Memorandum of Understanding for Hydropower Technology Development

Action Plan

External Version 1, December 2023

U.S. Department of Energy's Water Power Technologies Office

The Tennessee Valley Authority

Nomenclature or List of Acronyms

AMM	advanced manufacturing and materials
DOE	Department of Energy
EAP	emergency action plan
GHG	greenhouse gas
HFI	Hydropower Fleet Intelligence
MOU	memorandum of understanding
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
R&D	research and development
TORCH	Training, Outreach, and Recruitment for Cybersecurity in Hydropower
WPTO	Water Power Technologies Office

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Introduction

On January 5, 2023, the Tennessee Valley Authority (TVA) and the U.S. Department of Energy (DOE), through its Water Power Technologies Office (WPTO), signed a Memorandum of Understanding (MOU) regarding hydropower technology development.[1] The MOU is meant to facilitate collaboration on the shared interest of demonstrating the feasibility, operability, and affordability of emerging options for hydropower fleet adaptation. This adaptation is largely centered on the operational flexibility necessary to meet the needs of a dynamic electric grid and evolving river systems. The MOU tasked the participants (TVA and WPTO) with developing a yearly action plan. This action plan outlines joint efforts over the coming year with the purpose of laying out an actionable framework to deliver on the goals set forth in the MOU.

The primary topic areas of partnership as noted in the MOU include:

- **Climate Change Adaptation.** The participants intend to continue efforts to best project the impacts of climate change on river operations so that river operating policies can adapt to provide for optimal operations.
- **Hydropower Fleet Asset Management.** The participants intend to pursue advances in hydropower fleet asset management, particularly around modeling reliability under new fleet missions and optimizing investment strategies.
- **Valuation of Hydropower.** The participants intend to pursue improved quantification of the value of energy, capacity, and ancillary services provided to the electrical grid by hydropower generators, including pumped storage facilities.
- **Pumped Storage.** The participants intend to continue efforts to explore the role, value, and technological options for deploying new pumped storage in service of the evolving grid and decarbonization.
- **New Turbine Demonstration.** The participants intend to evaluate the potential of emerging turbine designs for use nationally and in the TVA fleet.
- **Workforce Development.** The participants intend to develop training opportunities to help fill the hydropower workforce pipeline. These opportunities aim to prepare the national hydropower operations sector for upcoming retirements and industry changes.
- **Emerging Opportunities.** The participants intend to explore additional hydropower opportunities of joint interest that emerge over the period of the MOU.

This External Version 1 (2023) of the action plan provides high-level summaries of ongoing and proposed projects that will address these topic areas. The MOU and the action plan are nonbinding agreements, meaning that they do not obligate WPTO and TVA to allocate funding or staff time. The projects, topics, outcomes, and other information presented in this external action plan may change at any time with agreement between the participants.

[1] https://www.energy.gov/eere/water/articles/us-department-energy-and-tennessee-valley-authority-sign-memorandum

Roles and Responsibilities

WPTO will be the primary driver for DOE. WPTO's mission is "to enable research, development, and testing of new technologies to advance marine energy as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid." WPTO's Hydropower Program facilitates research and development (R&D) across several activity areas focused on topics such as hydropower fleet modernization, environmental technologies and analyses, and low-impact hydropower technologies, among others. This R&D is conducted through work with DOE's national laboratories and other partners. WPTO's partners generally provide modeling, data collection and analysis, and technical assistance. WPTO also works with industry and academia through a variety of funding mechanisms, like prizes, funding opportunity announcements, and small business innovation research grants.

WPTO's role in the action items outlined in this plan will generally focus on funding development, project management, and research dissemination. This means that WPTO will identify the expertise needed for a given action item, determine the appropriate funding mechanism for the activity, develop the project scope, and oversee project execution. WPTO will also facilitate collaboration between TVA and relevant partners, helping to ensure effective communication toward projects' goals.

Colin Sasthav (colin.sasthav@ee.doe.gov) is the primary point of contact for WPTO on this effort.

TVA's hydropower mission is to deliver clean and reliable power to the citizens of the Tennessee Valley, while maintaining all of the nonpower benefits provided by the valley's rivers. TVA is one of the largest electric utility companies in the United States, serving seven southeastern states with a diverse fleet that includes 29 hydropower plants and one pumped storage plant. In addition to electrical power generation, TVA also manages the water resources within its region of operation, which includes river system management, flood control, and irrigation through its hydropower dams. While TVA is a federally funded agency, it operates as a for-profit public utility company.

TVA's role in the action items outlined in this plan may often include the provision of in-kind support through staff time, access to facilities, and equipment. TVA may also provide direct R&D funding to project partners on a case-by-case basis. TVA will generally focus on techniques and technologies that allow its hydropower system to adapt to the changing needs of the Tennessee Valley and the electricity industry more generally. TVA may host demonstrations of more mature technologies anticipated for near-term, utility-scale deployment, whose benefits outweigh the costs and risks to TVA's ratepayers. Combining WPTO's mission focused on water power R&D with TVA's mission of applied hydropower and river management will serve as a test bed for concepts to be used nationally.

Curt Jawdy (cmjawdy@tva.gov) is the primary point of contact for TVA on this effort.

As directed by the MOU, both TVA and WPTO are responsible for updating this action plan yearly as activities progress and priorities change. The participants will kick off each cycle with an annual planning meeting in the spring, prior to budget preparation for the coming fiscal year. A second collaboration meeting will be held each Fall to update progress within each area and work through issues of concern. Collaboration will be ongoing between frontline staff working within each area. The MOU runs through January 5, 2028.

Action Items

The following sections lay out a series of action items or projects of active collaboration between the participants for the seven topic areas identified in the MOU. The projects within each topic area are denoted as either ongoing or proposed, depending on whether funding has been secured. Each action item includes a general description of the project concept, timeline, and progress steps. The funding for each project is handled on a case-by-case basis, depending on the priorities and available budgets.

Topic 1. Climate Change Adaptation

1.1. Climate and Water Temperature Modeling (Ongoing)

Under evolving climate conditions, it can be difficult to project the impacts of climate change on hydropower infrastructure and operations. Building on the large-scale hydroclimate projections developed from the SECURE Water Act Section 9505 study[2], this project is using a set of high-resolution models and assessment approaches to explore scientifically rigorous and engineering-feasible approaches to mitigate various types of climate change-induced risks at the river-basin scale.

Simulations are being conducted related to dam safety, river management, and hydrothermal impact analysis that can be further explored in future research projects with WPTO. More specifically, Oak Ridge National Laboratory (ORNL) is assisting TVA in selecting suitable climate models and downscaling climate projections that TVA is using to drive operational water/energy management models for impact assessment. Overall, the project team is developing suitable data, tools, and techniques to bridge the scientific climate change findings with a utility's operational needs. The project will identify a general practice to help hydropower stakeholders across the country evaluate climate impacts and adaption strategies.

The project started in April 2022 through a WPTO-funded effort with ORNL and has an expected end date of September 2025. TVA has provided funding and staff time as well. Major outcomes will include a report assessing climate impacts specifically on TVA's water management mission, a journal manuscript about the model selection and downscaling methodologies, a presentation to TVA's Regional Resources Stewardship Council, and case studies on the thermal regimes at select reservoirs.

1.2. Understanding Reservoir Greenhouse Gas Emissions (Ongoing)

Hydropower reservoirs, like all inland waters, emit carbon dioxide, methane, and nitrous oxide gases to the atmosphere. Accurate quantification of greenhouse gas (GHG) fluxes is paramount for the hydropower industry as these emissions may be considered when evaluating hydropower's status as a form of renewable energy. However, estimates of GHG emissions from all reservoirs (including hydropower) are highly uncertain, with global estimates varying over an order of magnitude. Part of this uncertainty reflects natural variation in the physical, chemical, and biological factors that affect the generation and release of GHGs from reservoirs. This uncertainty also reflects methodological limitations in field measurements of GHG emissions, variation in sampling designs that limit comprehensive assessment of the spatial and temporal variables in GHG emissions, and biases in the types (e.g., size) and locations (e.g., temperate, tropical) of reservoirs with GHG measurements. WPTO has identified characterizing uncertainty of methane emissions from reservoirs as an important first step in identifying and mitigating risk from high-emitting reservoirs.

This project will utilize a coupled modeling-measurement approach to reduce uncertainty in GHG emission estimates, particularly methane, both within individual hydropower reservoirs and those across the United States. Development and validation of novel, in-situ GHG measurement technologies, combined with

[2] https://www.energy.gov/eere/water/hydropower-climate-change-assessment

comprehensive, statistically based monitoring designs informed by GHG emission models, will be critical components of this project. Sampling will occur on several TVA reservoirs to parameterize the models for reservoirs in the Southeast similar to TVA's.

The project started in October 2022 through a WPTO-funded effort with ORNL and has an expected end date of September 2025. TVA supports sampling activities in its reservoirs with staff time and equipment use. The proposed outcomes are two reports, one looking at GHG emission fluxes at TVA's reservoirs and another at a national scale.

Topic 2. Hydropower Fleet Asset Management

2.1. Hydropower Fleet Reliability Modeling (Ongoing)

A major challenge facing the hydropower community is maintaining cost competitiveness and security of existing hydropower assets given the fleet's age. The Hydropower Fleet Intelligence (HFI) project, led by ORNL, is addressing this challenge by aligning, correlating, and analyzing disparate national- and plant-scale datasets to provide actionable information to help U.S. hydropower operators make operations and maintenance decisions. Currently, these datasets separately track the cost, reliability, and condition of U.S. hydropower assets. A better understanding of correlations and interdependencies across these datasets will enhance hydropower asset managers' capabilities to optimize facility management for greatest benefit and value through predictive maintenance applications.

By using data to optimize the scope and schedule of maintenance and refurbishment activities, plants can reduce downtime and prolong plant life. TVA has already provided plant data and reliability models for its hydropower fleet. TVA will continue to work with ORNL by providing data, validation, and feedback while ORNL will disseminate any findings and resources (e.g., models, tools, reports) to TVA for implementation in its fleet management program. ORNL will provide a report recommending improvements to TVA's existing reliability modeling and providing Weibull curves for additional plant components.

The project started in 2014 as a WPTO-funded effort with ORNL. The short-term outcomes for the ORNL-TVA collaboration include journal articles on digitalization trends and predictive analytics, online tools for data orchestration and analytics, and a report recommending improvements to TVA's reliability modeling. These outcomes are targeted for completion by September 2024. HFI is a long-standing and adaptable project, so objectives will continue to be updated as the project progresses. TVA is providing in-kind support through staff time, data, and existing Reliasoft models of its hydropower fleet.

Topic 3. Valuation of Hydropower

3.1. Pumped Storage Valuation (Ongoing)

The valuation of pumped storage is particularly difficult given that storage assets are used to balance between load and generation. For integrated utilities such as TVA, no market signal exists by which to value pumped storage. Therefore, valuation is done with in-house capital expansion, production cost, and transmission modeling systems. The evolution of the grid due to decarbonization and decentralization is stretching these models.

In 2023, TVA submitted to WPTO an application for technical assistance in partnership with the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Argonne National Laboratory. The scope was to perform a set of modeling runs of increasing complexity, beginning with the relatively simple Pumped Storage Hydro Valuation Tool[3], moving on to a peer review of TVA

[3] https://pshvt.egs.anl.gov/

models, then running NREL models with TVA inputs, and finally a wide-open running of NREL economy-wide models over a range of scenarios.

TVA's application was accepted through WPTO's competitive solicitation, which was open to a wide hydropower industry audience. WPTO has a standard merit review and selection process that involves reviews from external stakeholders to minimize bias, and the MOU did not influence the selection process. The project will begin in fall 2023 and continue until fall 2025. The results of all modeling will be evaluated financially and tabulated in a final report. Major outcomes will likely include reports on improvements to TVA's models, case studies with various modeling assumptions, and financial analysis.

Topic 4. Pumped Storage

4.1. Pumped Storage Membrane System Testing (Ongoing)

Pumped storage can be a key solution for supporting a clean energy grid through large-scale energy storage. Closed-loop pumped storage is an approach that aims to minimize environmental impacts by creating the upper and lower reservoirs separate from natural water bodies. However, closed-loop designs can require significant civil works, like blasting and excavating, and rely on drawing water from nearby sources for initial filling and refilling. This project explores an innovative floating reservoir technology concept for closed-loop facility configurations. In this design, a lightweight floating membrane reservoir system can be easily fabricated and installed in existing water bodies to create one half of a closed-loop pumped storage system. This expedites filling and ideally maintains separation of local biota. This concept is unproven both mechanically and environmentally, so this project aims to test and validate the concept at lab and full scales.

Lab-scale testing of the pumped storage membrane system is planned in two phases. Phase 1 will be an approximately one-tenth-scale, proof-of-concept model that will be installed and tested in a flume at TVA's Norris Engineering Lab. These tests will assess the folding and unfolding behaviors of the bag under various flow and filling/emptying scenarios. Phase 2 addresses the safety and logistical aspects of membrane use, such as ascertaining loading and response of the membrane structure under different approach flow conditions. If successful, the project will progress to a full-scale prototype tested in a TVA reservoir. The team will study operational and environmental performance under realistic conditions such as flows, weather, and in-situ exposure to the environment.

This project began in 2017 as a WPTO-funded effort with ORNL. TVA joined through an interagency agreement in 2021 to conduct the scale model study. If Phase 1 is successful in late 2023, the full-scale demonstration is targeted for completion in fall 2025. Each phase of testing will result in a report on the testing results and lessons learned.

Topic 5. New Turbine Demonstration

5.1. Small Hydropower Test Facility Conceptual Design (Proposed)

Testing is an important step in the commercialization of new technologies. The hydropower industry, in particular, can be risk averse for technology adoption given the criticality of unit uptime, the tight cost margins for new small hydropower development, and the entrenched design thinking from more than a century of industry experience. However, climate goals and evolving grid conditions are accelerating the need for innovative small hydropower technologies and alternatives to conventional components. According to a 2022 ORNL report, the hydropower industry lacks the necessary infrastructure to test hydropower technologies at full scale.

Congressional language directed WPTO to investigate the potential for a hydropower test facility at an existing federal site. TVA has several sites that would be feasible candidates for this type of facility, particularly Melton Hill Dam, only a few miles from ORNL. The goal of this project would be to conduct a conceptual design of a hydropower testing center at one of TVA's hydropower facilities. Engineering contractors would

complete the engineering analysis, drawings, and cost estimates. This project would require one year to complete and is dependent on congressional direction and available funding.

5.2. Advanced Manufacturing for Hydropower Collaboration (Ongoing)

During the last decade, advanced manufacturing and materials (AMM) have revolutionized the energy sector, boosting the U.S. manufacturing industry and opening pathways to increased American competitiveness. ORNL, in collaboration with WPTO, created a scoping report[4] that explores the potential benefits for AMM in hydropower applications. Additive manufacturing, composite materials, in-situ repair techniques, self-healing coatings, and many other technologies have shown promise. The scoping report was informed by a workshop hosted at ORNL's Manufacturing Demonstration Facility in August 2022 with hydropower and AMM industry stakeholders, including TVA. The Manufacturing Demonstration Facility has been a hub for AMM technical assistance through DOE's Advanced Materials and Manufacturing Technologies Office, which hosts an ongoing Technical Collaboration Program[5]. TVA and WPTO continue to explore pathways like this for collaboration on this topic.

Topic 6. Workforce Development

As of May 2023, there are no active collaborations in this topic area, but both WPTO and TVA will continue to consider activities and keep in communication about ongoing activities and needs. For example, WPTO is funding the following two activities that would benefit from TVA engagement as mentors, recruiters, and advocates:

- In 2022, WPTO launched the Hydropower Collegiate Competition, an annual competition that calls on interdisciplinary teams of undergraduate and graduate students from a variety of academic programs to offer unique solutions to complex hydropower challenges. By participating in the competition, students gain industry experience, valuable exposure to hydropower career pathways, and greater knowledge of hydropower's potential to contribute to a clean energy future. TVA may engage as judges, industry contacts for students, or as sponsors for local teams.

- The Training, Outreach, and Recruitment for Cybersecurity in Hydropower (TORCH) project is a WPTO-funded effort at PNNL that started in 2023. The team aims to host cybersecurity recruiting events for college students and training events for hydropower professionals. The training curricula will be specific to cybersecurity challenges at hydropower plants, and the events will leverage virtual interaction with a scale model of a hydropower plant with a realistic control system. TVA may engage as recruiters and send staff as participants for the training program.

Topic 7. Emerging Opportunities

7.1. Modernizing Emergency Action Plans (Proposed)

TVA dams, like dams across the country, have emergency action plans (EAPs) that detail the actions that must be taken to protect life in the unlikely event of a dam failure. These action plans generally have static maps that delineate the boundary of flooding due to a dam break, as well as a general communication approach and actions for local emergency management. Unfortunately, the lack of detailed and time-based action sequencing could leave these frontline emergency management staff improvising when minutes count.

[4] https://info.ornl.gov/sites/publications/Files/Pub190558.pdf
[5] https://www.ornl.gov/content/work-us

The proposed work would build on detailed agent-based modeling that TVA has already performed. These models integrate flood wave hydraulics, warning dissemination, and agent-based evacuation modeling. The models have been used to estimate loss of life for prioritizing dam safety investments but have not been used to improve EAPs. This project will select a single existing TVA EAP to trial an improved EAP. A series of workshops will be held with TVA and local and state emergency managers, during which they will step through animations of evacuations for several breach scenarios. Department of Homeland Security layers for critical infrastructure and vulnerable populations will be used to help the local emergency managers lay out a well-informed and actionable plan. DOE expertise in disaster response and agent-based modeling will be utilized to improve the models and process.

TVA and the nation can build on this work to improve the safety of all people living downstream of dams. The proposed project would require approximately one year's worth of effort and result in a case study EAP update and a report on the applicability of the methodology to other dams across the United States.

7.2. Floating Vegetation Management and Modeling (Proposed)

Invasive floating vegetation is spreading throughout the nation's rivers and has detrimental impacts to hydropower and water-cooled generation sources. Many floating invasives can detach from the riverbed and float downstream, clogging intakes and making the grid less reliable and resilient. The behavior of these species is very poorly understood, particularly the cause(s) of detachment.

The proposed work would require approximately three years of effort and utilize ORNL's existing flumes to study the lifecycle of eelgrass and one or two additional invasive floating plants. The focus would be on determining the causes of mat detachment and developing nature-based solutions to protect downstream intakes from clogging. Major outcomes could include a report on eelgrass lifecycle and detachment modes and a report on recommendations for nature-based solutions.

7.3. Consequence-Driven Cybersecurity Analysis and Valuation for Hydropower (Proposed)

Cybersecurity is a critical factor in maintaining the reliability, availability, and safety of TVA's power grid and hydropower across the nation. Cybersecurity investments often do not provide additional revenue but provide value through risk reduction and threat mitigation, which could save money, equipment, and lives in the case of a cyberattack. This project proposes to develop a prototype decision-informing tool that uses mathematical reasoning to prioritize threats and the corresponding risk-reduction strategies.

The project would first develop a novel method for risk quantification using attack graphs, stochastic models, failure model analysis, and expert-informed consequence weights. The method would then be implemented as prototype software and tested on a TVA system. Cybersecurity teams at ORNL and TVA would collaborate on the necessary modeling and software development efforts. The project would require approximately two years of effort. Along with the model and software outcomes, the project would publish a report on the methodology and case study results.