5 HYDROPOWER MULTI-YEAR PROGRAM PLAN

Hydropower MYPP Organization and Structure

The following sections detail plans for each activity and sub-activity area in the Hydropower Program and is organized as follows:

- Activity 1 – Innovations for Low-Impact Hydropower Growth
- Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES)
- Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity
- Activity 4 – Environmental and Hydrologic Systems Science
- Activity 5 – Data Access, Analytics, and Workforce Development.

Each activity area section includes the following components:

- *Activity Overview:* This subsection contains a brief overview of the activity area and scope of effort.
- *Key Results and Performance Goals (2021-2025)*: This subsection highlights certain significant outputs or products within the activity area that are expected within the next five years. The key results and performance goals are critical to achieving the program's 2026-2030 objectives. The list of key results and performance goals is not intended to be comprehensive and may not include every output produced within the five-year timeframe.
- *Follow-On Objectives (2025-2030)*: This subsection identifies short-term outcomes that the program aims to achieve by 2030, resulting from the successful completion of the 2021-2025 Key Results and Performance Goals. These follow-on objectives logically lead to the intermediate and long-term outcomes and ultimate impacts defined in the program's logic model.
- *Activity Additional Details*: This subsection provides additional background information, context, and details on the program's activity area, such as links or interdependencies between or among the activities/sub-activities.
    - *Sub-Activity Overview*: This subsection summarizes the various elements that the sub-activity covers and highlights major areas of work to achieve overall activity performance goals and follow-on objectives. A flow diagram illustrates the timing and sequencing of major areas of work.
    - *Sub-Activity FY 2021–2025 Research Priorities*: These are the main efforts the program intends to support within the sub-activity.
    - *Sub-Activity Timing and Sequencing of Research Priorities*: This is a visual representation of the timing, sequencing, and relation of different research priorities to each other.
    - *Additional Details on Sub-Activity*: Additional background information, context, and details on the program's planned efforts within the sub-activity.

Hydropower Program Activity 1 – Innovations for Low-Impact Hydropower Growth

Overview

Technology innovation can enable the growth of additional hydropower capacity and generation as an economically competitive source of renewable energy in four resource categories: (1) development in "new stream-reaches" (sometimes also referred to as "greenfield" sites); (2) powering of currently NPDs; (3) adding generation technology to existing irrigation canals and other water conduits; (4) and upgrades at existing hydropower plants.[50] Different technology pathways addressed in this activity include the major powertrain and civil works components of a hydropower facility—primarily turbine technologies, hydraulic structures, and geotechnical approaches—with an emphasis on standardized, modular designs and approaches centered on environmental performance. Development and adoption of new technologies and strategies could lead to significant U.S. deployment of additional low-impact hydropower that integrates multiple social, environmental, and energy needs, while realizing value and revenue from a variety of sources.[51]

Activity 1 – Innovations for Low-Impact Hydropower Growth consists of the following sub-activities:

1. New Technologies and Advanced Manufacturing*:* Developing new cost-effective technologies that incorporate ecological and social objectives and leverage the latest advances in manufacturing and materials.
2. Testing Infrastructure Access and Development: Increasing access to existing testing capabilities and developing new testing infrastructure to speed development and ultimately enable commercialization of new technologies.
3. New Value Propositions: Identifying specific opportunities where hydropower investments can provide benefits across both energy and other sectors, including water security.

Performance Goals and Objectives

The key results, performance goals, and follow-on objectives are summarized in Table 14.

[50] While total capacity at existing hydropower plants could be expanded through the addition of new generators in existing or new powerhouses, it is expected that hydropower owner/operators will pursue these opportunities without the need for federal R&D investments, and therefore no specific activities or efforts are outlined in this document.

[51] Note: new PSH technologies and designs, and technologies to enhance unit and plant flexibility are addressed in Activity 2 – Grid Reliability, Resilience, Integration, and Storage (HydroWIRES). Sensors research that can better and more reliably assess the condition of hydropower plants will occur under Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity. Technologies targeted towards environmental monitoring and mitigation are addressed in Activity 4 – Environmental and Hydrologic Systems Science.

Table 14. Innovations for Low-Impact Hydropower Growth Performance Goals and Objectives

Key Results and Performance Goals (2021–2025)
• Develop datasets and interactive geospatial tools to identify development potential and site characteristics of new stream-reaches, NPDs, and conduit resources. • Publish R&D roadmap that identifies high-impact opportunities to leverage advanced manufacturing and materials in hydropower applications. • Complete testing and pre-commercial demonstrations of new cost-competitive technologies across each class of hydropower resource, with validated energy and environmental performance characteristics. • Complete development of a full-scale, federally sponsored hydropower test facility (or network of facilities). • Establish a framework for assessing costs and benefits of new hydropower projects, particularly those that could utilize new value propositions.
Follow-On Objectives (2026–2030)
• Project developers use geospatial tools to site and design new hydropower projects that balance social and ecological considerations, such as recreation, water quality, and biodiversity. • Technology developers actively pursue and apply high-impact advanced manufacturing opportunities for hydropower applications. • Deployment of new technology with revolutionary improvements in technology costs and environmental performance due to adoption of standardization and modularity principles, incorporation of advanced manufacturing and materials, and ability to test prototypes at full scales. • Increased developer interest in exploring hydropower projects that take advantage of new value propositions in addition to energy generation values.

Additional Details

The majority of hydropower capacity was installed between 1930 and 1990, first as part of the development of large federal multipurpose water projects, and later for a variety of reasons, including complementing the operation of large baseload coal and nuclear power plants, and cost-effectively balancing electricity load and demand on the transmission grid. Still, there is growth occurring today. Nearly 2.5 GW of new hydropower capacity was added to the grid from 2005 to 2019,[52] but overall, the pace of hydropower development has reduced considerably—especially in comparison to the rapid growth of other renewable energy resources. The results of the 2016 Hydropower Vision analysis imply that future development of hydropower projects is likely to remain limited without three major improvements: transforming the advancements in technologies; creating new project development methods that can achieve cost reductions; and meeting or exceeding sustainability objectives with minimal disruption to natural aquatic life, sediment, water flows, recreation, and other issues.

Though innovation is key to fostering additional hydropower development, new technologies alone may not be sufficient to enable hydropower growth, even with significant cost reductions. Optimal financial performance will depend on a project's ability to provide additional, steady value streams to balance project costs. In recent years, there has been increasing focus on the potential for new value propositions for hydropower projects—other than bulk electricity—that could open the door to non-traditional hydropower development. New value propositions may include co-development opportunities, business cases, and specialized markets in which energy from hydropower is not the principal motivation of the project, but rather a critical enabler of a larger suite of benefits.

[52] Uría-Martínez, R., Johnson, M., and Shan, R., 2021. "U.S. Hydropower Market Report." https://www.energy.gov/eere/water/downloads/us-hydropower-market-report.

Sub-Activity 1.1 – New Technologies and Advanced Manufacturing

Overview

This sub-activity consists of developing and advancing technologies for application in three identified resource classes: (1) new stream-reaches, (2) NPDs, and (3) conduits. As illustrated in Figure 12, each resource category follows a similar process—from characterizing the available resource to better target technology investments, to developing and testing technologies that can cost-effectively and sustainably utilize hydropower potential in the respective classes. Though efforts are illustrated linearly, many processes and steps are iterative and cyclical, such as technology development and testing.

FY 2021–2025 Research Priorities

The following are the research priorities that will be emphasized within the Sub-Activity 1.1 – New Technologies and Advanced Manufacturing:

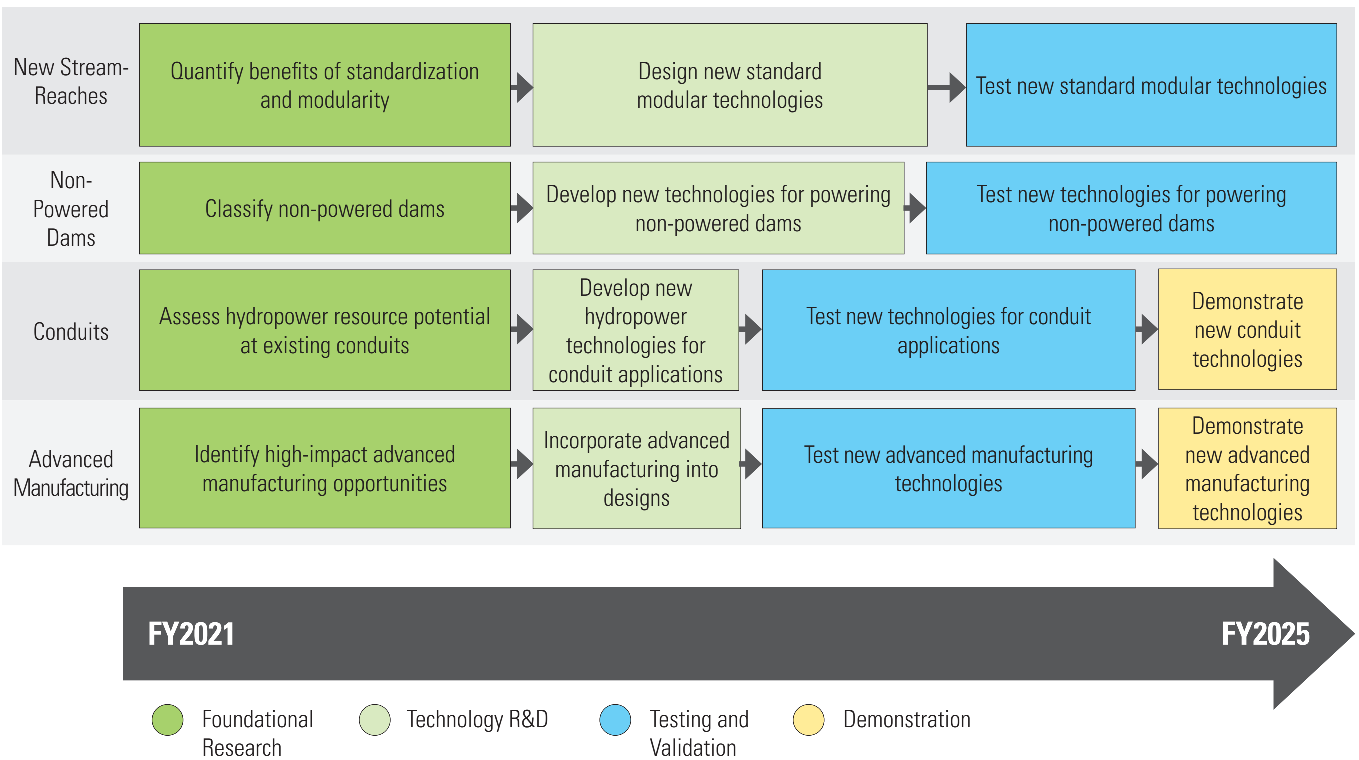
- **New Stream-Reach**
  - **Quantify benefits of standardization and modularity**: Perform techno-economic studies into past investments to quantify the potential benefits of standardization and modularity for new hydropower development, including increased environmental compatibility, lower costs, and shorter construction times.
  - **Design new standard modular technologies**: Use the results of the techno-economic study to revise design guidelines and support development of new standard modular technologies, targeting modules where additional improvements are needed.
  - **Test new standard modular technologies**: Evaluate the performance of new standard modular technologies at a partial and/or full scale.
- **Non-Powered Dams**
  - **Classify NPDs**: Perform a study to classify existing non-powered U.S. dams based on key attributes relevant for hydropower development and integrate those findings into a user-friendly geospatial tool.
  - **Develop new technologies for powering NPDs**: Informed by the classification study, develop design guidelines incorporating lessons learned about standardization and modularity, and support development of new technologies and construction methods to cost-effectively power NPDs.
  - **Test new technologies for powering NPDs**: Evaluate the performance of new technologies and methods for NPDs at a partial and/or full scale.
- **Conduits**
  - **Assess hydropower resource potential at existing conduits**: Perform a geospatial study to identify existing U.S. water conveyance systems and quantify available hydropower resource potential.
  - **Develop new hydropower technologies for conduit application**s: Develop technologies and methods to cost-effectively add hydropower to existing conduits and canals.
  - **Test new technologies for conduit applications**: Evaluate the performance of developed technologies for conduits and canals at a partial and/or full scale.
  - **Demonstrate new conduit technologies**: Conduct a field demonstration to validate new technologies at an existing conduit or canal.

- **Advanced Manufacturing**
  - **Identify high-impact advanced manufacturing opportunities**: Utilize creative funding mechanisms to identify high-impact advanced manufacturing opportunities for hydropower applications.
  - **Incorporate advanced manufacturing into designs**: Incorporate advanced manufacturing and materials with the potential to reduce costs or increase performance into the design of hydropower components.
  - **Test new advanced manufacturing technologies**: Evaluate the performance of new advanced manufacturing technologies and methods at a partial and/or full scale.
  - **Demonstrate new advanced manufacturing technologies**: Conduct a field demonstration to validate new advanced manufacturing technologies and methods in a real-world site.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 12.

Figure 12. Sub-Activity 1.1 – New Technologies and Advanced Manufacturing Research Priorities



Additional Details

New Stream-Reaches

New stream-reach development refers to new hydropower development in stream-reaches that do not currently have hydroelectric facilities or other forms of dams or hydraulic infrastructure. Roughly 75% of identified new stream-reach sites are low-head, or less than 30 feet, and therefore have lower power densities and potentially higher costs, given economies of scale for larger projects. Developing hydropower in new stream-reaches can also result in environmental impacts if not carefully sited, designed, built, and operated to balance ecological considerations, such as species diversity, water quality, recreation, and other physical processes within the ecosystem. These factors make small hydropower development in undeveloped streams—with design engineering, construction, equipment selection, environmental impact mitigation strategies, and total installed costs that are usually driven by very site-specific considerations—a complex and uncertain undertaking.

Since 2016, the Hydropower Program has invested in exploring standardization, modularity, and environmental compatibility to enable low-cost, environmentally sustainable hydropower growth in currently undeveloped streams. This new class of hydropower technology will be standard—meaning its geometry, local hydraulics, aesthetics, cost structure, and other salient design features are site-independent, with limited environmental impacts. It will also be modular, meaning that capacity and function can be scaled to a site through deployment of multiple components that are designed to integrate with minimum cost and maximum value. The SMH concept shifts the design philosophy from custom designing every facility to extract the greatest amount of energy possible and then mitigating impacts, to focus on first sustaining the important hydrologic, hydraulic, geomorphic, physiochemical, and ecologic processes that occur in streams and watersheds. Applying SMH practices can result in new projects that generate renewable energy at low cost while preserving—and in some cases enhancing—stream functionality.

In this sub-activity, the Hydropower Program will conduct an impact analysis on SMH investments to date—which include foundational research at Oak Ridge National Laboratory[54] and two public funding opportunities[55] —to closely examine and document the techno-economic benefits of standardization and modularity in terms of costs, construction time, and environmental impact, among others. The results of this analysis will reveal gaps (e.g., need for better design guidelines, or modules that have not been sufficiently advanced) and help guide the Hydropower Program's future investments in standard modular technologies.

Non-Powered Dams

Only 3% of the nation's roughly 90,000 dams are currently equipped with electricity-generating equipment. Existing NPDs can be retrofitted for hydropower generation without the costs and impacts of additional dam construction. Despite these opportunities, the NPD resources are also characterized by low heads and variable flows, and estimated costs can still be high in many cases where traditional generating equipment and civil configurations are planned. The U.S. NPD fleet is also incredibly diverse in terms of dam condition, purpose (e.g., flood control, water supply), engineered features, capacity, environmental attributes, and socio-economic considerations. For this reason, this sub-activity involves classifying NPDs based on characteristics and key variables relevant to hydropower development, which will result in a web-based tool for exploring NPD development opportunities. Subsequent efforts will focus on developing generalized designs and technologies for NPD hydropower development. Lessons learned regarding the benefits of standardization and modularity explored in the new stream-reach context will be leveraged to reduce costs, timelines, and environmental compatibility of NPDs.

Conduits

Conduit hydropower projects can be developed on existing water-conveyance structures, such as irrigation canals or pressurized pipelines that deliver water to municipalities, industry, or agricultural water users. There are many thousands of miles of existing conduits in the United States that are used to transport and distribute water and wastewater. Although water conveyance structures were not designed for energy generation purposes, excess energy can in many cases be harvested from these systems without the need to construct new dams or diversions. Mainly due to data limitations, the total conduit hydropower potential across states and/or regions is currently unknown.

In this sub-activity, a geospatial assessment will first be performed to identify locations with undeveloped conduit hydropower potential at existing water conveyance systems. This resource assessment will inform technology investments. For instance, hydropower development at conduit projects can be relatively complex and challenging

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[54] Oak Ridge National Laboratory, "Standard Modular Hydropower." https://smh.ornl.gov/.

[55] WPTO Past Water Power Funding Opportunities: https://www.energy.gov/eere/water/past-water-power-funding-opportunities (DE-FOA-0002080 and DE-FOA-0001836).

due to the need to manage multiple water use objectives to avoid any risk of disruption of water delivery while maximizing generation. New fit-for-purpose technologies that have been proven to be reliable could facilitate acceptance, and lead to widespread deployment of hydropower on existing water conveyance systems. Conduit hydropower projects can also take advantage of the expedited permitting process through the Hydropower Regulatory Efficiency Act of 2013 and its amendments in 2018—which provide an accelerated, 60 days or less pathway to acquiring FERC authorization for qualifying small hydropower projects. The sub-activity plans include sponsoring competitive real-world demonstrations of conduit hydropower technologies to serve as exemplary pilots for validating new technologies, while navigating the expedited permitting process.

Advanced Manufacturing
Over the last decade, advanced manufacturing has revolutionized many different parts of the energy sector, boosting U.S. manufacturing and opening pathways to increased American competitiveness. Advanced manufacturing can offer numerous benefits over conventional manufacturing techniques, such as enhanced design flexibility, decreased energy consumption, lower costs, and reduced time to market. While novel applications of advanced manufacturing have ushered in benefits in other energy sectors, the potential benefits for hydropower applications remain largely unexplored. This sub-activity will identify high-impact opportunities to apply advanced manufacturing to address hydropower's challenges, and advance these solutions through targeted investments, including prototyping and testing. These efforts will also be closely coordinated and carried out in partnership with EERE's Advanced Manufacturing Office (AMO).

Leveraging advanced manufacturing is critical for enabling new low-impact growth, but the opportunities identified will also benefit other activities in the Hydropower Program. For example, the use of advanced materials may lead to significant cost reductions for PSH facilities, a key objective of Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES). Additive manufacturing presents an opportunity to embed sensors within hydropower components for condition monitoring, thus supporting research under Activity 3 – Fleet Modernization, Maintenance and Cybersecurity to better and more reliably assess the condition of hydropower plants. Research under Activity 4 – Environmental and Hydrologic Systems Science could leverage advanced manufacturing to develop innovative environmental monitoring and mitigation technologies, such as the use of new materials for fish screens and development of miniaturized fish tags and micro-batteries.

Sub-Activity 1.2 – Testing Infrastructure Access and Development

Overview
This sub-activity would perform an initial scoping for a full-scale, grid-connected, federally sponsored hydropower test facility. Full-scale testing for a broad range of hydropower components—including hydraulic, mechanical, electrical, civil/structural, sediment, biological, safety, and instrumentation technologies—could be accomplished at a single facility or may require a network of multiple facilities to provide a greater range of capabilities. The near-term efforts of this sub-activity will focus on (1) performing an assessment of hydropower testing needs, including identification of testing components, scales, and capabilities that will provide value to the hydropower industry; (2) cataloging existing hydropower test facility capabilities; and (3) assessing the suitability of existing federal infrastructure to meet testing needs. These scoping efforts would inform any potential future activities related to the design, development, and operation of a full-scale test facility program.

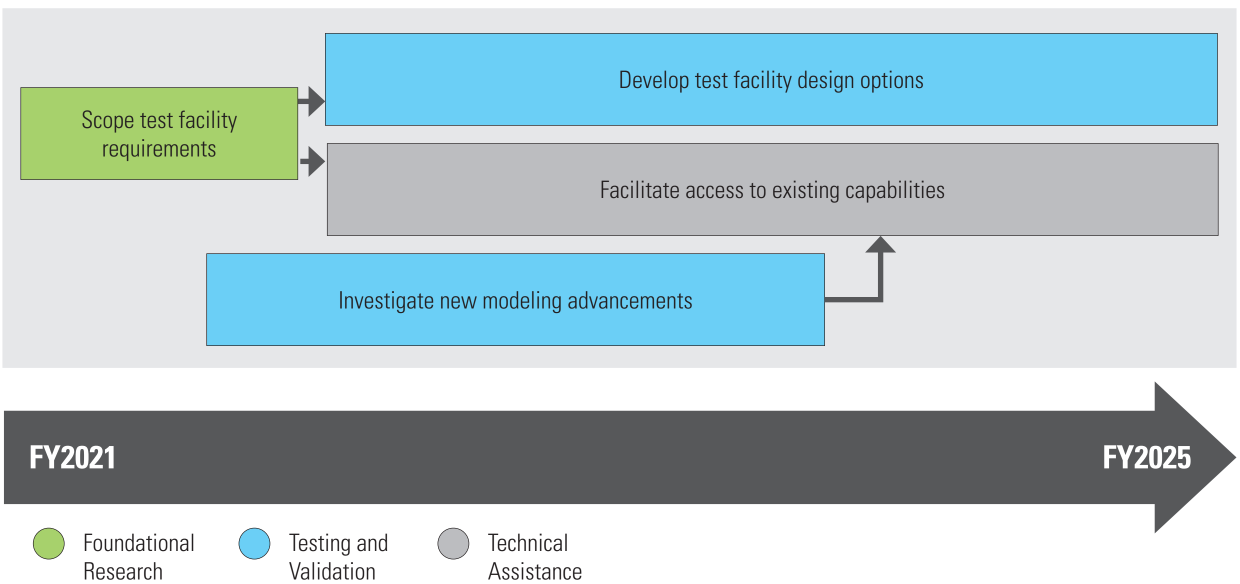
Concurrently, the sub-activity will continue to support smaller-scale testing at existing facilities to help advance new and unproven technologies at earlier stages of design. The sub-activity will also explore the latest advances in high-fidelity modeling that can complement or in some cases replace some physical testing, such as multi-body dynamics simulation and advanced computational fluid dynamics.

FY 2021–2025 Research Priorities
The following are the research priorities that will be emphasized within the Sub-Activity 1.2 – Testing Infrastructure Access and Development:

- **Scope test facility requirements**: Perform an assessment of hydropower testing needs and existing hydropower testing capabilities to inform the requirements and specifications for a full-scale hydropower test facility.
- **Develop test facility design options**: Develop design options for a full-scale test facility (or network of facilities) to meet the testing needs, requirements, and specifications identified in the scoping study.
- **Facilitate access to existing capabilities**: Utilize a technical assistance program to facilitate access to existing test facilities, capabilities, and expertise.
- **Investigate new modeling advancements**: Explore the application of advanced numerical modeling that may reduce the need for physical testing.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 13.

Figure 13. Sub-Activity 1.2 – Testing Infrastructure Access and Development Research Priorities



Additional Details
Hydropower growth is contingent upon validation of the safety, environmental acceptability, reliability, and performance of innovative technologies. New technologies represent risks to first adopters, making it difficult for technology developers to bring nascent and potentially disruptive technologies to market. Given the multi-objective nature of hydropower projects, deployment of technologies prior to validation could present risks to the ecosystem as well as both power and water costumers. Yet existing academic, private, and government-sponsored facilities have limitations of size, hydraulic capacity, and capabilities. In addition, federal permitting requirements limit opportunities for in-river, grid-connected testing of hydropower technologies.

Hydropower technology developers thus face a critical dilemma: new technologies are often not allowed to be deployed without being tested, yet the only way to test them at scale is through deployment. Therefore, there is a need for test facilities where emerging technologies can be tested, validated, and de-risked at full scale to ensure that operational, physical, and environmental requirements are met, and establish credibility with investors and decision makers.

Increased access to testing capabilities and infrastructure will support deployment of new hydropower by enabling validation of technology safety, performance, and reliability of innovative technologies. Testing capabilities and infrastructure developed in this sub-activity will also benefit other activities within the Hydropower Program. Examples of components developed under other activities that could benefit from testing and validation efforts include:

- Hardware and software to increase unit or plant flexibility, such as advanced controls and power electronics (Activity 2 – HydroWIRES).
- Sensors and instrumentation for condition monitoring, such as novel telemetry for cavitation detection (Activity 3- Fleet Modernization, Maintenance, and Cybersecurity).
- Environmental mitigation technology, such as fish passage systems (Activity 4 – Environmental and Hydrologic Systems Science).

Sub-Activity 1.3 – New Value Propositions

Overview

Identifying new value propositions—in concert with efforts to drive down costs and improve environmental performance—can enable hydropower to play an even greater role than it has historically. This sub-activity seeks to provide insight into alternative opportunities, co-benefits, business cases, and specialized markets that hold the potential to increase the value proposition for small and novel hydropower projects. Similar to WPTO's marine energy initiative, PBE, there are unexplored opportunities for new development in which hydropower is not the principal motivation of the project, but a critical enabler of a larger suite of benefits. For example, irrigation districts have been able to modernize their irrigation systems as a result of revenue and energy cost-savings from hydropower project developments. The installation of in-conduit hydropower, coupled with pressurized piping, can reduce evaporative water loss from open conduits, reduce energy use, and provide a predictable revenue stream to support regular operations and maintenance, in addition to further future water-efficiency modernizations.

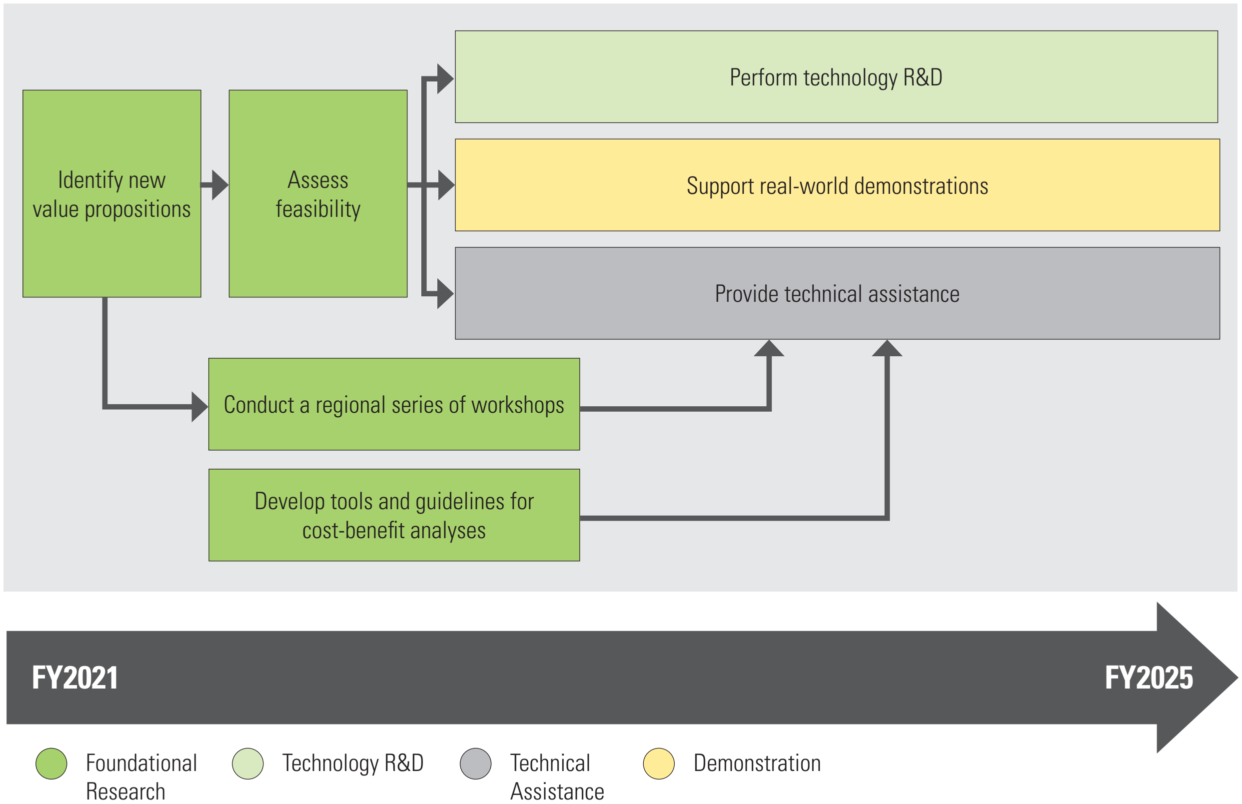
FY 2021–2025 Research Priorities

The following are the research priorities that will be emphasized within the Sub-Activity 1.3 – New Value Propositions:

- **Identify new value propositions**: Investigate new value propositions and alternative opportunities for new, low-impact hydropower development.
- **Assess feasibility**: Evaluate the technical and economic feasibility of identified value propositions and opportunities, and document barriers to their current realization (e.g., need for technology innovation).
- **Conduct a regional series of workshops**: Host a series of regional workshops to solicit feedback on, refine, and educate about identified value propositions and opportunities.
- **Develop tools and guidelines for cost-benefit analyses**: Produce tools and guidelines for stakeholders to evaluate costs and benefits of new, low-impact hydropower projects, including within the context of new value propositions.
- **Perform technology R&D**: When needed, and depending on the individual value proposition or opportunity, develop innovative technologies to enable the realization of a new value proposition.
- **Support real-world demonstrations**: Support real-world demonstration of new value propositions that currently demonstrate sufficient near-term readiness.
- **Provide technical assistance**: Administer a technical assistance program to encourage, enable, and assist relevant stakeholders in pursuing hydropower development in the context of new value propositions.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 14.

Figure 14. Sub-Activity 1.3 – New Value Propositions Research Areas



Additional Details

This sub-activity is intended to not only identify new value propositions and opportunities to provide mutual benefits, but to better understand the technical and economic feasibility of new opportunities. This process may lead to one or multiple pathways. For example, some opportunities may only prove to be feasible if new technologies are developed, which would lead to a technology R&D pathway under Sub-Activity 1.1 – New Technologies and Advanced Manufacturing. Alternatively, other opportunities may be found to be technically and financially feasible given current technologies and conditions, in which case federal investments in full-scale testing and demonstration could enable their more rapid realization and adoption. Lastly, some opportunities may be best enabled through further analysis, best practices and standards development, or other types of technical assistance. A regional series of workshops could help better define these various pathways and connect potential beneficiaries and stakeholders of new value propositions with hydropower stakeholders to catalyze cooperation at larger scales.

New Opportunities for Hydropower to Support Water Infrastructure Resilience

There are known opportunities for new development in which hydropower is not the principal motivation of the project, but a critical enabler of a larger suite of benefits that are currently underexplored by the industry. Such opportunities exhibit a diverse array of stakeholders, users, and benefits with the potential to benefit from non-traditional hydropower applications and innovative partnerships. These include:

1. **Irrigation Modernization**: Irrigation is a cornerstone of many rural and agricultural communities. The retrofitting of irrigation systems with in-conduit hydropower has resulted in community, energy, and water resilience, including a diversified revenue source, increased local energy reliability, increased agricultural productivity, and water savings.
2. **Water Supply and Treatment:** Co-development of hydropower through existing water conduits, delivery or pressure systems seems to have a clear business case, both in terms of added revenues and resilience for treatment facilities and energy generation. There are also ways in which hydropower on water distribution and treatment systems may power behind the meter applications for resilience and reliability within water networks or neighboring infrastructure.
3. **Source Water Recharge**: Exploration of surface and groundwater interactions and mitigation of groundwater depletion provide the potential for hydropower investment. Hydropower slows down water to build up head, and there are innovative designs with an eye specifically towards the recharge of groundwater using surface water that could enable an array of benefits to municipalities, irrigators, and ecosystems.
4. **Environmental Services**: Alternative hydropower development and environmental stakeholders such as nongovernmental organizations (NGOs) and interest groups can establish synergies leading to mutually positive outcomes in the forms of environmental restoration, positive impacts on biological diversity, optimizing environmental flows, or even environmental clean-up.
5. **Deferrable Loads**: A class of loads, characterized by the ability to be quickly ceased and restarted, is compatible with the increased variability posed by hydropower plants with limited storage or without storage entirely. The benefits of cloud computing and environmental restoration, among other activities, can be magnified through the coupling of these deferrable activities with a wide range of hydropower infrastructure types.
6. **Historic Preservation**: New hydropower development often competes with historic preservation. However, this need not be the case, as alternative hydropower applications can be used to aid and enhance historic preservation. New England is already showing interest in this market with its many historic dams and mills.
7. **Recreation**: Many economically important recreational industries rely on predictable water releases and flows (often managed by upstream hydropower and NPD facilities). Examples include rafting, boating, fishing, kayaking, boat racing, swimming, tubing, and the maintenance of riverside parks. Co-development of hydropower at whitewater parks or recreation facilities may be a present niche opportunity for mutual benefits.

Hydropower Program Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES)

Overview

Rapid changes in the U.S. electricity system, including changes in generation mix as well as markets and policy, have created new needs for storage, flexibility, and other grid services that hydropower and PSH are well-suited to provide. In response to these opportunities, the HydroWIRES Initiative seeks to understand, enable, and improve hydropower's contributions to grid reliability, grid resilience, and integration. HydroWIRES investigates additional value streams, enhanced flexibility, new operational strategies, and innovative technology solutions that enable new roles for hydropower and PSH. Efforts encompass industry- and national lab-led modeling, analysis, tool development, technical assistance, and technology R&D.

Activity 2 – Grid Reliability, Resilience, and Integration (HydroWIRES) consists of the following sub-activities:

1. Value under Evolving System Conditions: Understanding the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH.
2. Capabilities and Constraints: Investigating the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities.
3. Operations and Planning: Optimizing hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services.
4. Technology Innovation**:** Investing in innovative technologies that improve hydropower capabilities to provide grid services.

Performance Goals and Objectives

The key results, performance goals, and follow-on objectives are summarized in Table 15.

Table 15. HydroWIRES Performance Goals and Objectives

Key Results and Performance Goals (2021–2025)
• Publish regionally focused roadmaps for maximizing hydropower's value for reliability, resilience, and integration. • Release the first version of an asset-level cost-benefit assessment toolbox for owners and operators of hydropower and PSH plants, which integrates previous model and tool development focused on revenue opportunities, environmental outcomes, and machine impacts to inform asset-level decisions. • Release the first version of a system-level cost-benefit toolbox for system-level decision makers, such as planners and regulators, which integrates system values, system costs, externalities of hydropower, and the abilities of other resources. • Test innovative technology R&D at a small-scale PSH or flexible hydropower demonstration project, potentially including new PSH concepts and/or flexibility enhancement through hybrid controls and advanced operations.
Follow-On Objectives (2026–2030)
• Accurate representations in power system models of hydropower and PSH capabilities, such as the flexibility of modern designs and reservoir constraints, are widely utilized for research, planning, and unit scheduling. • Quantifiable improvement of hydropower plant operations, including coordination or co-location with other resources, to support greater needs for system flexibility. • Commercialization of new technologies for hydropower asset flexibility and deployment by hydropower owners and operators. • New PSH projects that utilize advanced technologies, system designs, and methods to lower costs/increase cost-competitive PSH deployment.

Additional Details

The U.S. electricity system is rapidly evolving, bringing both opportunities and challenges for the hydropower sector. Increasing deployment of variable renewable resources such as wind and solar photovoltaic generation have enabled low-cost, clean energy in many regions of the United States, while also creating a need for resources that can store energy or quickly change their operations to ensure power system reliability and resilience. Hydropower has historically been operated primarily as a baseload-scheduled or predictable peaking resource, generating energy over relatively long timeframes. However, this operational pattern is changing for some plants, particularly in regions with high variable renewable penetrations. Hydropower and PSH systems' technical characteristics make them well-suited to provide a range of storage, flexibility, and other grid services[56] that can enable integration of variable renewables.[57] The U.S. hydropower fleet of the future may therefore be operated and dispatched not solely for energy benefits but as a key source of flexibility to integrate variable renewables on the grid. Future changes are likely to differ by region and facility, based on the needs of the power system and the existing obligations of individual plants.

The HydroWIRES Initiative builds on and integrates a significant body of previous work within WPTO. The 2016 Hydropower Vision Report provided a baseline for hydropower's technical performance and illustrated challenges and opportunities to expansion of the hydropower fleet, but this report also highlighted research gaps in understanding the past, present, and future value of hydropower. Such questions motivated two flagship projects in what later became the foundational efforts for the HydroWIRES Initiative. First, the forthcoming Hydropower Value Study describes the current operational landscape of the hydropower fleet, including how flexibility has been valued in the past and what value drivers could be most important in future scenarios. Second, the congressionally directed PSH techno-economic assessment will result in a valuation guidance tool with a comprehensive, rigorous valuation methodology for the grid services that PSH can provide. This methodology will then be applied to two proposed PSH sites competitively selected through a 2017 Notice of Opportunity for Technical Assistance: the Banner Mountain site in Wyoming and the Goldendale site on the Oregon and Washington border.

The central hypothesis of HydroWIRES is that, as the electricity system undergoes rapid changes, the U.S. hydropower fleet is well-positioned to take on this new role by offering additional value streams, enhanced flexibility, new operational strategies, and innovative technology solutions. Work carried out in HydroWIRES thus traces these four opportunities, shown graphically in Figure 15.

56 Black start is example of a grid service, which hydropower is well suited to provide as discussed in this HydroWIRES report.

57 Hydropower's role in future renewable integration is discussed in more detail in a white paper, published by the International Energy Agency with contributions from the HydroWIRES team.

Figure 15. The Four HydroWIRES Research Areas

Industry Challenges	Corresponding Research Areas
As the electricity system is changing, there is limited understanding of which services will be needed, as well as limited ability to accurately value those services.	**1 Value Under Evolving System Conditions** Understand the needs of the rapidly evolving grid and how they create opportunities for hydropower and PSH. **What will the grid need?**
Hydropower and PSH capabilities are bounded by the interaction of machines, water, and institutions, and some of these bounds originate from legacy decisions that did not consider evolving grid needs.	**2 Capabilities and Constraints** Investigate the full range of hydropower's capabilities to provide grid services, as well as the machine, hydrologic, and institutional constraints to fully utilizing those capabilities. **What can the hydropower fleet do?**
There are gaps in information regarding how to optimize hydropower and PSH operations and planning in coordination with other resources.	**3 Operations and Planning** Optimize hydropower operations and planning—alongside other resources—to best utilize hydropower's capabilities to provide grid services. **How can hydropower best align what it can do with what the grid will need?**
Current hydropower and PSH technology may not be designed for flexible operation.	**4 Technology Innovation** Invest in innovative technologies that improve hydropower capabilities to provide grid services. **What new technology could expand what hydropower can do to meet grid needs?**

The research areas are intentionally cumulative, with the first and second research areas feeding into the third and then the fourth research areas. Structurally, the first two research areas establish a critical baseline understanding of what range of services may be most valuable for the future grid (depending on different ways it may evolve), together with what services hydropower can (and cannot) contribute. They provide needed insights into the services and attributes the hydropower fleet can and should be prioritizing. With a more complete picture of grid requirements facing hydropower resources and the actual ability and limitations of hydropower to respond to grid conditions, the third research area operationalizes this information by developing strategies to take advantage of hydropower's capabilities to contribute the services required by the evolving grid. The fourth area continuously integrates the findings from these three research spaces to inform technology needs and target innovation that can expand hydropower's capabilities to provide value to the grid. While the research areas are conceptualized as flowing in sequence, the dependence is not rigid. Work performed on individual HydroWIRES projects can often proceed in parallel, and a given project may span multiple research areas.

The government role of DOE in executing the HydroWIRES Initiative is essential, as challenges addressed by HydroWIRES related to reliability, resilience, and integration are national in scale and extend beyond the purview of any single utility or industry player. In describing the possible roles for hydropower under evolving power system conditions, HydroWIRES should explore future scenarios, equipment capabilities, operational paradigms, and market structures that reach beyond those considered by most planners and operators today. Thus, the activities under HydroWIRES will productively inform current as well as future actions by industry decision-makers.

Sub-Activity 2.1 – Value Under Evolving System Conditions

Overview

Rapid changes in the power system generation mix make it difficult to understand the different ranges of reliability services and associated technical capabilities the grid may require at different points in the future, and how this will differ from system to system. Estimating the future value of different types of capabilities and services is equally, if not more, challenging. The goal of this sub-activity is to provide both the hydropower industry and grid operators the tools, data, and analysis to understand how evolving characteristics of the power system (e.g., levels of wind or solar penetration, distributed generation, market prices, transmission constraints, and industrial electrification) drive grid needs, and thus be able to estimate the value of different hydropower capabilities within their own system. These goals will be achieved through three technical objectives: producing a grid services taxonomy, quantifying value drivers, and developing valuation methodologies and associated tools. Many of these research efforts have relevance beyond hydropower and will be closely coordinated with relevant offices as part of the ESGC.

FY 2021–2025 Research Priorities

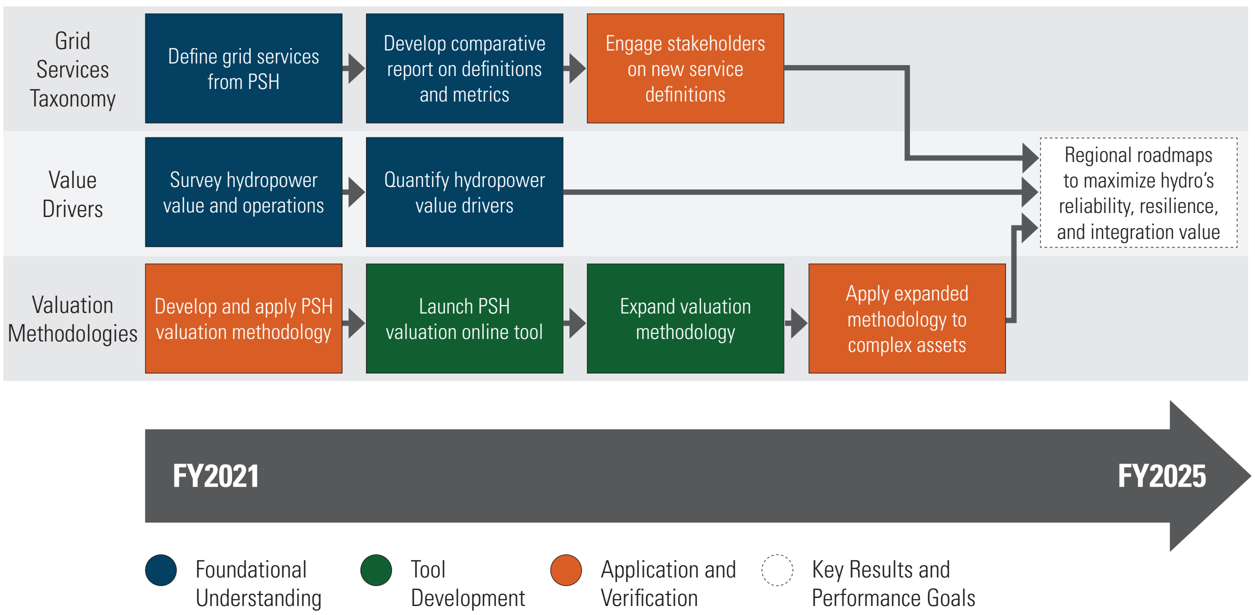
The following are the research priorities that will be emphasized within the HydroWIRES Sub-Activity 2.1 – Value Under Evolving System Conditions:

- **Grid Services Taxonomy**
  - **Define grid services from PSH**: Based on prior work, formalize a standardized set of grid services applicable to PSH in collaboration with industry partners.
  - **Develop a comparative report on definitions and metrics**: Understand how different grid services are defined across regions and countries, including how this can inform compensation mechanisms for hydropower and PSH.
  - **Engage stakeholders on new service definitions**: Engage stakeholders on metrics and definitions of new potential grid services that may be required in future systems.
- **Value Drivers**
  - **Administer a survey on hydropower value and operations**: Study how hydropower has been valued in the past, using case studies and historical data for different regions across the United States.
  - **Quantify hydropower value drivers**: Identify and quantify the factors (generation mix, market design, water availability, load shapes, etc.) that influence the value of hydropower resources to help understand their value under disparate future grid conditions.
- **Valuation Methodologies**
  - **Develop and apply PSH valuation methodology**: Finalize and publish a PSH valuation methodology and techno-economic studies for two proposed PSH plants.
  - **Launch PSH valuation online tool**: Based on the PSH valuation methodology, develop an easy-to-use online tool that will allow developers, regulators, and other stakeholders to better evaluate diverse value streams from PSH.

- **Expand valuation methodology**: Extend the previously developed valuation methodologies to conventional hydropower, hybrids, and other storage types (in addition to PSH).
- **Apply expanded methodology to complex assets**: In coordination with industry, apply the expanded valuation methodologies to a real-world proposed project with more complex technical, market, or multi-use characteristics.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 16.

Figure 16. Sub-Activity 2.1 – Value Under Evolving System Conditions Research Priorities



Additional Details
In producing a grid services taxonomy, HydroWIRES seeks to enable unified understanding of grid services and system benefits. While it will be important to create a general framework that can accommodate other technologies and resource classes in coordination with other DOE offices to fully address this problem, the taxonomy will be initially developed for advanced PSH valuation. Future work may include analyzing market design initiatives in different independent system operators/regional transmission organizations and their effects on market product definitions relevant for hydropower.

HydroWIRES also seeks to understand value drivers for hydropower in today's power system and investigate how they might evolve under different future system scenarios. These scenarios could be structured to understand how hydropower might be used in different resource mixes, what new system requirements and/or market products could be needed in the future, and which uncertainties would be the most impactful. Work has already been completed on how hydropower has been valued and compensated historically in various regions of the United States, and this may be extended in the future to include an analysis of prices and market dynamics of energy and ancillary services in countries (such as Austria, Brazil, Norway, Portugal, etc.) that have large amounts of hydro and hydro-based storage to better understand drivers for hydropower value in the United States.

Finally, this sub-activity will develop rigorous, widely applicable methodologies and tools that can be used to better assess the value of hydropower assets. While energy storage valuation capabilities have advanced significantly in recent years, valuing PSH plants presents several interesting technical challenges. For example, generating capacities of the plants are often large enough to significantly influence the supply-demand relationships in markets and change prices and value of the services that PSH plants can provide. Advancing valuation for conventional hydropower resources will be equally important as the use of flexible hydropower operations becomes more prevalent. Work has already been completed on standardizing the valuation process for PSH, and more work may be completed to extend this standardization to conventional hydropower, hybrids, and more. Under this sub-activity, efforts may include an evaluation of emerging power purchase agreement structures that are responsive to changing system needs.

Products from this sub-activity will also directly benefit and be utilized by efforts in Sub-Activity 1.3 – New Value Propositions, to help hydropower developers estimate revenue potential and anticipated power system benefits of new low-impact projects. Valuation of new hydropower projects could also help establish technology development targets (i.e., cost and performance characteristics necessary for favorable financial performance).

Sub-Activity 2.2 – Capabilities and Constraints

Overview

While hydropower plants with moderate-to-significant reservoirs and water storage capacities are some of the most flexible resources on the grid, the inherent technical capabilities of the individual plants are often constrained by a combination of factors such as the design or configuration of generation equipment; current and future water availability (e.g., in a cascading system), or institutional requirements to use water for environmental flows, navigation, and other purposes. HydroWIRES will provide new, accumulated data from across the U.S. hydropower fleet to understand the range and limits of hydropower's flexibility and identify opportunities at the plant and fleet level where flexibility and grid services can be increased. This will be achieved through four technical objectives: developing a flexibility framework; quantifying flexibility tradeoffs; improving short-term inflow forecasting; and improving modeling representation.

FY 2021–2025 Research Priorities

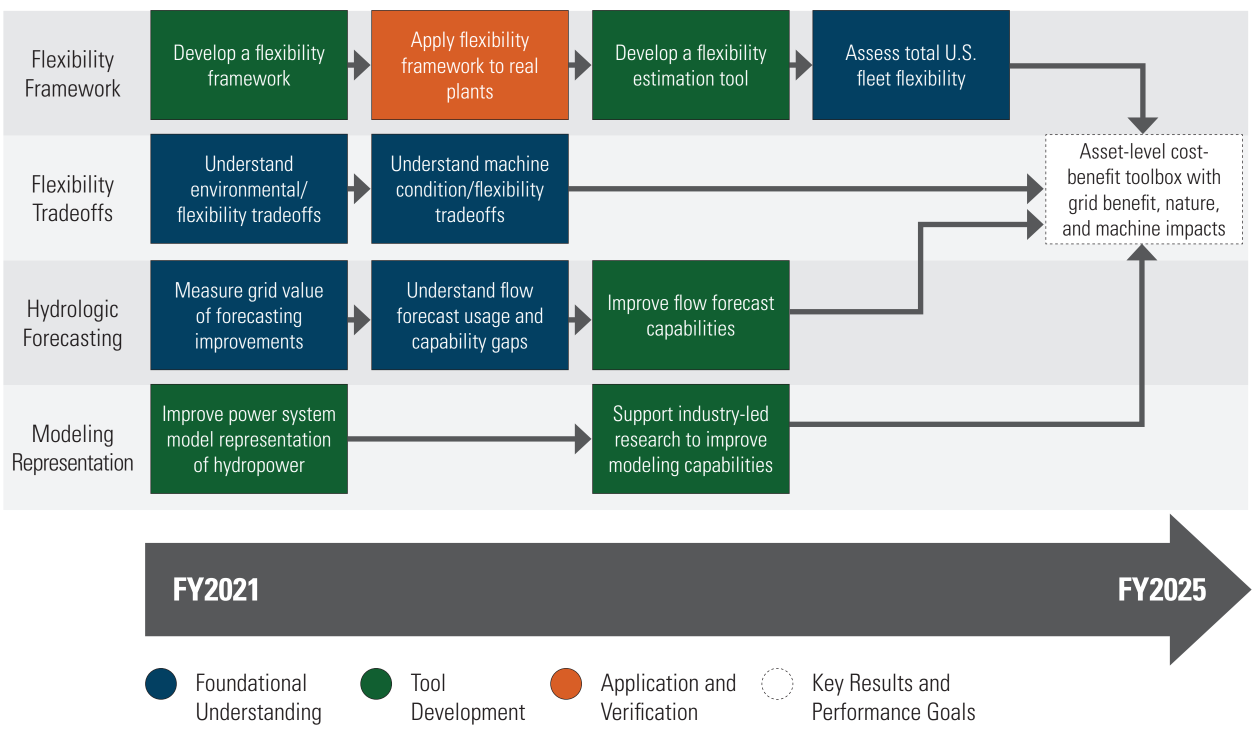
The following are the research priorities that will be emphasized within the HydroWIRES Sub-Activity 2.2 – Capabilities and Constraints:

- **Flexibility Framework**
  - **Develop a flexibility framework**: Develop a broadly applicable framework to estimate the amount of flexibility that a hydropower plant can provide.
  - **Apply the flexibility framework to real plants**: Apply the framework to real-world plants in coordination with owners and operators.
  - **Develop a flexibility estimation tool**: Launch an online portal that allows for an estimation of the amount of flexibility available from a particular asset, using the flexibility framework previously developed.
  - **Assess total U.S. fleet flexibility**: Complete a fleet-wide assessment of the total potential flexibility available in the U.S. fleet.
- **Flexibility Tradeoffs**
  - **Understand environmental/flexibility tradeoffs**: Comprehensively map the linkages between flexible operations and environmental outcomes through the hub of flow decisions.
  - **Understand machine condition/flexibility tradeoffs**: Quantify the impacts of flexible operations on plant equipment, enabling tradeoff quantification.

- **Hydrologic Forecasting**
  - **Measure grid value associated with improved flow forecasting**: Quantify the value of different potential short-term forecasting improvements to increase hydropower flexibility.
  - **Understand flow forecast usage and capability gaps**: Working with industry partners, understand forecast usage and identify the forecast model capabilities to prioritize for improvement.
  - **Improve flow forecast capabilities**: Support an industry-led effort to make the highest impact in water forecasting model capability improvements (as identified in previous work).
- **Modeling Representation**
  - **Improve power system model representation of hydropower**: Improve hydropower and PSH representations in power system models so that they better capture unique capabilities and constraints associated with hydropower.
  - **Support industry-led research to improve modeling capabilities**: Support an industry-led effort to improve targeted power system model capabilities relevant for hydropower and PSH.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 17.

Figure 17. Sub-Activity 2.2 – Capabilities and Constraints Research Priorities.



Additional Details

While many hydropower plants are capable of flexible operation, there is no clear quantification of how much potential flexibility exists in the fleet. Hydropower plants vary greatly in their impoundments, flow rates, machine capabilities, and other attributes, all of which affect how much flexibility and what types of grid services they can provide. Moreover, an individual plant's flexibility could change depending on the time of year, water demand patterns, the need to provide ecological flows, and water availability. Ongoing work focuses on categorizing and quantifying the types of operational flexibility that the range of hydropower plants can provide, which will be used for a future fleet-wide assessment of total hydropower flexibility available in the United States. A comprehensive, national assessment of the potential flexibility available in the U.S. hydropower fleet could enable improved planning and inform future discussions around renewable integration.

In addition to understanding the potential for flexible operations, equally important are the tradeoffs between operating flexibly versus meeting other objectives related to environmental performance, revenue opportunities, and machine wear and tear. Following the flexibility capability assessment, HydroWIRES will identify areas where there is a need for advanced tools, models, or platforms to help assess and evaluate tradeoffs within the hydropower facility or set of co-managed facilities. Current work seeks to understand the tradeoffs between flexibility and environmental outcomes, and complementary work focuses on the tradeoffs with cost, condition, and availability. In the future, these tools will be integrated into a unified cost-benefit analysis tool for asset-level decision makers.

This sub-activity also seeks to quantify and improve the accuracy and resolution of short-term inflow forecasting tools in conjunction with industry partners to enable more flexible operation. Long-term forecasting at decadal time scales, for example, will be investigated in other areas of the office's portfolio. If hydropower plants are required to operate more flexibly, inflow forecasting, and water management tools will likely require improvements in accuracy and resolution. Hydropower flexibility is a function of reservoir capacity; therefore, knowing exactly how much water will be available at a particular time can enable better planning and unlock additional operational capabilities. Work under this objective will first focus on identifying instances where forecasting tools are currently or prospectively insufficient in the context of increasing operational flexibility. Currently, the marginal value of improvements to these models is being quantified, and follow-up work will target key areas for model improvements.

The final technical objective of this sub-activity is to improve the representation of hydropower and PSH in power system models to capture their unique capabilities more accurately. There are fundamental differences in hydropower representation between grid models and water management models, creating a need for appropriate coupling. As markets increasingly regionalize and create transfer opportunities for large hydropower, precise models that capture the local operational realities will be critically important. HydroWIRES is currently exploring model improvements to hydropower representation in production cost models and capacity expansion models through multiple, parallel avenues. Future work may include testing these improvements with end-users to validate and scope further improvements.

Sub-Activity 2.3 – Operations and Planning

Overview

In addition to understanding the value of hydropower's flexibility and the fleet's technical ability to provide them under different circumstances, there is a need to better understand the competitive advantages and disadvantages that hydropower has in providing each of these services compared to other generation technologies for various system conditions. HydroWIRES will provide data and modeling tools to improve hydropower operations and planning—from both a project and power system perspective—to most effectively utilize hydropower's capabilities to contribute to grid reliability and renewable energy integration. This will be achieved through four technical objectives: (1) quantifying system reliability and resilience contributions; (2) comparing with other resources; (3) optimizing operations; and (4) quantifying system effects on operations.

FY 2021–2025 Research Priorities

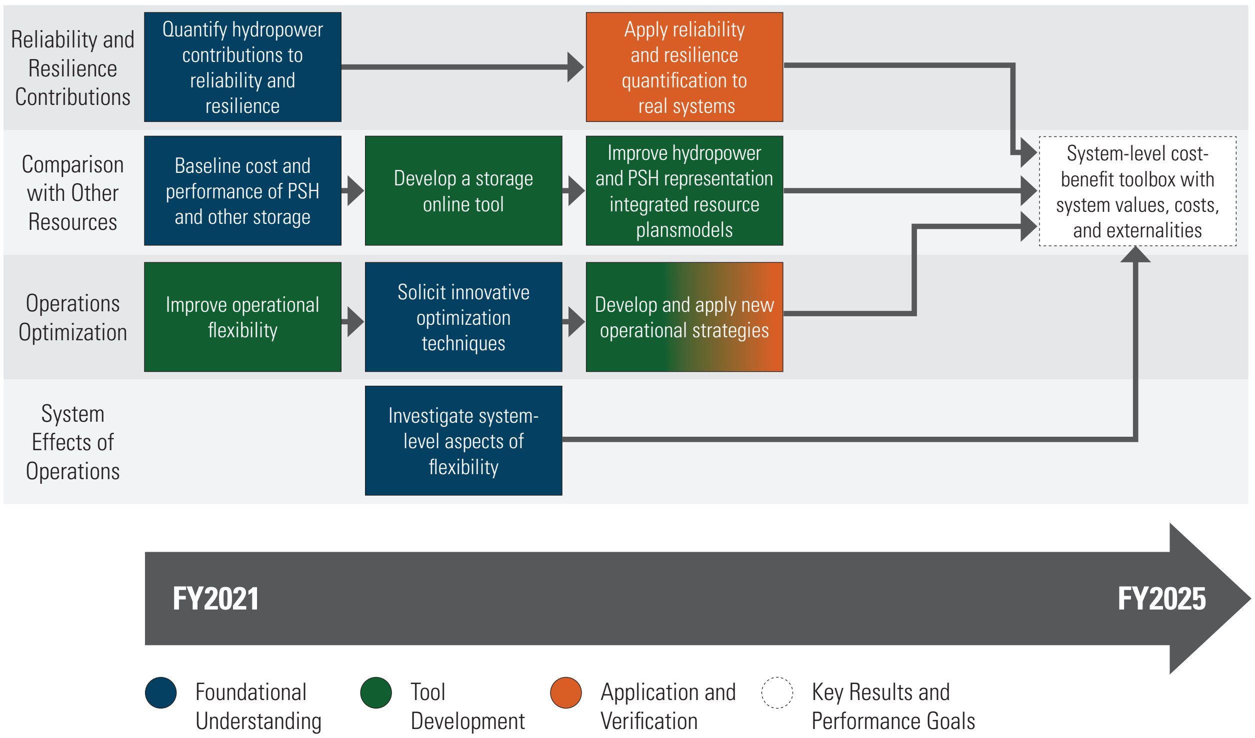
The following are the research priorities that will be emphasized within the HydroWIRES Sub-Activity 2.3 – Operations and Planning:

- **Reliability and Resilience Contributions**
  - **Quantify hydropower contributions to reliability and resilience**: Develop a framework to determine the contributions of hydropower to the reliability and resilience of the grid during contingency events.
  - **Apply reliability and resilience quantification to real systems**: Work with industry or other external partners on improved contingency strategies supported by hydropower.
- **Comparison with Other Resources**
  - **Baseline cost and performance of PSH and other storage**: Compile the latest data on costs and performance PSH alongside other storage technologies to allow apples-to-apples comparisons.
  - **Develop a storage online tool**: In coordination with other DOE offices, create and maintain a tool to serve stakeholders that provides them with the latest storage cost and performance data.
  - **Improve hydropower and PSH representation in integrated resource plans**: Work with planners to apply modeling tools that more accurately capture hydropower and PSH in integrated resource planning processes.
- **Operations Optimization**
  - **Improve operational flexibility**: Support industry-led efforts to increase the operational flexibility of hydropower plants.
  - **Solicit innovative optimization techniques**: Solicit innovative optimization techniques from other fields to apply to hydropower operations.
  - **Develop and apply new operational strategies**: Building on modeling enhancements and prior work, support industry-led efforts to develop new operational strategies that better meet system needs.
- **System Effects of Operations**
  - **Investigate system-level aspects of flexibility**: Investigate the links between increased fleet-scale hydropower flexibility and system-level attributes of ecology, air quality, or water use.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 18.

Figure 18. Sub-Activity 2.3 – Operations and Planning Research Priorities



Additional Details

The first technical objective is to quantify hydropower plant- and fleet-level contributions to system reliability and resilience requirements. While certain metrics are well-established (loss of load probability, expected unserved energy) and new reliability metrics are under development, these measurements represent system capability and condition and do not give insight into how hydropower fleets and individual assets contribute to reliability and resilience. In addition, given observed increases in the variety, intensity, and frequency of potential natural and man-made threats to electricity system reliability, electricity system resilience has also become an important system property to measure and to assure. Work is ongoing to develop a framework for quantifying hydropower and pumped storage contributions for reliability and resilience during adverse events. Future work may include technical assistance to end-users of reliability/resilience quantification tools and development of targeted improvements.

Not only is it important to characterize hydropower and PSH's various benefits and costs, but it is also important to put these in context through comparison with other resources to best inform planning decisions. While hydropower and PSH can provide a range of grid-system services, there are almost always other resources available that also can provide the same services. Therefore, there is a need to distinguish hydropower and PSH resources from other comparable technology solutions. Baseline work on identifying cost and performance parameters for PSH alongside other storage technologies has been completed and will feed the development of an online tool to inform utilities and developers. More work may also be directed toward capturing externalities for each technology type in these resource comparison studies in the future. In addition, targeted technical assistance efforts to utilities and regulators can support integrated resource planning processes and ensure the best available modeling tools are utilized to evaluate hydropower and PSH.

This sub-activity also seeks to develop operational strategies and associated tools that enable hydropower to better optimize its operations to provide grid services. At the plant level, the multi-objective nature of reservoirs creates challenges related to competing uses for water, which is further complicated in the case of cascading systems (i.e., rivers with multiple hydropower plants). Furthermore, this situation can lead to competition across different time horizons because an optimal strategy for the next day may be mutually exclusive with an optimal strategy for the next week. This objective seeks to enhance hydropower's potential utilization for grid services through new optimization approaches; develop an evolution of practice within operations modeling, computational improvements, and real real-time sensors; and advance other plant-specific techniques to address constraints or expand capabilities. Some work that analyzes operational strategies to maximize value of PSH plants under future grid scenarios has already been completed, and work on flexible operations of hydropower plants is ongoing. Technical assistance to owners and operators—to better optimize their systems and inform their decision-making regarding market decisions—may occur in the future.

The final technical objective of this sub-activity is to quantify effects of hydropower plant- and fleet-level operations on water availability, environmental, and other system properties. While HydroWIRES focuses primarily on hydropower's role supporting the electricity system, the changing operations of hydropower can also have impacts—both positive and negative—on other important variables of sustainable energy and water systems. This technical objective is strongly linked with Activity 4 – Environmental and Hydrological Systems Science. For example, scientific studies to determine the impact of flexible operations on particular species, performed in Activity 4, will be incorporated into larger, flexibility cost-benefit and tradeoff tools in this area of work. Therefore, work may include a scoping study of system-level changes associated with more flexible hydropower operations, including impacts on water end-use, reservoir emissions, river system ecology, and other cross-domain impacts.

Sub-Activity 2.4 – Technology Innovation

Overview

Many plants in today's fleet are designed primarily for steady generation in a narrow operating range, which can make them less suited for flexible operation for current grid needs. In addition, new PSH projects face significant deployment challenges including high capital costs and long lead-time to commissioning. HydroWIRES will support R&D for innovative technologies that improve hydropower capabilities to provide grid services, and support development of advanced PSH systems critical to drive the utilization of new PSH in the United States. This will be achieved through four technical objectives: identifying technology gaps, enhancing unit flexibility, enhancing plant flexibility, and developing new PSH approaches.

FY 2021–2025 Research Priorities

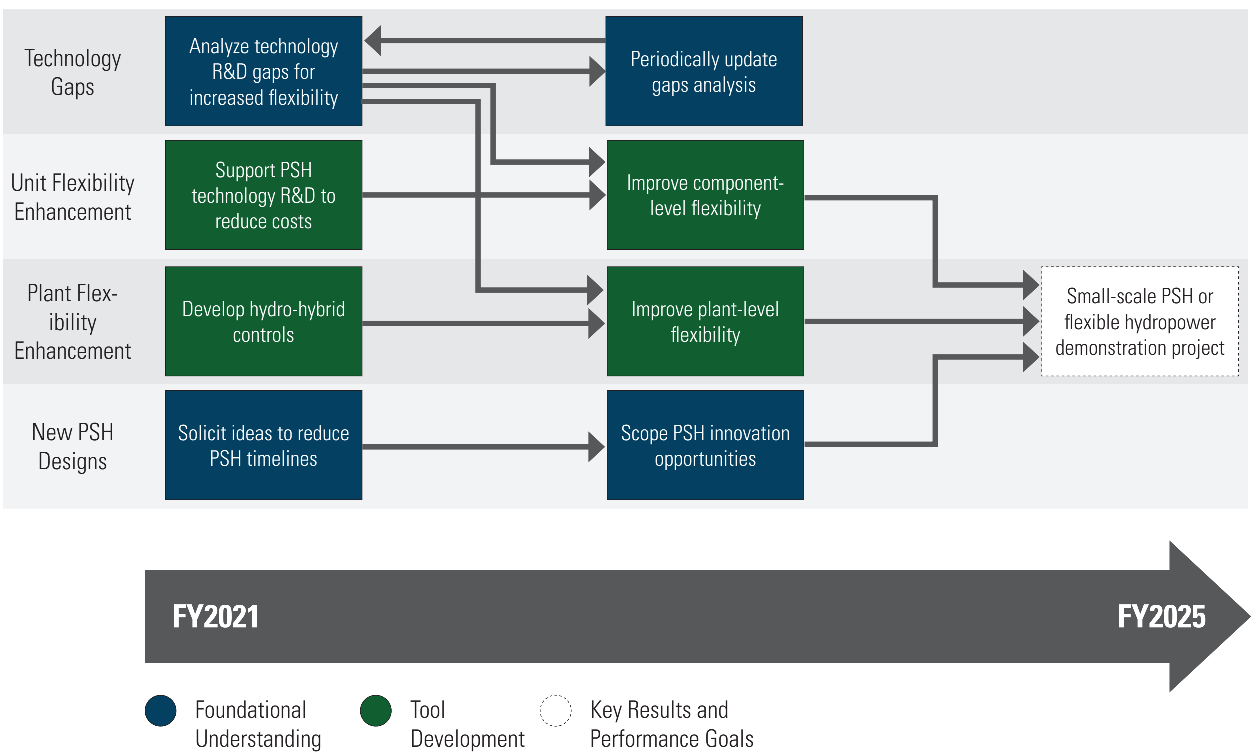
The following are the research priorities that will be emphasized within the HydroWIRES Sub-Activity 2.4 – Technology Innovation:

- **Technology Gaps**
  - **Analyze technology R&D gaps for increased flexibility**: Determine what technology gaps at the component- and plant-level could be addressed to enable increased hydropower flexibility.
  - **Update gaps analysis periodically**: Periodically update the gaps analysis to ensure that new technology R&D targets new value drivers for hydropower and PSH that may emerge.
- **Unit Flexibility Enhancement**
  - **Support PSH technology R&D to reduce costs**: Support innovative technology to reduce the cost per kilowatt of new PSH.
  - **Improve component-level flexibility**: Develop technology that can improve the flexibility of particular hydropower and PSH components.

- **Plant Flexibility Enhancement**
  - **Develop hydro-hybrid controls**: Develop controls for hybrid hydropower systems that allow for increased flexibility and improved grid services.
  - **Improve plant-level flexibility**: Develop technology that can improve the flexibility of hydropower and PSH plants.
- **New PSH Designs**
  - **Solicit ideas to reduce PSH timelines**: Solicit ideas from other industries and academia on how to reduce the total time to commissioning for PSH plants.
  - **Scope PSH innovation opportunities**: Complete a holistic evaluation of previous PSH technology R&D to identify the most fruitful avenues for future work in technology R&D, as well as for innovative project development.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 19.

Figure 19. Sub-Activity 2.4 – Technology Innovation Research Priorities



Additional Details

The first technical objective is to identify and map out technology innovations that enable hydropower plants to improve provision of grid services. Work under this objective will take stock of the state-of-the-art hydropower technology, specifically focused on capabilities for enhanced flexibility or provisions of other emerging system needs. This bottom-up assessment of technology gaps will outline opportunities for targeted technology R&D and their respective impacts. Future work may enable greater flexibility, building on previous work in the portfolio,[58] and including rigorous assessment to determine viable innovation pathways.

Once gaps have been identified, this sub-activity will further develop technology solutions that enable enhanced flexibility at the unit level. Possible innovations within this objective could include technologies that enable provision of new services, reduce barriers to dispatching units more quickly, reduce unit downtime, enhance the ability of a unit to achieve environmental objectives, and/or lead to greater ranges of unit operation. If successful, this objective will achieve outcomes such as faster response, longer duration response to frequency excursions, reduced wear and tear, faster repair methods, and reduced environmental impacts. Previous work on this topic includes external funding opportunities for advanced PSH development and research into pump-turbines for geomechanical storage. In the future, this goal may be furthered with an investigation into hybrid hydropower use cases and technology R&D to enable increased flexibility at the unit level, such as turbine design or penstock/draft tube architectures.

Complementing Sub-Activity 2.3 – Operations and Planning, this sub-activity will develop technology solutions that enable enhanced flexibility at the plant level. This objective builds from the gaps assessment to support advanced technologies and design innovations that preserve and enhance plant flexibility attributes, such as innovations at the level of the powerhouse, dam, and reservoir system. Innovations can include technologies that remove barriers to flexibility, new sensors that improve plant intelligence, structural and civil works enhancements that improve plant responsiveness, artificial intelligence approaches to plant management and maintenance that reduce forced outages, and new environmental technologies that increase the ability of a plant to deliver energy services, among others. Work is currently being done on the Hydropower and Energy Storage Systems project to combine hydropower with batteries, flywheels, or ultracapacitors to provide additional system services. More targeted technology R&D to enable increased plant flexibility is expected in the future.

The final technology objective in this sub-activity is to develop new technology concepts and approaches that overcome barriers associated with PSH deployment. There is little public information available about new designs that could offer benefits of pumped storage at competitive costs. To investigate such opportunities, this objective seeks radically new designs in PSH technologies that can meet cost reduction goals, competitive timelines to commissioning, and enhanced value without requiring the economies of scale and financial structures that make large, pumped storage economically viable. Currently, a baseline report on reducing the time to commissioning of new PSH projects, including analytical work on reducing excavation costs and novel technology configurations, is in progress. Potential future work could include small-scale PSH testing and demonstration for innovative technologies.

[58] For example, the Energy Storage Technology and Cost Characterization Report provides a basis of understanding for which technology gaps prevent PSH from being competitive with other storage alternatives.

Opportunities for Hybridization of Hydropower Assets

As the energy mix evolves to increased diversity of resources, there is an opportunity to integrate these resources at the point of interconnection to better take advantage of their unique capabilities. HydroWIRES will perform valuation analyses to determine if pairing hydropower with different generating and/or storage assets can lead to a more reliable and flexible system than the standalone alternative. Examples of hydro-based hybrids include:

- **Hydro and Storage**: Integration of hydropower and other energy storage technologies provides synergies that increase the value of both asset classes and improves provision of grid requirements from existing hydropower plants. Adding energy storage technologies such as Lithium-ion batteries can increase the flexibility of hydropower over short to medium timescales, enabling it to provide frequency regulation; in a complementary way, hydropower provides a reliable and predictable source of generation for charging the energy storage devices. The benefits of hybrid hydropower and storage systems will vary based on the market/power system context. In restructured markets, the benefits are principally revenue-driven as a result of participating in additional ancillary service markets, such as frequency regulation. In regulated markets, the hybrid system can provide an alternative paradigm for utilizing existing hydropower plants to meet reliability requirements. In microgrids, the system can provide power quality stability, decrease cost of operation, and enable greater deployment and operation of variable generation resources.
- **Hydro and Floating Solar Photovoltaics (or "floatovoltaics")**: Hydropower's flexibility makes it amenable to balancing the variable generation of solar plants, and in some cases, physically co-locating solar PV by floating it on a hydropower reservoir can provide benefits. In addition to operational complementarities, there are advantages of floating solar over land-based systems, including reduced reservoir evaporation and higher PV efficiencies due to cooling. In the case of PSH, floatovoltaics also provide a renewable energy source in situ to offset pumping costs.

Hydropower Program Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity

Overview

The Hydropower Program supports analysis, research, and development in three areas: (1) modernization; (2) maintenance; and (3) cybersecurity. Modernization refers to upgrading or adding new hydropower system capabilities. In the next five years, the modernization portfolio will primarily focus on hydropower fleet digitalization. Digital transformation refers to the application of digital capabilities to not only solve traditional challenges for hydropower but also enable access to a new range of opportunities for the industry. This is the initial focus of the modernization work because it represents one of the broadest opportunities for improvement in the hydropower sector, with the potential to reduce operation costs, improve system performance through continuous assessment and predictions, and ensure inter-generational knowledge retention. Maintenance research focuses on understanding and improving the specific procedures surrounding the preservation of hydropower systems. Maintenance represents the broadest component of asset management, where routine servicing to the system will maximize the remaining useful life of the asset. However, performance degradation or risk of failure will eventually require that the component be refurbished (activities intended to remove operational damage and increase remaining useful life) or replaced. Cybersecurity research focuses on assessing the complex regulatory landscape and helping asset owners to determine the possible benefits of different cybersecurity investments. This work includes the development of cyber surrogate capabilities, which are systems designed to help identify intrusions into the hydropower network by assessing aberrant network traffic or inconsistencies in system signals/operation. This is particularly valuable given both difficulty in incident identification and the potential long period between a malicious action and its detection.

Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity consists of the following sub-activities:

1. Modernization: Integrating digital capabilities into the hydropower industry to streamline workflows, reduce risks, and reduce costs through holistic monitoring and management of hydropower systems, as well as enabling the hydropower operators to take full advantage of digital solutions appropriate for specific sites.
2. Maintenance: Baselining maintenance costs, improving condition assessment datasets, and benchmarking causes of hydropower plant outages.
3. Cybersecurity: Maintaining hydropower plant security as facilities become increasingly connected to both digital systems and broad communication and control networks.

Performance Goals and Objectives

The key results, performance goals, and follow-on objectives are summarized in Table 16.

Table 16. Fleet Modernization, Maintenance, Cybersecurity Performance Goals and Objectives

Key Results and Performance Goals (2021–2025)
• Develop and make publicly available hydropower digital twin[59] capabilities (e.g., numerical models, computational codes, and underlying physics/engineering data) appropriately scaled for a diverse range of hydropower plant characteristics and operational profiles. • Publish valuation assessment guidance to facilitate right-sized investments into hydropower digitalization, maintenance, and cybersecurity. • Complete initial phases of research on fatigue and wear mechanisms for high-impact hydropower components, including both conventional and advanced materials, which can reduce forced outage instances and help design the next generation of hydropower components. • Develop hydropower plant cyber surrogate capabilities[60] that can be integrated into existing cybersecurity processes and reduce hydropower plant vulnerabilities.
Follow-On Objectives (2026–2030)
• Asset owners and equipment designers widely utilize new, open-access digital twin capabilities in efforts to improve system/administrative scheduling and condition-based predictive maintenance. • Demonstrated use of new valuation methodologies in hydropower plant capital planning processes as well as the use of these capabilities to identify cost reduction and capability improvement opportunities. • Use of better articulated wear/fatigue mechanisms by asset managers in maintenance scheduling as well as the integration of these insights into plant dispatch strategies. • Integration of cyber surrogate capabilities into hydropower cybersecurity processes to facilitate the rapid identification cybersecurity intrusions and improve overall system security.

Additional Details

Dams and reservoirs serve many purposes beyond hydropower generation, including recreation, fish and wildlife support, flood management, agricultural irrigation, drinking water supply, and cooling water for thermal plants. The average U.S. hydropower facility has been operating for over 64 years,[61] and as the fleet ages, it is critical to modernize facilities and incorporate state-of-the-art capabilities into hydropower infrastructure to ensure the nation can continue to have access to the wide breadth of benefits hydropower provides. Modernization of electrical, mechanical, and civil systems can improve efficiency and generation, increase system and grid reliability, enable new value propositions, and ensure critical infrastructure security. Effective modernization research first requires the development of landscape assessments to clearly articulate the state of the industry. Landscaping assessments can occur in parallel to the development of industry accessible valuation capabilities to clearly outline the costs and benefits that modernization would represent. Both the landscaping and valuation efforts are high-impact, short-term activities. In addition, these efforts help highlight the opportunities for new impactful research in hydropower digitalization, maintenance, and cybersecurity. The development of new capabilities (both tools and technologies) is also an integral component of Activity 3 – Fleet Modernization, Maintenance, and Cybersecurity. The development of new capabilities recognizes the importance of supporting systems throughout their maturation. Demonstration of new capabilities performance and benefits is particularly critical to ensure a smooth transition to industry adoption.

[59] Digital twins are mathematical based representations of systems that can be used in a host of applications including operations planning, assessing the impact of market entry, and upgrade/modernization investments.

[60] Cyber Surrogate capabilities are systems designed to help identify intrusions into the hydropower network by assessing aberrant network traffic or inconsistencies in system signals/operation.

[61] U.S. Energy Information Administration, 2017. "Hydroelectric generators are among the United States' oldest power plants." https://www.eia.gov/todayinenergy/detail.php?id=30312#.

As stated above, digitalization will represent the initial focus of the modernization effort given its significant potential to improve outcomes. This research will adapt and adopt capabilities from other, relevant sectors where possible and will consider how the capabilities produced by funded research can advance outcomes in other industries. Digitalization solutions from other relevant sectors, such as other forms of power generation, includes advanced sensing and signals processing capabilities. However, in many instances these need to be adapted to recognize both the varying structure of hydropower plants and the distributed nature of hydropower facilities, whereas the "digital footprint" for other industries tends to be much more repetitive and localized. Solutions in this diverse and distributed space can then be transferred to other industries with similar issues such as transportation and water infrastructure.

Maintenance research focuses on understanding and improving the specific procedures surrounding the preservation of hydropower systems. Maintenance represents the broadest component of asset management, where routine servicing to the system will maximize the remaining useful life of the asset. However, performance degradation or risk of failure will eventually require that the component be refurbished or replaced. These maintenance practices balance the need to service equipment to ensure system availability/performance and limit the risk of failure with both constrained resources and the desire to limit outage of the plant to perform the maintenance. To help the industry better strike this balance, WPTO works to: (1) improve condition assessment to determine component health more accurately; (2) develop novel condition monitoring capabilities to better assess a wide array of critical components; and (3) advance system wear/fatigue modeling to better understand how O&M practices contribute to the loss and preservation of system life. The enhanced information provided by this effort can be integrated into existing industry asset management practices and will enable more accurate decision making.

Cybersecurity research focuses on assessing the complex regulatory landscape and helping asset owners to determine the possible benefits of different cybersecurity investments. Furthermore, cybersecurity research focuses on leveraging relevant technologic solutions from other industries as well as developing novel capabilities uniquely suited for the diversity of hydropower infrastructure. This work includes the development of cyber surrogate capabilities, which are systems designed to help identify intrusions into the hydropower network by assessing aberrant network traffic or inconsistencies in system signals/operation. This is particularly valuable given both difficulty in incident identification and the potential long period between a malicious action and its detection.

These research efforts are designed to produce studies that holistically represent the state-of-the-industry and convey the value proposition of effective security, digitalization, and maintenance. This work will help ensure that solutions produced are "right-sized" based on both the future benefits they can provide and their associated costs. "Right sizing" specifically refers to the fact that the solutions will be applicable to many different scales and characteristics of hydropower facilities. In the long-term, the security, digitalization, and maintenance efforts aim to safeguard increasingly interconnected hydropower infrastructure, improve the value of operational paradigms, and reduce operation and maintenance costs, while improving system performance.

Sub-Activity 3.1 – Modernization

Overview

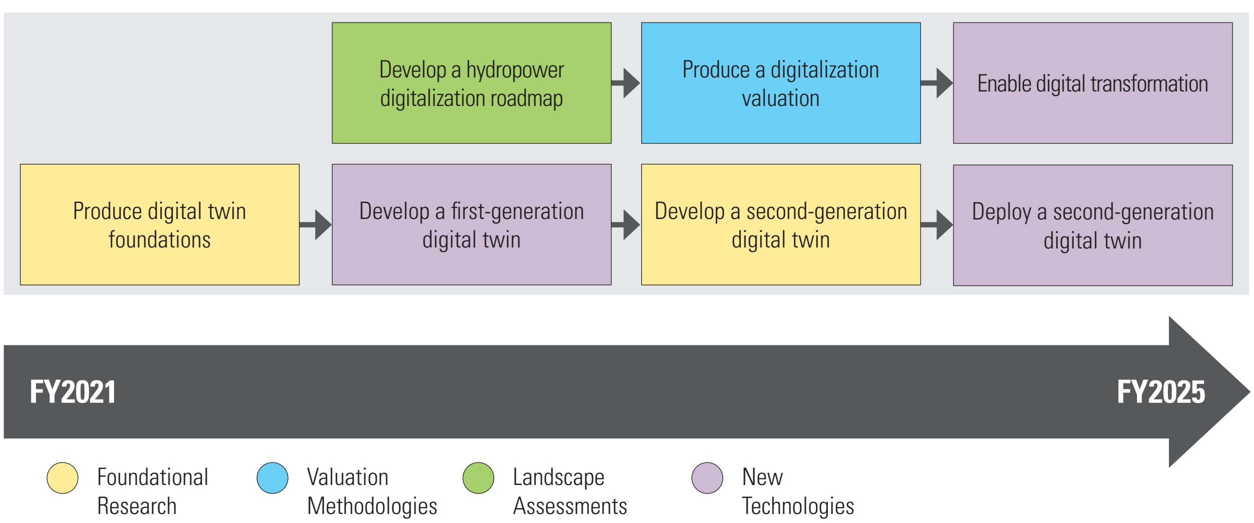
This research focuses on two efforts—digital twin capabilities development and enabling digital transformation. The latter of these refers to the integration of digital capabilities into the hydropower industry to streamline workflows, reduce risk, and reduce costs through holistic monitoring and management of hydropower systems. The Hydropower Program's overall hydropower digital transformation work will focus on enabling the hydropower operators to take full advantage of digital solutions appropriate for specific sites. In the short term, the Hydropower Program will conduct an assessment to fully describe the range of digital solutions and their relative applicability to different hydropower facilities. The fundamental barriers to uptake are a basic lack of information, such as costs, benefits, and applications, and lack of industry consensus on the opportunities and processes to integrate digital solutions into hydropower systems. The information from this broad assessment will be leveraged in subsequent efforts, which will develop a means to document the value of digitalization for hydropower facilities to help reduce the risk of uncertain return on investment into digital systems. Research in this area will culminate with an effort to enable a broader digital transformation of hydropower. While prior efforts largely focus on analyzing the applicability and value of existing capabilities, this work will be targeted at developing new digital solutions (or adapting capabilities from other industries). Work in this space will include improving return on investment via the refinement of supply/demand forecasting for system dispatch, reducing operational costs through system automation and remote operation, and increasing safety for operations staff.

FY 2021–2025 Research Priorities
The following are the research priorities that will be emphasized within the Sub-Activity 3.1 – Modernization.

- **Develop a hydropower digitalization roadmap**: Assess the applicability of various digitalization solutions to the hydropower fleet and document the implementation and integration process.
- **Produce a digitalization valuation**: Produce an industry-accessible means to document the value of different digitalization opportunities.
- **Perform a digital transformation**: Leverage prior efforts to develop the capabilities necessary to enable digital transformation, drive-value propositions.
- **Produce digital twin foundations**: Produce the coupled mathematical models that represent hydropower plants to create the foundations of hydropower digital twins.
- **Develop a first-generation digital twin**: Utilize the digital twin foundations to develop a first-generation hydropower digital twin.
- **Develop a second-generation digital twin**: Utilize the lessons learned from the first-generation digital twin to refine the underlying principles and application processes.
- **Deploy a second-generation digital twin**: Deploy the second generation of hydropower digital twins.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 20.

Figure 20. Sub-Activity 3.1 – Modernization Research Priorities



Additional Details

As stated above, the modernization of hydropower plants entails a broad swath of options from exchanging legacy mechanical hardware for newer systems to installing next generation system controls. Given this wide range of opportunities, the Hydropower Program has elected to focus primarily on digitalization within the scope of the MYPP. This focus on digitalization is based on the wide range of opportunities that it presents to the hydropower community and that many facilities are in various stages of digitalization. It should be noted that in the future, the breadth of the modernization work will likely evolve or expand to encompass a broader range of research opportunities (contingent on budget availability). Hydropower plant digitalization research is focused on the conversion of legacy systems to integrated digital capabilities, and the use of this unprecedented volume of new data that this provides to significantly improve hydropower outcomes, such as reducing costs, improving reliability, and increasing revenue. As the hydropower industry enters a new century of service, traditional operational practices must be updated to enhance technological competitiveness and enable hydropower facilities to maximize performance under increasingly complex operational, social, and environmental considerations. System digitalization can enable this by not only increasing the efficiency of current practices, but also by enabling novel capabilities and benefits that hydropower plants were unable to unlock previously. However, it is important to recognize the importance of ensuring "right-sized" solutions—or solutions that appropriately balance the resources necessary to implement the capability, the value provided by the solution, and the ability of the organization to appropriately manage the capability—given that hydropower facilities operate over a wide range of sizes, operational constraints, maturity, and resource availability. Given the broad impacts and potential benefits of digitalization, there is also overlap with several other activities. Notably, digitalization can play a significant role in the design and monitoring of next generation hydropower (Sub-Activity 1.1 – New Technologies and Advanced Manufacturing), and digitalization of hydropower plant controls can potentially have significant effects on unit and asset flexibility (Sub-Activity 2.4 – Technology Innovation).

The other primary focus of research is the development of digital twin capabilities. These are extremely useful tools which have been leveraged in many other industries but have largely not been utilized for hydropower systems due to the diverse nature of hydropower plants and the disparate nature of data needed to inform these models. While digital twin capabilities have been investigated in a preliminary fashion for the hydropower industry, this approach to the research is limited to specific facilities only and is not widely applicable to other locations. The proposed R&D noted here is focused on developing publicly available underlying capabilities, which can then be applied to the broader hydropower fleet. These "open source" capabilities will facilitate the democratization of digitalization, as the publicly available nature of this information will allow owners/operators to better benefit from their own data as well as provide the hydropower industry with a common foundation upon which they can build a myriad of novel capabilities. Supported by prior efforts, (including HydroSource, mapping of Cyber-Physical Structures, and a partnership with the Hydropower Research Institute) WPTO now has the necessary insight and convening power to gather the requisite information as well as the scientific capabilities to develop solutions that will be applicable to the broader fleet. This work will initially be focused on investigating hydropower systems and developing the mathematic-/engineering-based models necessary to fully describe the broader hydropower fleet. These underlying models will be developed in such a way that will accurately describe generalized classes of hydropower facilities that can later be tailored to specific facilities using project-specific data and information to calibrate and train the models. Once the generalized models have been developed, the first-generation digital twin representations will be deployed to specific hydropower facilities to test the viability of the models. Then, the results (and lessons) will be utilized to further refine the tools to improve accuracy and increase broad applicability to other hydropower facilities. The second-generation digital twin will then be developed and deployed to a wider range of hydropower plants to provide the hydropower plant owners and operators with new and more valuable information necessary to improve hydropower plant value.

Sub-Activity 3.2 – Maintenance

Overview

Efforts in this sub-activity capitalize on a rich history of foundational, asset-management research funded by WPTO. This historic work includes significant effort in baselining maintenance costs, improving condition assessment datasets, and benchmarking causes of hydropower plant outage. This work entailed significant input and coordination with numerous owners, regulatory agencies, and industry groups. The initial effort moving forward will focus on transforming the broader historical research effort into a specific, high value, capability which owners and operators can use in their standard asset management decision-making process. In the immediate and medium term, this capability is aimed at articulating the impact of dispatch variability on system costs, condition, and reliability. Articulating the impact is important to the hydropower industry as operations are becoming increasingly varied to facilitate the integration of variable renewables. This work has particular applicability to Sub-Activity 2.4 – Technology Innovation (under Grid Reliability, Resilience, and Integration). However, this work exclusively focuses on the nuances of system fatigue and reliability reduction whereas HydroWIRES focuses on the broader universe of flexible operation. Hence, reduced-order maintenance-focused data and models will likely be incorporated into broader HydroWIRES efforts.

FY 2021–2025 Research Priorities

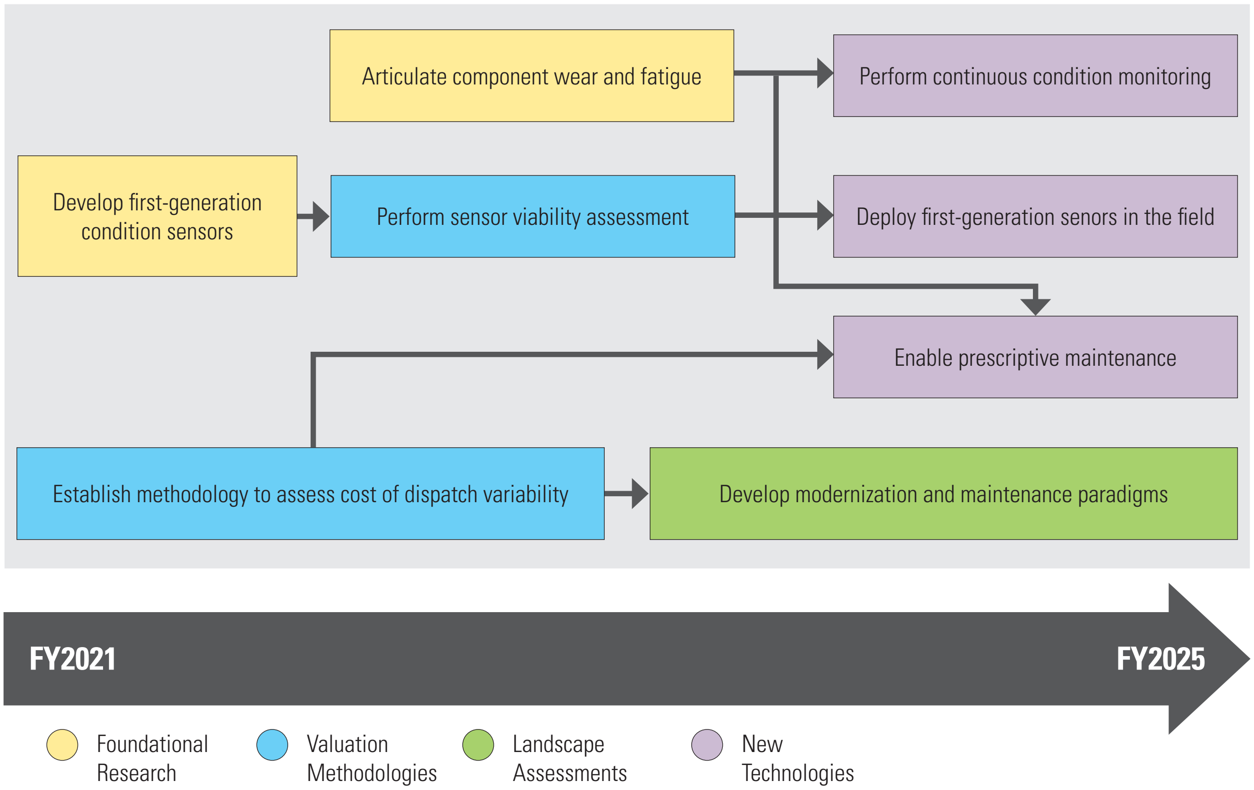
The following are the research priorities that will be emphasized within the Sub-Activity 3.2 – Maintenance:

- **Articulate component wear and fatigue**: Articulate the wear and fatigue mechanisms of critical hydropower plant components necessary to understand component reliability.
- **Perform continuous condition monitoring**: Create capabilities to continuously monitor asset condition and document operation within acceptable parameters.
- **Develop first-generation condition sensors**: Develop first-generation condition assessment sensors capable of improving and/or expanding monitoring capabilities.
- **Perform sensor viability assessment**: Assess the economic and performance viability of novel sensor capabilities.
- **Deploy sensors in the field**: Deploy sensors in the field to gather critical performance and reliability data.
- **Enable prescriptive maintenance**: Enable data-driven maintenance practices based on component health, risk of failure, and downtime coordination.
- **Establish methodology to assess cost of dispatch variability**: Create a methodology to assess the impacts of dispatch variability on cost, condition, and reliability.
- **Develop modernization and maintenance paradigms**: Produce guidance on the processes and trade-offs associated with modernization, overhaul, and maintenance decisions.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 21.

Figure 21. Sub-Activity 3.2 – Maintenance Research Priorities



Additional Details

Effective hydropower plant maintenance requires a combination of repairing and replacing system components as they age and lose effectiveness. Maintenance decisions must balance the risk of component failure and the associated cost of reduced performance against limited resources and outage planning. In addition, these decisions must be made under a range of uncertainties from both historic operation and current condition assessments. There is significant value to the hydropower industry from WPTO-funded research to develop data-driven solutions for asset maintenance planning and improving the understanding of the complex wear mechanisms of hydropower components. This research strategy will be effective in helping reduce the uncertainly and lost revenue potential associated with asset management decisions. Research reducing the O&M costs are particularly valuable for the hydropower industry, as the 2017 Hydropower Market Report indicated that O&M costs have grown 30 to 40 percent over the last decade for small, medium, and large hydropower facilities. This rate of increase significantly outstrips the growth of the Consumer Price Index.[62] Research in this area recognizes the site-specific nature of hydropower plant configurations, the diverse operational history, and the importance of engaging the broader hydropower industry and asset management community (including the Electric Utility Cost Group, the Center for Energy Advancement through Technological Innovation [CEATI], the North American Electric Reliability Corporation–Generating Availability Data System, and a host of utilities).

[62] Uría-Martínez, R., Johnson, M., and Shan, R., 2021. "U.S. Hydropower Market Report." https://www.energy.gov/eere/water/downloads/us-hydropower-market-report.

Information gathered through the application of the variability dispatch valuation methodology—as well as the broader asset management effort—will then be consolidated, along with other information, to produce industry guidance on maintenance and upgrade decisions. This guidance will clearly outline the decision making and administrative processes regarding maintenance and upgrade activates for various hydropower plant systems. This guidance will also help provide original equipment manufacturers with better visibility into the decision-making processes of asset operators and thereby provide more tailored solutions for future hydropower technologies.

In addition to this focus, the Hydropower Program is investing in sensors research to assess the condition of hydropower plants more reliably. The initial research will be targeted towards early-stage sensor concepts to gather fundamental data on performance, impact, and costs. In the medium term, the initial research will then be expanded to gather more detailed performance information and to document the ability of these sensors to provide sufficient benefit to justify their expense. Once the medium-term research has been performed, the Hydropower Program will partner with the hydropower industry and test first-generation sensors in the field to gather further information and to help build confidence regarding sensor efficacy and safety. The solutions developed from this initial deployment should be sufficiently mature to warrant commercial uptake to benefit the hydropower industry more broadly.

Finally, the Hydropower Program will begin efforts to better understand the fundamental wear and fatigue mechanisms of hydropower components. Full articulation of these processes is critical to assessing the remaining useful life of hydropower plant components and structures. While traditional efforts in this area have focused on a “top down” empirical modeling approach, data have been historically inadequate to fully document the processes. As a result, efforts will focus on a bottom-up physics- and experimental-based approach to ensure that system degradation is appropriately captured. This effort will begin with detailed investigations to the wear and fatigue mechanisms of high-impact components. The development of these models will help better articulate component reliability. The results of this effort will then be leveraged to develop a methodology to assess asset condition based on available data. This assessment methodology will recognize both the need to develop reduced order models, which do not require significant time and computational resources, as well as the fundamental lack of high-resolution historical data for a vast majority of components. The reduced order models will enable these assessments to be applicable to a majority of hydropower plants and thereby will have a broad impact on the hydropower industry.

Sub-Activity 3.3 – Cybersecurity

Overview

The cybersecurity sub-activity focuses on maintaining hydropower plant security as facilities become increasingly connected to both digital systems and broad communication and control networks. The work under this effort will involve the broad range of stakeholders in hydropower cybersecurity and leverage WPTO’s core hydropower technology capabilities with the broader cybersecurity expertise elsewhere in DOE, other federal agencies, and industry. Cybersecurity research focuses on conveying the complex impact propositions and process of hydropower plant security and then leveraging the lessons learned to produce novel technical capabilities—which the hydropower industry can apply to its diverse range of cyber structures. These efforts will initially entail a multi-year effort designed to articulate the value proposition of investing in cybersecurity upgrades. Created with the industry in mind, this methodology will enable ready comparison of these investments to other capital planning efforts, thereby enabling decision makers to efficiently dedicate resources. In addition, initial efforts during the multi-year period include documenting the status and trends of cybersecurity in the hydropower industry. This work will enable visibility on the complex hydropower cybersecurity landscape, a factor which has been widely acknowledged as a bottleneck to advancing the state of the art.

FY 2021–2025 Research Priorities

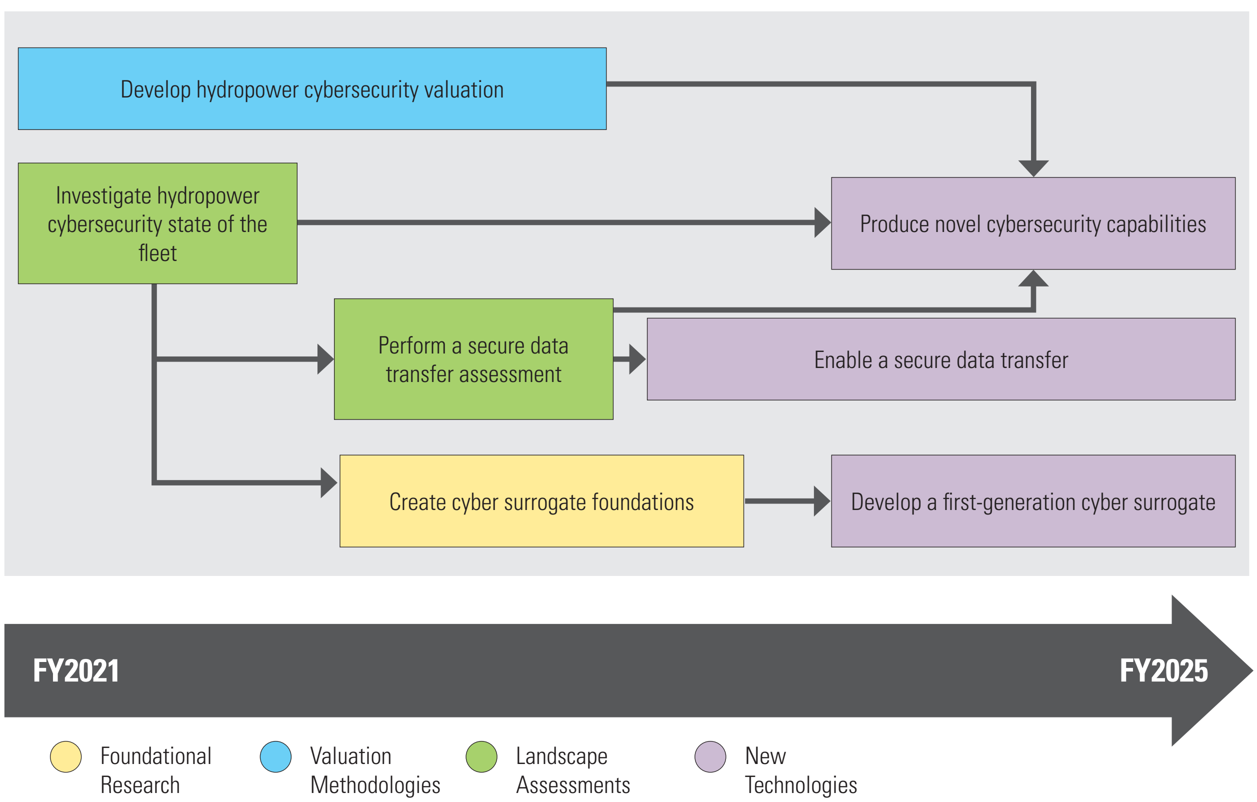
The following are the research priorities that will be emphasized within the Sub-Activity 3.3 – Cybersecurity:

- **Develop hydropower cybersecurity valuation**: Develop an industry accessible hydropower valuation method to enable informed investments in security improvements.
- **Investigate hydropower cybersecurity state of the fleet**: Investigate the hydropower fleet cybersecurity status and highlight opportunities for growth.
- **Perform a secure data transfer assessment**: Document existing capabilities for low latency data transfer and their applicability hydropower applications.
- **Enable a secure data transfer**: Enable and develop the use of low latency secure data transfer to be used in hydropower plant operation and decisions.
- **Create cyber surrogate foundations**: Create capabilities to document relevant system process foundation to developing a cyber surrogate.
- **Develop a first-generation cyber surrogate**: Develop first-generation cyber surrogate capabilities and assess its performance and develop lessons learned.
- **Produce novel cybersecurity capabilities**: Produce novel cybersecurity capabilities which can be integrated with a diverse set of preexisting cybersecurity process and structures.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 22.

Figure 22. Sub-Activity 3.3 – Cybersecurity Research Priorities



Additional Details

It should be noted that WPTO is making an active effort to coordinate efforts with other actors in this space, including the Department of Homeland Security (DHS); FERC; the Office of Cybersecurity, Energy Security, and Emergency Response (CESER); industry working groups; and individual owners. This coordination is foundational to ensuring uptake of the capabilities produced, as well as that the work sponsored by WPTO builds upon the office's unique capabilities and focuses on the most impactful areas in this space. Engagement with these partners is achieved in three primary ways: bilateral presentations of WPTO's and the other organization's portfolio followed by discussion of value proposition and next steps; presentations to working groups with broad representation such as CEATI's Infrastructure Protection and Security Interest Group and DHS's Dam Sector Cybersecurity Working Group; and engagement during the research process. The last of these is particularly important, as working with industry is foundational to getting the necessary information for research and has an additional benefit of facilitating uptake of the capabilities produced by WPTO.

This research will then help inform subsequent efforts focused around two high-value efforts that the Hydropower Program wishes to promote: secure data transfer and cyber surrogate development. Secure data transfer is extremely important because data transfer must be both high-speed (known as low latency) and secure for hydropower plants to take advantage of advanced analytics and cloud computing. While advanced analytics and cloud computing could be applied to a myriad of different hydropower systems, they are particularly applicable to fault detection and improved system dispatch. Initial research efforts will focus on documenting the state-of-the-transfer technology, its relative security, and its applicability to hydropower plants. In later stages of this effort, the research will be focused on demonstrating the application of this technology to hydropower facilities, providing insight into best practices, and integrating these capabilities with new technology.

In addition to data transfer technology, this sub-activity will begin developing cyber surrogate capabilities for hydropower facilities. These surrogates are designed to document the network and signal paradigms over a range of operating conditions and leverage an established baseline to act as an early warning system for network intrusion. Effective intrusion detection is particularly important as it can take many months to identify, a period in which the facility is uniquely vulnerable to malicious actors. Initial stages of this work will be focused on developing network communication and system operation baselines—mostly focused on operational technology components of the hydropower system—and abhorrent signal detection capabilities, which can be applied to a wide range of hydropower plants. Once this has been done, the prototype capability will be applied to a hydropower plant to help refine both the technology and the application process. The overall cybersecurity effort will then culminate in the development of active defense capabilities, which can be readily applied to the overall hydropower fleet. These active defense capabilities will help the hydropower industry move beyond its traditional layers of parameter-based defense and will provide dynamic and proactive security measures.

Hydropower Program Activity 4 – Environmental and Hydrologic Systems Science

Overview

While hydropower has tremendous value to the power system as a flexible, renewable resource, its long-term value is dependent on maintaining a high level of environmental performance across the fleet. The Hydropower Program develops new technologies, tools, and data to better understand and improve the environmental performance of hydropower facilities. WPTO's work focuses particularly on issues related to fish passage, water quality, and water release management. In addition, this activity area aims to provide a better understanding of potential climate impacts and risks associated with climate change and hydrologic variation. WPTO's initiatives seek to understand the physical risk to current hydropower and develop the climate risk strategies and decision-making tools to ensure future reliability, performance, and energy services provided by hydropower in supporting a 100% renewable future. Environmental and Hydrologic Systems Science focuses on: (1) developing monitoring and mitigation technologies to improve environmental performance; (2) supporting foundational and applied biological, environmental, and hydrologic systems science research to understand environmental impacts; and (3) establishing relevant standardized metrics to understand environmental impacts and improved performance.

Activity 4 – Environmental and Hydrologic Systems Science consists of the following sub-activities:

1. R&D to Improve Environmental Performance: Improving understanding of fish movement, habitat use, and survival through the development of advanced monitoring technologies, relevant metrics, and other impact assessment tools.
2. Hydrologic Systems Science: Addressing fundamental questions of hydrologic variation, impacts on ecosystems, and risks for operations and engineering of hydropower systems.

Performance Goals and Objectives

The key results, performance goals, and follow-on objectives are summarized in Table 17.

Table 17. Environmental and Hydrologic Systems Science Performance Goals and Objective

Key Results and Performance Goals (2021–2025)
• Complete field validations of novel and improved fish detection and tracking capabilities relevant for hydropower studies, including demonstration of environmental DNA and prototypes of acoustic telemetry tags for sensitive species and a self-powered acoustic fish tag. • Demonstrate innovative tools and technologies that are benchmarked for cost and performance, including innovative fish passage technologies and sensor systems. • Demonstrate real-time data collection, automation, and visualization to inform decision makers' choices to operate hydropower resources for enhanced environmental performance in water and species management. • Release a nationwide analysis and visualization platform that enables utilities and system operators to evaluate potential long-term water availability and climate change related risks to existing and new hydropower assets at meaningful local or regional scales. • Validate new technologies to more accurately characterize and model methane emissions from reservoirs and other water bodies.
Follow-On Objectives (2026–2030)
• A suite of demonstrated, cutting-edge tools and technologies for hydropower-specific environmental monitoring, mitigation, and decision-making that enable accurate data collection and predictive outputs with reduced cost and time and can be utilized for community developed standardized processes and FERC relicensing. • Quantifiable improvements in fish passage performance that can be linked to established fish population and restoration goals. • Documented improvements in real-time data collection and accuracy for species of concern and other environmental variables that inform hydropower operations and management. • Better understanding of the risks of long-term hydrologic variations to hydropower generation and flexibility and documented incorporation into licensing or other planning processes. • Accurate and widely agreed-upon characterization of methane emissions from U.S. reservoirs.

Additional Details

Efforts to improve sustainability and environmental performance of the nation's hydropower systems are inherently linked to modernization of the existing fleet, efforts to improve flexibility, and advancements necessary to develop additional low-impact hydropower. Additions of new hydropower may leverage existing infrastructure or be sustainably deployed in new areas if river functions and ecosystem services can be maintained or enhanced. Over the past decade, numerous advances in environmental monitoring technologies and data processing have occurred. Applied to hydropower, such techniques and tools enable more accurate evaluations of the potential environmental risks and impacts for species and water management.

Hydropower operations planning and investment need to appropriately incorporate advances in watershed science, hydrology, and river biogeochemistry to understand risks and opportunities for hydropower systems. Understanding the best available climate, hydrologic, and carbon cycle sciences will help advance our understanding of risks to hydropower generation and flexibility from long-term hydrologic variation, advance our understanding of water risks across plant and grid-scale energy systems, and develop methods to better assess, characterize, and contextualize reservoir methane emissions.

As noted earlier in this document, Activity 4 is crosscutting in nature and has many different ties to the work that will be undertaken in Activities 1-3.

Sub-Activity 4.1 – R&D to Improve Environmental Performance

Overview

The Hydropower Program provides information, data, and tools to the hydropower community that enable a better understanding of key environmental challenges, as well as technologies to monitor environmental performance and avoid, minimize, and mitigate impacts. This sub-activity is focused on improving understanding of fish movement, habitat use, and survival through the development of advanced monitoring technologies, relevant metrics, and other impact assessment tools. There is a large amount of synergy between these topics since monitoring and mitigation often go hand in hand and improvements are evaluated by relevant metrics.

Information from advanced monitoring technologies may also increase confidence in decision-making to reduce risk, provide better informed and more rapid impact evaluations, and provide more cost-effective solutions to better meet hydropower permitting and license requirements. Novel and applied monitoring and mitigation technologies have the potential to support the continued modernization of existing hydropower plants and inform basin-level planning and information needs to meet management objectives for healthy watersheds.

FY 2021–2025 Research Priorities

The following are the research priorities that will be emphasized within the Sub-Activity 4.1 – R&D to Improve Environmental Performance:

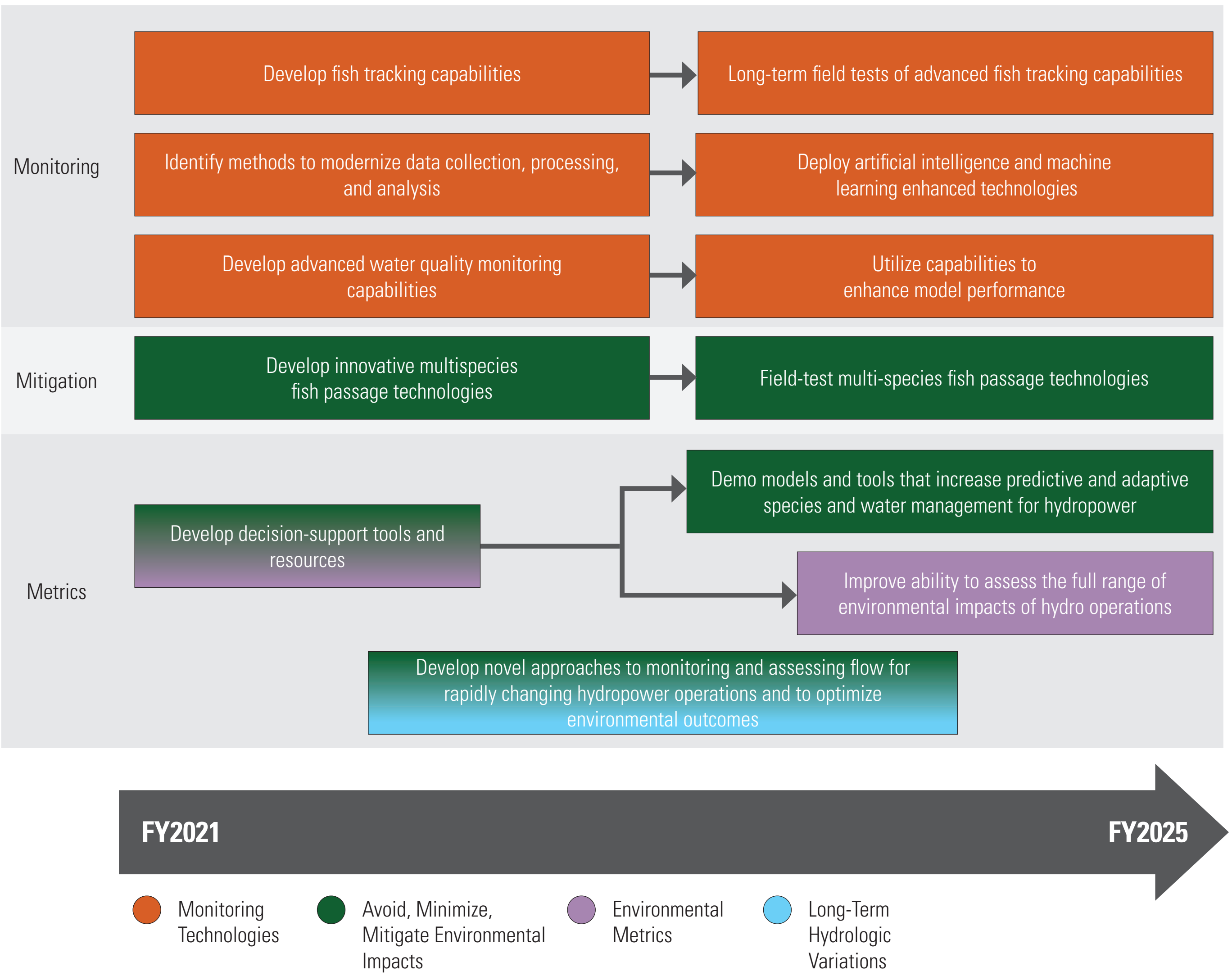
- **Monitoring**
  - **Develop fish tracking capabilities**: Provide more accurate and greater data for sensitive species over greater spatial and temporal scales.
  - **Long-term field tests of advanced fish tracking capabilities**: Conduct field tests to demonstrate advances in fish tracking capabilities.
  - **Identify methods to modernize data collection, processing, and analysis**: Identify and develop tools for data automation and investigate methods to apply artificial intelligence and machine learning for processing and analysis for rapid and real-time environmental assessments.
  - **Deploy artificial intelligence and machine learning enhanced technologies**: Demonstrate tools that utilize artificial intelligence and machine learning for environmental monitoring and quantify improvements in the data pipeline and cost reductions.
  - **Develop advanced water quality monitoring capabilities**: Research and prototype tools and technologies for more accurate and representative water quality measurements.
  - **Utilize capabilities to enhance model performance**: Develop more robust models and methods to inform real-time operations for improved water quality.
- **Mitigation**
  - **Develop multi-species fish passage**: Design and test innovative up- and down-stream fish passage technologies to support fish communities and prevent invasive species movements and investigate methods for relating technology choices to fish restoration goals.
  - **Field tests of multi-species fish passage technologies**: Quantify performance of innovative technologies and applied modeling capabilities to assess population-level impacts and restoration goals.

- **Metrics**
  - **Develop decision support tools and resources**: Provide information and science-based tools that utilize established environmental metrics and indicators.
  - **Access utility of tools in hydropower environmental assessments**: Demonstrate toolkits with hydropower stakeholders and assess capabilities to identify key environmental impacts and relevant mitigation methods.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 23.

Figure 23. Sub-Activity 4.1 – R&D to Improve Environmental Performance Research Priorities



Additional Details

WPTO efforts in this sub-activity are heavily focused on providing novel, fish tracking capabilities, advancing species detection methodologies, and providing novel sensors to assess core scientific and management questions. Activities also include developing applications to provide real-time and more robust data streams of key indicators of ecosystem health, such as dissolved oxygen. As technologies mature, the data may be applied to impact assessments and hydropower-specific monitoring for FERC licensing and compliance. The data may also be utilized to develop relationships for system-level understanding. The program regularly seeks both private and public partnerships to demonstrate the value of tools and real-time data for improved operations and management of fish passage, deployment of mitigation, and optimizing water releases for achieving both energy and environmental goals.

Monitoring
Since hydropower plants—and the environments they are deployed in—are extremely diverse, scientific knowledge gaps exist around biology, behavior, and interaction of many fish species with hydropower facilities. Core objectives for species monitoring include development of capabilities to monitor fish over larger spatial and temporal scales that may be realized through efforts to produce self-powered tags. Other tracking capabilities will be focused on integrating embedded sensors into tags to provide measurements of physiological and water quality variables that can correlate to health, habitat use and quality, and hydropower operations. The Hydropower Program will also focus on utilizing big data analyses and machine learning, collected with commercial-off-the-shelf technologies, which will support more rapid and cost-effective monitoring, as well as developing novel detection and sensor systems that utilize these techniques to enable more informed environmental management options.

Mitigation
Realizing the potential for future hydropower growth and optimization of the existing fleet will require overcoming several key technological, environmental, and market challenges. Novel and specialized technologies enable hydropower dams to cost-effectively reduce environmental footprints. The Hydropower Program's efforts to improve the environmental performance of hydropower include activities to avoid, minimize, and mitigate ecological impacts (e.g., water quality and quantity, up- and down-stream fish passage, biodiversity, Endangered Species Act-listed species, habitat, and instream flows). For example, to address water quality, WPTO is funding the development of technologies that may radically reduce water pollution risk, such as biodegradable oils and oil-free applications, as well as the development of tools for more robust methods of monitoring. In addition, to enable infrastructure longevity and address concerns of invasive mussels, this sub-activity is working towards solutions to prevent zebra and quagga mussel colonization and range expansion. Further, WPTO understands that variable and intermittent renewable energy integration call for more flexible hydropower operations (Activity 2 – Grid Reliability, Resilience, and Integration [HydroWIRES]), which may have a variety of different impacts on aquatic species and ecosystems. Therefore, the Hydropower Program will build upon studies to clarify the short-term effects hydropeaking (or the discontinuous releases of water through turbines to meet peak energy demands which causes downstream water flow fluctuations) on resources and assist in the development of novel monitoring approaches and flows for rapidly changing hydropower operations to achieve better environmental outcomes.

North America has a high diversity of fish species, including both migratory and non-migratory species. Such species of concern have a wide variety of upstream and downstream fish passage needs that are regulated at hydropower dams. Therefore, a core objective for species management is the development and evaluation of innovative fish passage technologies with an emphasis on multispecies passage to support resource agency biodiversity and fish restoration goals, fish protection, and adaptable passage for changing conditions. Fish passage technologies are assessed for environmental performance and benchmarked against evaluations of cost reduction pathways—particularly with respect to standard/modular designs, components, and applications of advanced and additive manufacturing (Sub-Activity 1.1 – New Technologies and Advanced Manufacturing) to reduce overall costs.

The Hydropower Program also supports foundational science through laboratory and field studies to assess ecological impacts—particularly the direct impacts of turbine passage to fish, and applications of advanced models and methods for evaluating population- and basin-level impacts. Furthermore, the program develops tools to enable more robust and real-time data collection for field evaluations of hydropower sites; computational fluid dynamics advancements that enable models of turbines and hydropower sites to be related to biological responses of fish; and applications of machine learning and artificial intelligence to automate and enumerate biological and environmental assessments.

Metrics

The Hydropower Program will leverage past efforts to identify appropriate environmental sustainability measures, metrics, and indicators of ecosystem health, and develop tools to identify and communicate key river functions during permitting, focusing attention on only relevant, potentially impacted resources. This sub-activity will pursue the development of widely accepted standardized practices to increase transparency in decision making, enable better environmental outcomes at lower costs, and reduce risk from environmental uncertainty.

Sub-Activity 4.2 – Hydrologic Systems Science

Overview

The Hydropower Program's hydrologic science portfolio addresses fundamental questions of climate change and hydrology, impacts on ecosystems, and risks/opportunities for operations and engineering of hydropower systems. Improving riverine ecological resilience and energy-water security requires better characterization of climate change variations in streamflow, snowmelt, and watershed storage, as result of changing weather patterns and long-term climate shifts. Better characterization of other important scientific gaps relevant to hydropower operations is also needed for climate adaptation. Areas of work within the Hydrologic System Science sub-activity mutually enhance hydropower production, energy security, water resilience, and overall ecosystem health by (1) incorporating scientific advancements, empirical studies, and modelling/simulation into our understanding of the water cycle and (2) identifying limitations and uncertainty of current methane formation analyses that inform future research areas for understanding potential reservoir emissions.

FY 2021–2025 Research Priorities

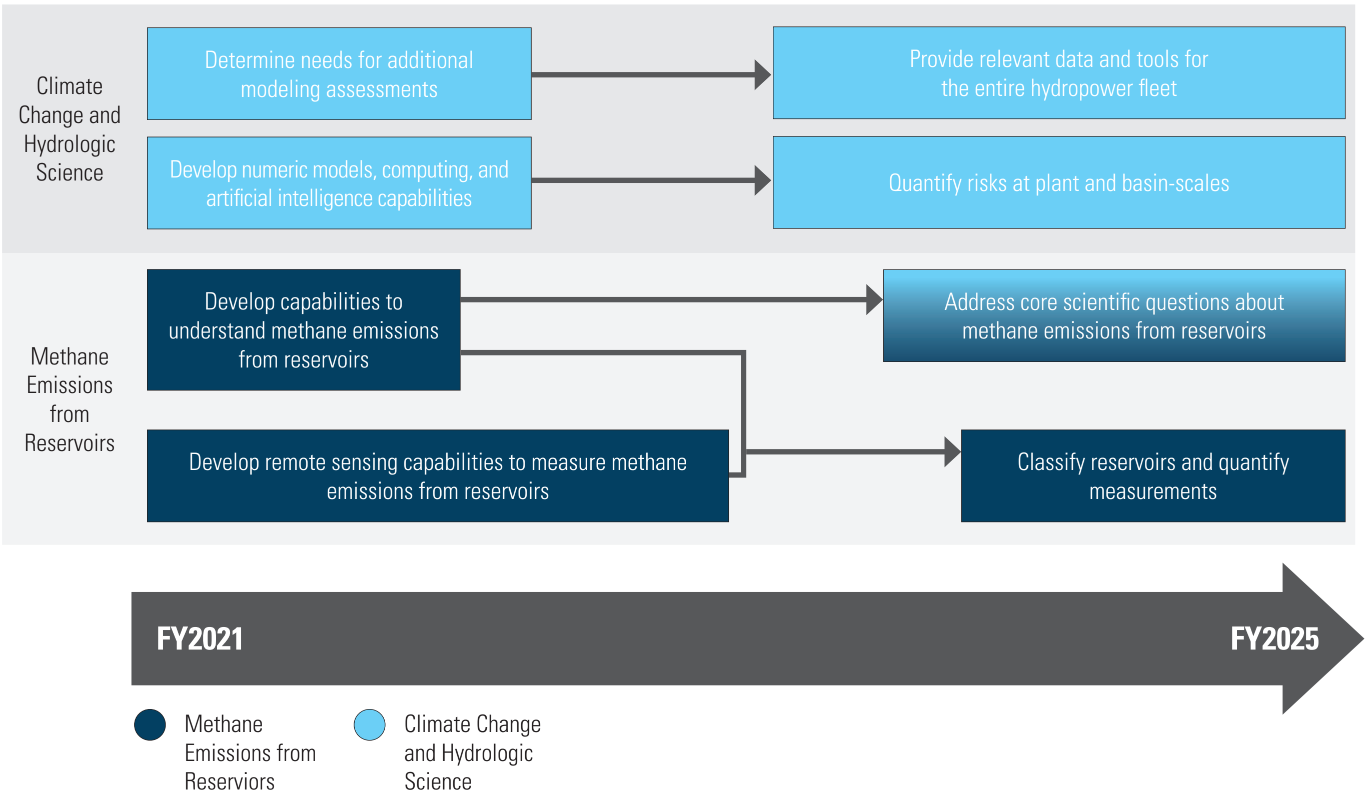
The following are the research priorities that will be emphasized within the Sub-Activity 4.2 – Hydrologic Systems Science:

- **Climate Change and Hydrologic Science**
  - **Determine needs for additional modeling assessments**: Assess the need to conduct additional modeling assessments or develop models with new capabilities.
  - **Provide relevant data and tools for the entire hydropower fleet**: Utilize modeling capabilities to clarify potential risks and uncertainties to better understand climate change and hydrologic variations.
  - **Develop numeric models, computing, and artificial intelligence capabilities**: Identify and apply advanced methods to increase understanding of basic hydrologic systems science and potential applications.
  - **Quantify risks at plant and basin-scales**: Develop tools for different user groups to investigate risks of climate change and evolving hydrology at different spatial scales.
- **Methane Emissions from Reservoirs**
  - **Develop capabilities to understand methane emissions from reservoirs**: Characterize the state of the science on methane emissions from reservoirs and other water bodies.
  - **Address core scientific questions about methane emissions from reservoirs**: Conduct foundational science on carbon transport and methane formation.
  - **Develop remote sensing capabilities to measure methane emissions from reservoirs**: Advance current and novel technologies to test and validate methane measurement capabilities for different types of reservoirs and water bodies.
  - **Classify reservoirs and quantify measurements**: Develop and utilize a reservoir classification scheme to assess risk and uncertainties of methane emissions.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 24.

Figure 24. Sub-Activity 4.2 – Hydrologic Systems Science Research Priorities



Hydropower Crosscut: Hydrologic Forecasting

Hydrologic forecasting focuses on progressing accurate and reliable riverine information to improve hydropower operations and strengthen basin-scale decision-making. Occurring over a wide range of timescales and integrated within hydropower processes at numerous decision points, operational forecasting of riverine streamflow, reservoir inflow, snowmelt, and other river ecosystem parameters are irrefutably important. WPTO's efforts will develop next generation hydrologic prediction models applicable to a broad range of locations and which leverage cutting-edge weather data, data assimilation techniques, cloud computing, novel remote sensing systems, and information from a host of sources.

There are important economic incentives for the hydropower industry to invest in new forecasting systems and methods. Specifically, where forecasts lead to clear market value in terms of revenue or avoided cost, and where advancements in forecast quality can affect operations, increase windows of reservoir optimization and overall system performance. In theory, advance foresight of variations in hydrologic parameters and reservoir levels, allows for better economic returns and optimal decision-making.

Advancements in forecasting can also influence the timing and nature of decision-making. Weekly, monthly, and seasonal forecasts products are evolving and there are interesting opportunities to consider these developments across water infrastructure planning and hydropower optimization. Developments in the fields of machine learning, big data, and artificial intelligence also could have implications for automating decisions or building decision-making around multiple and diverse datasets. Operational forecasting is an important strategic asset across the federal government, specifically at water mission agencies such as National Oceanic and Atmospheric Administration (NOAA) and United States Geological Survey (USGS) and represents a vibrant area to partner on future R&D activities for both industry and national interest.

WPTO considers forecasting as a crosscutting activity, negotiating programmatic connections across Environmental and Hydrologic Systems Science and the Data Access, Analytics, and Workforce Development, with some critical work relevant for HydroWIRES. Under Hydrologic Systems Science, the program will look to advance areas of hydrologic science, data production, and model prediction, with a focus on these areas across short and long-terms forecast products. Recognizing developments in water technology, spatial data integration, data access and curation, and the science of decision-making, forecasting is also a critical Data Access, Analytics, and Workforce Development activity with direct tie-ins to value (HydroWIRES Sub-Activity 2.2 – Capabilities and Constraints) and optimizing water infrastructure (water resilience). WPTO endeavors to utilize next generation hydrologic prediction models to impact the broader basin-scale/watershed space including reducing environmental impacts, improving hydropower plant performance and reliability, optimizing flexibility and grid value, informing risk-based decision-making, and long-term infrastructure planning.

Additional Details

A core objective of the program is to regularly evaluate the need for new models with capabilities to assess the effects of climate change on the U.S. hydropower fleet. Past efforts have focused on examining the potential effects of long-term climate trends on water availability for federal hydropower generation, based on the best available scientific information, and future. These efforts will extend and amplify analytical capabilities for non-federal, investor-owned hydropower facilities to understand future investment, operations, and business risks. The Hydropower Program also focuses on more foundational hydrologic work, particularly in the area of flow forecasting, by utilizing numerical modeling methods, high-performance computing, and machine learning to assess and manage future climate impacts to watershed-river-reservoir systems on streamflow, hydropower, and water temperature. The ultimate goal is to develop decision-making tools that provide a comprehensive understanding of water impacts and risks to both grid and hydropower operations, including sensitivities to varying climate-hydrologic drivers and infrastructure futures, ranging from individual generating assets and river reaches to regional- and national-scale threat assessments.

An emerging, complementary goal of the hydrologic science portfolio is utilizing the tools and capabilities developed and advanced to address the role of hydropower in responsible management of our water systems. As the interdependencies and subsequent risks in the power and water systems are better understood, so are the opportunities for integrated resilience. Given the position of hydropower squarely at the nexus of energy and water systems, the Hydropower Program seeks to understand how hydropower can serve as a tool to improve water resilience and security.

Methane Emissions

Numerous studies in past years have suggested that reservoirs and other waterbodies can serve as potential sources of methane emissions. However, many of these studies either focus on a handful of reservoirs, new reservoirs, a specific region, or conducted sampling with limited spatial and temporal diversity. As a result, large uncertainties remain in characterizing both the temporal and spatial variation of methane emissions from reservoirs. Providing more confidence in measurements and estimates is vital for understanding methane emissions for the U.S. hydropower fleet and the formation and cycling of this potent greenhouse gas. Other greenhouse gases (carbon-dioxide, nitrous oxide) are known to be produced in waterbodies and inundated areas as well. However, measured amounts in previous studies have been modest, and the transformation of molecules of organic carbon (with a global warming potential of one should carbon dioxide be produced) into methane (with a warming potential of more than 20) is the main issue of concern.

In this sub-activity, the Hydropower Program's goal is to characterize uncertainty in methane emissions from reservoirs by synthesizing the scientific research to date, identifying critical research gaps, and partnering with industry leaders and other NGOs to develop and improve new methodologies and technologies with the ability to collect both field-based and remotely sensed data on reservoir methane emissions.

Establishing foundational research questions for future scientific analysis will help to improve the understanding of methane emission uncertainty. It will be necessary to build partnerships with scientists, state and federal agencies, and practitioners for researching, disseminating, and improving the understanding of methane emissions from reservoirs. These partnerships are crucial to advancing the development of a classification scheme for reservoirs at low-, medium-, and high-risk of emitting methane and working with stakeholders to understand mitigation—a long-term goal for this sub-activity area.

Hydropower Program Activity 5 – Data Access, Analytics, and Workforce Development

Overview

As a technology-neutral, national research agency with access to some of the most advanced computing, data management, and analytics in the nation, DOE is well-suited to work closely with other agencies and stakeholders to improve the data landscape for important hydropower and river-related information. This can help enable the development and commercialization of new crosscutting analytical capabilities to weigh multi-objective tradeoffs and support stakeholder decision-making. Also, as a largely non-regulatory agency, DOE is in a unique position to help provide insights to identify areas with the greatest opportunity for hydropower regulatory process improvements. The Hydropower Program's efforts will focus on extracting lessons learned from the substantial record of development over the last century and will use its convening role to engage other federal agencies, tribes, the hydropower industry, and NGOs to share this information and develop ways to enhance stakeholder engagement and benefit regulatory processes. As the nation's energy and water systems become even more complex and intertwined, all of these goals aim to support improved decision-making and basin-wide management of river resources for multiple objectives, including energy, enabled by improved data and analytical tools. Lastly, WPTO has a unique vantage point given its strong partnerships across industry, academia, and the federal government. WPTO will leverage this unique perspective and expansive network to address another key challenge for the hydropower industry: its aging workforce. The Hydropower Program will expand on work conducted by the office to date in developing effective strategies to support STEM and workforce gaps in hydropower.

Activity 5 – Data Access, Analytics, and Workforce Development consists of the following sub-activities:

1. Data Access and Workforce Development: Identifying and improving access to valuable hydropower asset data, technology advances, and many other diverse types of dam and river-related information.
2. Data Analytics: Developing "evergreen" analytical capabilities that can be applied to a diverse range of hydropower-related investigations including basin-scale decisions, energy market applications, and hydropower relicensing processes.

Performance Goals and Objectives

The key results, performance goals, and follow-on objectives are summarized in Table 18.

Table 18. Data Access, Analytics, and Workforce Development Performance Goals and Objectives

Key Results and Performance Goals (2021–2025)
• Launch and improve the new externally oriented HydroSource online data portal with broad use-case capabilities. • Develop a standard suite of application programming interface (API) capabilities that will provide unprecedented access to power market information for the hydropower community. • Leverage machine learning and new big-data access approaches, in collaboration with FERC and other stakeholders, to increase access to information available in FERC's eLibrary. • Publish a report on the key issues on the time, cost, and uncertainty associated with U.S. hydropower regulatory processes. • Release a new hydropower-focused STEM/education portal and initiate new partnered efforts to provide data and informational support for high-priority hydropower workforce training needs. • Launch DOE's first-ever hydropower collegiate competition and hydropower-focused fellowship program, providing students of diverse backgrounds and disciplines the opportunity to develop key skills for a career in hydropower.
Follow-On Objectives (2026–2030)
• Significantly increased use of the HydroSource portal by a diverse set of stakeholders—beyond the current range of application—along with improved ease-of-use metrics and reviews from users. • Power market data are utilized by developers of new hydropower technologies to specifically target the greatest opportunities and approaches for growth and are incorporated into future technology development and project planning processes. • FERC and other stakeholders leverage eLibrary insights along with interdisciplinary big data approaches to improve licensing and relicensing study efforts while maintaining regulatory effectiveness. • Key issues identified in the U.S. hydropower regulatory process report are utilized by diverse hydropower stakeholders to agree upon and begin to operationalize regulatory process improvements. • Documented increases in hydropower early-career interest/opportunities and improvements in institutional knowledge-transfer landscape.

Additional Details

Although it is the oldest form of electricity generation in the country, there has historically been limited publicly available or easily accessible centralized data on the makeup, performance, costs, market participation, or regulatory best practices of the U.S. hydropower and pumped storage fleet. Accessibility and the ability to analyze a variety of other river and water data—including river ecology, flood control, hydrography, recreation, other socioeconomic uses, water quality, and water use—are limited. This limitation hinders the ability of diverse stakeholders to engage in integrated energy-water systems planning, particularly at the river-basin level. Improved access to existing data and new analytical capabilities that bridge multiple disparate sectors are also necessary to inform a well-designed long-term research strategy to support maintenance and expansion of the U.S. hydropower fleet, reduce its impacts, and identify ways to increase its contributions to grid reliability and resilience. A large amount of new information is also continually generated as the result of DOE-funded research, and this data must be transparent and made publicly available in a timely manner. Fundamentally, the Data Access, Analytics, and Workforce Development effort are designed to help address what is commonly known as the "80/20" situation regarding data analysis, where roughly 80 percent of time and resources are expended on accessing, aggregation, and preliminary data analysis, and 20 percent of resources are spent on solving the specific problem of interest. The development of centralized capabilities in this "80 percent" is important because they not only impact significant resource expenditures, but they can also help reduce redundancy across many different organizations involved in hydropower research.

Hydropower Permitting and Licensing

One of the more significant factors limiting the growth of U.S. hydropower is the length and uncertainty of the federal regulatory permitting process, most notably FERC licensing. A preliminary Oak Ridge National Laboratory licensing analysis of 49 projects in the FERC record indicates that the time from license application to license issuance ranged from 12.2 to 89.6 months with a mean time of 40.1 months.

As a non-regulatory agency, WPTO is in a unique position to evaluate and execute actions to advance effective licensing practices, share governance lessons between hydropower policies and practices, provide this information to stakeholders to better facilitate decision-making in the regulatory process, and take a higher-level perspective on the role of permitting in our national energy outlook. WPTO's role in this effort is exemplified by its successful facilitation of the memorandum of understanding (MOU) between FERC and the U.S. Army Corps of Engineers (USACE) to coordinate their dual regulatory authorities for private hydropower development at the USACE non-powered dams.

It is evident that regulatory processes associated with hydropower permitting are cost and time-intensive, and there is poor information and data available/accessible on regulatory process outcomes and drivers. As a result, WPTO is developing a suite of tools to assist not only federal regulators, but all stakeholders (e.g., hydropower developers, non-governmental environmental organizations, etc.) with navigation of the hydropower permitting process. Tools and data currently available include the RAPID toolkit (National Renewable Energy Laboratory), a comprehensive user-friendly guide to permitting regulations and best practices, in addition to a fleet-wide searchable database of hydropower environmental mitigation measures (Oak Ridge National Laboratory). WPTO's current efforts in the hydropower regulatory arena include development of an Environmental Decision-Support Tool (Oak Ridge National Laboratory) that would help stakeholders identify the most impactful and cost-effective studies necessary to determine the environmental impacts of proposed hydropower projects. Future efforts by WPTO to reduce the cost and uncertainty of hydropower permitting could include studies of the transferability of existing hydropower environmental impact data and a tool to search and identify significant environmental data and best licensing practices in the FERC eLibrary.

Finally, WPTO, with the assistance of a broad group of stakeholders from across the hydropower community, is currently conducting a comprehensive study of the entire federal permitting process for hydropower. This study will use both qualitative and quantitative analyses to determine the root causes for the costs and uncertainty associated with the process. While the study will stop short of making specific recommendations for regulatory process improvements, the study can be used by policy makers to identify the key areas of the process that need improvement.

Sub-Activity 5.1 – Data Access and Workforce Development

Overview

Data Access and Workforce Development focuses on identifying and improving access to valuable hydropower asset data, technology advances, and many other diverse types of dam and river-related information. The Hydropower Program also maintains information sharing platforms (the foremost being the HydroSource portal) to enable the dissemination and open exchange of information. There is also an increasing focus on work and coordination with other federal agencies and data-focused organizations to improve nation-wide coordination and access to river and water-related data. This takes the form of improving metadata structures and standards, database and data portal harmonization, and other big-data management improvements. Additionally, the Hydropower Program is committed to supporting the next generation of the hydropower workforce through access to educational materials and workforce development programs.

FY 2021–2025 Research Priorities

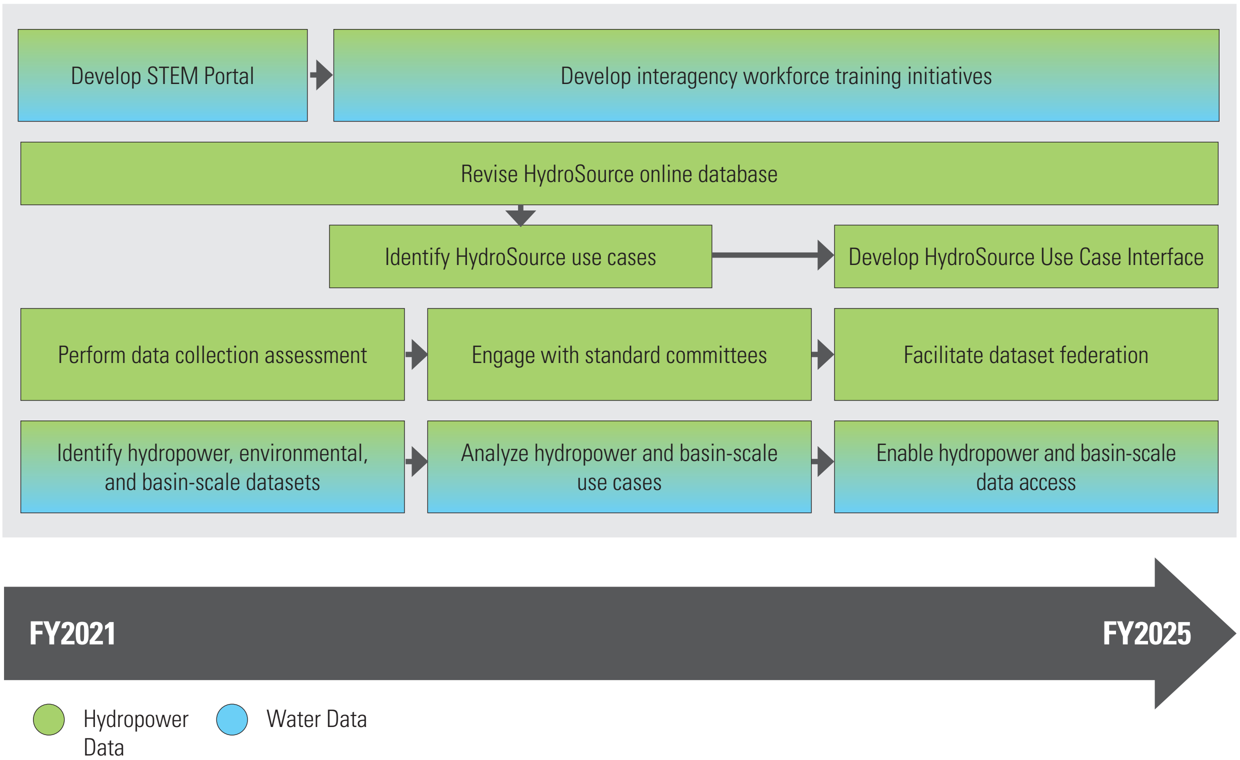
The following are the research priorities that will be emphasized within the Sub-Activity 5.1 – Data Access and Workforce Development:

- **Launch new workforce development programs for hydropower**: Establish DOE's first-ever hydropower collegiate competition and hydropower-focused fellowship program, providing students of diverse backgrounds and disciplines the opportunity to develop key skills for a career in hydropower.
- **Develop STEM portal**: Launch new, publicly available STEM portal for hydropower educational information and curricula.
- **Develop interagency workforce training initiatives**: Develop interagency and external partnerships that utilize information to support high-priority workforce training initiatives.
- **Revise HydroSource online database**: Continuously revise, improve, and expand the HydroSource database to provide state-of-the-art access to relevant hydropower data.
- **Identify HydroSource use cases**: Work with a diverse set of stakeholders to understand the range of use cases for the HydroSource Database.
- **Develop HydroSource use case interface**: Based on high-value use cases, develop user interfaces to collect relevant HydroSource data and synthesize it into the appropriate structure.
- **Perform data collection assessment**: Document the drivers and potential solutions to the collection of low data quality and low data availability.
- **Engage with standards committee**: Engage with the relevant standards committees to bring the process of improving data collection.
- **Facilitate dataset federation**: Develop a process to facilitate data federation and synthesis from multiple sources.
- **Identify hydropower, environmental, and basin-scale datasets**: Identify relevant datasets held by a diverse set of stakeholders along with the dataset characteristics.
- **Analyze hydropower and basin-scale use cases**: Analyze available datasets to identify a range of potential data uses cases and their associated value proposition.
- **Enable hydropower and basin-scale data access**: Work with appropriate partners to facilitate the broad availability of hydropower and basin-scale data.

Timing and Sequencing of Research Priorities

The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 25.

Figure 25. Sub-Activity 5.1 – Data Access and Workforce Development Research Priorities



Additional Details

The flagship effort in this sub-activity is HydroSource—the most comprehensive repository of hydropower-relevant data in the United States. HydroSource was originally developed to primarily meet internal DOE analytical and research needs, but that focus is shifting to enhance publicly available access to information to serve the data needs of a diverse user base. A wide range of relevant stakeholders will be engaged to understand use cases for various types of information and the value proposition for different data needs. Based on use case information, access to the HydroSource data will be iteratively improved through the development of different graphical user interfaces to enable ready investigation of high value and crosscutting datasets. Ongoing research will also focus on enabling effective dataset synthesis. This data synthesis is critical for much of the data access work because analyses in this space requires low latency—or as small of a period of possible between data being collected and data being available for analysis—to access data located in a range of locations with diverse structures. This will initially be focused on engaging with stakeholders to help improve data collection quality and to develop necessary quality assurance and quality control capabilities. Once this has been addressed, WPTO will engage established data standards communities to ensure federation and synthesis capabilities reflect industry best practices. These capabilities will enable access to unified, federated, consistent, and correlated hydropower and other water-related datasets, most which are of diverse structure and resolution. This unification, federation, and correlation broadly refers to the issues associated with leveraging multiple, heterogeneous, datasets. Given that the data is structured differently it is first necessary to enable ready and consistent comparisons between the datasets before any insights can be taken away from them.

This sub-activity also entails improving access to multidisciplinary basin-scale information as hydropower interacts with and is influenced by a broad range of other water sectors. This effort will start by identifying the sources of basin-wide information that are most valuable to different stakeholder and user groups (e.g., specific types of river ecology, flood control, hydrography, recreation, other socioeconomic uses, water quality, infrastructure resilience and water use data) and the associated characteristics of the identified datasets. Once this has been completed, the available information will be assessed in coordination with stakeholders and other water-data-focused agencies and organizations to articulate the range of use cases that these data could enable and the associated value proposition. Based on the results of this assessment, data access and visualization capabilities will be developed in coordination with various data holders to enable access to the necessary information for the identified use cases.

Finally, this sub-activity focuses on developing and providing access to educational information and workforce development opportunities to support a vibrant and evolving U.S. hydropower workforce. There has been a noted lack of easily accessible, publicly available basic information on hydropower resources, technologies, environmental issues, opportunities, and linkages to a variety of other scientific and technical fields. Tools and best-practices to support knowledge transfer to incoming generations of workers are also needed. The Hydropower Program will also stand up its first-ever collegiate competition and hydropower-focused fellowship program, while also assisting efforts led by interagency or external partners to address the hydropower industry's workforce development needs.

Sub-Activity 5.2 – Data Analytics

Overview

Sub-Activity 5.2 – Data Analytics is focused on developing "evergreen" analytical capabilities that can be applied to a diverse range of hydropower-related investigations including basin-scale decisions, energy market applications, and hydropower relicensing processes. It should be noted that the capabilities (which can come in the form of open-source computer code, analysis processes, etc.) are the focus of this effort rather than the results of a discrete application of the capabilities. The development of these broadly relevant analytical capabilities will significantly reduce the time and resources needed to perform research in a host of hydropower applications funded not only by WPTO but also by a wide range of other stakeholders. This focus on a centralized set of capabilities however necessitates that the solutions will remain functional as they age. These "evergreen" capabilities—or capabilities that remain continuously relevant and functional—ensure the continued functionality of secondary applications and analysis dependent on these data analytics. Efforts in this sub-activity are focused on the development of a robust, centralized set of analytical capabilities which access information from a diverse set of repositories to synthesize results. One notable application in this space is the development of capabilities to readily access and analyze power market information. While this data and its analysis is extremely valuable to hydropower owners when planning for the future, equipment manufactures when targeting cost/capabilities, and developers when considering the rate of return for hydropower installations, the about of information required and its analytical process are complex and resource intensive. Advancements in this space would empower improvements in data driven decisions and allow a range of new actors to engage with the hydropower industry. While overall capabilities in this space have been developed to varying degrees, existing systems have been developed in an ad hoc fashion, with limited coordination across the hydropower and other relevant sectors. This effort focuses on the development of centralized, efficient capabilities to perform data manipulation, analytics, and visualization for high-value application. These open-sourced capabilities will hopefully enable improved decision-making based on expanded, relevant big data access without incurring the extensive upfront cost of developing new, custom capabilities.

FY 2021–2025 Research Priorities

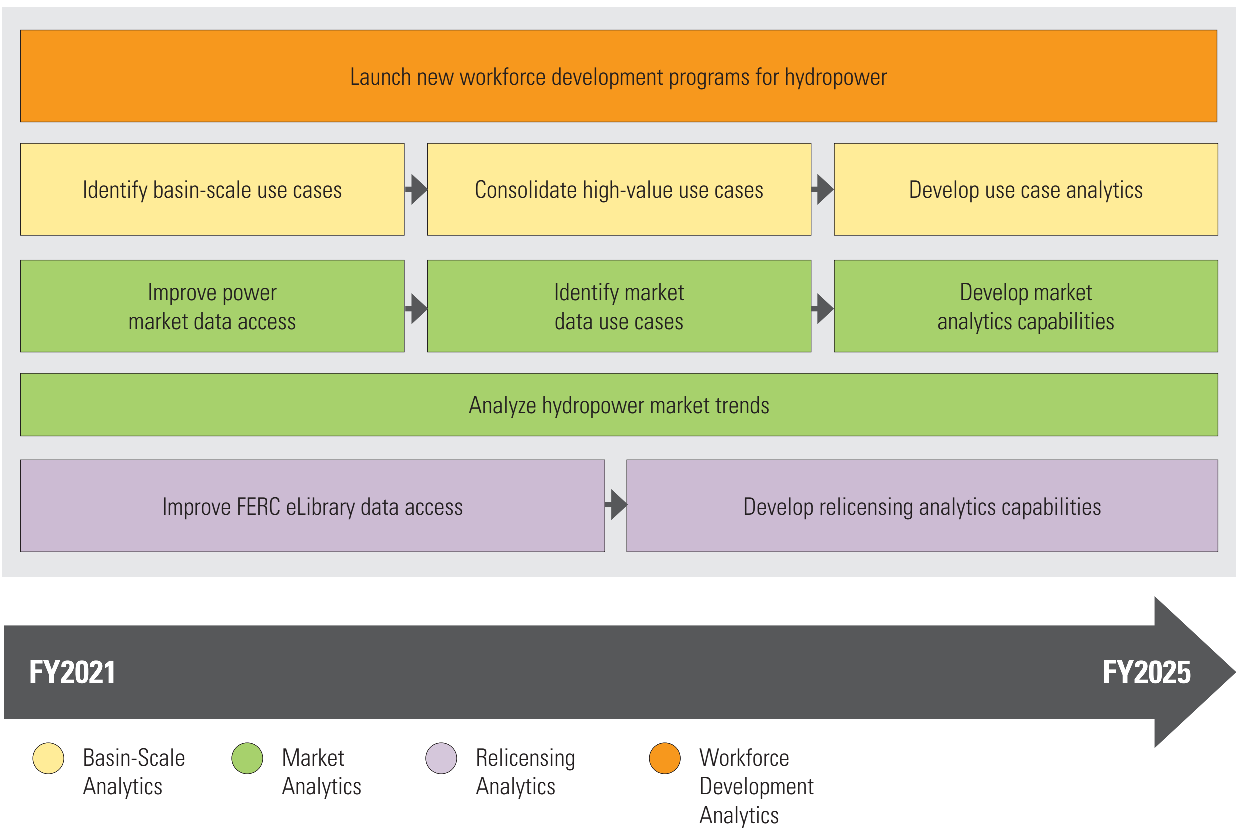
The following are the research priorities that will be emphasized within the Sub-Activity 5.2 – Data Analytics:

- **Identify basin-scale use cases**: Identify uses case and major data gaps for basin-scale decision analytics.
- **Consolidate high-value use cases**: Produce the capabilities to synthesize the diverse datasets necessary for the use case analytics.
- **Develop use case analytics**: Produce broadly accessible analytics around the identified use cases.
- **Improve power market data access**: Develop a common suite of tools to facilitate access to relevant power market data.

- **Identify market data use cases**: Document a range of use cases for power market data, in combination with other sources of information, and their associated impact.
- **Develop market analytics capabilities**: Produce broadly applicable analytics based on the identified used cases.
- **Analyze hydropower market trends**: Continue to analyze important trends in hydropower via the Hydropower Market Report.
- **Improve FERC eLibrary data access**: Leverage natural language processing algorithms to enable unprecedented access to FERC eLibrary data.
- **Develop relicensing analytics capabilities**: Leverage data from a diverse set of sources to facilitate the constant and efficient relicensing process.

Timing and Sequencing of Research Priorities
The timing and sequencing of FY 2021–2025 research priorities are summarized in Figure 26.

Figure 26. Sub-Activity 5.2 – Data Analytics Research Priorities



Additional Details

Efforts in basin-scale analytics are focused on enabling planning through collaborative engagement processes and improved replicability. Work will initially be focused on documenting the range of use cases associated with basin-scale, energy-water planning efforts, their associated value proposition, and any relevant gaps in data necessary to enable these analytics. Once the documentation has been completed, the capabilities—needed to consolidate and source the data necessary to inform these analytics—will be developed, with priority being placed on high value proposition use cases. After this, use case analytics and visualization capabilities will be developed in coordination with relevant stakeholders. One of the important efforts in this space is efforts in reservoir inflow forecasting, as improved forecasting has the potential to improve a host of hydropower outcomes including system revenue, reliability, and socio-environmental outcomes. This work will both inform and be informed by research in Sub-Activity 4.2 – Hydrologic Systems Science. Initial data analytics efforts in this space will focus on articulating the use cases and value metrics associated with inflow forecasting improvement because "improvement" can take numerous forms (including different timeframes and error reduction metrics) and should be targeted on improvements which have the most impacts. Armed with these improvement metrics, the development of new inflow forecasting capabilities in Sub-Activity 4.2 – Hydrologic Systems Science can target the highest value improvements in metrics. It should be noted that these metrics will be combined with the insights provided by research in Sub-Activity 2.2 – Capabilities and Constraints, which is focused on articulating the benefits that various improvements in inflow forecasting can have on the stability of the electric grid.

In addition to this effort, the Hydropower Program will aim to make power market data more readily available to the hydropower community. This data has significant potential to improve outcomes across a wide spectrum of current and planned hydropower outcomes—particularly when combined with other information, such as new-stream reach development potential when considering new hydropower development, or site-specific improvements in flexibility when assessing the rate of return of different capital investments. The initial phase of the work will entail engaging with stakeholders in both the hydropower industry and power markets. Once this has been done, a library of available, accessible data will be developed in an open-source environment. While this standard library is being developed, the Hydropower Program will continue to pursue its ongoing effort to document hydropower markets and trends in the Hydropower Market Report.[63]

The final effort in this sub-activity will work on providing information and tools in the hydropower relicensing process to ensure it is applied consistently and predictably. As hydropower plants continues to age, a considerable number will soon go through relicensing processes. While these are important regulatory requirements, they are also time and resource intensive to complete. For that reason, the Hydropower Program is working to improve efficiencies via big data access capabilities (by reducing the time and resources necessary to collect data). This will initially be focused on improving access to the FERC eLibrary, which acts as a central repository of information fundamental to any big data-based approach. This rich history of information will provide unprecedented visibility on consolidated licenses, which have the potential to evolve as conditions change. Once improved access to the FERC eLibrary has been completed, work to reduce the relicensing burden—while still maintaining standards—will be coordinated with a broad set of stakeholders. This effort will be explored with a robust stakeholder set and will be based around efficient approaches to obtaining new data, understanding the value of the collected data, and addressing delays in analyzing and processing that data within the existing regulatory framework.

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63 Uría-Martínez, R., Johnson, M., and Shan, R., 2021. "U.S. Hydropower Market Report." https://www.energy.gov/eere/water/downloads/us-hydropower-market-report.

Hydropower Strategic Partnerships and Crosscutting Activities Overview

Coordination and collaboration with other DOE offices and government agencies is essential to optimize federal investments, leverage resources, avoid duplication, ensure a consistent message to stakeholders, and meet national energy goals. WPTO's Hydropower Program maintains partnerships with other DOE offices and federal agencies as shown in Table 19.

Table 19. Summary of Collaborations Other DOE Offices and Federal Agencies

DOE Office	Collaboration Description
Office of Science	WPTO coordinates with the Office of Science on initiatives and advancements related to artificial intelligence and machine learning applications (Activities 4 and 5), including actions identified in the Office of Science's Artificial Intelligence Town Hall report. Work on modeling potential long-term hydrologic changes (Activity 4) is also coordinated with the Biological and Environmental Research program.
Artificial Intelligence and Technology Office (AITO)	WPTO plans to coordinate on initiatives and advancements related to artificial intelligence and machine learning applications (Activities 3, 4, and 5) with this new office. Artificial intelligence is critical to asset management, including machine condition monitoring and assessment, for potential improvements through image recognition and signals analysis.
Office of Electricity (OE)	WPTO works closely with OE through numerous efforts in HydroWIRES, and OE staff serve on the HydroWIRES Executive Board.
CESER	WPTO coordinates with CESER on cybersecurity research to streamline efforts and leverage existing capabilities.
Power Marketing Administrations (PMAs)	WPTO engages the Bonneville Power Administration and Western Area Power Administration (WAPA) in conversations to determine how WPTO's Hydropower R&D activities, most notably HydroWIRES (Activity 2), can be applied to real-world challenges faced by the PMAs on hydropower's role in grid resilience and flexibility. WPTO is currently engaging WAPA staff in a series of webinars to identify specific R&D projects of mutual interest.
EERE Office	**Collaboration Description**
AMO	Through Oak Ridge National Laboratory's Manufacturing Demonstration Facility, WPTO partners with AMO to jointly fund efforts by hydropower technology developers to discover ways of utilizing advanced manufacturing techniques for new and innovative components with an emphasis on cost reduction (Activity 1 – Innovations for Low-impact Hydropower Growth). WPTO also coordinates with AMO under the Water Security Grand Challenge on projects pertaining to hydropower's role in maintaining and enhancing the nation's water infrastructure.
Solar Energy Technologies Office (SETO)	WPTO collaborates with SETO on the North American Renewable Integration Study (NARIS), the North American Energy Resilience Model (NAERM), and staff regularly serve as merit reviewers for each other's external solicitations.
Wind Energy Technologies Office (WETO)	WPTO collaborates with WETO on several grid-system analysis projects.

Federal Agencies	Collaboration Description
USACE	WPTO has multiple long-standing collaborations with the USACE related to technology, sustainability, and modernization of the federal fleet that stem from the Sustainable Hydropower MOU (WPTO, USACE, and U.S. Bureau of Reclamation). WPTO continues to advance the Juvenile Acoustic Salmon Telemetry System, co-funded by USACE, and continues to utilize Ice Harbor Dam as a testbed for new technologies coming out of the national laboratories. In addition, WPTO staff facilitated an MOU between FERC and USACE to ensure an efficient process for non-federal hydropower development at Corps dams.
U.S. Bureau of Reclamation	WPTO has multiple long-standing collaborations with Reclamation related to technology, sustainability, and modernization of the federal fleet that stem from the Sustainable Hydropower MOU (WPTO, USACE, and Reclamation). For example, the recent Fish Protection Prize to develop new ideas and mature viable technologies to prevent fish from being entrained in diversions and intakes. WPTO and Reclamation regularly provide portfolio overviews to establish areas of mutual interest for collaborations, often resulting in WPTO supported technologies being demonstrated at Reclamation sites.
U.S. Department of Agriculture (USDA)	WPTO supports the MOU between USDA and DOE based on mutual interest in rural energy development and the development of technologies that support and advance rural and agricultural communities. Collaboration with USDA has highlighted opportunities for future mutually beneficial work.
FERC	WPTO works closely with FERC staff to provide technical information pertaining to its mission to determine environmental effects of proposed hydropower projects and to establish a more streamlined regulatory process for hydropower licensing. For example, WPTO staff facilitated an MOU between FERC and USACE to ensure an efficient process for non-federal hydropower development at USACE dams.
NOAA, U.S. Fish and Wildlife Service, USGS	Through the Federal Hydropower Working Group, WPTO regularly interacts with subject matter experts at NOAA, the U.S. Fish and Wildlife Service, and the USGS to understand regulatory technology transfer barriers and obtain feedback from researchers on topics related to species and water management, including fish passage and forecasting. In 2018 and 2019, WPTO and these agencies developed two Environmental R&D Summits to identify hydropower research needs and priorities. WPTO also engages with NOAA on inflow forecasting improvements, as accurate knowledge of streamflow timing and water availability is foundational to hydropower operation. NOAA manages the River Forecasting Centers, which provide riverine data and predictions to a wide range of stakeholders. WPTO is considering more formalized near-term collaborations on topics of mutual interest.

Energy Storage Grand Challenge

Building on DOE's Advanced Energy Storage and Grid Modernization Initiatives, ESGC is a comprehensive program to accelerate the development, commercialization, and utilization of next-generation energy storage technologies and sustain American global leadership in energy storage. The vision for the ESGC is to create and sustain global leadership in energy storage utilization and exports in order to develop a domestic manufacturing supply chain that does not depend on foreign sources of critical materials.

The ESGC includes the following five tracks:

- The Technology Development Track will focus DOE's ongoing and future energy storage R&D around user-centric goals and long-term leadership.
- The Manufacturing and Supply Chain Track will develop technologies, approaches, and strategies for U.S. manufacturing that support and strengthen U.S. leadership in innovation and continued at-scale manufacturing.
- The Technology Transition Track will ensure that DOE's R&D output transitions to domestic markets through field validation, demonstration projects, public-private partnerships, bankable business model development, and the dissemination of high-quality market data.
- The Policy and Valuation Track will provide data, tools, and analysis to support policy decisions and maximize the value of energy storage.
- The Workforce Development Track will educate the workforce, who can then research, develop, design, manufacture, and operate energy storage systems.

The Hydropower Program participates extensively in the storage challenge, primarily through the HydroWIRES initiative described in Activity 2. HydroWIRES R&D in Sub-Activity 2.1 – Value Under Evolving System Conditions contributes directly to the Policy and Valuation track and will be closely coordinated with the modeling improvements and valuation frameworks undertaken through the broader DOE effort. Likewise, the assessments of hydropower's ability and operational requirements to operate flexibly and provide grid services under different conditions, encompassed in HydroWIRES Sub-Activities 2.2 and 2.3, will directly inform the storage use cases and technology pathways developed in the ESGC Technology Development track. Lastly, new innovations in PSH, undertaken in Sub-Activity 2.4 – Technology Innovation, will be key elements of the broader storage challenge's work in both Technology Development and Manufacturing and Supply Chain.

Water Infrastructure and Resilience

Infrastructure and ecosystem resilience, water security, and energy-water system complexity are vital research areas for the hydropower community when thinking about the evolving long-term future of hydropower. It is important to consider hydropower systems, facilities, and other non-powered dams as multipurpose water infrastructure projects instead of solely viewing them as existing or potential future energy assets. Water resilience research by WPTO will advance tools, models, sensors, and other pioneering technologies to consider broad developments of water infrastructure and hydropower's unique position at the nexus of energy and water systems. DOE's previous crosscutting efforts on the energy-water nexus provided a strong basis of understanding for this work as well as the Water Security Grand Challenge and WPTO's activities supporting hydrologic systems science and data access and acquisition.

Over the past few years, the Hydropower Program has funded a number of small research projects looking at how hydropower infrastructure and research tools could improve water system resilience. Some of these early efforts include considering opportunities to realize value from integrating hydropower into irrigation modernization activities (Sub-Activity 1.3 – New Value Propositions); capitalizing on hydropower's benefits and services for local energy reliability, improved economic outputs, and restored water resources (Sub-Activity 1.3 – New Value Propositions); and understanding and mitigating water risk, especially in the power system (Sub-Activity 3.3 - Cybersecurity).

Near-term future activities would include new technology development and support, methods for incorporating resilience strategies in municipal water systems, and advanced modeling and forecasting for more accurate assessments of risk. The outcomes expected are a mix of both technology advancement and analytical frameworks for improvement of water infrastructure—recognizing DOE's capabilities to provide direct investments in novel technologies and advanced analytical and computational tools. The economic incentives specific to hydropower's infrastructure and technologies provide a compelling advantage to drive wider water infrastructure evolution and innovation.

In future funding years, WPTO will look to execute on new visualization and operational planning tools providing insight into specific energy-water interactions and drivers to demonstrate and facilitate cooperation and optimization across energy and water assets. A systems-level approach for mutual water resilience will be undertaken across water and energy sectors to solve challenges in communications and control at multiple levels and scales. The work would also undertake new water and power co-design/co-optimization demonstrations that realize system wide benefits. In addition, data acquisition and access underpin water security and resilience, and the availability of actionable information is imperative to the Hydropower Program's activities seeking to balance a wide range of factors (Sub-Activity 5.1 – Data Access and Workforce Development and Sub-Activity 5.2 – Data Analytics). Finally, the water resilience-focused activities will directly engage many of the river system predictions, models, and decision-making science advanced by WPTO's Hydrologic Systems Science activity. This can better inform hydropower's role under changing future conditions to improve management of our water infrastructure and strengthen river basins facing hydrologic variations and changing projections of water availability (Sub-Activity 4.2 – Hydrologic Systems Science). This strategic initiative will be encapsulated in a report that documents the research to date, stakeholder outreach and engagement, and a roadmap.

Other Key Partnerships and Collaborations

Federal

In 2010, DOE (through WPTO) signed an MOU with the U.S. Department of the Army (through USACE and the U.S. Department of the Interior (through the Bureau of Reclamation) to advance mutual goals for greater development and utilization of clean, reliable, cost-effective, and sustainable domestic hydropower generation. In 2015, the MOU was renewed for another five years to provide a framework for collaboration on the following topics: (1) technology development, (2) hydropower sustainability, (3) quantifying hydropower capabilities and value in power systems, (4) asset management, and (5) information sharing, coordination and strategic planning. Key accomplishments from this partnership include:

- Development of a national database of existing U.S. hydropower infrastructure.
- Demonstration and commercialization of Pacific Northwest National Laboratory's Sensor Fish and a microbattery powered fish tag for sensitive species.
- Establishment of an MOU between USACE and FERC for a streamlined regulatory process for adding power to USACE NPDs.

DOE has once again committed to working with USACE and the Bureau of Reclamation by signing a new MOU on August 24, 2020. This new MOU will leverage resources to facilitate enhanced collaboration and coordination on technology research, development, and demonstration, and identify and engage in mutually beneficial research projects that support the hydropower industry and the federal agency core missions. The MOU and resulting action plan will detail overarching topics to increase sustainable hydropower generation and flexibility, while identifying a specific set of activities that the agencies will collectively undertake. These commitments were designed to represent a new approach to hydropower development that will result in clean, renewable power generation. Five topic areas were developed and include: (1) Asset Management, (2) Value of Hydropower, (3) Workforce, (4) Water Supply Reliability, and (5) Environmental Outcomes.

WPTO continues to partner with the Bureau of Reclamation on fish protection, a major challenge to hydropower and water users. For example, in a 2019 prize competition—the Fish Protection Prize—crowdsourced ideas to reduce fish entrainment impacts at water diversions and intakes. Selected ideas are incubated at national laboratories to prepare concept stage winners for technology advancement and commercialization. An ongoing prize contest that aims to mature viable concepts is currently being led by WPTO in partnership with the Bureau of Reclamation and supported by experts from USGS, NOAA, and the national laboratories.

Building off these past successes, WPTO is working with the MOU partners to discuss potential collaborations and aligned R&D opportunities. The Federal Inland Hydropower Working Group (FIHWG)—comprised of 15 federal agencies with roles in hydropower—was formed as an outcome of the MOU. WPTO will evaluate opportunities to collaborate more closely with FIHWG partners, such as NOAA, USGS, U.S. Forest Service, and Environmental Protection Agency, to leverage resources and/or accelerate beneficial outcomes through partnerships on specific topics. These strategic partnerships could support demonstration of new WPTO-developed technologies and more flexible operating regimes at federal facilities. Furthermore, these partnerships can facilitate applications of advanced manufacturing of legacy hydropower parts components, and support uptake of advances in Environmental R&D and Hydrologic Systems Science areas (e.g., development of advanced water quality and other sensor packages, fish passage research, flow forecasting, hydrologic modeling).

International

U.S.-Norway Memorandum of Understanding

In February of 2020, DOE and Norway's Royal Ministry of Petroleum and Energy made a commitment to collaborate on hydropower R&D by signing an Annex to an existing MOU on energy research. This MOU Annex brings together WPTO and the Norwegian Research Centre for Hydropower Technology to plan and coordinate hydropower R&D activities; develop, share, and implement results; increase understanding of hydropower's role in the future energy mix; and provide input to international discussions regarding hydropower.

Hydropower faces similar challenges and opportunities in the United States and Norway, and both countries are committed to enabling hydropower to support their respective electricity systems. Collaborative R&D under this Annex may include research in a number of areas:

- Markets and value
- Hydropower plant capabilities and constraints
- Monitoring and control technologies
- Environmental design solutions
- Environmental impacts and tradeoffs
- Flexible operations and planning
- Technology innovation.

Discussions between DOE national laboratories and Norwegian researchers have already identified specific opportunities for collaboration. Comparing capabilities of Norwegian and U.S. power system models is underway in order to identify opportunities for co-developing models and benchmarking model performance. Other work will include collaboration on digitalization, asset management, and component fatigue/wear modeling. In the environmental arena, there could be opportunities for collaboration on fish tags, environmental sensing using environmental DNA, and balancing environmental objectives with flexible operations. In the future, a formal researcher exchange program could benefit some or all of these efforts.

IEA Hydropower Technical Collaboration Programme

WPTO is actively involved in the IEA Hydropower Technology Collaboration Programme (TCP), supporting a number of annexes. HydroWIRES efforts are closely aligned with annex IX: Valuing Hydropower Services, and WPTO is actively engaged in this work stream. Environmental and new development efforts in WPTO support Annex XII: Hydropower and Fish, and Annex XVI: Hidden Hydro, respectively. WPTO also serves as a Deputy Chair of the Hydropower TCP Executive Committee.

International Pumped Storage Forum

The International Pumped Storage Forum, co-funded and led by the United States, aims to provide a platform to understand and shape the role of PSH in future power systems. Through the establishment of a multi-stakeholder network, the forum seeks to serve all stakeholders to expand and transfer best practice and experience with the aim of delivering sustainable, affordable and reliable power for all, while contributing to climate mitigation goals. The forum engages in activities such as, but not limited to, the following areas:

- Improve understanding of the role of PSH in providing storage and flexibility services, and the capabilities, values, costs, and potentials of PSH in addressing the needs of future power systems.
- Explore the full value of PSH's wider services beyond the power system, such as regulating water availability for society, industry, and agriculture, reducing the impact of flood and drought, and helping to adapt to climate change.
- Develop guidance and tools to support the design of market and policy frameworks that appropriately compensate and incentivize PSH development.
- Support the R&D of innovative and complementary technologies to enhance PSH.
- Ensure that all PSH development is sustainable and aligned with good environmental, social, and governance practice.