MEMORANDUM OF UNDERSTANDING FOR FEDERAL HYDROPOWER

6/2/2021

CONTENTS

LIST OF ACRONYMS

3D	three-dimensional
AM	additive manufacturing
ANL	Argonne National Laboratory
BPA	Bonneville Power Administration
Corps	U.S. Army Corps of Engineers
CRSP	Colorado River Storage Project
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DT	digital twin
EPTC	Electric Power Training Institute
ERDC	Corps' Engineer Research and Development Center
FERC	Federal Energy Regulatory Commission
FES	firm electric service
FY	fiscal year
HDC	Corps' Hydroelectric Design Center
MDF	Manufacturing Demonstration Facility
MOU	memorandum of understanding
NHA	National Hydropower Association
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
PMAs	Power Marketing Administrations
PNNL	Pacific Northwest National Laboratory
POCs	persons of contact
PSH	pumped storage hydropower
Reclamation	Bureau of Reclamation
R&D	research and development
RD&D	research, development, and demonstration
SEPA	Southeastern Power Administration
SWPA	Southwestern Power Administration
VERs	variable energy resources
WAPA	Western Area Power Administration
WPTO	Water Power Technologies Office

INTRODUCTION

On August 24, 2020, the U.S. Department of the Army (through the U.S. Army Corps of Engineers), U.S. Department of Energy (through the Water Power Technologies Office), and the U.S. Department of the Interior (through the Bureau of Reclamation) signed a Memorandum of Understanding (MOU) for Federal Hydropower. The MOU outlined a vision for the future of collaboration among the Agencies, which stated that the Agencies will leverage their resources and efforts to help position Federal hydropower to meet the Nation's need for reliable and affordable renewable energy. The MOU called for an Action Plan, within 90 days of the signing, designed to identify research and development opportunities to ensure hydropower maintains its critical role in the U.S. power system, both as a clean and renewable source of bulk power and as a key provider of flexibility that facilitates increased generation from variable generation resources.

This Action Plan provides the framework for collaborations that will address emerging hydropower issues and enhance technology research, development, and demonstration (RD&D) in five topic areas: (1) asset management, (2) value of hydropower, (3) workforce, (4) water supply reliability, and (5) environmental outcomes. Under each of the five topic areas, the Agencies, in collaboration with the Power Marketing Administrations (PMAs), proposed projects based on industry needs.

These projects will inform deliverables and outline the resources contributed by each Agency and the PMAs. Successful projects will lead to the following outcomes:

- Enhanced digitalization of hydropower systems that reduce operation and maintenance costs, improve investment analyses, and enhance system planning.
- Increased capabilities in asset management for better stewardship of hydropower infrastructure investments.
- Improved understanding of hydropower's unique capabilities and how to properly value and compensate for its contributions in different types of electricity markets.
- Enhanced training of the Agencies' existing workforce and improved recruitment pipelines for engineers and operators to enter the workforce.
- Accelerated reinvestment in industries that intersect with hydropower power resources and provide broader societal benefits, like the modernization of irrigation infrastructure to benefit the agricultural sector.
- Increased access to information that identifies environmental mitigation costs and enables pathways to reduce mitigation costs while maintaining environmental stewardship and compliance.
- Improved understanding of pumped hydropower storage systems that can store power generated at off-peak times, leading to better environmental outcomes downstream.

ACTION ITEMS

TOPIC 1: Asset Management

Digital Twin Development

Problem: The existing hydropower fleet is facing a broad range of challenges and opportunities as assets age and new technologies become available. One of the most notable challenges is effective management of operations and maintenance (O&M) costs. For all but the largest hydropower plants (>500MW), O&M costs have been increasing faster than the Consumer Price Index from 2007 to 2016. Small, medium, and large hydroplants have seen an inflation-adjusted increase in costs of 20% in comparison to the CPI increase of 16%[1]. In addition, hydropower plants are operating in an increasingly varied and interconnected environment.

Hydropower plants are increasingly being used to firm non-dispatchable generation from variable renewables leading to uncertainty about maintenance and refurbishment impacts and the potential to increase the risk of costly forced outages. One tool that addresses these challenges is the hydropower digital twin (DT). Fundamentally, hydropower DTs are coupled equations that accurately represent the operation of hydropower systems (e.g., component wear, flexibility, and environmental impact). While DT development allows for unprecedented insight into the operation of hydropower facilities, there are long-standing challenges created by diverse hydroplant designs, various sensor configurations, and complex system physics. The digital twin capabilities developed through this effort will address these challenges by creating multi-physics models that can simulate hydroplant operation at sufficient resolution to meet a diverse range of hydropower needs. These multi-physics systems will be developed around hydroplant archetypes, which can be further customized to individual plants through site-specific data. The specifications of the twin will be informed through targeted stakeholder outreach to ensure the twin can answer the highest impact industry questions and be readily integrated into industry processes.

Description: The Water Power Technologies Office (WPTO) and partner organizations are currently in the foundational research stage of this effort, focusing on understanding the most impactful DT application and scale that will help focus the first generation DT, the multi-physics models that will enable them, and how they can most effectively be implemented by industry. Researchers will compile data for these models through industry outreach by gathering significant existing information held by project partners, the National Laboratories, and through a literature review. As the research matures, the team will put significant effort toward developing coupled multi-physics equations that are sophisticated enough to answer the needs of industry, but simple enough to be implemented by stakeholders with a range of resources. These equations, which are the building blocks of DTs, must then go through a verification and validation procedure to ensure they accurately reflect reality. Finally, these capabilities must be deployed in a series of pilot studies to refine the models and their implementation process, as well as to build industry confidence in their capabilities. The MOU

[1] Uria-Martinez, R., Johnson, M., & O'Conner, P. (2018). 2017 Hydropower Market Report. Oak Ridge: U.S. Department of Energy.

participants are in a unique position to effectively develop a broadly applicable DT solution for the hydropower industry given the rich dataset and experience available.

Impact: The successful development of DT capabilities has numerous potential benefits to the Federal hydropower system and the broader hydropower industry, including reduced O&M costs, improved capability investments, limited outages, and better overall system planning. These benefits are made possible through the development of accessible digital system models, which accurately simulate facilities' operations. One of the clearest examples of the impact of DT capability is reduced maintenance costs (i.e., cleaning, repairing, and replacing parts). DT provides unprecedented visibility into when maintenance needs to occur, so it is performed at the "optimum" time rather than at regular intervals. DT capability has the potential to improve broader asset management outcomes by enabling "big data" approaches to system management like predicting future O&M needs under different market conditions for more effective capital planning.

Agency Roles:

Lead Agency: WPTO will lead the overall DT effort, funding National Laboratory staff to research, prepare documents, and develop DT products. Corps' Engineer Research and Development Center (ERDC) will act as the lead agency for a sub-effort focused specifically on the cooling model for stators.

Participating Agencies/Organizations: ERDC, the Bonneville Power Administration (BPA), and the Southwestern Power Administration (SWPA) are also participating in this effort. In the short term, the participants will largely be providing perspective and guidance to the research team around how the developed capabilities can be most valuable. As the project matures, this will likely expand to sharing data to inform both the development and application of the DT. Regarding the Stator Cooling Model, WPTO and Reclamation will provide perspective and guidance into model development and applicability to the broader DT concept.

Time/Effort: The DT work sponsored by WPTO began at the start of FY 2021. The project will yield a range of incremental deliverables, starting with a report on the value of DTs for hydropower applications, as well as a report on the DT specifications and design needed to meet these value proposition. The capabilities will then mature over the next several years, targeting the deployment of pilot studies by 2026. For the Stator Model, the timeline to complete the project will be relatively short, estimated to take from 3 to 6 months.

Scope & Location: The DT capabilities envisioned in this project are designed to be an open framework that is broadly applicable to the domestic hydropower fleet. The Stator sub-effort will be implemented at Corps' hydropower facilities and made available to the broader partners.

Final Product: While the final product of this work will be DT Open Framework, there will be a host of deliverables as the concept matures. These can be broadly categorized around the value, implementation, and development of the DT. The goal is that the DT and additional deliverables will enhance end user confidence in the tool's capabilities and value. The Stator model sub-effort will result in both a model and an ERDC technical report on the process of reviewing, optimizing, validating, and implanting the algorithm.

Equipment Failure Mode Analysis Database

Problem: Equipment maintenance is the largest single cost for the Federal hydropower and PMA transmission programs. Maintenance management has the potential to be a large cost saver for hydropower programs in the Reclamation and Corps. Maintenance management specifically referees to the maintenance of assets while controlling costs and timelines to maximize system efficiency. Given the increasing maintenance costs and aging system infrastructure, effective system management is critical to reducing costs and maintaining the high reliability of hydropower assets. Managing PMAs' transmission line maintenance also offers savings opportunities both fiscally and in terms of opportunity costs for maintenance personnel. Condition-based maintenance and reliability-centered maintenance are attractive alternatives to time-based maintenance and could help realize cost savings while improving equipment reliability. One of the challenges to these alternative maintenance strategies is the time and research required to identify how and why hydropower equipment fails.

Description: DOE National Labs will research and analyze equipment failure data from Corps and Reclamation to create a database of failure mode information for different pieces of hydropower generation and transmission related equipment. The project will start with equipment common to the Federal hydropower system, such as transformers, circuit breakers, insulators, etc. Identifying failure modes can ultimately lead to online condition monitoring to preclude frequent inspections and to alter maintenance practices to focus on critical areas of equipment maintenance.

Impact: The development of realistic component failure mode models and analytics has the potential to reduce O&M costs, as well as to improve hydropower plant reliability. This is because these models will allow for more prescriptive maintenance and allow operators to better detect Supervisory Control and Data Acquisition (SCADA) signals, which can indicate approaching component failure.

Agency Roles:

Lead Agency: WPTO will lead the Equipment Failure Mode Analysis effort, funding National Laboratory staff to research and prepare deliverables around component failure modes and signals.

Participating Agencies/Organizations: Reclamation, Corps, BPA, and SWPA are also participating in this work. Reclamation and Corps will play a critical role in this effort, as they will provide data needed to perform the research as well as guidance to the research team to ensure the findings reflect actual hydroplant operations.

Time/Effort: 3 – 6 months to gather historical failure data
1 – 3 years for labs to analyze data and comprise database
3 – 6 months to identify additional projects on monitoring and maintenance

Scope & Location: The scope will initially focus on common equipment such as transformers, circuit breakers, and insulators, then expand to cover all critical components to mission delivery. The priority of different components will be selected based on a combination of their criticality, pervasiveness, and availability of information to produce and validate the system models.

Final Product: Failure mode analysis database of hydropower and transmission equipment.

Cold Spray

Problem: Cavitation is a common phenomenon that negatively effects hydropower facility performance which may cause severe erosive damage of metal components such as the runner and draft tube. Today, hydropower facilities are often required to operate at less than ideal conditions due to changing power system requirements, which further exacerbate cavitation damage. Cavitation damage can lead to increased maintenance and repair costs, lost revenue due to downtime and power replacement costs, decreased operating efficiencies, and reduced service life of equipment.

The most common technique to repair cavitation damage is arc welding, where filler material is welded onto the component to replace material lost by wear. However, high heat input and melting associated with arc welding degrades the base metal and negatively impacts the properties of the original component, increasing the frequency of repairs and outages.

Description: WPTO is seeking a site to perform a field demonstration of novel cold spray technology for cavitation repair that would improve traditional arc welding techniques typically utilized by hydropower facilities. WPTO and BPA have invested in advancing the cold spray concept toward commercialization for cavitation repair of hydropower metal components. Led by DOE's Pacific Northwest National Laboratory (PNNL), initial efforts focused on proof-of-concept activities, such as coupon (sample size specimens of the base metal) testing with various cold spray formulations. Figure 1 identifies cold spray chemistries with a significant decrease in mass loss during cavitation testing for base metals treated with cold spray versus arc welding and even the untreated base metal itself; this data demonstrates promise for full-scale applications.

In FY21, the team is pursuing a roadmap of activities needed to re-risk the technology and perform a field demonstration:

- Process Optimization: Transfer the cold spray process from fixed equipment (non-portable) to portable equipment for manual application. Activities include a series of trials to understand the effect of human input variables, such as travel speed, attack angle, and stand-off distance variation.
- Field Demonstration: Includes pre-spray planning activities, as well as post-spray inspection and testing. Planning and preparation tasks consist of development of various plans (safety, environmental, inspection) and outlining any facility modifications and procurements necessary to perform the field application. Post-spray inspections include visual inspections, coating adhesion testing, thickness measurement, and metallography.
- Post-Demonstration Inspections: Longer-term periodic monitoring and testing of the cold spray deposited during the field application to determine performance in preventing cavitation erosion.

Impact: Experimental results have shown that a cold sprayed large area coupon has significantly less mass loss compared to the base metal and arc welded surfaces when exposed to cavitation. Initial cost analyses also indicate that repair costs using cold spray are comparable to arc welding, and result in a shorter payback period due to reduced outages. A field demonstration would serve to validate the technology at full scales and, if successful, catalyze widespread adoption.

Agency Roles:

Lead Agency: WPTO is funding PNNL to perform laboratory cold spray trials and process optimization. BPA is currently co-funding this effort and working with WPTO and PNNL to identify a field demonstration site among the Federal hydropower fleet.

Participating Agencies/Organizations: Reclamation and/or Corps will be participating by providing access to a Federal hydropower facility in the BPA service territory for testing during an already planned outage for the field demonstration.

Time/Effort: Ongoing. FY 2021 will focus on process optimization and planning for an FY 2022 field demonstration. Post-spray inspection will be needed for a certain amount of time after initial deposition.

Scope & Location: The field demonstration will take place at a Corps or Reclamation hydropower facility within the BPA service territory.

Final Product: Report summarizing results of field demonstration to inform hydropower owner operators and support their selection of repair processes.

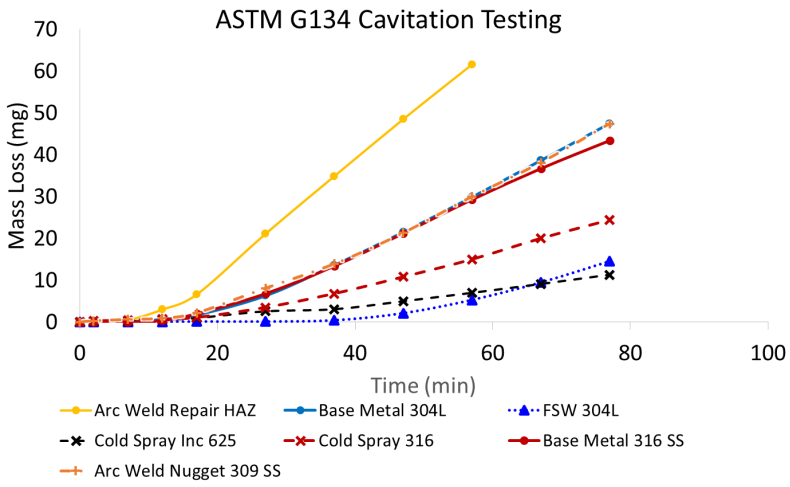


Figure 1. Cavitation repair methodology performance assessment.

Advanced Manufacturing Roadmap

Problem: Over the last decade, advanced manufacturing has revolutionized the energy sector, boosting the U.S. manufacturing industry 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 these novel applications of advanced manufacturing have ushered in benefits in other energy sectors, the potential benefits for hydropower applications remain largely unexplored.

Description: WPTO is developing an Advanced Manufacturing Roadmap that identifies high-impact opportunities to leverage advances in manufacturing and materials for hydropower applications. DOE's Oak Ridge National Laboratory (ORNL) and the Manufacturing Demonstration Facility (MDF) are supporting this effort by organizing and summarizing the solutions submitted to DOE's Innovations in Advanced Manufacturing for Hydropower (I AM Hydro) Prize; analyzing and developing metrics to evaluate the potential impacts of advanced manufacturing technologies and methods for hydropower applications; and undertaking stakeholder outreach. WPTO will use this information to identify high-impact opportunities for the hydropower industry and prioritize them for future R&D investments. Stakeholder engagement will be a crucial portion of this effort to ensure the most important needs of the hydropower industry are being addressed.

WPTO and MOU partners will collaborate in (1) categorizing and evaluating the potential impact of advanced manufacturing technologies and methods (e.g., corrosion/erosion resistance, weight, reliability, costs, etc.) based on metrics; and (2) prioritizing activities by reviewing preliminary drafts and determining how identified opportunities could address challenges faced by the federal hydropower fleet.

Impact: An Advanced Manufacturing Roadmap can help guide targeted investments and research in advanced manufacturing technologies and methods to help address the needs and goals for the Federal fleet. By serving as reviewers, Reclamation and Corps can ensure that the biggest challenges and opportunities for hydropower are being targeted for solutions.

Agency Roles:

Lead Agency: WPTO, with ORNL support, will develop a Roadmap to guide advanced manufacturing research investments.

Participating Agencies/Organizations: Reclamation and Corps will serve as reviewers, providing in-kind time and expertise to advise on the challenges and opportunities for the Federal hydropower fleet.

Time/Effort: Following the closure of the I AM Hydro Prize on October 30, 2020, ORNL will begin an opportunities analysis during FY 2021. Upon completion, WPTO will utilize this information to inform an Advanced Manufacturing Roadmap.

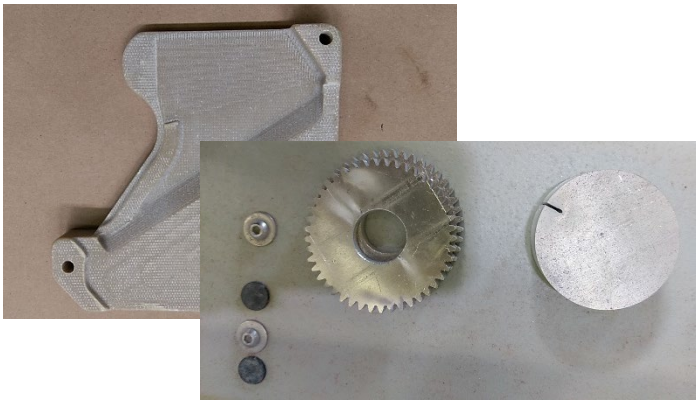
Scope & Location: The Roadmap will consider opportunities applicable to hydropower assets across the United States fleet, both Federal and private.

Final Product: An internal Advanced Manufacturing Roadmap for Hydropower to inform investments in near- and long-term, high-impact opportunities in advanced manufacturing.

Additive Manufacturing for Hydropower Components

Problem: The Federal hydropower fleet is faced with an increasingly aging infrastructure comprised of many features and parts that require costly and time-consuming maintenance, replacement efforts, and expenditures. As hydropower facilities age, the equipment can require parts that are no longer produced or are costly to create using traditional methods. Research in three-dimensional (3D) metal printing as it relates to the hydropower industry is limited, if not altogether lacking. Reclamation is proposing to identify the potential benefits from 3D metal printing technologies to improve performance and reduce system downtimes.

Description: In the past several years, the 3D printing field has grown exponentially, introducing new technologies, methods, materials, applications, and business models, and consistently expanding the list of metal materials available for use. Metal printing is a new way to engineer and manufacture parts. Instead of traditional material subtraction and machining, material is added, and final finishes machined. Benefits from using these approaches can include reduced cost of material, improved design parameters, and reduced labor costs. Exploring the ability to capture the benefits from 3D metal printing could improve designs, decrease costs, and lead to longer service lives for hydropower



equipment. The purpose of this initial effort is to build on existing research at Reclamation to learn about potential hydropower applications of different additive manufacturing (AM) technologies and methods, gain confidence in the material properties from AM components, understand design techniques used to develop parts, perform material testing, and install parts where feasible. Further, more research is needed to better understand the costs, benefits, and scalability of AM. Through the MDF, WPTO will provide guidance regarding best practices and technical capabilities for AM of hydropower components.

Impact: Research results could lead to increased availability and reliability, as well as decreased O&M expenses at hydropower facilities, through improved designs, lower material costs, and longer service lives.

Agency Roles:

Lead Agency: Reclamation

Participating Agencies/Organizations: WPTO and ORNL

Time/Effort: 3–4-year effort from 2018–2022

Scope & Location: Reclamation facilities and the MDF. Current components include log boom anchor (completed, testing, and installing at Nimbus Dam), slinger ring (Grand Coulee), governor part (Glen Canyon)

Final Product: A final report documenting the potential opportunities, costs, and benefits of using 3D metal printing for legacy components for owner/operators to consider in their asset management plans.

TOPIC 2: Value of Hydropower

Value of Hydropower Project 1: Hydropower Value within Regional Electricity Markets

Problem: Additional deployment of variable energy resources (VERs) and other industry changes are creating an increased need for dispatchable generating capacity and flexibility on the power system. Hydropower, as a carbon-free resource that provides both capacity and energy as well as a full range of flexibility and critical reliability services, will become increasingly important and valuable as the industry moves forward. There is a need to understand the value hydropower provides today and how it may change in the near future so that Federal agencies, as well as their customers, can make informed decisions.

Description: This project will develop three to five case studies of the value of hydropower in the Western Area Power Administration (WAPA) service territory. WPTO's *Hydropower Value Study,* which includes a survey of hydropower operations, capabilities, and constraints in different areas of the United States, will serve as a starting point for this project. WAPA case studies may help to inform the HydroWIRES Regional Roadmaps for Hydropower Value effort being developed to better understand hydropower operations and contributions to the grid, and how they may vary regionally in the US.

The case studies will be further defined and developed in collaboration with the intra-agency Federal Hydropower MOU Action Plan team along with WAPA's customers. Potential case studies may include:

1. Current and future value of hydropower contributions to ancillary services[2], resource adequacy, system flexibility, inertia, black start, and overall system resilience along with mechanisms to properly compensate for these services.
2. Impacts of variable renewable generation on the operation and economics of hydropower resources.
3. Impacts on how hydropower operations may be modified as a function of the different markets in which hydropower products are currently sold or may be sold in the future. This includes bilateral, real-time, day-ahead, and fully integrated markets.
4. Possible changes in emergency operations of the hydro plants. As the proportion of non-dispatchable generation grows, the hydro units may increasingly be called on to firm up deliveries when renewable resources are not producing or when batteries are depleted. The value of emergency energy is likely undervalued under the current market paradigm.
5. Metrics for flexibility of projects to measure and compare aspects of flexibility of hydropower projects.

Impact: This project would enable a better understanding of the full range of value of Federal hydropower, customer utilization, and how WAPA uses ancillary services to balance the grid considering increased penetration of renewables. In addition, a better understanding is needed of how hydropower operations will be affected by the proliferation of proposed new market structures in each area.

[2] Ancillary services include Scheduling, System Control and Dispatch; Reactive Supply and Voltage Control; Regulation and Frequency Response; Energy Imbalance; Generator Imbalance; Spinning Reserves; and Supplemental Operating Reserves. (Source: FERC *pro forma* Open Access Transmission Tariff.)

Agency Roles:

Lead Agency: The full scope of this is the subject of discussions among WAPA, Reclamation, and WPTO. WAPA is proposed as the lead for this project, including working with customers. WAPA would coordinate with their customers as part of the development of this report. Details of contributions, involvement, and timing will depend on the scope and are still tentative.

Participating Agencies/Organizations: WPTO may be able to contribute modeling expertise through the HydroWIRES initiative and could align its ongoing work on Quantifying Hydropower Value Drivers to benefit this project. Reclamation is proposed to provide in-kind support of expertise and time.

Time/Effort: Timing and level of effort for each case study will be determined via conversations between the agencies and PMA customers.

Scope & Location: The project could include case studies on selected hydropower value topics across WAPA.

Final Product: The final product will include a report (or a series of reports), depending on the timing of the individual case studies, to inform WAPA hydropower operations and market participation, and provide other hydropower owners/operators with transferable takeaways from each case study.

Value of Hydropower Project 2: Marketing Federal Hydropower with Drought Conditions, Additional Renewable Resources, and Changing Markets

Upper Colorado River Hydropower: Flexibility for Colorado River Storage Project (CRSP) Firm Electric Service (FES) Hydropower Customers as They Address the Impacts of Increased Renewable Resources

Problem: This proposed research focuses on potential flexibility improvements to hydropower operations to address customer challenges due to distributed renewable generating resources, sometimes referred to as behind-the-meter resources, to meet retail electrical demand and for following "load" on a daily and hourly basis. As variable renewable generation is added to the service area of those utilities that receive CRSP FES, the electrical power supply needs will change; for example, FES hydropower customers may subsequently schedule their FES hydropower allocations differently than in the past. WAPA needs to know if these potential changes to the customers' daily scheduling patterns will affect the operation of CRSP Federal hydropower resources and the degree to which WAPA can accommodate the desired changes. Reclamation needs to know how renewable generation additions may result in modifications to dam operations (within existing operating criteria).

Goals: The goals for this research are: 1) to model potential changes in CRSP FES hydropower customers' daily patterns of federal energy to understand how WAPA can provide value to FES hydropower customers under existing contractual obligations, 2) to understand how changes in daily patterns will impact firming power purchase expenses, and 3) to plan for possible changes in the operation of CRSP dams within existing operating criteria.

Description: This is a case study of CRSP power. This research will focus on the hydropower features located in the Upper Colorado River Storage Basin. A test year will be selected 3 to 7 years in the future from the start of the study. The renewable resource additions made by WAPA's customers as well as estimated renewable resource additions within their service area will be added to the existing customer electrical generation resources. Because the Western Interconnection (WI) is an integrated grid in which a change in one part of the system affects all other parts, the expansion of supply-side resources including wind and solar energy resources will also be incorporated into the case study. The FES customers' power system will then be modeled—with these renewable generating resource additions—to determine whether and how FES customers might modify their daily schedule of WAPA power. It will then estimate whether firming expenses will increase, what potential operational changes could add value to the hydro resource, and to what degree existing contractual arrangements can accommodate these changes in daily patterns.

Impact: This project will enable better planning and coordination with Reclamation to operate CRSP powerplants, regarding potential impacts of increased renewable penetration.

Agency Roles:

Lead Agency: WAPA will be the lead agency for this project.

Participating Agencies/Organizations: WPTO will provide support in the form of expertise and funding, with work from DOE's Argonne National Laboratory (ANL) and National Renewable Energy Laboratory (NREL). Reclamation will also be providing in-kind time for technical support

Time/Effort: This research is expected to take between 9 to 14 months.

Final Product: A public report of the analysis and a presentation of summary results that will inform WAPA planning for future operations of the CRSP. The report will include themes and approaches that can be used by hydropower operators in other markets as well.

Lower Colorado River Power: Hydropower Modeling and Optimization under Diverse Conditions

Problem: More accurate hydropower modeling is needed to better understand the capabilities of hydropower in evolving market conditions and environmental changes and provide flexible, operationally sound, solutions to meet the demands of these changing conditions.

The electricity environment has changed dramatically over the last twenty years and is expected to continue changing in the following ways:

- Renewable energy resources are increasing, changing the way grid operators think about balancing the grid.
- Historic droughts are taking place, changing how water and hydropower are managed.
- There is increased cooperation among balancing areas to manage the grid.

Extensive development of solar generation in Arizona, California, Colorado, and Nevada, coupled with the ongoing extended drought, places the dams of Reclamation's Lower Colorado Basin powerplants on the leading edge of these challenges.

Drought in the early 2000s prompted the Department of the Interior to develop the "Colorado River 2007 Interim Guidelines" which coordinated operations between Lake Powell (Glen Canyon Dam) and Lake Mead (Hoover Dam). The Interim Guidelines are in effect until 2025 and are now being supplemented by the recently passed Drought Contingency Plans, which are agreements between the Colorado River Basin states to reduce the risk of water storage levels in Lake Powell and Lake Mead that are extremely detrimental to hydropower resources.

Goals: The goals of this project are: (1) to improve hydropower modeling in energy production cost models to better inform decision-making about hydroelectricity production and river operations, and (2) to use these improved modeling products to study how to optimize Lower Colorado River Basin hydropower in the face of increased inverter-based renewable generators and drought scenarios. Specifically, detailed modeling and analysis will be completed to understand how Reclamation's Lower Colorado Basin dams have been operated for power, how they have been represented in energy production cost models, how they can be optimized, and how such improvements may build on the value of the hydropower generation to the customers. A production cost model will be improved in order to provide a more detailed analysis for hydropower, and an optimization model will be developed in order to quantify and improve the value of hydropower services to the grid, including energy production, ancillary services and flexibility.

Description: The study will have three stages. Stage One will improve the hydropower representation of Hoover, Parker, and Davis Dam operations in PLEXOS using a near future (2024) scenario. Stage Two will test the interaction between hydro and renewables using the improved hydropower representation in future scenarios. This stage will include "stress test" high renewable energy futures using NREL's detailed wind and solar resource data. Stage Three will evaluate the value of hydropower and the coordination of hydro and renewables under a range of hydrologic conditions, including drought conditions. This stage will require the development of an hourly simulation/optimization model for Parker/Davis. To evaluate the value of hydropower, the contractual requirements of the Federal projects that encompass the Lower Colorado Basin dams, managed by WAPA, will be evaluated, including the requirement for purchase power. Under a non-contingent scenario, there is a contractual obligation to deliver a specified amount of energy, which if not generated, must be purchased on the market. This purchase to shore up and deliver the contractual obligation is referred to as purchase power.

Impact: Improved energy production cost modeling for hydropower will benefit dams in the Colorado Basin as well as other river basins under similar conditions. Thus, this project will provide direct benefits to improve management of hydropower in the Upper and Lower Colorado Basin. This project will deliver Reclamation and WAPA-wide benefits in four hydropower arenas. First, it will result in the development of an optimization/simulation hourly model for the Parker/Davis Dams. Second, it will inform how Reclamation runs its hydropower resources under evolving electricity market dynamics. Third, it will incorporate a range of drought scenarios and identify how to best deploy water resources for electricity production under those conditions. Fourth, it will inform WAPA of how contractual requirements, along with the evolving electricity market and changing water availability, may affect the financial requirements and purchase power. These objectives address the second and third goals of the *Omnibus*

Public Land Management Act of 2009, Section 9504 (b)(1) which are "(B) to increase the efficiency of the use of water resources" and "(C) to enhance the management of water resources, including increasing the use of renewable energy in the management and delivery of water". These objectives also address the mandate of the *Flood Control Act of 1944* to market power "in such a manner as to encourage the most widespread use thereof at the lowest possible rates to consumers consistent with sound business principles," and supports the core mission of WAPA to market and deliver clean, renewable, reliable, cost-based federal hydroelectric power and related services. In this case, the project has the potential to produce additional energy per unit of water delivered (increase efficiency), to provide additional value and understanding to the quantity of hydropower produced (enhancing management and reliability), and to inform on the contractual and financial requirements of hydropower (improving planning).

Agency Roles:

Lead Agency: WAPA will be the lead agency for this project.

Participating Agencies/Organizations: DOE's Water and Power Technology Office will be providing support in the form of expertise and funding. DOE's ANL and NREL. Reclamation will also be providing in-kind time for technical support

This project will be conducted by WAPA's CRSP Management Center, WAPA's Desert Southwest Region (DSR), NREL, and Argonne.

Time/Effort: This research project will last for two years.

Value of Hydropower Project 3: HydroWIRES Pumped Storage Hydropower Valuation Framework (Pilot: Mt. Elbert Overhaul/Upgrade Evaluation)

Problem: Pumped storage hydropower (PSH) supports various aspects of power system operations as an energy storage technology; however, determining the value of PSH plants and their many services and contributions to the system is complex. Additionally, many PSH facilities across the US are mature assets that may soon need to evaluate upgrade opportunities. These challenges affect both Federal and non-Federal PSH plants.

An important example, owned by Reclamation, is the Mt. Elbert Pumped Storage Powerplant (Mt. Elbert). Mt. Elbert is located outside of Leadville Colorado, above 9,000 feet of elevation and is a feature of the Fryingpan-Arkansas Project. The power plant was constructed in the late 1970s and commissioned in the early 1980s. Mt. Elbert houses two 100-MW generators with the capability to reverse each unit and be utilized as motors to pump water back up the penstocks to refill the upper reservoir. The main powertrain components of the power generation equipment are original and have begun to deteriorate at an accelerated rate. This has led to the need for an economic decision and valuation analysis to determine the most cost-effective path forward through refurbishment, replacements, upgrades, increased efficiency, and potential operational improvements. Mt. Elbert's utilization by Loveland Area Projects (LAP) FES customers has reduced over the past decade due to the decrease in benefit margins from a regional influx of low-cost wind, solar, and gas generation providers within the Colorado region. The increase in capabilities and regional footprints of these low-cost alternative generation sources have resulted in, at least on the surface, making the value to the FES customer's portfolio for Mt. Elbert and other small hydropower generation less apparent every year.

Description: Through its HydroWIRES initiative, WPTO has developed a PSH Valuation Guidebook to provide a framework and methodology for the valuation of a PSH facility. The valuation methodology has been applied to two competitively selected PSH projects proposed for development—Goldendale and Banner Mountain—and the DOE National Laboratory team has worked closely with the developers of these projects. The Valuation Guidebook was recently released, and techno-economic analyses for Goldendale and Banner Mountain will be published in the coming months. This new project will apply the PSH Valuation Guidance and modeling to develop a cost-benefit and decision matrix valuation report for Mt. Elbert.

Impact: By utilizing DOE's PSH Valuation Guidance, Reclamation will be able to evaluate the value of Mt. Elbert and inform decisions regarding potential upgrades. Additionally, this project will provide further validation that the Valuation Guidance is a method for evaluating new and existing PSH facilities.

Agency Roles:

Lead Agency: Reclamation's Missouri Basin Region will be leading this project.

Participating Agencies/Organizations: WPTO will be supporting the project by cost-sharing with Reclamation and providing in-kind time and experience with the Valuation Guidebook. WAPA's Rocky Mountain Region will also be supporting the project with in-kind time and expertise.

Time/Effort: 1–2 years, depending on scope and valuation questions of interest.

Scope & Location: Mt. Elbert will be evaluated using the PSH Valuation Guidance.

Initial Product: The initial deliverable will be to determine the overall scope of the investigation and the exact focus areas to be investigated in more detail. This initial scoping effort will also decide how long the overall modeling effort will take to develop and ultimately provide the final deliverable as described below. The initial deliverable is expected to take approximately 4–6 months to develop the in-depth scoping effort that will be used to determine the specific model focus areas.

Final Product: The Mt. Elbert study will focus on studying plant operations, water operations, facility limitations, maintenance outages, transmission line restrictions, and marketing strategies that will be used to analyze, recommend, and prioritize actions to improve the value of the facility within the Reclamation portfolio. Market factors will be investigated to better understand the impact they are having on Reclamation facilities. Coordination with LAP FES customers on current and future operations would inform the report. The goal of the report is to understand the full use of the facility, the value in the energy market, factors to consider when operating the facility for the greatest value, the capital investment needed to continue or advance the value to support customer uses, the bulk electric system, and the market. The report should also help to understand the cost-benefit for needed upgrades and develop a matrix for the prioritization of the continuous improvements needed at the facility, which will be used to demonstrate the overall monetary and non-monetary value of Mt. Elbert to the LAP FES customer's portfolio. These aspects of the report will provide recommendations and guidance to help inform a plan for Mt. Elbert. Lessons learned will be incorporated to improve the PSH Valuation tool currently in development under HydroWIRES.

TOPIC 3: Workforce

Training Needs Analysis & Development of Training

Problem: Reclamation, WAPA, BPA, and Corps are challenged with hiring staff with the skills necessary to operate and maintain the hydropower generation and transmission assets. These assets and the skill sets needed to support them are somewhat unique and often not available in workforce pools. When hiring journey-level employees, training gaps are identified; without structured training plans and resources, new employees must obtain needed skills in a less than ideal manner. The Agencies have had pockets of successful apprenticeship experiences when training resources and well-developed programs are supported.

Description: WAPA's Electric Power Training Institute (EPTC) has developed online training in basic electrical theory and some more advanced topics. Collaboration among the Agencies to develop an organized training path in fundamental electrical and mechanical concepts would result in a better base of knowledge for new hires and enhance current staff's knowledge. There would be efficiencies gained by having a well-defined baseline training and not reinventing the training in each of the Agencies. Instructor-led sessions would also ensure that students have the opportunity to access instruction and evaluation through the training process, which is often left to the student to search among their peers.

Impact: Increasing the knowledge level of the Agencies' workforce will mitigate training gaps, provide structured training plans, and result in better-maintained assets, increased asset life, and less downtime. Further, these impacts would lead to a more reliable and cost-stabilized product for power customers.

Agency Roles:

Lead Agency: EPTC will lead the effort through their training resources with Reclamation and Corps as co-leads. Reclamation, Corps, and participating PMAs with applicable staff positions will assist in data gathering.

Participating Agencies/Organizations: Reclamation, Corps, WPTO, WAPA, and BPA will commit to having at least one person to aid in the development of the program.

Time/Effort: This program would require funding and or in-kind commitment to maintaining the training resources within EPTC. Training expertise would be required from each Agency to define the program content along with continuous evaluation. All Agencies would commit at least one member to the development team to determine the basic knowledge necessary in each course and the courses required for a good foundation to enter the hydropower workforce.

To determine the common knowledge, skills, and abilities need, each Agency would submit their apprenticeship programs, including contracted courses and college curriculum used. To further define the effort, duties of the employees based on position descriptions and surveys of actual job assignments would be submitted over the diverse regions of the Agencies. It is anticipated that surveys would require weighting to determine the relative need for each knowledge area identified.

Scope & Location: The apprenticeship and knowledge enhancement program would be available for any of the Agencies' personnel. The program material would be housed in a platform under the EPTC with assistance in content and development of individual courses by all Agencies.

Final Product: The surveys and analysis of agency position descriptions and duties will produce a reference report to establish common levels of competence and specialty needs. The training program would contain multiple disciplines and provide a common training path for entry-level employees, current employees, and new hires, which would include higher-level, discipline-specific training topics. The program will be distance learning-oriented, with live instructor-led and recorded training sessions. The program will include feedback and evaluation for the students and their supervisors throughout the curriculum and within individual courses. Periodic feedback will be gathered from students and supervisors to determine if the knowledge enhancement was effective and applicable to the duties required.

Hydropower Collegiate Competition

Problem: Hydropower workers in many occupations—especially supervisors/managers, engineers, skilled craft workers, and other professionals—are older than the average overall U.S. workforce. Approximately 26% of the hydropower workforce is age 55 and older and will reach retirement age within the next decade. Even if the U.S. does not see growth in the hydropower sector in terms of the overall number of jobs, a significant increase in demand to hire skilled workers based on retirements alone is expected. This situation is exacerbated by the fact that few hydro-focused degree programs currently exist, and that's largely because the demand for those courses does not exist. Today's students interested in energy are often drawn to the "new" technologies and may not see hydropower as an exciting field. Furthermore, whether a student enters the hydro workforce or the power sector more broadly, hydropower and PSH are important system-level assets, and new entrants to the power sector stand to benefit by understanding their contributions to grid flexibility and reliability.

Description: A hydropower collegiate competition would be designed based on a collegiate competition model that DOE and NREL have successfully implemented for other technology sectors, including wind and marine energy. The hydropower competition would bring together bright, soon-to-be workforce entrants to solve real-world problems with partner hydropower operators and utilities. Teams would consist of (5–10) students and a faculty advisor. Each team would work to propose a solution to a problem faced by that organization, which is broadly applicable across the hydro industry. The competition could be organized around a single issue/call to action, or it could be divided into tracks focusing on different issues. By offering different tracks, the competition could address multiple needs of the hydropower industry, meet multiple goals of the co-organizers, and attract students from diverse disciplines and even school types. The competition organizers will target and market to 4-year university undergrads, grad students, students from trades and community colleges, and students from tribal colleges.

Impact: The competition would address the aging workforce and recruitment challenges faced by the hydro industry at large by introducing 75+ students to opportunities in hydropower. Federal partners can take advantage of the competition to advertise job and internship opportunities and recruit new talent. Even if participating students do not enter the hydropower workforce, they may enter another field within the power sector and begin their careers with an appreciation of hydro and PSH's contributions to grid flexibility and reliability. Further, students would address real-world challenges faced by hydropower facilities and may yield results that are broadly applicable to the industry.

Agency Roles:

Lead Agency: WPTO will serve as the lead Federal agency. WPTO funds would support administration, communications, travel for administrators, judge honoraria, team stipends to cover travel and any costs associated with producing competition deliverables, and onsite expenses.

Participating Agencies/Organizations: Reclamation, Corps, the PMAs, PMA customers, and tribal organizations will be invited to support the competition as a co-organizer, financial sponsor, or an in-kind sponsor. In-kind sponsorship could include helping to develop the topic areas and rules for the competition, serving as a team mentor or judge, presenting in an informational webinar for participating students, helping to promote the competition, networking with the students, and sharing career opportunities, etc.

Time/Effort:
Timeline: The exact timeline of key milestones depends on the structure co-organizers agree to for the competition, but WPTO envisions the competition would be organized to allow faculty advisors to incorporate the competition into a semester's coursework. Before the final pitch session, students would prep for the competition and be expected to take advantage of educational offerings (such as webinars with guest speakers from industry) organized by DOE National Laboratories and other co-organizers.

Future Competitions: This would be designed as a pilot competition. In the weeks leading up to culmination, co-organizers would discuss whether to repeat the competition and, if so, the appropriate frequency and format of future competitions. If the co-organizers decided to repeat the competition, they would announce the next competition at the same time winners are announced. If the decision is made to not continue the competition, no announcement would be made.

Scope & Location: The competition would culminate at an in-person event, ideally alongside an industry conference to ensure ample networking opportunities. If necessary, the competition would be designed to seamlessly shift to culminating virtually. Pre-competition activities, such as preparing proposals and presentations and participating in educational webinars, would take place virtually in the months prior.

Final Product: A hydropower-focused collegiate competition that engages 75+ students from across the country to propose solutions to hydropower industry challenges while learning about opportunities in the field.

Building out a Hydropower STEM Portal

Problem: Hydropower and pumped storage play an increasingly critical role in the U.S. power sector, but there are not enough new entrants to the workforce to keep pace with current and future planned retirements. Additionally, the industry needs to continuously attract new talent to ensure a skilled, diverse workforce and to continue to operate and modernize facilities to serve our evolving power systems. Industry needs to inspire the next generation of hydropower workers by connecting students and educators with materials to learn about hydropower and explore career pathways. Also, university students may have the ability and desire to conduct research that is directly relevant and beneficial to the hydro community, but they may not have the connections or insight into the relevant issues facing the hydropower community to know which research topics to pursue.

Description: The new Hydropower STEM portal, funded by WPTO and hosted by NREL, will provide students and educators with materials and opportunities to learn about hydropower and explore career pathways. NREL is aggregating existing resources from several reputable sources into this new portal and will invite MOU partners to advisory meetings and incorporate their Agencies' resources and opportunities into the portal, such as information on training programs and jobs. The MOU agency partners will provide feedback to NREL and WPTO on the development of the portal in general. A near-term example will be the development of a section informing students of industry-relevant research topics for consideration. In turn, MOU partners will reference the portal on their websites. As the platform for the portal (OpenEI, or Open Energy Information) is wiki-like, anyone can provide suggested additions/edits directly to the portal or to NREL, who is responsible for curation.

Impact: The new STEM portal will offer a central point of access for publicly available hydropower STEM and workforce development resources, as well as career opportunities. MOU partners will be able to leverage the portal to share their educational materials, as well as public opportunities for training, jobs, and internships. In this way, the portal will help educators introduce the future workforce to hydropower and connect interested candidates with opportunities in the Federal hydropower community. The portal will also direct users to important issues in the industry that could benefit from further academic research, helping to align university research with the needs of the hydropower industry.

Agency Roles:

Lead Agency: WPTO

Participating Agencies/Organizations: Reclamation, Corps, SWPA, BPA, and WAPA will advise the portal development, contribute resources, and disseminate the portal to interested students, educators, and employers. Tribal organizations and PMA customers will also be invited to provide feedback on portal development and dissemination.

Time/Effort: The hydropower STEM portal already exists and has stable funding for maintenance through WPTO's STEM project with NREL and the Hydropower Foundation (as a subcontractor). The time needed from non-WPTO MOU partners would be minimal to advise the future development of the portal, contribute resources, and help disseminate.

Scope & Location: Online at https://openei.org/wiki/Hydropower/STEM

Final Product: New pages within an online portal informing students of hydro challenges and interesting research questions/topics to pursue. Also, educational materials and information on training, internship, and job opportunities for Reclamation, Corps, and the PMAs will be integrated into the portal.

TOPIC 4: Water Supply Reliability

Irrigation Modernization Visualization Tool for Grant Applicant Support

Problem: The irrigation infrastructure associated with the agricultural sector is aging, and some systems are over 100 years old. Irrigation systems embody the water-energy nexus—energy may be required to convey water, and water is needed to generate energy, particularly hydropower. Reclamation, the nation's largest wholesale water supplier, relies overwhelmingly on hydropower to meet water conveyance energy demands on Federal Reclamation Projects.

Opportunities may exist to improve irrigation system performance through capital and technological investment and shifts in operations—delivering water conservation and hydropower benefits and continuing to meet all water delivery and environmental commitments. Specifically, improvements may help curb irrigation system electricity (e.g., hydropower) demand through more efficient pumps and conveyance infrastructure, which may contribute to incremental hydropower and the possibility of additional (conserved) water made available to existing hydropower facilities.

Improvements in sensing technologies, a need for additional clean energy generation, changing environmental policies, growing population, and the overall value of this infrastructure to farmers and society coalesce as the motivation behind this work. Irrigation modernization provides irrigation districts with a set of options to improve their systems to address both internal and external challenges and prepare for the future. However, modernization can be a complicated and expensive process involving numerous stakeholders, including state, Federal, and tribal policymakers, non-governmental organizations, and irrigation district customers.

Grant programs exist that deliver financial support to irrigators to help modernize irrigation systems. One example is Reclamation's WaterSMART Water and Energy Efficiency Grants program, which provides 50/50 cost-share funding to irrigation and water districts, tribes, states, and other entities with water or power delivery authority. Projects from this program conserve and use water more efficiently; increase the production of hydropower; mitigate conflict risk in areas at a high risk of future water conflict; and accomplish other benefits that contribute to water supply reliability in the western U.S.

Description: WPTO's Irrigation Modernization project aims to inform reinvestment in irrigation systems to provide diverse societal benefits. A core activity of the project is developing a tool to help irrigation district stakeholders plan modernization projects through quantifying the costs and benefits of specific infrastructure changes. WPTO will provide an in-depth introduction to and demonstration of the visualization tool, including current and future functionality, to offices at Reclamation. WPTO and Reclamation will work together to explore potential future work allowing WPTO to better understand Reclamation and Reclamation's stakeholder needs to improve the tool's capabilities to better define how it could be used by potential grant applicants under Reclamation programs such as WaterSMART.

Impact: For WPTO, the goal is for this collaboration to improve the utility and reach of the visualization tool it is funding. For Reclamation, the tool may be used by operating partners and stakeholders to develop grant applications.

Agency Roles:

Lead Agency: WPTO is funding the development of the visualization tool.

Participating Agencies/Organizations: Reclamation is providing in-kind support by coordinating meetings with different offices and advising WPTO.

Time/Effort: A pilot version of the tool will be developed during FY 2021.

Scope & Location: The project is focused on the western United States where surface water resources are critical for agriculture. The project is currently using a series of case studies around the western United States to test the visualization tool, but the objective is to increase utilization of the tool in as many U.S. jurisdictions as possible.

Final Product: This work will result in a robust visualization tool capable of quantifying the various value streams and components associated with irrigation modernization activities and serving as a resource to grant applicants.

Water Supply Risk and Assurance

Problem: Reclamation and Corps serve, in part, to deliver reliable water supply across the United States, which are critical to the health, economy, and security of the nation. Assessments of water supply reliability may vary by basin location and by authorized, potentially competing, functions (e.g., water deliveries, hydropower, recreation, environmental, navigation, etc.). Large pieces of water infrastructure, as well as the water and power distribution systems they are integrated with, change more slowly than the adjacent systems and surrounding context. As an example, the bulk power system is changing rapidly with the integration of more variable renewable generation, and demands for water are ever-increasing at the same time that natural availability is changing.

It is understood by MOU partners that risks exist to water supply reliability, and therefore all the uses that depend on that water; however, no shared Federal framework exists for discussion based on defining risk and mitigation. There is a need for common definitions to ensure the utility of any future projects under this Water Supply Reliability topic area.

Description: MOU partners will meet, and Corps and Reclamation will describe how their respective agencies are considering water supply reliability and defining water supply risks, particularly as it relates to hydropower production; they will also note the strategies they've identified to mitigate noted risks. This initial task will function as a "discovery," which will allow all the MOU partners, including WPTO and the PMAs, to better understand how Corps and Reclamation are considering the issue. Discussions will also occur on specific cases to provide a granular look in addition to the high-level overview. A summary of these discussions will be captured reflecting MOU partner input and next steps proposed that can be taken to increase collaboration as each agency carries out ongoing activities. These discussions will also provide a foundation for potential future research under this MOU, which will be captured in the summary. We will include the tribal water administrators and tribal agricultural programs for their involvement, ideas, and participation in these discussions as it pertains to water supply programs operated on Indian Reservations.

Impact: This project will lay the foundation for more meaningful collaboration and potential future projects that deliver real value and align with partner agencies' missions.

Agency Roles:

Lead Agencies: Reclamation, Corps, WPTO, and PMAs

Time/Effort: 3–6 months to document and distribute agency materials on water supply reliability, risk definitions, prioritization, and potential mitigation strategies. 6–9 months to compile agency input and summarize discussions and potential next steps.

Scope & Location: MOU partners to share agency material, followed by workgroup sessions to present and discuss. Follow-up workgroup calls to propose and consider the next steps.

Final Product: A summary of discussions, including an outline of the next steps.

TOPIC 5: Environmental Outcomes

Fish Protection

Problem: When using water resources, Federal agencies must comply with regulations regarding fish protection, including addressing entrainment (downstream fish passage) at diversions and intakes for water supply, irrigation, and power generation at hydropower facilities. These regulations are designed to ensure hydropower facilities do not pose unacceptable environmental risks. Entrainment is the movement of fish and other aquatic organisms along with the flow of water out of river, lake, or reservoir habitats into unnatural environments that may be harmful. For instance, entrainment into water diversions and intakes can deplete biodiversity and impede fish recovery efforts for threatened and endangered species. To address this, technologies such as screens have been developed to prevent fish entrainment in a way that does not cause injury to the organism. While effective fish exclusion for some species and life stages can be achieved, improvements are needed to increase effectiveness and decrease the costs associated with fish exclusion devices. Recently, WPTO and Reclamation identified a variety of meritorious concepts for fish protection as outcomes of two prize competitions; however, only a few winning concepts are progressing with National Laboratory voucher support and cash prizes.

Description: WPTO, Reclamation, and Corps share an interest in advancing fish protection and exclusion technologies at dam intakes, river canal diversions, and pipes for irrigation or municipal water supplies. Novel technologies and improvements to existing methods hold promise for enhancing fish passage and exclusion technologies' performance, meeting restoration goals and regulatory requirements by reducing fish injury and mortality, and potentially reducing costs of deployments through innovative manufacturing, materials, methods, and designs. WPTO has funded decades of basic and applied research to advance understanding of impacts to fish and develop tools and technologies to improve fish passage. Reclamation and Corps, as hydropower operators, have extensive expertise in site-specific fish passage and exclusion engineering, understanding potential effects to fish, and management of these technologies at their facilities. Reclamation and Corps are also knowledgeable of regional efforts within basins.

Since 2018, WPTO and Reclamation have been collaborating on the Fish Protection topic in the form of both ideation and technology advancement/reduction-to-practice prize competitions where solutions are crowdsourced. This prize competition partnership has proven successful at identifying novel approaches to fish protection and exclusion methods. Winning solvers are continuing to advance their ideas with support from National Laboratory and agency staff.

In 2020, WPTO and Reclamation launched the *Fish Protection Prize*[3] to fuel innovation to support fish protection. This prize built on the initial scoping stage, the *Fish Exclusion Prize,* which Reclamation led in 2019 with in-kind support from WPTO and Corps. The *Fish Exclusion Prize* focused on obtaining diverse ideas that could reduce fish entrainment into diversions and intakes. The *Fish Protection Prize* was led by WPTO and administered on the American Made Challenges HeroX platform. It included three stages (concept, incubate, and pitch) and concluded with a live pitch contest at the September 2020 American Fisheries Society meeting.[4] While three final winners were selected from this pitch contest to receive a

[3] https://americanmadechallenges.org/fishprotection/
[4] https://afsannualmeeting.fisheries.org/fish-protection-prize/

combination of cash prizes and National Laboratory voucher support, there were other submissions deemed meritorious by the judges. WPTO and Reclamation agreed to identify means for supporting projects and clarifying future R&D pathways for solvers with different technology readiness level ideas. Further coordination between WPTO and Reclamation, and inclusion of Corps, will help the agencies identify high-priority research needs and potential mechanisms for funding and advancing this critical area.

Impact: Under the MOU, Reclamation and Corps will benefit from continued collaboration on Fish Protection topics to:

- Advance meritorious fish protection/exclusion technologies identified through prize competitions
- Identify and advance additional fish passage for both upstream and downstream passage
- Identify funding opportunities to support ongoing research and new projects across the MOU Agencies
- Identify research expertise/labs and field sites for testing of different stage technologies
- Clarify potential pathways for R&D and commercialization of promising technologies at different technology readiness levels.

Agency Roles:

Lead Agencies: WPTO and Reclamation will fund this work (pending the outcomes of WPTO's work above).

Participating Agencies/Organizations: Corps

Time/Effort: Existing collaborations on Fish Protection between DOE and Reclamation have been ongoing for the past two years and will continue into FY 2021, with support and testing of the three winning *Fish Protection Prize* ideas at PNNL. Of note, one idea from the fish exclusion prize competition has been proposed for an R&D assessment at ERDC. Moving forward, the Agencies will collaborate under the MOU to achieve topic area goals in the next 3–5 years as follows:

Year 1 – Summaries from Fish Protection Prize winners will be completed. Results from lab-supported research and the steps innovators take in business development will provide an indicator of concept viability. The Agencies will meet to discuss Fish Protection R&D road mapping for future activities, including, but not limited to, prize competitions, materials to support private sector/solver community concept advancement, and additional topics/concepts to fund.

Year 2 – There is potential to develop an R&D campaign for Fish Protection Prize meritorious proposals (e.g., seed funding to partner with labs, opportunities for deployment, additional voucher-type evaluations by research staff who can also publish technical assessments). DOE and Reclamation will outline viable models.

Year 3 – Critical assessment of Fish Protection technologies and costs.

Scope & Location: Ongoing activities to advance winning Fish Protection Prize solutions is underway at PNNL with support from Reclamation, NREL, and WPTO. Additional work could be at other National Laboratories, Reclamation, and Corps research labs, or hydropower and water management facilities. The appropriate agencies will reach out to interested tribes to discuss activities and proposals.

Final Product: Summary document providing recommendations on future funding pathways for viable ideas from *Fish Protection Prize* and *Fish Exclusion Prize* competitions, traditional research at labs or Federal facilities, and additional programming to evaluate meritorious technologies through partnering with businesses. For example, this could be applied to some of the non-winning solutions received in *Fish Protection Prize*. This could also inform a research roadmap and/or prioritization of research needs for fish passage and protection.

Environmental Cost Areas Research

Problem: Increasing costs associated with Federal hydropower environmental mitigation is a major driver of rates charged to Federal customers. In some cases, environmental costs account for a third or more of the rate. While Federal hydropower rates continue to rise, the wholesale energy rate is in decline. This economic phenomenon results in increasing rate pressures for the Federal hydropower programs, as their rates approach or exceed the wholesale energy rate. To alleviate these rate pressures, the primary sources of environmental costs need to be identified, followed by a determination of how to mitigate these costs while maintaining environmental stewardship and compliance. To date, no comprehensive database of Federal hydropower environmental costs exists to determine the most effective research needed to mitigate those costs.

Description: Reclamation, Corps, and WPTO and DOE National Labs will cooperate in the creation of a comprehensive environmental cost database for the Federal Hydropower System. WPTO can assist in efforts to both standardize the collected information and relate the data to existing National Laboratory data on mitigation and environmental metrics from the non-Federal hydropower fleet in the United States. Using this database, the primary cost drivers for environmental mitigation will be identified along with the associated impacts on energy rates. Further analysis will determine the most logical areas to focus on future environmental cost mitigation research, leading to new project ideas to mitigate these costs. Cost mitigation techniques could include new technology to reduce the impact of hydropower facilities and associated dams, alternative operations methods to reduce environmental impacts, or research into more cost-effective ways provide environmental protection.

Impact: A database of mitigation costs to inform cost reduction efforts and provide benchmarks for new technologies.

Agency Roles:

Lead Agency: Reclamation and Corps

Participating Agencies/Organizations: Reclamation, Corps, and WPTO will support the effort through coordination of resources at the National Labs.

Time/Effort: 3–6 months to gather cost data
3–6 months to compile project ideas to mitigate environmental costs

Scope & Location: Initially Reclamation and Corps will research and identify cost drivers in consultation with DOE/WPTO and the National Labs; thereafter, the interagency team will convene to identify potential action plan projects.

Final Product: A database of federal mitigations and costs and an action plan to most effectively mitigate environmental costs.

Hybrid Hydropower Storage for the Downstream Environment

Problem: Flow fluctuations created by hydropower facilities to meet electricity demand, also known as hydropeaking, causes rapid changes in water depth, velocity, and temperature, which may impact environmental outcomes (e.g., fish and wildlife habitat quality and availability, bioenergetics of river-dependent species, recreation, availability of water supply, etc.). While operating hydropower plants in run-of-river mode may create more desirable environmental outcomes than operating in peaking mode (e.g., reduced impacts of dewatering, rapid changes in habitat, etc.), run-of-river operation limits operational flexibility and reduces the ability of the plant to respond to the needs of the grid. One potential solution for achieving better environmental outcomes downstream of the plant includes creating hybrid hydropower storage systems (e.g., batteries that can be used to store power generated at off-peak times). Hybrid storage systems allow for relatively stable flow releases and preserve operational flexibility that allows the plant to respond to needs of the grid.

Description: WPTO is currently investigating connections between environmental flows and the needs of the grid under the HydroWIRES Initiative project, "Improving Hydropower Benefits by Linking Environmental and Power System Trade-Offs Through Flow Release Decisions." A variety of products are being produced under this effort:

- A hierarchical dataset of environmental outcomes and a dataset cataloging environmental flow requirements of non-Federal projects from 50 Federal Energy Regulatory Commission (FERC) licenses
- A grid outcome to flow decision linkage map that documents steps between grid outcomes and the hydropower flow decisions' interactive web tool
- A flow to environment linkage map web tool that can identify pathways for creating energy-environment win-wins
- Three case studies that explore win-win scenarios, including assessments of Yadkin-Pee Dee River system and Reclamation's Glen Canyon Dam, and inclusion of an economic tool to value operational flexibility.

This work will lay the groundwork to better evaluate services that hydropower provides and environmental and economic considerations related to different flow decisions. Support provided by the MOU Agencies to enable information sharing and inform case studies and/or tool development for future work is essential to evaluate methods and enable technology transfer. Other support may include explorations of the use of batteries to normalize outflows from hydropower dams, reduce environmental impacts of hydropeaking, and/or alleviate transmission issues.

Impact: Information and tools will enable better assessments of tradeoffs between flexibility and environmental outcomes.

Agency Roles:

Lead Agency: WPTO will leverage existing efforts and capabilities being developed under the HydroWIRES initiative and resources available at the National Labs

Participating Agencies/Organizations: Reclamation

Time/Effort: Resources and tools from the HydroWIRES "Improving Hydropower Benefits by Linking Environmental and Power System Trade-Offs Through Flow Release Decisions" project will be applied to

case studies in FY 2021. When this effort is completed, the MOU Agencies will work together to outline research needs and next steps to better assess opportunities for energy-environment win-wins that consider hybrids. This may include defining additional case studies to use and apply existing products or to build out scenarios that examine battery storage or supporting the development of a variety of tools.

Scope & Location: The HydroWIRES "Improving Hydropower Benefits by Linking Environmental and Power System Trade-Offs Through Flow Release Decisions" project tools apply to Corps and Reclamation facilities across the nation. They could be augmented or applied to additional cases to identify win-wins and to map out constraints to and benefits of flexibility to reduce the environmental impacts of hydropeaking. Further, the economics of pathways, mitigation at sites with hydropeaking, and other topics could be assessed in terms of enhanced flexibility of hybrid systems.

Final Product: Documented research needs and recommendations which could lead to a roadmap. There is also the potential for applications of HydroWIRES tools or the development of novel tools to assess costs and benefits of flexibility.

Oil-Free Hydropower Technologies for Environmental Protection

Problem: The MOU Agencies have an interest in the development of oil-free hydropower equipment that reduces the risk of water pollution from accidental oil spills and leakages. European Union countries are advancing with this topic but have not identified reliable solutions, particularly at the scale of the Federal hydropower systems, nor have they been able to validate reliable, long-term solutions. From a regulatory perspective, moving toward oil-free equipment minimizes the potential for lawsuits, payouts, fines, and damages resulting from violations of water quality standards. There is a lot of value to moving to oil-free technologies; however, small capability for pilot studies focused on testing and monitoring oil-free materials, extensive costs, and a lack of funding has limited advancements in this area. Finding a solution for oil-free lubricants could have a large positive impact on the Federal hydropower system in developing a solution that will enable long-term environmental protection while potentially reducing costs of purchasing oil and mitigating potential spills or leakages.

Description: It was noted that for unit rehabilitation, the idea of utilizing an oil-free hub is intriguing, but there are uncertainties in solutions and reliability that cannot be answered without pilot field studies and testing. There is the opportunity to design and test an oil-free hub; however, teardown, monitoring, and interim field evaluation are financial and logistical obstacles. In addition, there is interest in other oil-free technologies, including electrical transformers, hydraulic devices, switchgear, cast coils, bushings, etc. Needs for monitoring materials, durability, wear, reliability, etc. must be best addressed with a field-driven R&D program that this initiative would pursue and resolve.

Corps' Hydroelectric Design Center (HDC) has capabilities to examine the business case for oil-free hub investments. This includes defining the base case of oil-filled hubs, then assessing risk, lifecycle costs, and costs to penalties and operations. Next, oil-free hub alternatives are compared to quantify financial and environmental values that could be achieved. WPTO and DOE's National Laboratories can support efforts to develop requirements for various oil-free applications along with respective functional requirements (such as load-bearing capacity, rpm, life expectancy, environment, etc.), which may be helpful to the manufacturer(s) and for defining testing requirements. WPTO can also facilitate conversations with original equipment manufacturers, design consultants, and bearing manufacturers to inform these efforts.

Impact: A document that summarizes risks, lifecycle costs, and the business case for oil-free technologies. Novel designs for oil-free technologies that reduce the risk of water pollution.

Agency Roles:

Lead Agency: HDC can provide the lead to this pilot testing program.

Participating Agencies/Organizations: Reclamation, WPTO, and appropriate PMAs can cooperate with HDC as needed for review and advising.

Time/Effort: To be determined depending on the final product. R&D would be limited to the development and testing of oil-free lubricated equipment for the Federal hydropower fleet.

Scope & Location: R&D would be limited to the development and testing of oil-free lubricated equipment for the Federal hydropower fleet. Field sites within the Federal fleet would be identified to perform the pilot study. If the field site is a hydropower project marketed by a PMA, the project design and test plan will need to be coordinated and approved by the applicable PMA.

Final Product: A business case will first be developed documenting the economic and environmental value in finding solutions for oil-free lubricated hydropower equipment compared to the current oil-filled condition. The final products(s) may include:

- A report out on the three-agency work to date around oil-free hubs (to include lab testing completed to date, potential sites, etc.)
- A report out identifying remaining critical unknowns
- A pilot study that would field test and advance the application of oil-free hub equipment.