4.1.3.2: Develop test and performance certification mechanisms.
Developing mechanisms to evaluate new technologies, and providing performance certification to increase product reliability and acceptance, can help ensure a healthy and competitive suite of hydropower technologies for the future. In particular, a facility for full-scale testing of new technologies on the grid would benefit original equipment manufacturers trying to market their technologies, and would give developers reassurance about the performance of nascent technologies.

There may also need to be extensions or supplements to existing turbine performance test codes to address new technologies. A set of industry standards and certifications for emerging technologies (e.g., modular PSH, technologies developed with additive manufacturing) can help maintain standardization across the industry as innovative products are introduced. Improved cost and performance characterization of new hydropower technologies can increase investor confidence, as well as encourage development and adoption of these technologies.

ACTION 4.1.3: Validate Performance and Reliability of New Hydropower Technologies
Validating performance of new hydropower and PSH technologies can increase investor confidence, thereby facilitating greater deployment of new capacity.

Deliverable: Data, validated models, peer-reviewed studies, and testing mechanisms that provide information on the performance and reliability of new hydropower and PSH technologies.

Impact: Improved feasibility and overall performance of new hydropower and PSH projects.

Key Objectives: Optimization, Growth

Growth Sectors Addressed: Upgrades, NPD, Conduits, NSD, PSH

Timeframe: Fleet benchmarking and performance testing (4.1.3.1) are helpful for new technologies, and, as such, efforts to develop and deploy methodologies to perform these actions could begin in the near future. Feasibility studies for performance testing mechanisms (4.1.3.2) are already being explored, and such efforts may continue until the right mechanisms are available to test a variety of new hydropower technologies.

Action	Deliverable	Impact
Action 4.1.3.1 Develop and apply broadly enhanced methodologies for benchmarking and performance assessment across the industry.	New fleet benchmarking tools, new performance standards, new methodologies for performance data collection.	Increased fleet reliability, efficiency gains in fleet operation, improved confidence in financial outlays.
Action 4.1.3.2 Develop test and performance certification mechanisms.	Technology testbeds, standards and methods to certify new designs, accepted certification protocols for emerging technologies, validated models and information on performance and reliability of new technologies.	Accelerated adoption of new hydropower technologies.

ACTION 4.1.4: *Ensure Hydropower Technology Can Support Increased Variable Renewable Generation Resources.*

Rationale for Actions

Existing technologies, operational methods, and system-based practices are in place to ensure that hydropower facilities are operated safely, and that equipment wear and tear is minimized. Hydropower provides ancillary grid support services—such as frequency regulation and voltage support—that are prerequisites for reliable grid operation. These capabilities can help support successful integration of large amounts of variable renewable generation. Doing so, however, can result in increased wear and tear on hydropower equipment. The following actions can ensure the existing fleet is prepared to accommodate increased flexible dispatch of hydropower with minimal damage to equipment.

ACTION 4.1.4.1: Develop new criteria for assessing hydropower equipment performance related to grid support and response.
A new suite of criteria for assessing hydropower equipment from "water to wire" (generation to interconnection) can aid in understanding the effects of variable renewable generation on the equipment and in identifying common failure modes. Assessing equipment performance under different modes of operation (such as increased frequency of starts and stops) is an important step in mitigating damages and maximizing efficency when new variable renewable generation resources are incorporated. Such new criteria are likely to require more robust data collection protocols to enable analysis and decision making related to hydropower support of power systems.

ACTION 4.1.4.2: Share lessons learned and best practices across the hydropower fleet.
Several hydropower operators have developed "in-house" monitoring systems and other methods and procedures to respond appropriately to changes in operation and to evaluate equipment performance in order to mitigate damage to their facilities. Such practices are often costly; as such, small hydropower

ACTION 4.1.4: Ensure Hydropower Technology Can Support Increased Use of Variable Renewable Generation Resources

Technology innovation can minimize increased wear and tear on hydropower and PSH machinery that results from increased penetrations of variable renewable generation resources, such as wind and solar, in power systems.

Deliverable: Criteria and guidelines that enable plant owners to assess hydropower equipment performance and make risk-informed operations and maintenance (O&M) plans and investments that accommodate increased flexible dispatch of hydropower; more robust equipment that can withstand demands placed on hydropower as a result of increased penetration of variable renewable generation resources.

Impact: Hydropower systems that are adapted to meet variable generation from increasing penetration of variable renewable generation resources, resulting in a more resilient and stable electric grid.

Key Objectives: Optimization, Sustainability

Growth Sectors Addressed: Upgrades, PSH, NSD

Timeframe: Efforts to develop new criteria for assessing hydropower equipment performance as relates to providing grid support (4.1.4.1) could begin immediately. Results from such assessments can then be analyzed and applied in the design of more robust equipment (4.1.4.3). Hydropower operators who have monitoring systems in place and provide existing grid support can begin sharing best practices and lessons learned across the industry (4.1.4.2). Building upon existing research, the value and performance of PSH and other advanced adjustable-speed technologies can be validated and demonstrated (4.1.4.4) on an ongoing basis.

Action	Deliverable	Impact
Action 4.1.4.1 Develop new criteria for assessing hydropower equipment performance related to grid support and response.	New criteria for assessing hydropower equipment performance.	Increased understanding of effects that flexible operation of hydropower in response to variable renewable integration into power systems can have on hydropower equipment.
Action 4.1.4.2 Share lessons learned and best practices across the hydropower fleet.	Workshops and other outreach efforts to communicate lessons learned, peer-reviewed reports, and guidelines on best practices.	Increased collaboration within the hydropower industry, improved reliability of small hydropower plants, increased support for variable renewables.
Action 4.1.4.3 Design more robust technologies and materials to withstand new operating conditions.	New technologies and materials that can better withstand stresses arising from variable and extreme operating conditions.	Reliability improvement, O&M cost reductions, increased support for variable renewables.
Action 4.1.4.4 Demonstrate and validate advanced technologies for adjustable-speed hydropower and PSH units.	Validation studies, implementation of adjustable-speed hydropower and PSH technologies.	Wider adoption of advanced technologies, more flexibility provided to the power system.

owners may not be able to implement them. There are opportunities for larger hydropower operators to share these methods and procedures with smaller hydropower producers who might benefit from the lessons learned and best practices without incurring high costs. Several industry consortia already exist for sharing of best practices—these forums can be encouraged and enhanced.

ACTION 4.1.4.3: Design more robust technologies and materials to withstand new operating conditions.
Hydropower units are robust, but their service lives are consumed as they are operated and subjected to cycles of starts and stops. Technologies and materials that extend lifetimes and decrease the frequency of occurrence of equipment failures will also reduce production costs and make hydropower facilities more valuable under existing operating conditions, and under more dynamic conditions caused by increased penetration of variable renewable generation.

ACTION 4.1.4.4: Demonstrate and validate advanced technologies for adjustable-speed hydropower and PSH units.
Adjustable-speed units are able to meet varying load requests with greater efficiency than fixed-speed units and provide fast frequency response associated with the expansion of variable renewable generation resources. While there are no adjustable-speed PSH units operating within the United States to date, such units have been deployed successfully in Europe and Asia. Adjustable-speed PSH units typically have greater operational ranges than fixed-speed units and can provide additional regulation service in the pump mode of operation. Opportunities to convert existing fixed-speed units to adjustable-speed technology should be explored. Studies comparing the U.S. context to that of Europe and Asia may yield insight into how adjustable-speed technology may deliver value for U.S. facilities. Ternary pumped storage designs may also be considered to address needs for flexible generation or load.

4.2 Sustainable Development and Operation

Increasing the amount of hydropower available to meet the nation's need for electrical energy requires a holistic approach to project development that incorporates sustainability objectives.[6] Development at new and existing hydropower facilities should be compatible with social, environmental, and economic values that account for a future in which climate change may influence water quality and supply, as well as demand for increased amounts of renewable energy. Addressing these challenges will involve extensive stakeholder collaboration, whereby sustainability objectives are implemented in balance during hydropower development. To achieve optimum delivery of power and non-power benefits, such collaboration should examine and consider interactions of a particular hydropower project with other hydropower and water resource projects, as well as other water uses within a basin or watershed. Reservoir operations and other basin/watershed factors or competing uses and demands should be evaluated during regulatory processes associated with development. This can help to ensure that a given project is compatible with and supports multiple objectives under changing energy demands and hydrologic conditions.

Relevant and accessible climate and runoff forecasts will be needed to facilitate planning for possible future conditions. Hydropower operations and water storage management will need to respond to changing climatic conditions and evolving trends in demand for water, as society becomes increasingly interested in more renewable energy and less reliant on carbon-based energy. The use of near- and long-term climate forecasts to predict changes in water availability, temperature regimes, and energy demand at relevant scales for decision making poses a significant challenge; applied research could help advance development of accurate and cost-effective

6. Examples of sustainability objectives related to hydropower include: (1) environmental aspects such as mitigating loss of aquatic connectivity; maximizing persistence of native species and communities; mimicking natural flow, sediment, and water quality regimes; (2) social aspects such as ensuring public health and safety; providing low-cost, reliable energy; and supporting cultural heritages; and (3) economic aspects, such as maximizing market/economic values; providing generation flexibility; providing other attributes such as recreation or flood control; and providing job opportunities.

temperature and runoff forecasting capabilities. Such information will need to be made readily accessible and translatable to a range of stakeholders in order to facilitate collaborative project development.

Hydropower development involves resource balancing; that is, hydropower as a renewable energy source must be balanced with other objectives such as ecosystem health, recreation, transportation, municipal water use, and other energy production. Aspects of hydropower operations, including reservoir elevations, the timing and magnitude of flow releases, downstream target elevations and flows, downstream water quality targets, ramping rates, and other thresholds, can have substantial effects on critical non-power resources. In addition, water uses for hydropower production within a basin are often interdependent—and potentially at odds—with other types of water use facilities or objectives. Accurately characterizing and addressing these interdependencies at new and existing facilities, and within the context of evolving climate conditions, will be necessary to ensure multiple objectives are met as effectively as possible in future development. Therefore, developers and stakeholders should mutually communicate their plans and interests as soon as possible in the development process to ensure tradeoffs and balancing are better understood from the outset. Likewise, stakeholders should become engaged early to fully understand the value and tradeoffs of the proposed development. As demand for water shifts due to population growth and climate change, the need for collaborative balancing of water resources will increase and hydropower can play a significant role in helping to provide a source of reliable and renewable energy.

ACTION 4.2.1: *Increase Hydropower's Resilience to Climate Change.*

Rationale for Actions

As the effects of climate change on weather become more pronounced, not only will there be large shifts in water availability and timing, but the frequency and severity of extreme events and climate-driven changes (e.g., severe drought or flood/high water) may intensify. Proactive steps can increase hydropower's resilience to climate change and allow hydropower to help mitigate the effects of such extremes. When droughts or other extreme events occur, alternative operational scenarios can be implemented to better align storage and operations with altered water availability and energy demand. Since climate change is a global issue, greater international outreach and sharing of best practices could provide quicker returns on some of these actions.

ACTION 4.2.1.1: Develop hydropower-focused climate change assessment framework.

Climate change is expected to affect future hydrologic conditions, such as snow accumulation; amount and timing of runoff; and frequency of extreme temperature, extreme precipitation events, and droughts. How these potential hydrologic changes may influence hydropower operation is not well understood at a scale relevant to site- or project-scale decision making, and the ability to better forecast and plan for future conditions is needed. The rapid evolution of climate science and the heavy computational burden associated with earth system modeling necessitate a shared approach to maintaining understanding of future climate trends. Work is needed to digest pre-processed hydro-climate projection data (e.g., precipitation and temperature) to support quantitative operational assessment at existing or planned hydropower facilities. The River Management Joint Operating Committee study (led by Bonneville Power Administration)[7] for the Pacific Northwest and the DOE-led assessment of the potential impacts of climate change on hydropower at federal facilities [1] are examples of how regional or basin-scale hydropower and climate change assessments could be established and tailored for needs of hydropower stakeholders in different regions. The U.S. Department of the Interior's Bureau of Reclamation (Reclamation) basin studies [2] also provide pertinent examples.

7. The committee, commonly known as RMJOC, is a sub-committee established through direct funding Memorandum of Agreements between Bonneville Power Administration, Reclamation, and the U.S. Army Corps of Engineers. More information is available on the Bonneville Power Administration website (*http://www.bpa.gov/power/pgf/ClimateChange/Part_I_Report.pdf*).

ACTION 4.2.1: Increase Hydropower's Resilience to Climate Change
Providing frameworks for assessing climate change impacts can improve the ability of hydropower projects to operate under resultant increases in variability (e.g., temporal and spatial changes in water availability or water use).

Deliverable: Tools to forecast water availability and assess changing energy demands.

Impact: Improved ability to forecast climate conditions that affect water availability and energy demand.

Key Objectives: Optimization, Sustainability

Growth Sectors Addressed: Upgrades, NPD, Conduits, NSD, PSH

Timeframe: Actions to develop a climate change assessment framework (4.2.1.1) can begin immediately, along with development of the data to populate that framework (4.2.1.2). The climate data repository would transition to the ongoing delivery of data products, with periodic updates as new climate data become available. Development of information on how climate change would influence water demand (4.2.1.3) will depend upon data from the repository and would be updated as climate projections change. Development of operational and storage scenarios that can help offset climate impacts (4.2.1.4) could begin as soon as initial estimates of potential impacts are available (under 4.2.1.3), and would continue until alternatives are defined.

Action	Deliverable	Impact
Action 4.2.1.1 Develop hydropower-focused climate change assessment framework.	Framework for incorporating the effects of climate scenarios on water availability and energy demand into hydropower planning processes.	Improved ability to include future climate scenarios in planning.
Action 4.2.1.2 Develop climate data repository for hydropower operational studies.	Workshops and other outreach efforts to communicate lessons learned, peer-reviewed reports, and guidelines on best practices.	Increased collaboration within the hydropower industry, improved reliability of small hydropower plants, increased support for variable renewables.
Action 4.2.1.3 Develop scientific information on the influence of climate change on water demands.	Tools to improve predictions of operational flexibility and constraints.	Improved understanding of the future effects of climate change on hydropower infrastructure.
Action 4.2.1.4 Evaluate operational and storage scenarios to help offset climate change impacts.	Alternative scenarios for hydropower system configurations and operations.	Enhanced ability for hydropower facilities to respond to and help offset climate change impacts.

ACTION 4.2.1.2: Develop climate data repository for hydropower operational studies.
A common climate data repository, similar to the Downscaled Climate and Hydrology Projections led by Reclamation [3], could be established to streamline the preparation, evaluation, and validation of downscaled climate data for hydropower operational studies. These joint efforts may reduce the duplication of investment by each entity and could help realize regional consensus more efficiently.

ACTION 4.2.1.3: Develop scientific information on the influence of climate change on water demands.
Climate change may influence water availability for hydropower generation, as well as for competing water demands and environmental requirements (e.g., household consumption, irrigation, maximum instream temperature, minimum streamflow). This may indirectly affect future hydropower operations. While increasing air temperature may influence competing water demand and instream temperature, quantification of such effects on future hydropower generation is challenging and remains an open scientific question. The existing tools, data, analyses, and concepts that were developed for local operational purposes may not be directly applicable to planning and decision making focused on addressing potential climate change consequences. To increase understanding of how hydropower might have to adapt to future climate conditions, further research efforts should focus on developing an integrated quantitative assessment approach for (1) estimating instream temperature in the unregulated stream-reaches

based on the downscaled hydro-climate projections; (2) estimating future competing water usage in the context of climate change; and (3) developing tools to provide credible forecasts of runoff and temperature that can support decision making.

ACTION 4.2.1.4: Evaluate operational and storage scenarios to offset climate change impacts. Water systems management aims to meet a number of objectives for existing conditions and usually includes contingencies for extreme conditions. Hydropower facility managers can refine or expand existing operational strategies and water management guidelines to address increasing frequency and severity of extreme events and climate-driven changes in water and electricity demand. A suite of operational and storage scenarios would be useful to inform this process (e.g., co-locating facilities with flood control and water supply). The basis for any changes can center on Actions 4.2.1.1, 4.2.1.2, and 4.2.1.3, and, in particular, on climate model predictions and information that focus on regional or finer scale forecasts to inform management of rivers, river basins, and reservoirs.

ACTION 4.2.2: *Improve Coordination among Hydropower Stakeholders.*

Rationale for Actions

Water users with a wide variety of objectives share a common resource. The distinct objectives and constraints that govern procedures, rules, and success measures for institutions chartered or authorized to own, operate, market, or regulate hydropower facilities may differ from the objective and constraints of other stakeholders. When multiple hydropower facilities with distinct owners are hydraulically dependent on a basin (meaning that water releases and reservoir

ACTION 4.2.2: Improve Coordination among Hydropower Stakeholders

Improved coordination and collaboration among hydropower stakeholders can facilitate better realization of multiple objectives (e.g., social, environmental, electricity generation) through hydropower development planning.

Deliverable: Processes that support coordinated water scheduling and planning. **Impact:** More rapid and less costly development of shared solutions, leading to greater deployment of sustainable hydropower. **Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH	**Timeframe:** Efforts to identify successful water management collaborations (4.2.2.1) can begin immediately and would transition to adding new examples once initial lists are completed. Development of an education and illustration process for complex, multi-owner water scheduling and planning strategies (4.2.2.2) can begin immediately and would transition to demonstration when tools are completed. Seeking opportunities to coordinate licensing within a basin (4.2.2.3) can begin immediately and could continue until a full cycle of license renewals is complete.

Action	Deliverable	Impact
Action 4.2.2.1 Identify examples and lessons learned from successful coordinated water use and management.	List of past collaborations that achieved multiple project purposes.	Greater potential for future collaboration that satisfies multiple objectives.
Action 4.2.2.2 Develop and demonstrate an education and illustration process for complex multi-owner water scheduling and planning strategies.	Tools that improve communication of water use alternatives.	Improved ability to collaborate within a multi-user, multi-stakeholder system.
Action 4.2.2.3 Identify and evaluate opportunities to coordinate licensing outcomes among facilities in the same basin.	List of opportunities for coordination among facilities in a given basin.	Improved overall operational flexibility.

elevations at one facility affect outcomes at facilities upstream and downstream), these intricacies can create inefficiencies in basin-wide water utilization for hydropower production and other water use benefits, such as recreation and instream flows. Stakeholders who are affected by hydropower facilities typically have discrete values and objectives (e.g., water rights) that govern their response and acceptance of outcomes at individual or multiple facilities. Stakeholders need knowledge of the basin-wide context for water management in order to enable more efficient basin-wide use of water. Although many venues exist for stakeholders to collaborate (e.g., National Hydropower Association regional meetings), continued improved collaboration among stakeholders can lead to satisfactory solutions of multi-use water management situations.

ACTION 4.2.2.1: Identify examples and lessons learned from successful coordinated water use and management.

The value of collaboration among hydropower stakeholders has been demonstrated in many hydropower regulatory arenas, most notably through settlement agreements. Success stories from collaboration in multi-objective water management processes should be made available to stakeholders for use within the context of both relicensing existing hydropower facilities and developing new hydropower facilities. For example, in the Vernita Bar Agreement, federal and state agencies, tribes, and utilities collaborated to reach a negotiated solution to protect salmon spawning habitat in the last free-flowing reach of the Columbia River in the United States, above Bonneville Dam. During collaborative discussions associated with hydropower development, sustainability should be considered in siting, design, and operation. For example, a proposed hydropower location must be screened for its site-scale environmental footprint and its context at the basin scale; without proper planning and siting at the basin scale, opportunities for more optimal and balanced outcomes might be missed. Drawing upon lessons learned will help avoid or mitigate any environmental, cultural, and economic effects of a facility. Lessons learned from water use collaborations should be applied in other settings as appropriate.

ACTION 4.2.2.2: Develop and demonstrate an education and illustration process for complex multi-owner water scheduling and planning strategies.

Multi-owner water scheduling, planning, rights, and laws are a challenge due to the complexities involved and the array of possible strategies. Water uses can include irrigation and municipal water supply as well as hydropower. While many forms of reservoir planning and management tools and models exist, the outputs and presentation of such models may be viewed as a "black box" (i.e., the results are not readily available to multiple stakeholders). New tools, or enhancements to existing tools and models, could benefit stakeholders by allowing improved viewing of water use scenarios and a more interactive way to evaluate how scenarios influence multiple objectives. This should allow constraints, competing uses, benefits/costs, and trade-offs to be understood, and could improve the transparency of decision making within a collaborative environment.

ACTION 4.2.2.3: Identify and evaluate opportunities to coordinate licensing outcomes among facilities in the same basin.

The single-project approach to licensing can sometimes provide fewer benefits than a jointly optimized approach among projects (federal and non-federal) located in the same basin or watershed. Joint licensing/relicensing processes could lead to better outcomes from power, environmental, and social perspectives. However, not all projects in a basin have coordinated license terms that would facilitate such an approach. The possibility of synchronizing license terms could be a normal consideration in determining future license terms, and could be done so in the context of applicable laws and regulations pertaining to licensing and relicensing. Options to encourage licensees early in their license term to participate in joint water management or mitigation efforts should be explored. Where possible, the opportunity to align license terms among different hydropower projects on a given river or basin could also be examined and pursued. The intent would be to seek better outcomes (e.g., where an action at one project can mitigate the impact of another project). Coordinated approaches have been used in the past and proven beneficial for involved parties. A coordinated watershed plan for a given river or basin could be developed, along with an agreement to implement it and a mechanism for implementation (e.g., synchronizing licenses, joint escrow account for mitigation).

ACTION 4.2.3: *Improve Integration of Water Use within Basins and Watersheds.*

Rationale for Actions

Planning for hydropower development is a matter of resource balancing. Sustainable hydropower development involves resource management trade-offs among multiple objectives, such as ecosystem management, recreation, commercial navigation, flood control, agricultural and municipal water supply, and other energy production—all while still allowing economic hydropower generation. These trade-offs can be reflected in responses in hydropower operations, such as minimum/maximum reservoir elevations, minimum flow releases, downstream target elevations and flows, downstream water quality targets, ramping rate restrictions on flow releases, and other thresholds. Early communication and integration of plans and interests by developers and stakeholders can help identify constraints and foster balancing of water use objectives so long as new tools are developed in concert with water resource policy to ensure the end products are feasible within the context of real-world water management.

ACTION 4.2.3.1: Explore options beyond the bounds of individual hydropower projects to mitigate any adverse project effects.

Limiting mitigation to the area of direct project environmental effects can reduce effectiveness and increase costs in cases where other promising off-site mitigation options might be available. In general, off-site mitigation is considered only when implementation of measures at the project is not feasible.[8] Moreover, FERC's 2006 Settlement Policy states that a relationship must be established between a proposed measure and project effects or purposes, and

ACTION 4.2.3: Improve Integration of Water Use within Basins and Watersheds
The development of innovative tools and approaches can increase opportunities for better integration of multiple water uses and objectives.

Deliverable: Processes to improve integration of water use within basins and watersheds.

Impact: Potential to increase hydropower production with minimal impact to other water uses.

Key Objectives: Optimization, Growth

Growth Sectors Addressed: Upgrades, NPD, Conduits, NSD

Timeframe: Exploring options for mitigation beyond project bounds (4.2.3.1) could begin immediately and continue until options are identified and a list made available. Development of a catalog of basins with potential for hydropower development and mitigation of other impacts (4.2.3.2) would begin immediately and continue until the delivery of a catalog of opportunities. Increasing the contribution of water management, ecological, and mitigation models to water use planning (4.2.3.3) will require starting immediately to ensure that better tools become available in the near term. Additional phases of effort will involve communicating the benefits of those improved models and facilitating their application in water use planning processes.

Action	Deliverable	Impact
Action 4.2.3.1 Explore options beyond the bounds of individual hydropower projects to mitigate any adverse project effects.	Options for more effective and less costly mitigation activities.	Greater flexibility in mitigating for hydropower development.
Action 4.2.3.2 Develop a catalog of basins with potential for both hydropower development and mitigation of related impacts.	A catalog of hydropower development and associated mitigation opportunities.	Reduced environmental impacts of development with a corresponding increase in power production.
Action 4.2.3.3 Increase the contribution of water management, ecological, and mitigation models to water use planning.	Identification of enhancements to existing tools and the development of new tools.	Improved water utilization at basin-wide scales.

8. See 90 FERC ¶ 61,087 (2000).

actions required under measures should occur physically and geographically as close to the project as possible. If off-site mitigation is appropriate, there are different potential approaches for it within a basin. For example, parties might consider establishment of a mitigation banking-type system in which contributions could be stored for collective restoration as projects come up for relicensing. Such avenues could be explored as part of the development process within the context of what is and is not within FERC jurisdiction and consistent with applicable FERC policy (e.g., on Settlement Agreements), although some settlement provisions may not be enforceable by FERC. Any identification of basin-wide hydropower opportunities would be done in conjunction with basin-wide planning and evaluation of energy, environmental, and social benefits/impacts. While regulatory timelines might increase due to more coordination, outcomes are expected to be more favorable to a wider array of stakeholders.

ACTION 4.2.3.2: Develop a catalog of basins with potential for both hydropower development and mitigation of related impacts.

The hydropower community would benefit from better understanding of environmental and other valued characteristics of river basins with development potential. This action would use existing resource assessment reports [4, 5] and information to create an enhanced inventory (such as Reclamation's WaterSMART program [6], or DOE's series of basin scale studies[9]) that identifies not only power generation potential, but also key environmental or other attributes (e.g., potential for water supply, recreation, fisheries). Hydropower developers could then factor these data into project planning. This inventory would feed into tools that help development stakeholders identify the lowest risk sites for successful development and the opportunities for basin-scale collaboration among sites. Doing so would require information about resource values and would ideally be accomplished under a comprehensive effort for watershed planning, i.e., not limited to hydropower development. This catalog of information could define important issues and effective mitigation strategies earlier in the development process and provide better understanding of both. This would aid in determining project costs, benefits, and trade-offs, and could provide for study of needs that would allow new projects to come to fruition more expeditiously. This action can encourage developers to look for win-win opportunities that deliver increased power and improved environmental conditions, recreational opportunities, or benefits to other water users.

ACTION 4.2.3.3: Improve the contribution of water management, ecological, and mitigation models to water use planning.

Numerous tools and models exist that allow project and reservoir operations to be modeled at both the project and basin scales. Existing tools should be evaluated to assure they can address future conditions in a manner that enables the most efficient and effective operations to be identified relative to power and non-power resources. Such evaluations could identify improvements to existing tools and models, or identify the need for new tools and models. For example, models for hydraulics and other attributes (e.g., water quality, socioeconomics) already exist. However, capabilities to forecast more complex environmental and socioeconomic outcomes as functions of operational and developmental decisions (e.g., flow regimes, water surface elevations, allocation of storage across seasons, and deployment of mitigation technologies) could enable assessment of likely outcomes of alternatives during regulatory and operational decision making.

ACTION 4.2.4: *Evaluate Environmental Sustainability of New Hydropower Facilities.*

Rationale for Actions

Energy development of any type involves a certain amount of risk, and it is important that such risk be managed. Unknowns regarding the environmental sustainability of a proposed facility are often a cause of concern for affected stakeholders. Concerns over sustainability issues surrounding hydropower are difficult to address without having agreed upon quantifiable, scientifically defensible sustainability metrics, models, and methods for hydropower. The lack of suitable metrics or best practices make it more difficult and time consuming to demonstrate that a

9. See *http://basin.pnnl.gov/*.

ACTION 4.2.4: Evaluate Environmental Sustainability of New Hydropower Facilities
Developing quantifiable environmental sustainability metrics and applying them to the development and operation of new hydropower facilities can lead to greater consistency in permitting processes, and qualification for national, state, and local renewable energy goals.

Deliverable: Scientifically rigorous and generally accepted environmental sustainability criteria for new hydropower project development and operation, including potential protocols and assessment tools that are cost effective to implement.

Impact: Assure stakeholders and decision makers have consistently defined and scientifically defensible sustainability criteria to support new hydropower development and operations that are responsive to environmental and socioeconomic considerations.

Key Objectives: Growth, Sustainability

Growth Sectors Addressed: NPD, Conduits, NSD, PSH

Timeframe: Continued advancement of hydropower-relevant environmental research (4.2.4.1) is crucial to increasing hydropower sustainability and should continue in perpetuity. The remaining actions should occur consecutively. Metrics for evaluating environmental sustainability (4.2.4.2) of new hydropower development are already being created under DOE-funded efforts. Based on these metrics, tools and protocols (4.2.4.3) could be developed to evaluate environmental sustainability of individual new hydropower facilities. Successful development of sustainability metrics and tools could also be used to support a certification process for new facilities that meet such metrics. Therefore, a review of the potential relationship between existing low-impact hydropower certification processes and opportunities to advance sustainability metrics for new hydropower (4.2.4.4) should be explored.

Action	Deliverable	Impact
Action 4.2.4.1 Continue to conduct research on environmental needs and solutions.	Scientific articles and tools that provide a more precise understanding of hydropower impacts on different environments.	Environmentally-improved technology/plant designs and project/system management.
Action 4.2.4.2 Develop metrics for evaluating environmental sustainability for new hydropower development.	Metrics that effectively measure and track sustainability.	Improved integration of sustainability objectives during development.
Action 4.2.4.3 Develop tools and protocols for assessing and designing for environmental sustainability at new hydropower facilities.	Tools to evaluate and assess sustainability of a specific site.	Ability to identify hydropower and PSH facilities that are environmentally sustainable.
Action 4.2.4.4 Explore benefits, drawbacks, and models in order to develop or expand upon existing certification programs.	Peer-reviewed studies analyzing the pros and cons of a sustainability certification for new hydropower facilities.	Expansion of sustainability certification options for new hydropower development that could result in access to new revenue streams and greater acceptance of hydropower across stakeholders.

project is sustainable, which can delay the regulatory process and sometimes result in potential new projects being abandoned because the assessment cannot be made or agreed upon. The goal of this action is to develop rigorous and scientifically defensible environmental sustainability metrics for new hydropower development, and the appropriate tools and protocols to measure and assess them. Opportunities to use the developed metrics and tools for new facilities, such as including them within existing sustainability certification processes or creating additional certification processes, should also be evaluated. Existing environmental sustainability certifications already provide benefits to developers, such as greater consistency in permitting processes and qualification for national, state, and local renewable energy goals and targets. An expanded certification could offer the same benefits for new hydropower development.

ACTION 4.2.4.1: Continue to conduct research on environmental needs and solutions.
Much of the environmental world is still not understood in enough detail (i.e., scale and resolution) to inform precise technology/plant design or project/system management. The stressor metrics developed in Action 4.1.2.1, for instance, must be underpinned by the environmental science documenting the impacts of the stressors on organisms as well as their effect on the surrounding ecology. Resolving the impacts of hydropower-induced stressors is a prerequisite to developing technologies or management schemes that work to minimize those stressors. Basic and applied environmental research must continue to advance and be published in all realms that affect hydropower, from fish biology to environmental flows, to make hydropower more environmentally sustainable.

ACTION 4.2.4.2: Develop metrics for evaluating environmental sustainability of new hydropower development.
A comprehensive set of metrics could achieve a range of objectives. It could promote common understanding of key aspects of sustainable development to inform permitting and licensing processes; build credibility with communities and stakeholders; help avoid actions unlikely to be sustainable; focus new development toward the most sustainable opportunities; and reduce the environmental impacts of future hydropower development. Some metrics would apply at the project level, while others would need to consider a larger basin-scale context. Such metrics could be developed by the scientific community through close collaboration with stakeholders to evaluate whether the objectives the stakeholders have defined are being met.

ACTION 4.2.4.3: Develop tools and protocols for assessing and designing for environmental sustainability at new hydropower facilities.
Following the development of the sustainability metrics described in Action 4.2.4.2, tools and protocols to measure sustainability at individual hydropower facilities are suggested to be developed. Measuring environmental sustainability of new hydropower facilities is important not only to recognize those facilities that measure favorably but to identify areas that can be improved. Developers can incorporate such tools and sustainability indicators into their design to gain stakeholder acceptance, facilitate regulatory and permitting process, and ensure environmental stewardship actions are effective.

ACTION 4.2.4.4: Explore benefits, drawbacks, and operating models in order to develop or expand upon existing certification programs.
Since 2000, the Low Impact Hydropower Institute has operated a certification program that offers recognition for hydropower projects that meet low impact criteria across a range of environmental benchmarks, such as fish passage and water quality. These criteria were formally revised in March 2016 to include, among other adjustments, a new emphasis on the scientific basis for agency recommendations and mitigation. As of 2015, the Low Impact Hydropower Institute does not consider PSH projects or projects that involve construction of a dam or diversion after August 1998 [7]. Projects that are ineligible for the Low Impact Hydropower Institute may respond to similar incentives to reduce impacts through recognition and certification of responsible operation.

Advancing nationally accepted sustainability certification for new hydropower and PSH facilities could present many opportunities to developers, such as better access to environmental markets and the incentives they provide, qualification in state and national renewable energy goals and targets, and improved stakeholder acceptance. The benefits and drawbacks of such a certification program, along with different potential operating models for one, should be carefully evaluated to determine if it would be overall beneficial to both the environment and the hydropower community. An environmental sustainability certification program could use the metrics, tools, and protocols developed in Actions 4.2.4.2 and 4.2.4.3 to assess the environmental sustainability of new hydropower facilities. Such a program would need to be developed with input from stakeholders, industry, and decision makers, and would acknowledge and be incidental to FERC licensing, which establishes foundational sustainability requirements. The certification program would be for optional certification above and beyond licensing.

4.3 Enhanced Revenue and Market Structures

Hydropower and PSH play a pivotal role in grid operation due to unique performance attributes and long-lasting facilities. In addition to providing peaking and baseload energy generation, capacity, and ancillary grid support services, hydropower and PSH offer operational flexibility and dispatchability, energy storage, and essential reliability services benefiting the entire power system. These include on-demand generation supporting integration of variable renewable generation resources, load shifting, greenhouse gas reduction, and increased overall efficiency and reliability of system operation.

Improved market structures and compensation mechanisms could more appropriately reward the services required by an increasingly renewable grid—services which have been provided by existing hydropower and PSH for decades (potentially without compensation), and could be provided in the future by new hydropower projects. Actions in this area include determining how much flexibility is provided by hydropower in existing grid operations, exploring opportunities to enhance market eligibility (particularly eligibility and participation in renewable and clean energy markets), recognition to properly value flexibility, and examining how and at what time scale settling of energy markets can allow better use of hydropower flexibility in integration of variable renewable generation resources.

Decisions to move forward with a prospective hydropower development project (new or existing) rely heavily on the project's pro forma (i.e., benefits/costs, overall financial performance). Because actions identified in this section have the potential to influence project pro forma statements and the decision to proceed with development, the actions that follow are suggested for both near- and long-term implementation.

PSH energy storage technologies are unique because they function as both generation and demand resources. This presents some challenges to their treatment in electricity markets. Historically, most U.S. electricity markets have treated PSH generation and demand functions separately; thus, the operation of PSH may not be fully optimized over its entire generation/demand cycle. This frequently results in the failure to use the full capabilities of PSH to provide maximum benefits to the power system. Improving the valuation and revenue of PSH services would help optimize their operation to benefit the entire system and stimulate new projects through improved economic performance. This may be achieved and validated through modeling and observation of global examples in which enhanced market recognition accommodates the unique contributions of PSH, and through examination of potential approaches for system operators (independent system operators [ISOs] and regional transmission operators [RTOs]) to schedule PSH units within electricity markets.

Actions related to improved valuation and revenue carry cost implications, which in turn can imply the value of potential policy formulations. The actions identified in this section are intended to inform these policy considerations, but such considerations are not incorporated into the actions themselves. Additionally, actions identified in this section can apply to both the federal and non-federal hydropower fleet, as appropriate.

ACTION 4.3.1: *Improve Valuation and Compensation of Hydropower in Electricity Markets.*

Rationale for Actions

Hydropower facilities have many operational characteristics that make them suitable to provide numerous services and contributions to the power system, such as fast ramping and low-cost operating contingency reserves. These characteristics are unique from other energy generation sources, both renewable and conventional. The potential for and benefits of these services need to be better understood, and revenue streams should be established to properly compensate the various types of products and services hydropower provides. Existing proposals for market design enhancements and other emerging trends can be examined and leveraged where appropriate, including recognition in tariffs and rate-setting.

ACTION 4.3.1: Improve Valuation and Compensation of Hydropower in Electricity Markets
Enhancing existing market approaches and developing new approaches can help facilitate full recognition and compensation of the suite of grid services, operational flexibility and system-wide benefits offered by new and existing hydropower.

Deliverable: Recommendations for new market revenue mechanisms that can compensate hydropower and PSH for operational flexibility and other services. **Impact:** Availability of appropriate financial incentives for the operational flexibility and other services that hydropower can offer.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** The actions in this section can influence the pro forma statements of hydropower projects, and are thus recommended for immediate or near-term implementation and long-term use.

Action	Deliverable	Impact
Action 4.3.1.1 Quantify operational flexibility of hydropower.	Quantification of hydropower's operational flexibility and its value to the electricity system.	Improved valuation of hydropower's operational flexibility, expanded development of other renewable technologies, and portfolio optimization.
Action 4.3.1.2 Enhance market recognition of flexibility and other services.	A set of recommendations for improved market recognition enhancements and compensation mechanisms.	Improved market treatment of operational flexibility and other services.
Action 4.3.1.3 Increase temporal resolution of electricity markets.	A set of recommendations for improved market settlement.	Better use of hydropower's flexibility for integration of variable renewable generation.

ACTION 4.3.1.1: Quantify operational flexibility of hydropower.
Hydropower and PSH facilities are generally recognized for their fast ramping and flexible operational characteristics, and both are capable of providing significant amounts of operational flexibility to the power grid (flexibility and ramping being similar in terms of ability to start/stop quickly and change output quickly). This flexibility is especially valuable for load/generation balancing and for supporting high levels of variable generation (e.g., ramping capabilities, inertia, and frequency response). However, many hydropower facilities operate under a range of environmental and operational constraints, resulting in actual contributions to power system flexibility that are often lower than their technical capabilities. There is a need to review and build upon existing information and to continue research and analyses to quantify how much operational flexibility and ancillary grid services hydropower provides to the electricity system (e.g., ramping, capacity, storage, voltage regulation/support, reactive power). Similarly, there is a need to determine the value of such flexibility and services in different markets in the United States, including the degree to which flexibility and services are undervalued or not compensated. The science associated with ramping and other avenues to increase use of hydropower's flexibility potential while still satisfying all environmental and other operational constraints also merit investigation. The ability to effectively gather the necessary information will be an important factor in performing these examinations.

ACTION 4.3.1.2: Enhance market recognition of flexibility and other services.
With levels of variable renewable generation resources increasing, the power grid requires greater levels of operational flexibility, and, as such, market recognition and compensation mechanisms should keep pace. While most electricity markets include revenue provisions for energy, capacity, and some ancillary grid services, markets could be improved to include revenue mechanisms that recognize and

compensate for some of these services and contributions, including those designated as essential reliability services by the North American Electric Reliability Corporation. The operational flexibility of hydropower facilities is already supporting the transition to greater deployment of variable renewable generation resources and can support and enable even higher levels cost effectively. However, market or other revenue mechanisms that properly value the economics of operational flexibility and provide adequate revenue streams for its contributions to power grid balancing can be examined. Improvements of market recognition or provisions to appropriately compensate power facilities that provide operational flexibility and other system-wide services would assure the long-term viability of hydropower, and contribute to increased integration of variable renewable resources and more reliable operation of the entire power system. Examination and compilation of existing proposals to enhance market design also merit consideration, including recognition in tariffs and rate-setting.

ACTION 4.3.1.3: Increase temporal resolution of electricity markets.
While all electricity markets in the United States calculate sub-hourly prices as part of the real-time dispatch, many electricity markets are still cleared (settled or "trued-up") on an hourly basis, making it difficult for flexible generation resources to benefit from their operational flexibility on sub-hourly timescales (e.g., 15 minutes or less). Moving towards sub-hourly markets could inform potential options for greater fidelity at the scale on which the grid actually operates. This would provide financial incentives for hydropower and PSH units to increase use of operational flexibility for intra-hourly load/generation balancing, as well as providing additional energy arbitrage (price differential) opportunities for PSH. Studies conducted under this action (which should involve grid operators, market participants, and regulators) can pertain to sub-hourly markets as well as sub-hourly settlements of markets, since study in both areas can aid in discerning potential options for each pathway.

ACTION 4.3.2: *Improve Valuation and Compensation of PSH in Electricity Markets.*

Rationale for Actions

As an energy storage technology, PSH provides numerous services and contributions that benefit not only the generation components of the power system, but also transmission, distribution, and demand. For example, incorporating PSH into grid system operations contributes to more efficient dispatch and utilization of other generating units, thus lowering overall electricity generation costs; reduces cycling, ramping, and wear and tear of thermal generating units; reduces curtailments of excess variable renewable generation (by creating load and storage for variable generation); postpones the need for investments into new transmission and distribution facilities; provides significant operational flexibility and reserves that support high penetration of variable renewables; contributes to primary frequency response and voltage support; provides system inertia; and contributes to increased reliability of system operation. While most electricity markets include revenue provisions for energy, capacity, and certain ancillary grid services, market recognition and compensation mechanisms could be improved for these services and contributions to overall grid function and reliability. The treatment and scheduling of PSH in existing electricity markets could be improved to better reflect the value and unique characteristics of PSH and duty cycle (percent of time pumping or generating), which includes both generation and demand functions.

ACTION 4.3.2.1: Improve the valuation of PSH services.
PSH is a versatile energy storage technology that provides numerous services and contributions to the power system. In addition to energy, capacity, and ancillary grid services, PSH facilities provide many benefits to the broader power system that are not typically compensated in existing electricity markets. By building upon existing research and information, as well as examining global examples, studies of these benefits can be conducted to determine the full value (revenue potential) of various PSH services, increase understanding of how their contributions to the power system are undervalued, and help improve these valuations.

ACTION 4.3.2: Improve Valuation and Compensation of PSH Services in Electricity Markets
Enhanced market rules related to scheduling and operation of PSH in electricity markets can facilitate use of the full value of this energy storage technology.

Deliverable: New market rules and revenue mechanisms that recognize the unique role and value of PSH in the power system and provide appropriate compensation for PSH services and contributions. **Impact:** Adequate financial incentives for the full range of services and contributions that PSH provides to the power system.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** PSH **Timeframe:** All actions in this section can begin immediately and simultaneously.

Action	Deliverable	Impact
Action 4.3.2.1 Improve the valuation of PSH services.	Quantification of PSH services and contributions, including system-wide benefits.	Improved understanding of the various benefits that PSH provides to the entire power system, portfolio optimization and expanded development of other renewable technologies.
Action 4.3.2.2 Evaluate enhanced market recognition for PSH.	Report of potential market recognition enhancements.	Accelerated development of new PSH projects or upgrades to existing PSH projects.
Action 4.3.2.3 Investigate potential for RTOs and ISOs to provide input on scheduling PSH units in electricity markets.	Recommendations for improved scheduling of PSH plants in electricity markets.	Better utilization of PSH resources, improved integration of variable renewable generation, and lower electricity generation costs.

ACTION 4.3.2.2: Evaluation of enhanced market recognition for PSH.
Rules for scheduling and compensation of generating resources in electricity markets are not generally favorable for energy storage technologies. For instance, the scheduling and market settlement procedures for PSH and other storage technologies fail to take into account the unique nature of these technologies as both generation and demand technologies. Also, the inadequate valuation and compensation of PSH plants for many system-wide services make it hard for project developers to financially justify new PSH projects. At a minimum, this action would entail a coordinated review with entities having the ability to drive change (e.g., owners, regulators, RTOs/ISOs) and a resulting report identifying services that are not being fully or fairly rewarded. The report would include recommendations regarding development of adequate revenue mechanisms that could properly compensate PSH units for the full suite of services they provide.

ACTION 4.3.2.3: Investigate potential for RTOs and ISOs to provide input on scheduling PSH units in electricity markets.
In most RTOs and ISOs, PSH plants provide separate generation and demand bids into day-ahead and hour-ahead markets. Because each PSH plant typically bids into the market individually, there can be a lack of wider system perspective and coordination. Investigating the potential for system operators to provide input on scheduling PSH resources as part of the overall system optimization could help maximize the system benefit created by the energy and other ancillary and essential reliability grid services that PSH plants produce and could lower overall electricity generation costs. This action can include examining and reporting on how PSH plants have historically been handled and scheduled in different ISO/RTOs. This action could also include recognizing that ISO/RTO system operators would not control PSH plants, but rather provide input for their scheduling (e.g., PSH owners would need to retain full control in order to meet other requirements, such as FERC license requirements).

ACTION 4.3.3: *Remove Barriers to the Financing of Hydropower Projects.*

Rationale for Actions

Electricity market conditions are such that few utilities sign power purchase agreements for terms up to or beyond 20 years, which is well short of the 50-year-plus operational life of hydropower assets. The resulting lack of guaranteed revenue over the long life of a hydropower project limits the availability of conventional (i.e., commercial bank) financing sources, as conventional energy sector investors will not provide lower cost debt financing beyond the life of guaranteed revenue streams. Additionally, a lack of standard reporting and loan documentation increases the transaction and due diligence costs of financing site-specific hydropower projects. Regulatory and permitting uncertainty is also an important factor that can affect or delay financing. These problems are particularly acute for developers of smaller projects, because it can be more challenging to obtain lower levels of financing (i.e., $50 million or less). Traditional investors and lenders tend to make financing more available for larger scale projects with funding requirements in the hundreds of millions. As such, the pool of available financing for small hydropower projects may be limited. Additionally, incentives at the state or local level could provide financial support for small projects that have difficulty acquring traditional financing. Although power purchase agreements for 50 years or more would not be likely on a regular basis for any project, having certainty for a longer revenue stream would be beneficial. Financing for large-scale projects (i.e. $1 billion or more for a merchant PSH project) also faces challenges, such as high upfront risk and long development timeframes. Risk-sharing mechanisms and partnerships warrant an investigation relative to financing and ensuring maximum ratepayer value.

ACTION 4.3.3: Remove Barriers to the Financing of Hydropower Projects The economics of developing new hydropower projects can be improved by facilitating access to low-cost capital and investors with long-term perspective.	
Deliverable: Educational tools, financial instruments, documentation, and outreach activities that improve access to low-cost, long-term financing for small and independent developers and that address small hydropower financing issues. **Impact:** Dramatic reductions in the effective cost of bringing new hydropower projects to commercial operation.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** All actions in this section can begin immediately and simultaneously.

Action	Deliverable	Impact
Action 4.3.3.1 Standardize documentation for hydropower projects.	Standardized hydropower project documentation, e.g., power purchase agreements, leases, cost and performance reporting.	Reduced due diligence costs (mainly for small developers) and increased confidence on the part of financial institutions regarding investment in hydropower projects.
Action 4.3.3.2 Conduct outreach to municipalities.	Outreach and education programs.	Increased access to lower cost, longer term public capital, resulting in reduced cost of financing for hydropower projects.
Action 4.3.3.3 Conduct outreach to institutional lenders and investors.	Outreach and education programs; possible new financial instruments.	Increased access to lower cost, longer term capital, resulting in reduced cost of financing for hydropower projects.

ACTION 4.3.3.1: Standardize documentation for hydropower projects.
The preparation of documentation, such as power purchase agreements, leases, and other contracts, for hydropower projects (as well as other renewable energy resources) is typically done on an ad-hoc, project-by-project basis. This lengthens the development process and increases the cost of due diligence by financial institutions. This in turn makes investment more difficult, particularly for smaller projects with lower dollar values at stake. Standardized documentation developed collaboratively with investors—inclusive of research and use of existing documentation and mechanisms—can facilitate timely, less expensive evaluation of projects. This would be expected to decrease costs and development time directly for small developers, while lowering the barriers to investment by financial institutions. This action includes assessing potentially applicable examples of standardized documentation (as long as that information can be reasonably shared or exchanged) in other energy generation industries.

ACTION 4.3.3.2: Conduct outreach to municipalities.
Municipalities can have access to lower cost capital (such as tax-exempt bonds) and planning horizons that align well with the long productive lifetime of hydropower projects. Creative financing arrangements, such as sale and lease-back arrangements with municipalities and local public power utilities, can extend the availability of this low-cost and potentially long-term financing to privately developed projects. The long life of hydropower assets also generally provides long-term stability in the form of steady energy costs. Outreach activities such as educational documents, media campaigns, workshops, and developer-municipality "matchmaking" could ultimately lower the cost of capital for many new hydropower projects. The standardized documentation from Action 4.3.3.1 could flatten the learning curve for municipalities that might invest in hydropower. Additionally, streamlined or simplified public-private partnerships or other procurement mechanisms can be examined for their applicability to conventional hydropower and PSH development.

ACTION 4.3.3.3: Conduct outreach to institutional lenders and investors.
Institutions such as pension funds, banks, and insurance companies seek long-term stable returns on their investments. This long-term view is highly complementary to the long asset life, comparatively lower risk profile, and proven track record of hydropower projects. However, these same organizations are generally attracted to large investment opportunities in the hundreds of millions of dollars. Engagement with this subset of financial institutions can serve a mutual educational purpose and can help hydropower developers begin to identify the information, project features, and investment mechanisms (e.g., securitization or large, multi-project portfolios) necessary to increase the willingness of institutional investors to finance hydropower.

ACTION 4.3.4: *Improve Understanding of and Eligibility/Participation in Renewable and Clean Energy Markets.*

Rationale for Action

The ability of hydropower facilities to participate in the nation's various renewable and clean energy markets varies widely from state to state and efforts to improve and expand overall recognition and eligibility of hydropower in these markets can result from this action. In addition, initiatives such as the U.S. Environmental Protection Agency's Clean Power Plan will offer states the additional opportunity to incentivize hydropower and participate in state trading programs. Knowledge of the rules and administrative requirements needed to effectively and fully participate in state and federal clean energy market programs requires clear and understandable guidelines for a wide range of business and hydropower ownership types.

ACTION 4.3.4.1: Create toolkits to assist developers (particularly smaller developers) in understanding what types of renewable and clean energy markets are available, how their projects can qualify, and how to overcome specific barriers.
The complex eligibility rules surrounding hydropower's participation in renewable and clean energy markets can be difficult for smaller developers to navigate. State- and federal-level policy rules should

ACTION 4.3.4: Improve Understanding of and Eligibility/Participation in Renewable and Clean Energy Markets Creating a set of tools to better understand policy rules and market eligibility can help reduce confusion and point developers towards the highest value markets for which their hydropower projects are eligible.		
Deliverable: Transparent standards by which hydropower of all sizes can participate in clean energy markets, replacing existing ad hoc eligibility standards. **Impact:** Improved economics of sustainable hydropower projects through the provision of revenue from environmental markets.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** Toolkits to assist developers in understanding renewable markets can be developed immediately to allow developers to participate in such markets in the near future.	
Action	**Deliverable**	**Impact**
Action 4.3.4.1 Create toolkits to assist developers (particularly smaller developers) in understanding what types of renewable and clean energy markets are available, how their projects can qualify, and how to overcome specific barriers.	Developer toolkits.	Increased participation of developers in renewable and clean energy markets.

be documented and compiled into toolkits that can be used by smaller hydropower developers. This centralized repository of market eligibility information (which could also include information on potential off-takers) can help reduce confusion and point smaller developers towards the highest value markets for which their hydropower projects are eligible. This effort can also help improve and expand overall recognition and eligibility of hydropower in such markets.

4.4 Regulatory Process Optimization

Existing regulatory processes are intended to ensure that hydropower development is carried out responsibly and consistently. The regulatory processes for hydropower have value to stakeholders to the extent that desired outcomes are achieved or enabled. Those outcomes can include stewardship of natural resources, energy development, socioeconomic improvements, and many other water resource uses, which vary from region to region.

As with many regulatory processes, the broad spectrum of the hydropower regulatory environment has evolved over time rather than having been planned and implemented at one point in time as a unified, fully efficient, integrated process. As a result, hydropower project developers face a complex set of approval and compliance processes administered by various authorities including FERC, federal and state resource agencies, local governments, and tribes. In some cases, agencies operate on an independent schedule outside of the FERC process as required by or allowed under their statutory authority, such as the U.S. Army Corps of Engineers' Section 404 and 408 regulatory processes. Additionally, certain agencies have mandatory conditioning authority. While this complexity can ensure that important potential impacts are assessed and mitigation measures are implemented, it also results in uncertainty in study and administrative costs and schedules that can make it challenging to undertake, finance, and complete projects. The actions described in this section are intended to assist parties in navigating regulatory processes, and not to propose additive components, requirements, or modifications to regulations. The final action proposes evaluating the process from a process improvement perspective, identifying opportunities to make steps more efficient while also being consistent with environmental protection statutes and equally protective of affected resources.

Considering the collective regulatory experience from multiple perspectives may identify opportunities to enhance the effectiveness of the process in terms of both project development and environmental stewardship. Costs, risks, and implementation timeframes may be reduced by providing stakeholders with an increased knowledge base, easier access to information relevant to their projects, and increased capabilities for collaboration. Achieving the same or improved outcomes more quickly and predictably will reduce the risks and costs to developers and encourage investment in new projects by the financial community, without a reduction in environmental protection. Section 2.4.6 in Chapter 2 of the *Hydropower Vision* provides examples of process enhancements that have had positive effects on licensing costs or timelines without changes in regulations.

Because data collection associated with project licensing and relicensing is ultimately the responsibility of hydropower owners, these processes may occur in isolation from others who are carrying out similar efforts. While collaborative groups do share best practices and successes in safety, design, operations, and maintenance,[10] there are opportunities to do more to identify and share best practices for informing and navigating the overall regulatory process.

For example, scientific studies carried out as part of the regulatory process are site-specific, but they may reveal methodologies or findings that could be used by the technical practitioners in other processes to develop answers more efficiently. Benefits in environmental and energy generation performance could be realized if this cutting-edge science were better disseminated and integrated into the the regulatory process. Greater adoption of scientific advances could also inform policy considerations, as has happened in the past with improvements in hydropower operations to meet environmental objectives. For example, Wanapum Dam in eastern Washington on the Columbia River is using best available science to establish fish passage solutions that require less water to meet FERC's fish survival requirements than was required using traditional voluntary spill; sustainability objectives are being addressed with minimal impact on generation capacity. Providing specific actionable alternatives through the *Hydropower Vision* roadmap has the potential to impact other projects similarly in the future. With the establishment of a unified and comprehensive mechanism(s) for collaboration and dissmenination of the best available science, mutual benefits could be realized for participants and regulators by increasing approval process efficiency.

ACTION 4.4.1: *Provide Insights into Achieving Improved Regulatory Outcomes.*

Rationale for Actions

The success of hydropower development and energy production, and the role of regulation in that success, are matters of perspectives, values, science, and technology. While future hydropower development and regulation are uncertain and may occur differently than in the past, the historical record can be useful to reveal how desirable and undesirable outcomes—subjective and objective—are correlated with specific practices during regulatory processes. The voluminous public records of hydropower regulation (e.g., FERC's eLibrary, documentation from federal hydropower agencies related to the National Environmental Policy Act) are the sources for such assessments. Disparate perspectives and values of stakeholders embedded in this historical record can be identified, analyzed, and used to classify outcomes according to rubrics for issues such as environmental and human health, environmental disturbance and alteration, economic well-being, cost of energy, energy security, and quality of life. The investigative, assessment, and decision-making processes embedded within this historical record can also be characterized and classified to establish a recurring set of practices that can be correlated with these outcomes.

The objective of this *Hydropower Vision* roadmap action is not to subjectively characterize specific historical development as good or bad overall; rather, it is to provide factual analyses and a summary, based

10. Examples include the National Hydropower Association's Operational Excellence, the Electric Power Research Institute, the Centre for Energy Advancement through Technological Innovation, and the Hydro Research Foundation.

on past experience, of the outcomes stakeholders can expect if certain practices are followed in hydropower regulatory processes. The products of this action could be a set of definitive and peer-reviewed reports, backed by a searchable catalog of hydropower development experiences, that identify multiple indicators of success, identify best (and worst) practices, and quantify the impacts of employing those practices in the regulation of hydropower development and operations. With this information in hand, participants in regulatory processes can choose to implement validated best practices tied to well-defined measures of success and avoid practices that are unlikely to yield benefit. This will provide more consistency, certainty, and clarity of actions, decisions, and outcomes within regulatory processes.

ACTION 4.4.1.1: Develop indicators to measure outcomes of hydropower regulatory processes. Stakeholders of hydropower development and operations have different perspectives and values that give rise to different objectives, priorities, and measures of success. Universal agreement on a limited and prioritized list of objectives and associated indicators of success in achieving those objectives is unrealistic. A pragmatic and useful activity would be to assemble—through comprehensive dialogue among stakeholders—a key set of candidate objectives, success indicators, and failure indicators. This effort would be aligned with and contribute to plans for measurable performance in permitting of infrastructure through environmental and social outcome metrics as called for by the White House under Executive Order 13604 in March 2012 [8]. Objectives and indicators are likely

ACTION 4.4.1: Provide Insights into Achieving Improved Regulatory Outcomes
Identifying and disseminating best practices can help lead to successful energy, environment-related, and socioeconomic outcomes of the hydropower regulatory process.

Deliverable: A series of definitive and peer-reviewed reports, backed by a searchable catalog of hydropower development experiences that identifies indicators of success from multiple perspectives, identifies best (and worst) practices to be encouraged (and avoided), and quantifies the impacts of using best practices to participate in the regulation of hydropower development and operations. **Impact:** Ability of all participants in regulatory processes to make use of validated best practices tied to well-defined measures of success; more consistency and certainty of actions, decisions, and outcomes, with the goal of further increasing the sustainability of hydropower.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** The development of indicators to measure outcomes of regulatory processes (4.4.1.1) could begin immediately and would end when those indicators are published. Cataloging the relationships between practice and outcome in regulatory processes (4.4.1.2) would begin immediately and would end with the delivery of the catalog. Characterization, validation, and dissemination of successful practices (4.4.1.3) would grow out of actions 4.4.1.1 and 4.4.1.2 and continue until those successful approaches are published.

Action	Deliverable	Impact
Action 4.4.1.1 Develop indicators to measure outcomes of hydropower regulatory processes.	Peer-reviewed technical publications that evaluate various indicators of success in meeting the objectives of hydropower regulatory processes.	Greater clarity and consensus in discussions among hydropower regulatory stakeholders.
Action 4.4.1.2 Classify and catalog the relationships between practice and outcome in hydropower regulation.	Searchable catalog, tied to existing databases, of hydropower regulatory experiences enabling investigation of relationships between outcomes and facility, developmental, and regulatory process characteristics.	Data-driven insight and decisions about how to most effectively accomplish hydropower development and relicensing within regulatory processes.
Action 4.4.1.3 Characterize, validate, and disseminate successful practices.	Peer-reviewed technical publication(s) describing the empirical evidence on stakeholder use of best practices.	Evidence-based choices by hydropower developers, owners/operators and regulators on how to scope and execute their work while complying with regulatory processes.

to address issues such as environmental and human health, environmental disturbance and alteration, economic well-being, cost of regulation or compliance, cost of energy, energy security, and quality of life. These would then be exercised against several historical regulatory test cases to determine which of the objectives or indicators (1) are implementable based on site-specific information in the historical record; (2) provide useful indications of success; and (3) would enhance decision making in the regulatory process.

ACTION 4.4.1.2: Classify and catalog the relationships between practice and outcome in hydropower regulation.
With a useful set of indicators for assessment, a comprehensive and consistent assessment of a representative sample of outcomes (under existing regulations) becomes feasible. Coordinated research among stakeholders can extract from the historical record a database of regulated hydropower projects, regulatory actions, and outcomes suitable for formalized analyses. Such a database could draw from and contribute to the Federal Infrastructure Permitting Dashboard,[11] established to facilitate early collaboration of infrastructure project reviews; synchronize, align, and reduce time associated with permitting and environmental review timelines, when appropriate and practicable; and increase accountability by making more project information available to the public. Combined with increasing availability of hydropower facility and footprint attribute information (i.e., physical, electro-mechanical, ecological, and socioeconomic characteristics), this information can support studies that track trends of the relationships between practice and outcome in hydropower regulation. It should be noted that not all data are public and that the usefulness of such a database must be demonstrated in order to encourage greater information sharing.

ACTION 4.4.1.3: Characterize, validate, and disseminate successful practices.
A comprehensive database of regulatory outcomes and the factors that influence those outcomes will enable analyses and yield findings that can underpin regulatory best practices. Examples of candidate best practices could include more emphasis on multi-facility or basin-scale scoping for studies and decision making; explicit incentives for collaboration among disparate stakeholders during the regulatory process; use of standardized designs; and strategies for dealing with the schedule and cost uncertainties (from the developer perspective) engendered by aspects such as mandatory conditioning or potentially redundant/overlapping process characteristics. Within this study effort, researchers can also investigate the variability of outcomes of regulatory processes to understand which factors are most responsible for variation in regulatory outcomes and which led to the most sustainable outcomes. In this way, hypothesized best practices can be validated and distributed, ultimately resulting in a more efficient execution of the regulatory process.

ACTION 4.4.2: *Accelerate Stakeholder Access to New Science and Innovation for Achieving Regulatory Objectives.*

Rationale for Actions

Science is expected to continue to add to the understanding of ecological response, socioeconomic response, and human reaction to actions such as hydropower development and operation, for both new and existing technologies. Science and technology advancements may also improve the feasibility and robustness of remote sensing and field data collection needed for greater understanding of natural and human systems responses to hydropower development and operations. Incorporating new science and technology for use in specific regulatory processes could contribute to better outcomes.[12] However, these developments may also lead to increased costs, resource requirements, and risks for stakeholders that must be considered. New science may also present new uncertainty, which can translate to increased risk for decision makers. Collaborative frameworks are needed to pilot the use of new science and technology in regulatory process compliance, assess the costs and benefits of such innovative pilot efforts, refine the science and technology, and disseminate the results and guidance to a wide audience of stakeholders nationwide.

11. Available online at *https://www.permits.performance.gov/about.*

12. DOE shares new science information with stakeholders through reports and inter-agency collaborations such as the Federal Inland Hydropower Working Group.

ACTION 4.4.2: Accelerate Stakeholder Access to New Science and Innovation for Achieving Regulatory Objectives

Improving the ability of stakeholders to use new science and innovation can enhance environmental outcomes; increase the value of hydropower facilities; and reduce costs of permitting, licensing, and compliance.

Deliverable: Disseminated unbiased information to stakeholders on the availability and applicability of new citable science findings and the validated performance of innovative technologies. **Impact:** Accelerated, justified, and efficient adoption of scientific developments that may improve outcomes of regulatory processes by increasing confidence in the value of innovative approaches. **Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH	**Timeframe:** The development of collaborative methodologies to accommodate competing uses for water resources (4.4.2.1) could begin immediately and end with publication. A forum of scientists, practitioners, and stakeholders to assess science and technology innovations (4.4.2.2) could be established immediately and would continue as long as needed. Creating a database of new and emerging technologies and associated studies (4.4.2.3) could begin immediately and would continue to add new technologies as they develop.

Action	Deliverable	Impact
Action 4.4.2.1 Develop and encourage the use of collaborative methodologies to accommodate competing uses for water resources.	Published research and guidelines for hydropower stakeholders who desire to use collaborative methods in complying with regulatory processes.	More efficient and less contentious pathways to regulatory outcomes.
Action 4.4.2.2 Establish a forum to assess the efficacy and usefulness of new science and technology innovations affecting environmental impact or mitigation.	An established and documented forum wherein participants collectively debate and assess the efficacy and usefulness of new science and technology innovations with the potential to influence regulatory decisions about environmental impact and mitigation.	Much of the disagreement and debates about the efficacy and usefulness of new science and technology will occur outside of and prior to a specific regulatory action.
Action 4.4.2.3 Create a database of new and emerging technologies and associated studies.	A database of performance, economics, and environmental effects of new and emerging hydropower technologies.	Faster acceptance of new technologies by the hydropower community.

ACTION 4.4.2.1: Develop and encourage the use of collaborative methodologies to accommodate competing uses for water resources.

To participate most effectively in decision making, institutional and individual stakeholders should have a fact-based understanding of the relationships between decisions and outcomes. In an ideal forum, they would also have a thorough understanding of the myriad physical, institutional, regulatory, and legislative constraints that limit alternatives for managing hydropower development and associated impacts. Research can draw from existing sources pertaining to a wide array of forums in which decisions are made, or new research could be undertaken to reveal how stakeholders assimilate such complex information, understand motivations, develop trust, negotiate compromises or solutions, and make decisions within their organizations and in collaboration with other institutions. Additional research may provide methodologies for communicating and explaining complex information to stakeholders. It may also provide evidence that greater understanding among stakeholders can improve regulatory decision making and compliance by more quickly identifying alternatives that meet constraints and best deliver on multiple objectives.

ACTION 4.4.2.2: Establish a forum to assess the efficacy and usefulness of new science and technology innovations affecting environmental impact or mitigation.

Regulatory processes for hydropower aspire to use the best available science as well as transparency and robust decision rationale. However, the realities of gaps in science—along with limited time, resources, and information—can result in outcomes that are unsatisfactory from the perspectives of some stakeholders. An independent multi-stakeholder forum of experts, functioning outside the jurisdiction of and disinterested from any specific regulatory process or agency, may be able to vet new science (e.g., peer-reviewed journal publications), transparently debate the importance and applicability of that science to classes of water resources and ecological problems, and accelerate the piloting and adoption of new science into specific hydropower development contexts. Such a forum can enable scientific debate to occur unconstrained by the schedule of specific regulatory processes, but would make the results of such debates available to regulatory participants.[13] Recognizing that "one size does not fit all" will be important with respect to assessment of new science or studies not directly related to a specific project.

ACTION 4.4.2.3: Create a database of new and emerging technologies and associated studies.

New or emerging technologies may have characteristics that enhance their ability to generate power, improve environmental conditions, or achieve economic viability. Those benefits will only be realized if those technologies are actually identified, selected, and implemented. To accelerate the adoption of promising technologies, a database can be created to capture studies that demonstrate how they have performed from engineering, economic, and environmental perspectives. That body of knowledge could assist developers in objectively selecting equipment that is likely to meet their needs, regulatory requirements, and the objectives of other stakeholders. Regulators and other stakeholders would be able to access the database to make their own evaluations of how technologies are likely to perform.

ACTION 4.4.3: *Analyze Policy Impact Scenarios.*

Rationale for Actions

Decision makers in government, industry, non-governmental organizations, and the general public at the state and federal levels can benefit from analyses and prognostics that integrate modeled responses of markets, power systems, other infrastructure, river systems, ecosystems, water systems, and socioeconomic conditions with policy alternatives. There is a need for tools and methodologies to aid in evaluating potential impacts of policy options on a variety of factors. These tools could be used to assess proposed regulatory processes for hydropower licensing, new understanding of environmental impacts, new legislation relevant to energy and water systems, availability of new technology to mitigate impacts of hydropower development or reduce costs of deployment, and incentives for deployment of hydropower and other energy generation technologies. Modeled scenarios may need to include multiple objectives at the facility, river system, and power system scales, as well as aggregate effects of those multiple objectives at regional and national scales. Analyses and prognostics should reveal regional variations of responses and illustrate how such responses may vary through time.

ACTION 4.4.3.1: Develop a coordinated set of models that can reveal the national, regional, and local effects of policy alternatives.

The *Hydropower Vision* draws heavily on DOE's Regional Energy Deployment System (ReEDS) model to analyze hydropower development scenarios under a least-cost objective for meeting future demands for electricity. The ReEDS model does provide a set of impacts as a consequence of least-cost deployment, but stakeholders and decision makers may desire more information about deployment scenarios based on multiple objectives (e.g., a to-be-defined sustainability objective and a least-cost objective). This added detail will likely require additional modeling and analysis tools that are compatible, complementary, and even coupled with the ReEDS model. As was the case with ReEDS, any of these new models would need to be validated before use. While the least-cost objective is universal for all regions of the United States, other objectives (e.g., sustainability or economic impact) may have regionally varying definitions, importance, and priorities, and thus require different formulations for different regions. Stakeholders could use this common model framework and develop their own objectives and scenarios to initiate

13. The National Wind Coordinating Committee (*www.nationalwind.org*) is one example of this type of forum.

discussions (as described in 4.4.3.2) regarding policy alternatives. Differing perspectives of municipal utilities, investor-owned utilities, and independent power producers also need to be considered in the analysis.

ACTION 4.4.3.2: Create a framework for developing scenarios, policy alternatives, and predicted outcomes for consideration by all stakeholders. Policy analyses require not only models but also development of possible scenarios and strategies for addressing the challenges included in those scenarios. While the *Hydropower Vision* addresses macroeconomic scenario issues such as natural gas price and availability, there are a host of other hydropower-specific challenges that will be relevant to stakeholders and decision makers since hydropower development occurs under evolving regulatory contexts. Examples include revenue and benefits of hydropower, threatened and endangered aquatic species management, and water quality management. Just as modeling capabilities need to become more refined and multi-objective, the scenarios and policies that are translated into modeled objectives, constraints, and other inputs must also be more detailed. Specific institutions and stakeholder groups will have differing priorities for scenarios and policies to be analyzed. However, such priorities can be accommodated into a transparent and common framework for defining, modeling, analyzing, and reporting the outcomes of scenarios, strategies, and policies around hydropower relicensing and new development.

ACTION 4.4.3.3: Review and report on existing regulatory process and propose potential improvements. Because the regulatory process includes agencies at both the state and federal levels, hydropower licensing processes can go beyond original estimated timelines. FERC reported on this issue in its 2001

ACTION 4.4.3: Analyze Policy Impact Scenarios

Improving the ability to assess potential impacts of policy options on markets, power systems, ecosystems, and populations—all on local, regional, and national scales—can inform decision makers.

Deliverable: An integrated capability to specify and model policy scenarios and anticipate the resulting effects on hydropower capacity, production, value, and impacts within the broad, nationwide energy context. **Impact:** Realistic projections of the possible outcomes of policy scenarios that enable regional and national decision makers and stakeholders to consider alternatives and make well-informed decisions. **Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH	**Timeframe:** Developing a coordinated set of models able to assess policy alternatives (4.4.3.1) can begin immediately and would continue until models are delivered. Creating a framework for developing scenarios, policy alternatives, and predicted outcomes (4.4.3.2) can also begin immediately. This action will evolve into ongoing application of the framework. Work can begin immediately to report on the causes of delays in the regulatory process and propose solutions (4.4.3.3) and would continue until delivery of a comprehensive report.

Action	Deliverable	Impact
Action 4.4.3.1 Develop a coordinated set of models that can reveal the national, regional, and local effects of policy alternatives.	A transparent collection of models with documentation and guidance on use, and interpretation of results for both the state and federal level.	Ability to capture full effects of policies and educate decision makers on mechanisms to achieve desired impacts.
Action 4.4.3.2 Create a framework for developing scenarios, policy alternatives, and predicted outcomes for consideration by all stakeholders.	A template, methodology, and set of scenarios that are crafted by, transparent to, and understood by hydropower development stakeholders.	Ability to address the sustainability of hydropower through multiple scenarios.
Action 4.4.3.3 Review and report on existing regulatory process and propose potential improvements.	A report presenting data on the variety of causes for regulatory process inefficiencies, with a roadmap addressing opportunities for improvement.	Catalyze changes that lead to efficiency gains in the regulatory process.

publication, *Report on Hydroelectric Licensing Policies, Procedures, And Regulations Comprehensive Review and Recommendations Pursuant to Section 603 of the Energy Act Of 2000.* This action proposes a report that would seek to update and expand on this aspect of the FERC 603 report to initiate a national dialogue to seek potential improvements. In addition to analyzing data available through FERC and other state, tribal, and federal agencies, the report would gather information from surveys and workshops conducted with the hydropower community to identify opportunities for improvement and propose potential solutions. The report would seek to catalyze changes that can lead to efficiency gains in implementation of regulatory processes.

The proposed national dialogue identified in this action could consist of a collaborative, multi-stakeholder effort led by a neutral entity such as the National Academy of Science. This effort would allow stakeholders to collaboratively brainstorm ideas for achieving the process improvement opportunities with the greatest impact, absent a specific initiative to pursue any of the ideas. Ideas with broad support might be further discussed in terms of how to implement them. The purpose of identifying the highest opportunities for process efficiency improvement and ideas as to how they might be achieved is to inform stakeholders, regulators, and policy makers as to where to focus efforts to have the greatest impact on improving process efficiency.

ACTION 4.4.4: *Enhance Stakeholder Engagement and Understanding within the Regulatory Domain.*

Rationale for Actions

The crux of this action is to ensure that all stakeholders have knowledge and understanding necessary for them to have trust and participate effectively in hydropower development, decision making, and regulatory processes. Given more than 100 years of hydropower development, there is a wealth of information available from which lessons can be learned, but much of that information is not generally accessible or is not cataloged in ways that make it readily available to inform new undertakings.

ACTION 4.4.4.1: Develop an enhanced regulatory information portal.

FERC's website features extensive information with respect to the hydropower industry, including specifics on licensing/relicensing, compliance, administration, and actions that need to be taken.[14] This information from FERC is beneficial to novice and expert users alike. However, since hydropower licensing involves many entities beyond FERC, it may be beneficial to either build upon what FERC has established or develop a new information portal that addresses not only FERC's processes, but also offers links and information with respect to the treatment of hydropower in each U.S. state (particularly if the specific project does not fall under FERC jurisdiction) and those of other federal agencies. Ideally, such a system would afford users a convenient, user-friendly portal that synthesizes regulatory requirements, processes, technical guidance, and findings from multiple jurisdictions, including FERC, the U.S. Army Corps of Engineers, Reclamation, state environmental offices, and state and federal natural resource agencies. The best practices from Action 4.4.1 could eventually be integrated into this portal. The beginnings of this action are reflected in the RAPID (Regulatory and Permitting Information Desktop) toolkit[15] under development at DOE, but go beyond the scope of that project.

ACTION 4.4.4.2: Facilitate access to relevant historical regulatory information.

While hydropower development is often characterized as a site-specific undertaking, there are geospatial, ecological, socioeconomic, and political themes that are common to groups of development projects. The commonalities can be leveraged to improve effectiveness and efficiency in designing projects and mitigation strategies for sustainable development and operations (e.g., less novel or extensive studies needed

14. For example, *http://www.ferc.gov/industries/hydropower.asp*
15. RAPID is available via OpenEI at *http://en.openei.org/wiki/RAPID*

ACTION 4.4.4: Enhance Stakeholder Engagement and Understanding within the Regulatory Domain
Activities under this action will ensure all stakeholders have access to the knowledge and experience necessary to participate effectively in planning, decision making, and regulatory processes.

Deliverable: A user-friendly portal synthesizing hydropower regulatory requirements and processes; a hydropower development knowledge management system for experts; and tools and guidance for enhancing stakeholder understanding of complex water and energy issues. **Impact:** More robust outcomes, reduced costs, greater efficiency, and better engagement from stakeholders in hydropower development and regulation. **Key Objectives:** Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH	**Timeframe:** Work to develop an enhanced regulatory information portal (4.4.4.1) can begin immediately and would end with the delivery of that portal. Efforts to facilitate access to relevant historical regulatory information can begin immediately (4.4.4.2) and would continue until a comprehensive knowledge management system is delivered. Development of advanced methods of communicating process complexities to non-technical stakeholders (4.4.4.3) can begin soon and would end with the delivery of guidelines, formats, tools, and facilities.

Action	Deliverable	Impact
Action 4.4.4.1 Develop an enhanced regulatory information portal.	A convenient, user-friendly portal that synthesizes regulatory requirements and processes from multiple jurisdictions, with specific guidance for novice developers.	Reduced cost and less effort required to parse requirements and gather information.
Action 4.4.4.2 Facilitate access to relevant historical regulatory information.	A comprehensive knowledge management system for hydropower development, with advanced geospatial registration and thematic indexing of information content.	Ability for expert stakeholders to quickly and efficiently locate, within the national history and experience, relevant information for a specific proposed hydropower development.
Action 4.4.4.3 Develop advanced methods of communicating process complexities to non-technical stakeholders.	Specific guidelines, formats, software tools, and facilities for conveying water management and power system complexities and scenario outcomes to non-technical stakeholders.	Ability for non-technical stakeholders to better understand issues, develop trust in decision-making processes, and become more effective in helping to craft solutions.

to satisfy regulators). However, the sources of relevant information are many and varied, which makes searching and assimilating data from those sources difficult even for expert analysts, designers, and regulators. A comprehensive knowledge management system for hydropower development leveraging DOE's investment in the National Hydropower Asset Assessment Program,[16] which has implemented advanced geospatial registration and thematic indexing of a robust set of hydropower information, would address this challenge. Other examples of knowledge discovery efforts include the DOE Bioenergy Knowledge Discovery Framework,[17] and Tethys[18] for marine and offshore wind energy knowledge management.

ACTION 4.4.4.3: Develop advanced methods of communicating process complexities to non-technical stakeholders.

Technical complexity can be a barrier to effective and sustained participation by non-technical stakeholders in hydropower development and regulatory processes. River systems, power systems, and ecosystems include network complexities, dynamics, and tradeoffs that can confound even technical analysts in the short term. Enhanced capabilities to visualize and communicate those complexities in ways that are intuitive to stakeholders may lead to greater engagement, trust, and contributions to solutions from stakeholders. Conversely, the absence of understanding

16. More information about the National Hydropower Asset Assessment Program is available at *http://nhaap.ornl.gov/*.
17. More information about the Bioenergy Knowledge Discovery Framework is available online at *https://www.bioenergykdf.net/*.
18. More information about Tethys is available at *http://tethys.pnnl.gov/*.

may lead stakeholders to discount objectives and impacts, and can diminish their trust and effective engagement. Such capabilities can be provided through a combination of specific guidelines, formats, software tools, and visualization facilities for conveying water management and power system complexities and scenario outcomes to non-technical stakeholders. An example of this that proved successful was DOE's Basin Scale Opportunity Assessment in Oregon's Deschutes Basin [9]. This assessment used a suite of visualization tools to communicate complex issues to a diverse set of stakeholders so that they might make informed decisions regarding trade-offs in the Basin.

4.5 Enhanced Collaboration, Education, and Outreach

The hydropower community is long-standing and complex, comprising many types of companies, organizations, and agencies, each with unique interests, perspectives, and operating mandates. Although the community has continued to work toward individual and common goals, such as regulatory process efficiency and greater environmental sustainability, there are significant opportunities for improved communication and collaboration. Realizing these opportunities can provide mutual benefit within the hydropower community as well as present the value of hydropower to others, including those who rely on hydropower for clean, renewable energy or to support the continued development of variable renewable generation resources like wind and solar.

To increase acceptance of hydropower's benefits and impacts, objective information regarding the technology as an established, reliable, low-carbon renewable energy source, its importance to grid stability and reliability, and its ability to support variable generation should be articulated and disseminated. Since discussions of renewable energy are closely linked to environmental impact, hydropower information should provide fact-based details regarding environmental considerations and existing regulations, and how projects are designed and operated to comply with them in an environmentally responsible manner. Whether or not hydropower (either new or existing) should be included or excluded from renewable or clean energy incentive programs or market compensation mechanisms is dependent upon the goals of specific policies and their related programs.

The fleet of federal hydropower projects produces nearly half of all domestic hydropower generation. A wide range of data exists on the performance, characteristics, and value of these assets. Given the varied objectives of federal hydropower projects, there are different levels of investment that may be applied to maintaining and upgrading these assets for energy generation. To help inform investment decisions, the available data could be compiled to better quantify the full range of contributions and the long-term potential of the federal fleet to help meet the nation's renewable energy supply and grid reliability needs.

Although there are collaborative groups and initiatives—such as those of the International Centre for Energy Advancement through Technological Innovation—that share best operating practices and performance benchmarks, these efforts are not always fully available to the broader hydropower community. Hydropower facility owners and developers could benefit from a national-scale effort to identify and regularly update best practices (including an environmental stewardship component) for maintaining, operating, and constructing generation facilities. Investigation and implementation of ongoing best practices programs and related benchmarking can enable the industry to achieve its full potential as a reliable and low-cost renewable energy source.

To both maintain the industry and have it grow to the potential levels of deployment identified in the *Hydropower Vision,* the United States will need to sustain and increase its qualified, well-trained workforce to maintain and build new hydropower plants. Many of the individuals with the knowledge of how to most effectively design, construct, and operate hydropower plants are nearing retirement. To motivate younger workers to enter the field, hydropower-specific curricula can be implemented within vocational and university programs for students interested in technical skills, engineering, and development of renewable energy. Workforce-needs assessments tied to potential industry growth scenarios would provide baseline data on numbers of required workers with specific skill sets. For detailed information on the hydropower workforce, see Section 2.8 in Chapter 2.

ACTION 4.5.1: *Increase Acceptance of Hydropower as a Renewable Energy Source.*

Rationale for Actions

The goal of this action is to articulate and disseminate objective information regarding hydropower as an established and reliable, low-carbon, renewable energy source; its importance to grid stability and reliability; and its ability to support variable generation. This includes information on its existing and historical contribution, as well as its future potential. Discussions of and objectives for clean, renewable energy are linked to considerations of effective environmental stewardship, including avoided or mitigated impacts to affected aquatic resources or impacted lands. This action should highlight hydropower advancements that have been made in addressing environmental considerations, existing environmental regulations with which hydropower projects must comply, and the ongoing need for individual hydropower projects to be designed and operated in as environmentally responsible a way as possible if net-positive clean energy benefits are to be realized.

ACTION 4.5.1: Increase Acceptance of Hydropower as a Renewable Energy Resource

Demonstrating and communicating that hydropower is a core renewable energy source can both increase public understanding and encourage inclusion of hydropower in clean energy planning and markets, as appropriate.

Deliverable: Publication and communication of data and reports highlighting hydropower's benefits as a renewable energy resource as well as how hydropower can be designed and operated within sustainability principles to supply low-carbon energy. **Impact:** General public awareness and acceptance, increased eligibility for energy credits, new low-impact hydropower development.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** The activities in this section could begin as soon as possible. Actions 4.5.1.1 and 4.5.1.2 would be ongoing, while action 4.5.1.3 would be completed when an assessment study is published.

Action	Deliverable	Impact
Action 4.5.1.1 Conduct outreach and education on hydropower as a renewable energy resource.	Fact-based information disseminated via communication initiatives.	Public, stakeholder, and policy maker awareness and acceptance.
Action 4.5.1.2 Conduct outreach and education regarding the environmental and social considerations of hydropower projects.	Fact-based information disseminated via communication initiatives.	Improved stakeholder perception of hydropower and closed-loop PSH in an environmental context.
Action 4.5.1.3 Assess the inclusion of hydropower in renewable energy markets and incentive programs.	Publication of an assessment study and related workshops.	Refined understanding of whether or when hydropower can be included effectively in broad renewable energy incentives or standards.

Dissemination of information can support the acknowledgement of hydropower as a renewable energy source and, as such, should be considered in clean energy planning efforts. Whether or not hydropower (either new or existing) should be included or excluded from renewable or clean energy incentive programs or market compensation mechanisms is dependent upon the goals of specific policies and their related programs.

ACTION 4.5.1.1: Conduct outreach and education on hydropower as a renewable energy resource.
Outreach should be conducted to increase awareness and acceptance of hydropower's renewable energy attributes. This outreach could share fact-based information and science-based analysis to inform the general public, stakeholders, and policy makers. This outreach can be implemented through published reports, academic channels, webinars, and educational websites, as well as via in-person meetings with decision makers.

ACTION 4.5.1.2: Conduct outreach and education regarding the environmental and social considerations of hydropower projects.
This action will raise general awareness of the environmental and social considerations to be addressed in all new hydropower development and existing project modernization, in accordance with existing regulations. This action requires conveying the environmental priorities and challenges, along with appropriate and adequate mitigation techniques, to a range of stakeholders. To facilitate this process, information should be compiled into digestible formats that incorporate examples and success stories, and made available through channels such as public meetings, municipalities and other public agencies, advertisements or service announcements, social media, websites, and fact sheets.

ACTION 4.5.1.3: Assess the inclusion of hydropower in renewable energy markets and incentive programs.
To fully understand the existing position of hydropower in renewable energy markets, it is necessary to conduct a full inventory and analysis of renewable energy incentives such as renewable portfolio standards. This study will include assessing whether and why hydropower is or is not considered a renewable technology in each evaluated market, and the impact of renewable energy incentive programs on the growth of hydropower relative to the growth of other technologies. This study can help clarify commonly misunderstood or confusing topics, such as whether a technology needs to be new to qualify as renewable. It can also provide industry and policy makers with a deeper understanding of key factors influencing whether hydropower is, or could be, included to aid in achieving the objectives of such programs or standards. It may include recommendations for increasing the effectiveness and consistency of approaches between incentive programs with similar objectives.

ACTION 4.5.2: *Compile, Disseminate, and Implement Best Practices and Benchmarking in Operations and R&D.*

Rationale for Actions

A retrospective benchmarking study of hydropower fleet reliability and efficiency can support identification of the leading performance indicators as well as shortfalls in performance, including those related to environmental and social objectives. Several hydropower industry groups have developed best practices for various aspects of the business, but no single industry group has developed or compiled a complete library of these documents. This action will identify best practices that have enabled top performance—including operational, maintenance, environmental mitigation, and water management practices— as well as practices that are needed, including steps for their development and dissemination. Formalized cataloging of best practices can enable more efficient hydropower planning and allow the industry to transfer such knowledge to the future workforce.

ACTION 4.5.2: Compile, Disseminate, and Implement Best Practices and Benchmarking in Operations and R&D

Compiling and disseminating methods and best practices from leading performers in all segments of the hydropower industry can drive improvements in hydropower performance.

Deliverable: Biannual report on U.S. hydropower fleet performance; compilation of hydropower best practices. **Impact:** Lowered costs and increased revenue for hydropower facility owners and developers. **Key Objectives:** Optimization, Growth, Sustainability	**Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** The actions in this section are near term and assumed to be sequential. Actions can begin as soon as possible and continue until objectives are met.

Action	Deliverable	Impact
Action 4.5.2.1 Carry out a retrospective study on operational performance of the hydropower fleet.	A report to benchmark historical hydropower fleet reliability and performance, including identification of highly efficient facilities.	Increased understanding of most effective practices, which can potentially lead to improved performance, lowered costs, and increased revenue.
Action 4.5.2.2 Document and compile proven best practices, as well as processes or procedures for which best practices remain to be developed.	A publicly accessible compilation of existing and required global best practices, incorporating nonproprietary information.	Increased understanding of most effective practices, which can potentially lead to improved performance, lowered costs, and increased revenue.
Action 4.5.2.3 Document best practices to fill gaps identified in Action 4.5.2.2.	Dissemination of previously undocumented best practices.	Increased understanding of most effective practices, which can potentially lead to improved performance, lowered costs, and increased revenue.

ACTION 4.5.2.1: Carry out a retrospective study on operational performance of the hydropower fleet. Benchmarking studies can identify high-performing facilities in the hydropower industry in terms of reliability, safety, efficiency, and environmental performance. Doing so is expected to provide the analytical basis for identifying and characterizing the most effective approaches, methods, and technical solutions, i.e., "best practices." These studies can also help form a better understanding of the condition of equipment, the future for predictive maintenance and failures, and the impacts of operating equipment in innovative ways in order to respond to increasing amounts of variable generation in the grid.

ACTION 4.5.2.2: Document and compile proven best practices, as well as processes or procedures for which best practices remain to be developed. Certain best practices have been previously identified and documented by hydropower industry groups. This action will entail reviewing those practices in the context of the data gathered in Action 4.5.2.1 and developing a list of additional processes and procedures that lack established best practices in order to identify gaps. A publicly accessible compilation or library of existing and required best practices would then be established, incorporating nonproprietary information for use by existing facilities and personnel. The information can also be used to plan future hydropower and to train the future hydropower workforce.

ACTION 4.5.2.3: Document best practices to fill gaps identified in Action 4.5.2.2. Characterization and dissemination of previously undocumented best practices to fill gaps identified in Action 4.5.2.2 can provide the industry with a complete set of best practices for developing, maintaining, and operating hydropower facilities.

ACTION 4.5.3: *Develop and Promote Professional and Trade-Level Training and Education Programs.*

Rationale for Actions

Hydropower owners/operators will need to replace retiring hydropower workers with employees who have knowledge of hydropower, its characteristics, state-of-the-art practices, and developing trends and opportunities for improvement. New workforce members should be inspired and supported by hydropower-specific learning opportunities in education programs, from pre-college to trade, to ensure and maintain a high-quality, well-trained workforce. This includes providing basic information to students and the public about hydropower as a clean, renewable resource; promoting science, technology, engineering, and math education to ensure a highly skilled workforce; training the workforce to be ready for employment so companies have assurance that applicants are prepared; and developing hydropower curricula modeled after successful initiatives in other technologies, such as the KidWind project, the DOE's Wind for Schools project, and the National Energy Education Project.

ACTION 4.5.3.1: Gather baseline data on the workforce to perform future workforce assessments.
This action entails an in-depth data-gathering effort with industry to assess the labor needs of the U.S. hydropower industry, in collaboration with current DOE efforts on assessing the hydropower workforce. To evaluate progress and future needs, workforce data under potential growth scenarios and new technology deployments will be compiled and analyzed, including analyses to gain a better understanding of the numbers and role of women, minorities, and veterans in the existing workforce. This action will be

ACTION 4.5.3: Develop and Promote Professional and Trade-Level Training and Education Program
Evaluating and developing comprehensive training and education programs, with engagement from high school to university and trade school levels, can help encourage and anticipate the technical and advanced-degree workforce required to meet the industry's long-term needs.

Deliverable: Hydropower-related science, technology, engineering, and math promotions, curricula, and other data and educational materials for education and training programs at community colleges, universities, and training facilities.

Impact: A stable, highly qualified, well-trained workforce for new and existing hydropower projects, including development, construction, O&M, and upgrades.

Key Objectives: Optimization, Growth, Sustainability

Growth Sectors Addressed: Upgrades, NPD, Conduits, NSD, PSH

Timeframe: The activities in this section begin with short-term data gathering and curriculum formulation, leading to a set of actions that must be implemented on an ongoing basis to meet industry needs.

Action	Deliverable	Impact
Action 4.5.3.1 Gather baseline data on the workforce to perform future workforce assessments.	Report on hydropower workforce needs.	Valid baseline from which to identify workforce needs.
Action 4.5.3.2 Develop hydropower-specific curricula.	Curricula specific to hydropower technology.	Inspired, informed students; increased youth interest in hydropower.
Action 4.5.3.3 Promote hydropower as a career choice.	Outreach material such as a Hydropower Career Map.	Consideration by students of hydropower as a prospective career.
Action 4.5.3.4 Encourage greater employment readiness.	Guidebook; training manual/program.	Trained, qualified workers to ensure the responsible operation and development of hydropower projects.

essential in informing future workforce investments, such as training programs, and tools and techniques to effectively capture and transfer knowledge from workers leaving the workforce.

ACTION 4.5.3.2: Develop hydropower-specific curricula.

This action will involve assessing, enhancing, and disseminating hydropower-related curricula based on the baseline data and labor needs assessment in Action 4.5.3.1. The identification of effective existing age- and level-appropriate curricula for high school, university, and trade schools could facilitate targeted education and inspire students to consider hydropower as a professional field. New curricula may also be developed under this action, which would require collaboration between industry and educational institutions to ensure appropriate messaging and the core information to be transferred. Examples of similar efforts include an initiative of the DOE's Wind Program known as Wind for Schools,[19] which reached thousands of students and teachers.

ACTION 4.5.3.3: Promote hydropower as a career choice.

This action will promote hydropower as a stable industry with solid job prospects. By applying the curricula developed in Action 4.5.3.2, students in high school, university, and trade schools can be exposed to the field of hydropower and increase the prospects of them selecting hydropower as a career. This will also inspire the next generation of thinkers and innovators to apply their knowledge and ideas to design and develop innovative hydropower technologies. A Hydropower Career Map could be modeled after the existing Wind and Solar Career Maps [10] to show students the variety of jobs available in the field of hydropower. Collaboration among academia and operators, original equipment manufacturers, and federal hydropower owners could facilitate recruiting, internship, and communication efforts for engineering and trade school students.

ACTION 4.5.3.4: Encourage greater employment readiness.

To enable the incoming hydropower workforce to be prepared for potential internships or entry-level hydropower positions, rigorous on-site training programs could be collaboratively expanded for greater industry participation in conjunction with universities, community colleges, and vocational schools. Initiatives such as the Hydro Research Foundation's Research Awards Program,[20] a DOE graduate student research program, and the Western Area Power Administration's Electric Power Training Center can stimulate interest in the hydropower field and develop a skilled hydropower workforce.

19. More information about DOE's Wind for Schools program is available at *http://apps2.eere.energy.gov/wind/windexchange/schools_wfs_project.asp*.

20. More information about the Hydro Research Awards Program is available online at *http://www.hydrofoundation.org/research-awards-program.html*.

ACTION 4.5.4: *Leverage Existing Research and Analysis of the Federal Fleet in Investment Decisions.*

Rationale for Actions

DOE's Oak Ridge National Laboratory estimates that, through hydropower power plants operated under the U.S. Army Corps of Engineers and Reclamation [11], the federal government owns and operates 49% of the installed hydropower capacity in the United States. These facilities contribute significantly to the nation's renewable electric supply. Extensive data about the asset performance and condition can continue to inform federal decisions regarding improvement and modernization of the federal fleet.

ACTION 4.5.4.1: Compile and disseminate data from existing federal reports and other reports about the condition and performance of the federal fleet.
The U.S. Army Corps of Engineers, Reclamation, and Power Marketing Administrations already provide extensive publicly available information about the performance of federal hydropower assets and the value of these contributions. These exist in the form of thorough performance goals and data, condition reports, annual financial statements, and plans for infrastructure maintenance and investment. Under this task, data from these various sources would be compiled and presented in a report for use by analysts and decision makers.

ACTION 4.5.4: Leverage Existing Research and Analysis of the Federal Fleet in Investment Decisions
Extensive research data about the federal hydropower fleet exist and should be made available in compiled form to be used by policy makers and agency staff in making federal investment decisions.

Deliverable: Reports that quantify the condition and performance of the existing hydropower fleet in contributing to the national energy supply and grid stability, including data, validated models, and potential for performance improvement. **Impact:** Well-informed decision makers able to make investment decisions regarding the existing federal hydropower fleet, including opportunities for performance and the role of the fleet in providing power and grid services in evolving energy markets.	**Key Objectives:** Optimization, Growth, Sustainability **Growth Sectors Addressed:** Upgrades **Timeframe:** This action could begin immediately. Resulting report(s) should be updated continuously as the federal fleet evolves and/or new data become available.

Action	Deliverable	Impact
Action 4.5.4.1 Compile and disseminate data from existing federal reports and other reports about the condition and performance of the federal fleet.	Aggregated list of data sources, including agency reports, financial statements, and investment plans.	Greater knowledge of information about the federal fleet and the range of actors involved in the decision making process.

ACTION 4.5.5: *Maintain the Roadmap in Order to Achieve the Objectives of the Hydropower Vision.*

Rationale for Actions

This roadmap is intended to be a living document, regularly modified using an evolving and collaborative process of periodic reviews, informed by analysis activities. Roadmap updates will be used as a means to track progress toward the objectives and principles identified in the *Hydropower Vision.* These reviews will assess effects and suggest redirection of activities as necessary and appropriate through 2050 to optimize adaptation to changes in markets and in policy or regulatory factors. As new types of projects are implemented, knowledge of environmental impacts and mitigation expands, and new industry opportunities and challenges arise, stakeholders of all types should actively engage with DOE to revisit and revise the roadmap. This will allow the roadmap to both reflect changing circumstances and maintain momentum toward a set of mutual benefits for the nation.

ACTION 4.5.5.1: Regularly update the *Hydropower Vision* Roadmap.

Accurate tracking and reporting of performance, growth, cost and pricing trends, O&M experience, technology developments, and other data provide a valuable record of progress in hydropower technology and market conditions as well as indication of issues that require attention for national benefit. This record can inform deliberations and analysis of deployment, policies, and R&D priorities, as well as provide ongoing perspective on the status of hydropower deployment in the United States relative to previously proposed roadmap actions. As such, stakeholder effort in assembling a thorough and accurate record of U.S. experience with hydropower—in all of its applications—and updating proposed actions accordingly is valuable.

ACTION 4.5.5: Maintain the Roadmap in Order to Achieve the Objectives of the *Hydropower Vision*
The *Hydropower Vision* roadmap should be regularly updated by tracking hydropower technology advancement and deployment progress, and prioritizing R&D activities.

Deliverable: Periodic publicly available reports that update roadmap actions in response to progress in technology advancement, hydropower deployment, and changes in market conditions. **Impact:** Ongoing availability of up-to-date information and recommendations to inform DOE and other stakeholders in planning and decision-making efforts.	**Key Objectives:** Optimization , Growth, Sustainability **Growth Sectors Addressed:** Upgrades, NPD, Conduits, NSD, PSH **Timeframe:** Maintaining the roadmap will require periodic evaluation of industry progress and roadmap relevance at approximately 3-year intervals, resulting in updates as appropriate.

Action	Deliverable	Impact
Action 4.5.5.1 Regularly update the *Hydropower Vision* roadmap.	Periodic, publicly available reports that update roadmap actions in response to progress in technology advancement, hydropower deployment, and changes in market conditions.	Ongoing availability of up-to-date information and recommendations to inform DOE and other stakeholders in planning and decision making.

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