Volume II: Complete Evaluation Results and Appendices

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This report details the results of the 2022 WPTO Peer Review. The purpose of the review was to evaluate projects funded by DOE from FY 2019 through FY 2021 for their contribution to the mission and goals of the office, assess progress against stated objectives, and appraise WPTO's overall management and performance.

This volume (Volume II) includes the complete program-, activity area-, and project-level evaluation results, as well as the report appendices. Volume I includes a letter from the director, the executive summary, synopses of the program-, activity area-, and project-level evaluation results, and WPTO's response to the 2022 Peer Review findings.

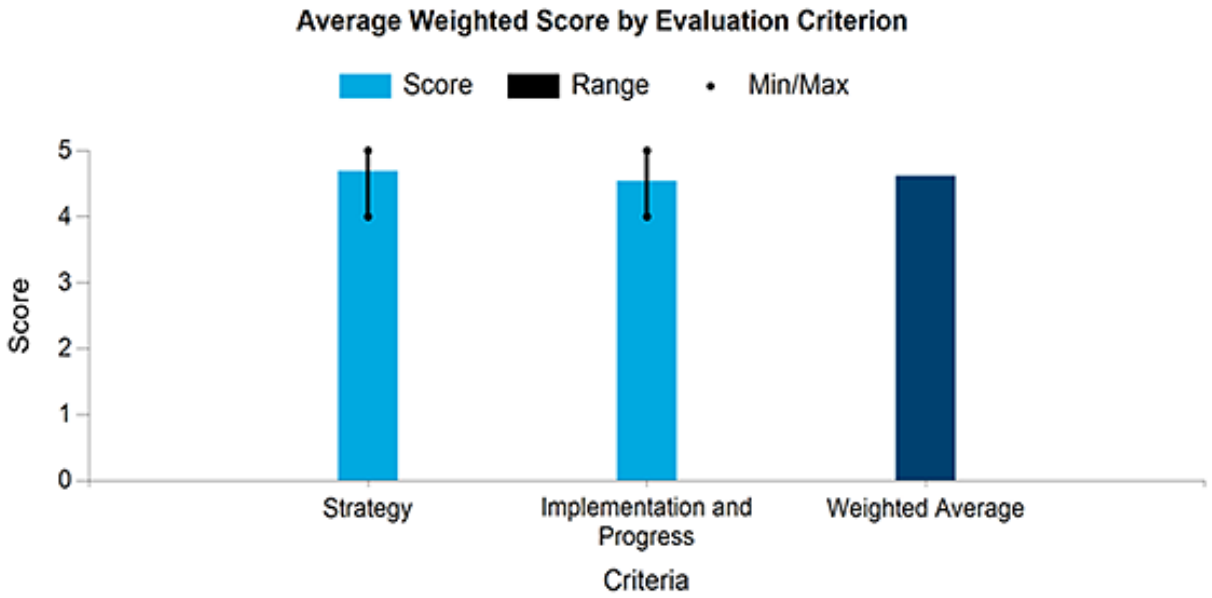
The results in Volume II are organized as follows:

- **Program and Activity Area Evaluations**: The complete results of the peer reviewers' scores on the program and activity area and aggregated anonymous feedback. Each activity area subsection includes the following components:
  - **Project Evaluations**: These are individual project reports, which constitute 1-2-page reports summarizing the results of each project evaluated during the review process. Each report includes the following elements:
    - *Project Name and Recipient*: The full project name is listed as the heading with the recipient underneath. The recipient indicates the organization tasked with leading the project. (This may include multiple organizations in situations where the project has more than one recipient.)
    - *WBS Number or Award Agreement*: A unique identifying code. Project evaluations for each activity area are ordered by WBS number, followed by award agreement number, from lowest to highest.
    - *Summary Table*: Each report provides reference information about the project, including the name of the presenter(s) or the PI(s) and project start and end dates.
    - *Project Descriptions*: Project descriptions are compiled from the project summaries that the PIs submitted for each project.
    - Project Score: A bar chart depicts the average scores for each evaluation criterion, the range of scores per criterion given to the project by the individuals within the Review Panel, the average project score, and the average of all the projects in the activity area per criterion.
    - *Aggregated Reviewer Feedback*: Anonymous verbatim comments made by the Review Panel, edited only for grammar and clarity. Each bulleted response represents the opinion of one reviewer. In a limited number of cases, reviewer remarks deemed inappropriate or irrelevant were excluded from the final report.

Table of Contents

Hydropower Program Evaluation

WBS:	1
Presenter(s):	Tim Welch



Aggregated Reviewer Comments

- The overall impression of the Hydropower Program is that it has evolved and performed very well since the last peer review. It has focused on developing mechanisms and funding research that aim to enhance hydropower performance to enable a flexible, reliable, and resilient grid. The program is very well managed and organized. The team demonstrates that it has defined the strategy and work in accordance with the MYPP strategy to meet its vision, mission, and intended outcomes. This is further supported by how the R&D projects all align with the program's priority areas and demonstrate adherence to the program's rationale. This is only achievable through effective communication that enables them to form the building blocks for the program. The FAST Commissioning Prize under HydroWIRES is a brilliant example of how they leverage appropriate funding mechanisms to achieve outcomes. It was very interesting to learn more about how they developed their approach. The reviewer also finds that the program has extensive communication with excellent understanding of the needs of the industry and other stakeholders. The program has successfully developed a strategy and funds research that enables them to face challenges that will benefit the industry, all the way through the value chain to end users. The reviewer believes it will have a great impact on the sector, and it is on the path to address critical challenges. It could be of interest to also measure the program's impact by identifying a suitable set of metrics. The program is very well organized, which is evident through how they balance their role as a public entity and successfully manage the program with excellent accomplishments and results. The program demonstrates good stewardship of taxpayer funds by transparently communicating program priorities and resulting investments. The program effectively disseminates results and accomplishments, and it may be beneficial to create a library gathering everything for interested parties.
- Slides 24–25 and Tim's discussion (as the reviewer remembers) were helpful to see the strategy of the program and how the five activity areas fit together. The reviewer indicated this part of the presentation would have had more meaning and scaffolding to hang onto if it had been given after the activity area and project reviews. The reviewer might even consider reversing the entire order, meaning start with projects, then activity area, and then program (after the peer review overview for reviewers, of course). Slides 13–16 showed funding

information, but the reviewer did not see enough information to determine whether the program leverages the appropriate funding mechanisms and whether it funds the most relevant studies (not that the reviewer is yearning for a lengthy discussion of funding mechanisms). The studies that were funded do seem relevant, but the reviewer would have to see all the studies that were not funded to say they were the most relevant. (The reviewer apologized if they are getting hung up on unintended details with the wording.) The program seems to balance priorities well and is quite transparent. The reviewer believes the communication plans to stakeholders are in place but were not provided this year to reviewers, which left some gaps in their understanding of how progress and results were disseminated.

- The Hydropower Program has a sound foundation, strategy, and approach for implementation. The reviewer appreciates the insights provided by all parties during the peer review. The program team did a fantastic job ensuring reviewers understood the details about the program and its foundation. They outlined and provided the supporting documentation reviewers needed to consider during the review. Furthermore, the reviewer feels like they had enough information and details about the program, activity area, and each project to provide a good, independent review of each.
- This ongoing program is certainly well organized and focused on achieving its goals. The value of this work to the water power industry is huge, and the reviewer applauds the leadership and staff for their efforts. To ensure that new ideas are evaluated and captured effectively, the reviewer recommends establishing a point of contact for the new technologies arena specifically to guide anyone inquiring as to which program and funding opportunity would be the best fit for their idea. The mass of programs and projects must be very difficult to track and organize. It is certainly daunting to an outsider to understand all the facets of your work. The reviewer recommends doing a gap analysis and creating a chart that shows how these past, current, and planned projects fit into the MYPP. There is still an emphasis on "technology" testing and deployment, which speaks of R&D and the labs. The reviewer recommends changing the wording to "innovation and technology," which recognizes that ideas come from many sources and may not count as true "technology." The reviewer cautions being careful not to assume that small hydro equals low impact, just as it is wrong to assume that medium or large hydro is not low impact. There is a need for evaluation tools and models for hybrid power systems. Encouraging developer interest in other value propositions sounds good; however, one must recognize that for the past 14 years, wholesale electricity prices have been very low, which pinches profitability, investments, and any desire to be altruistic. Gaining interest in going beyond operating the facility is going to have to show how the developer can truly benefit from it. This is a huge challenge. While competitions may be a cool idea, the implication is that there are winners and losers, which may mean some good proposals may not be funded. The reviewer still sees that pre-funding reviews have not shielded WPTO from funding less-than-useful projects and that external projects get a lesser priority than those proposed by the labs.
- The reviewer is very impressed with WPTO and its ability to draw out from the industry what is important, where are the gaps, what are the needs, where are the barriers, etc., which they have been successfully doing for years. They gather this information through direct interface with associations, participation at industry conferences, webinars, and one-on-one meetings with individual companies. They then take this information and determine how to fill these needs through requests for information, lab calls, funding opportunity announcements (FOAs), etc. Thus, bottom line, they listen to the industry, then develop funding opportunities for research, fund the research, and then fill the gaps for the industry. It is a powerful partnership between academia, government, and industry. The reviewer considers it a DOE best practice! The reviewer considers all the research funded by WPTO as relevant and meaningful.
- Overall, the reviewer believes that the program is moving effectively in a number of different areas that will support the future development of hydropower in the United States. The reviewer is impressed with the diversity of studies and research that have been done and are ongoing. There are several areas the reviewer noted in their specific responses that need different direction or additional work. The reviewer provided specific comments in the various responses to identify these areas.

- The Hydropower Program is well defined and presented and aligns well with the MYPP. It is logical and includes easy-to-understand descriptions and vision, including performance goals and intended outcomes. Please consider if the area of regulatory processes is getting enough attention. It seems to be an area that causes significant efforts, both in terms of schedule time and cost, for any new development and for relicensing. The regulatory processes are usually much more demanding than any technical issues in project development. The reviewer feels that this is a very significant issue when it comes to project costs and should be addressed accordingly. The performance goals (under Data Access, Analytics, and Workforce Development) only include publishing a report on the key issues on time, cost, and uncertainty associated with U.S. hydropower regulatory processes. The reviewer is not sure this is sufficient to address such a big issue, even if this might be more of a political issue than a subject of research.
- The WPTO strategy has stayed consistent for the past several years, which has allowed themes to be developed and projects proposed and most executed effectively. Obviously, the delays over the past two years have caused some projects to stretch beyond what might be considered reasonable (e.g., SMH). Additionally, there seems to be a consistent pattern of certain national labs and independent firms (such as Kearns and West) getting significant funding year in, year out. The reviewer inquired if this is a bread-and-butter source of additional funding for them. The presence of other smaller firms always showing up and securing funded work shows great initiative on their part but without real market-ready solutions resulting. One area that needs unrelenting improvement is the FERC licensing process—not just at the federal level but at the very inconsistent state level. In the 10 years the reviewer has been developing their small hydro business and projects, there has been little effective headway. Without this, the reality of affordable small-scale hydro, not just on unpowered dams but also stream reach, will not be achieved. Equally—and this is something the reviewer commented on some four (?) years ago when last engaged in a peer review—there seems to be an absence of any way of measuring the investment rates of return for the various projects, which, if they are to be built, will need to be financed by banks and investors. Inconsistent metrics also seem to appear too often. LCOE or monetary cost per kilowatt (kW) are a couple examples where the approved cost method (LCOE) or all-in cost per kW seem to be more about marketing than reality. Construction is the major cost driver for many hydro projects, yet few, if any, construction firms seem to be attracted to participate in the FOAs, so there tend to be theoretical rather than real-life examples of methods that can be implemented and really address where the real costs lie. Dam safety is now a real cost challenge for small hydro. The FERC Dam Safety Part 12D rules now weigh very heavily on the industry. A five-year review now costs approximately $100,000. Work needs to be done with FERC Dam Safety to develop processes that are effective, appropriate, and affordable. This should be a focus area for WPTO. The best results seem to come from projects where there is a real industrial partner alongside the national lab and inventor, such as on the design and development of composite turbine runners or the cold spray cavitation mitigation projects. Finally, the Loan Programs Office is desperate to fund hydro projects, but small-scale hydro (e.g., multiple sites in different locations, maybe using a couple of technologies, selling power into different markets) does not lend itself to meeting the office's criteria. The reviewer has been working at this for seven years and is inclined to give up. However, this is an important source of funding, and a bridge has to be built between small hydro and the Loan Programs Office. The reviewer inquired whether this is a potential area for WPTO study.
- The program is very well laid out regarding strategy and implementation. There is also good overall alignment between the MYPP, the Hydropower Program, activity areas, and projects.
- The strategy and plan outlined in the MYPP are clear, comprehensive, logical, and well thought out. The programs and projects reviewed are in line with the plan and outlined goals. Often the words "hydropower community" were spoken in terms of audience and stakeholders. Even through discussions and Q&A, it is unclear that the hydropower industry embraces that environmental nongovernmental organizations and state agencies are critical components of that community. The reviewer believes WPTO embraces this expanded and appropriate view. However, the reviewer thinks WPTO needs to do more to ensure the broader stakeholder

community participates and is effectively communicated with, and WPTO needs to work to get the hydropower industry to understand the need to be as inclusive as possible. There was a recurring theme of the need to strengthen communication overall—for the program as well as the individual projects and programs. Part of this may be that the presentations did not consistently or effectively present information on communication.

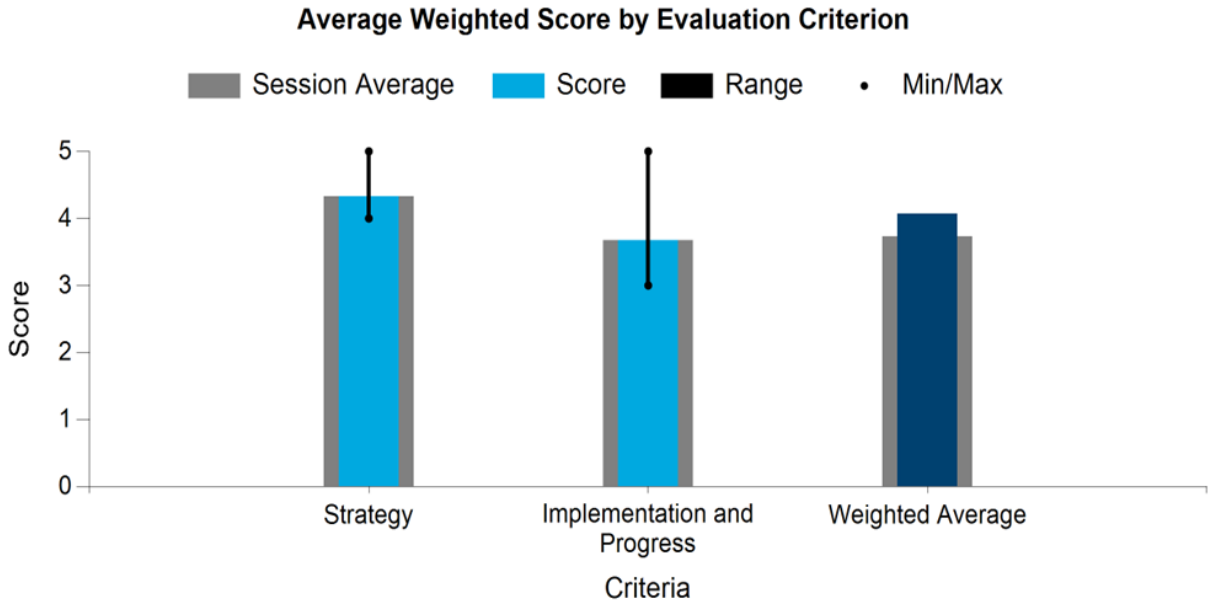
- As articulated in the MYPP, the Hydropower Program has a well-articulated mission and vision. Its activities are based on a set of challenges drawn from the large stakeholder community that participates in the Hydropower Vision report and from many other interactions with industry, national labs, nongovernmental organizations, and others. The challenges are nicely translated into a program logic model that describes the five major challenges to be addressed and the related program areas, approaches, and activities to address the challenges, expected intermediate and long-term outcomes, and the expected impacts. The MYPP has been built to address the needs of stakeholders and industry, is rational, and leverages appropriate funding mechanisms (e.g., financial assistance, prizes and competitions, national lab-led R&D, and a few others). Regarding implementation and progress, the Hydropower Program is funding a wide range of projects that include relevant technologies, tools, and studies. These projects are spread across the challenge areas identified in the hydropower logic model including new low-impact hydropower development; grid reliability and integration of high levels of renewable energy; fleet modernization and maintenance; environmental and hydrological systems; and data access, analytics, and workforce development. Through its publications, website, press releases, and the peer review, the program is transparent in communicating its priorities, activities, and results. The program is making a good effort to disseminate its project results, though the effectiveness, especially at the project level, is still evolving. Based upon the information presented for review, including the presentations and Q&A during the peer review itself, it is clear that the Hydropower Program is well conceived with good leadership and excellent and effective staff. It is making effective use of its budget and producing good results.
- WPTO addresses R&D activities that are appropriate and timely for both the industry and stakeholders. Funding for projects seems to be allocated in a way to ensure equitable investments to support the vision, mission, and goals of the program. Notable strengths include a focus on current needs for environmental sustainability including improved data collection techniques and technology. Notable weaknesses include an inefficient communication strategy to promote prizes/competitions and dissemination of information. Including a well-defined communication and outreach approach into funding opportunities could alleviate some of the disconnect between researchers and practitioners in the field.
- Regarding long-term challenges facing the industry, the presenter mentioned that even since 2016 (when the Hydropower Vision report was published), there have been a lot of changes in the energy industry that can affect hydropower. The reviewer agrees. In just five years, things have changed a lot, and it seems the program needs to be flexible so it can adapt quickly to a rapidly changing energy industry. In particular, it seems the expanding focus on climate change and how to address or adapt to it needs to come more to the forefront in the Hydropower Program. In particular, it would be useful to have parts of the program start to examine very specific trade-offs between environmental impacts and benefits of hydropower relative to reducing carbon emissions. There is a lot going on at WPTO with a lot of individual projects and initiatives. As a first-time peer reviewer, it was hard to see what the overall strategy is (even after reviewing the MYPP) and how all these programs combined or individually fit into the overall program strategy. That said, after re-reviewing the MYPP and hearing all the presentations, the reviewer thinks they got a better handle on things, and their sense was that most of the programs are a good fit and support WPTO's long-term strategy(ies). In the future, for the benefit of first-time peer reviewers, it might be good to have an initial overview session that demonstrates how the various programs fit into the overall strategy. The reviewer knows this would not be easy, but it would be helpful, and it could be revisited at the end of the peer review week. After learning and hearing more about the individual programs, reviewers could better assess each program's fit within the overall program strategy. A recurring thought the reviewer had (and that others raised) for many of the programs was the need to better

emphasize how the program will be communicated to the public, and how to make end users aware of the program, results, and deliverables. At the end of the day, the success of each program will be best judged by end users and by demonstrating who, how, and where each program's end product (e.g., tool or database) or results (e.g., research results) are being used by the public. WPTO should really emphasize getting the word out about all these programs beyond the immediate hydropower community or NHA. All these programs are fantastic, but WPTO needs to make more people aware of them and get them into the hands of users. In particular, the reviewer thinks emphasis should be placed on making sure the word gets out to educational institutions, which are full of students and researchers who might put these products to good use immediately. There seems be some confusion and disagreement over the strategy in terms of who is the intended beneficiary of these hydropower programs. This is hard to articulate, but it seems like some of the programs are intended to aid opponents of hydropower rather than to help proponents of hydropower. In this reviewer's track, there were a couple of programs on which reviewers disagreed about the benefit of the program to the hydropower community, and the reviewer provides those comments later. The reviewer would also note that the many references made throughout the week to "The Uncommon Dialogue" makes it appear as though that "agreement" suggests a common understanding of the value and benefits of hydropower. It is clear not everyone sees it that way, and the reviewer would caution WPTO to make sure not too much weight is put on that document, which is really a political tool, not necessarily a document that represents the interests of the hydropower community. The reviewer expressed thanks for being invited to participate as a peer reviewer. On the whole, the Hydropower Program and the projects reviewed were very impressive and so were WPTO staff and PIs. WPTO is doing some great work.

Innovations for Low-Impact Hydropower Growth

Activity Area Evaluation

WBS:	1.1
Presenter(s):	Katie Jackson



Aggregated Reviewer Comments

- This program is huge in scope and involves many facets of NPD hydroelectric development. The staff have delved deeply into many of those facets using existing tools and databases. They are to be congratulated for their efforts to further hydro fleet development. However, much of the relevance of the work in medium and larger projects is moot as most viable sites have been evaluated. There are certain key facets that need recognition going forward. The financial objectives of the owner/developer/investor will govern the type and acceptable return on investment. To that end, the cost per megawatt (MW) capital cost and cost per megawatt-hour operating costs are of prime importance. The reviewer recommends considering the characterization of types of projects by these factors and the primary stakeholders being served by a project's results. Having said that, costs of wholesale electricity are increasing, which will translate into more medium-sized (1 MW to 5 MW) NPD projects becoming viable, assuming these increases are permanent. Key to that development is the at-risk investment of permitting, licensing, and design costs. The presumption that modularity and standardization are cost effective is challengeable and may only apply in limited applications. The program does not adequately address the significant impact of transmission interconnection regulatory challenges on project viability, cost, and timetable. The reviewer inquired what advanced tools and technologies can be brought to bear to assist the regional transmission organizations in evaluating applications quickly and efficiently.
- Overall, the type and focus of the various projects included in this presentation were a valuable contribution to the potential development of hydropower. The new product lines, including the use of composites for hydro runners and the cold spray application, were very impressive and promise to be useful procedures going forward. The tools developed to identify and characterize NPD opportunities were also impressive and hopefully will spur new developers and development activities moving forward. The reviewer shares several of their colleagues' opinions that the potential for new stream development is very limited, and tools and designs related to SMH for new stream development will not find a very large audience. In the reviewer's view, the

largest potential for new in-stream development may be higher-head projects located in areas with significant topography that involve a small diversion dam, a long flowline, a penstock, and a powerhouse with the Pelton turbine. There were several of these types of facilities proposed and licensed in the 1980s, and there may be other potential sites in the Western United States. The potential (including locations) for these types of sites could be the subject of a small, focused study. In regard to development at NPD sites, one area of potential new research is in the use of siphons. The reviewer recognizes that siphons have been used at several sites successfully. One major cost in the development of any NPD is that of cofferdams and the connection required between the upstream pool and downstream powerhouse. The use of siphons for this type of project could make many projects more feasible. The reviewer is unsure what the issues are regarding the use of siphons, but any type of additional technical research and design criteria could be very helpful in the implementation of new development at existing lower-head dams. This is particularly true for the many USACE navigation dams that have an upstream pool located close to the elevation of the dam crest. The study and the background information for interconnection is very valuable. The process, cost, and time required for interconnection is very problematic, particularly for smaller hydro projects. The reviewer views the current study as a starting point to provide information for various parties to promote better procedures. This likely would require action by FERC.

- The presenter really carries a broad burden—well done. Some of the elements of the program are excellent, including research and accomplishments for new manufacturing techniques where the right size and type of company is attracted, and the results show. The NPD explorer tools and conduit assessment are also excellent, but with the techniques defined, they need to reach across the country as most NPDs for small hydro are in the East and Midwest, and it is similar for canal systems. The solutions coming out of the standard modular approach appear to lack sufficient focus on the regulatory aspects (federal and state), and none of them even seem to assess whether the end product will, in fact, realize internal rates of return that will attract investors. Investors do not care about LCOE or cost per kW. They want to know total project returns, the price per kilowatt-hour, and how many kilowatt-hours will be generated (which, of course, includes all the elements that go into the LCOE and cost per kW metrics). In driving for internal rates of return, the projects would have to determine the price of power they would have to obtain. This is critical as these projects cannot survive on merchant pricing. Because 60% of a project's cost sits in construction, the focus on trying to find low construction cost solutions is important, yet it is hard to see any hydro construction companies getting involved. The only one the reviewer knows of is French, and the precast solutions they are coming up with seem to have potential, but it is unclear what FERC Dam Safety will have to say about them and the ability to meet their criteria. More firms need to be attracted into these FOAs; the same old names keep appearing. Maybe fewer bigger awards are needed to really attract folks who otherwise must focus on billable work as opposed to R&D. Finally, real, live testing of the solutions is needed and creating a run-of-river (RoR) test center could be tough, but a conduit test center could be less so. The investment dollars will be great. The reviewer recommends looking at Voith's Handelsheim, a German R&D center where they have a river running through the test center. Finally, the reviewer inquired whether enough time is spent looking outside the boundaries of the United States to find best practices/technologies. If there are solutions out there, the reviewer wondered how to bring them back to the United States under license, etc., so that good U.S. content can be manufactured and provided.

Project Evaluations

Alternative Opportunities for Hydropower

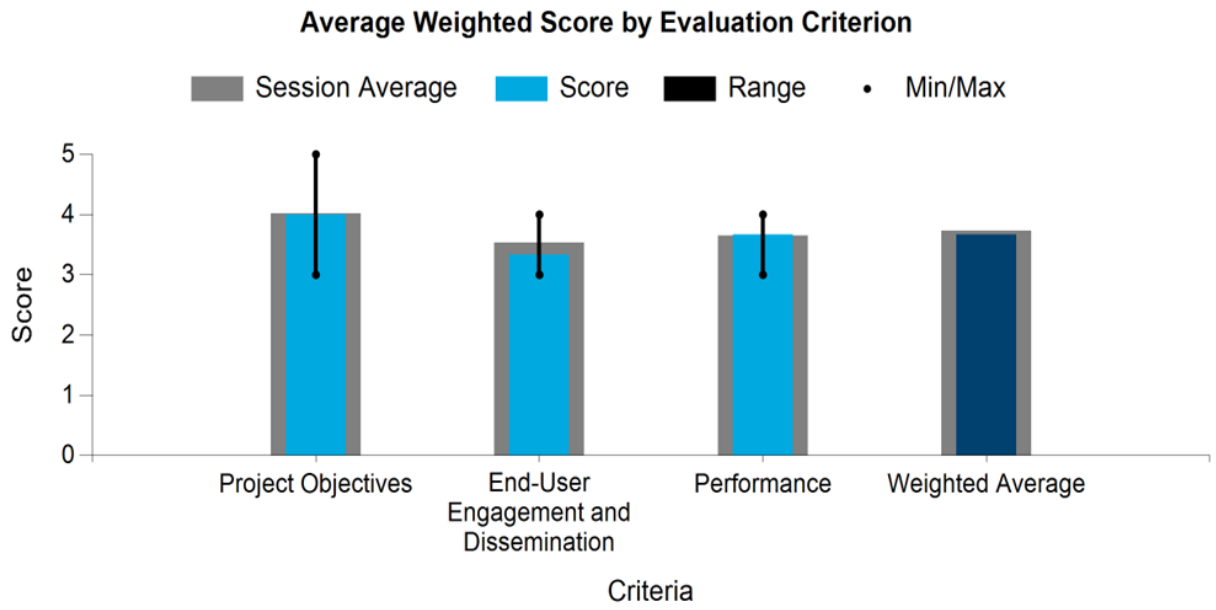
Idaho National Laboratory (INL), PNNL

WBS:	1.1.1.102
Presenter(s):	Rajiv Prasad; Thomas Mosier
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021

Project Description

PNNL and INL are jointly investigating new value propositions for hydropower. Adoption of new technologies and strategies could leverage both energy and non-energy drivers in new business models that enable growth of additional hydropower capacity. Within the water-energy nexus, hydropower can be integrated in projects that sustain water supplies, improve environmental outcomes, and increase facility and community resilience using new, untapped value streams.

Project benefits, associated beneficiaries, and value streams that deliver the benefits are identified through extensive stakeholder outreach. Potential new projects are assessed using data from known examples, and the lessons learned will result in public-facing guidance for such projects. Additional research is being identified to quantify values from non-traditional drivers, including social and environmental improvements. Successful completion of this work will result in increased stakeholder interest, deployment of new hydropower projects, and availability of local renewable energy.



Aggregated Reviewer Comments

- Electricity is the great enabler of so many environmental and societal benefits. Hydropower is inherently in a great position to power water-based benefits, although it is not alone in doing so. The issue is to define the drivers and the symbiosis of values so mutually beneficial outcomes can be achieved. Herein lies the key, and it is apparent hydro is not the lead player in this effort. It is led by the needs of the community or other stakeholders looking for a power solution that includes an untapped water resource. That way, the supply of power mandatory to achieve the outcome is not an end unto itself. This is not a hydro issue; it is an agricultural, water supply, or other need fulfillment program.

- The concept of evaluating potential revenue and benefit alternatives for hydropower development appears to be a very worthwhile undertaking, although the results appear to be somewhat uncertain at this time. The program identified five specific areas where hydropower could combine with other development alternatives to provide greater benefits. These five areas were reportedly referenced in a 2020 report to WPTO. The presentation did not provide a reference to this report, and the reviewer was unable to locate it on any of the laboratory websites. Therefore, the reviewer was not able to evaluate the specific potential of any of the five alternatives. To date, it appears the team has not identified any specific beneficiaries who would benefit from this work other than the general area of agricultural organizations. It would be useful to have future work identify specific organizations, groups, or development groups that could benefit from the identification of the combined hydropower opportunities.
- Generally, the reviewer agrees with the approach, and the array of benefits are what any developer of new hydro on unpowered dams must consider. The reviewer thinks the team dismissed a very important benefit: the historical/preservation aspect. The perspective of the project was more Western based, than nationally, or more particularly in the old industrial base of the United States where most of the best, small unpowered dams exist. In the East, water drove industry, water power was replaced, and yet the dams and mills remained. These are considered burdens, fish impediments, or important assets, depending on the interest groups consulted. The reviewer recommends considering the whole project boundary, including interconnection. If the site is good (flow, watershed, etc.) and the dam is stable and will remain, the state historic organization, a preservation group, or the National Park Service may have an important say in the process and, if not fully engaged, may cause a project to become stranded. FERC will rarely override these groups in they are against a project. However, stakeholder engagement and a 360 view of what hydro can bring is well highlighted in this project.

Groundbreaking Hydro and I AM Hydro Prizes

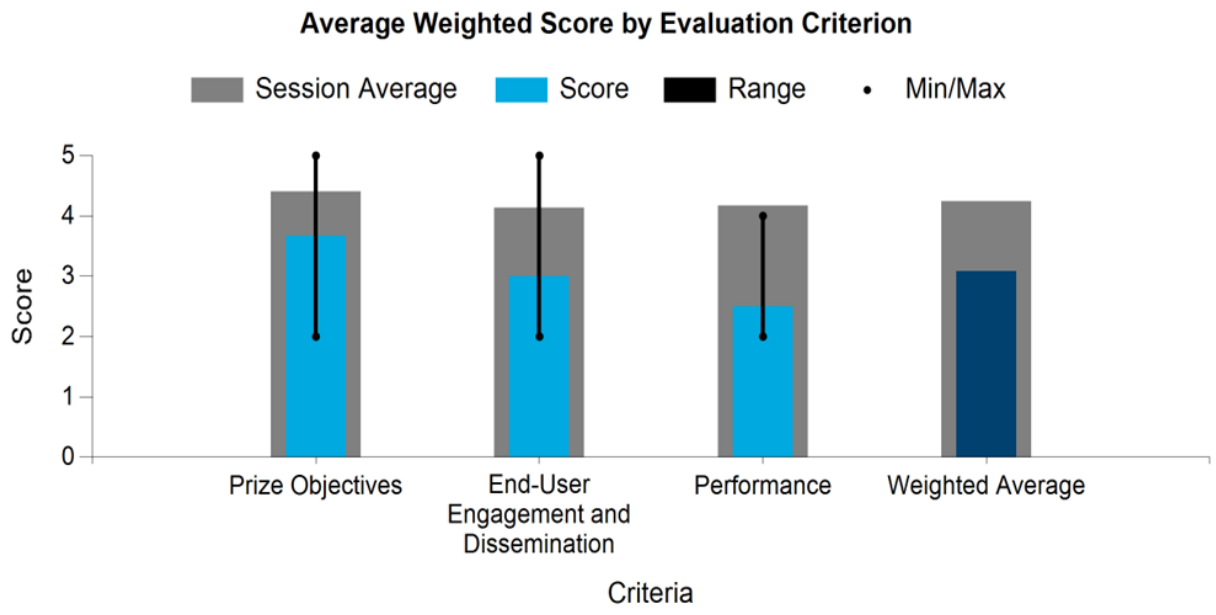
NREL, ORNL, WPTO

WBS:	1.1.1.401
Presenter(s):	Katie Jackson; Scott DeNeale; Tessa Greco
Project Start Date:	02/01/2020
Planned Project End Date:	09/30/2021

Project Description

The Hydropower Geotechnical Foundations Prize (Groundbreaking Hydro Prize) encouraged innovative solutions to reduce cost, time, and risk associated with hydropower foundation development. These solutions were to be analyzed and further explored by the ORNL hydropower technical team if sufficient quality applications were received. The Groundbreaking Hydro Prize offered a total of $300,000 in cash prizes to elicit and advance innovative concepts for low-head (up to 30 feet of hydraulic head) hydropower geotechnical foundation technologies.

The I AM Hydro Prize encouraged innovative solutions for employing advanced manufacturing materials, coatings, or processes to reduce the cost for hydropower development. Results from the prize were to be analyzed by ORNL and incorporated into an advanced manufacturing roadmap to inform WPTO activities and investments. The I AM Hydro Prize sought to identify new ideas with the potential to have a disruptive impact in the hydropower industry and offered up to $250,000 in cash prizes.



Aggregated Reviewer Comments

- In general, because there were two named prizes in this material and the presentation, it was difficult to understand the differences between the two prizes (Groundbreaking Hydro and I AM Hydro). The large number of eligible, not-on-topic submissions makes it difficult to determine how successful the prize approach was to achieving the program's objectives. The not-on-topic ideas may have other value. It seems the majority of the end-user engagement and dissemination was post-prize development versus pre-prize development. The technical approach of the winners is unclear. The winners are listed, but the quality of their work is unclear.

- The prize program is a clever way to circumvent other requirements while encouraging new ideas, and so it is most commendable. However, the low participation is either due to low monetary awards to attract professionals, too tight a scope, or insufficient communication. It is a great approach, but the reviewer thinks the presenters should rethink their objectives and determine their audience. The reviewer recommends seeing what prize programs have been used by other federal agencies to benchmark this one.
- The reviewer appreciated the use of workshops for feedback, presentations to industry groups, and the evidence of meaningful partnerships. Those are good practices. Direct technical assistance is valuable and beneficial in these settings, and the reviewer highly recommends including direct technical assistance in every prize package. It has the potential to influence the sustainability of the project. The R&D roadmap that identifies high-impact opportunities to leverage advanced manufacturing and materials in hydropower applications is a significant output. While there was a sincere effort to engage stakeholders, including using the advisory group throughout the project's lifespan, this project presented issues with its implementation that need adjustment. The reviewer encourages continuing with the white papers and best practices documentation. The reviewer appreciated the team's efforts in leveraging funding outside of normal constructs. The team noted they received fewer applicants and meritorious solutions than initially hoped during this prize session. The reviewer inquired whether this is a prize design issue or a communication issue. Attracting innovation from relevant communities requires an integrated and robust communications strategy. The reviewer would have appreciated a bit more information about the nature of the outreach and engagement in the presentation. End-user engagement is critical to the success of these projects, and in this case, it seems the communication effort did not yield the expected results. The reviewer encouraged exploring the factors that influenced low participation and determining if it was a prize design/award amount problem or a communication problem.
- The format for the prize contest would not work for most private engineering consultants. The amount of prize money is likely not sufficient to interest most consultants to use unbillable time to develop new concepts. The reviewer suggests that a different concept be considered for a prize contest in the future. This would involve a two-phase approach whereby the initial phase would be the submittal of a one- or two-page document describing the potential concept. Based upon the submittal, several parties would be selected to move to phase two. Phase two would involve a more detailed development of the concept and require documentation of the concept that could be published after contest completion. The consultants' work under phase two would be paid under a lump-sum payment. The reviewer believes this would be a more attractive arrangement for many private consultants, and it is important these concepts are published so the entire hydropower industry could become aware of new cost-saving procedures and concepts.
- The drive for innovation and the concept of awards is admirable. However, the poor results indicate the solicitation was either too broadly defined or unclear such that much time was wasted by the applicants and the team in the process. These projects need to attract the top engineering firms, working with the national labs to really come up with market-driven innovation. They will not move off billable work to undertake these studies unless they can really see what is in it for them. The rewards did not reflect the worthy objectives of this FOA.
- The teams did a good job analyzing the technology need and communicated this information to a broad range of stakeholders. The group should continue to investigate why the response was so low. More work is needed to refine the technology need.

Standard Modular Hydropower Technology Acceleration

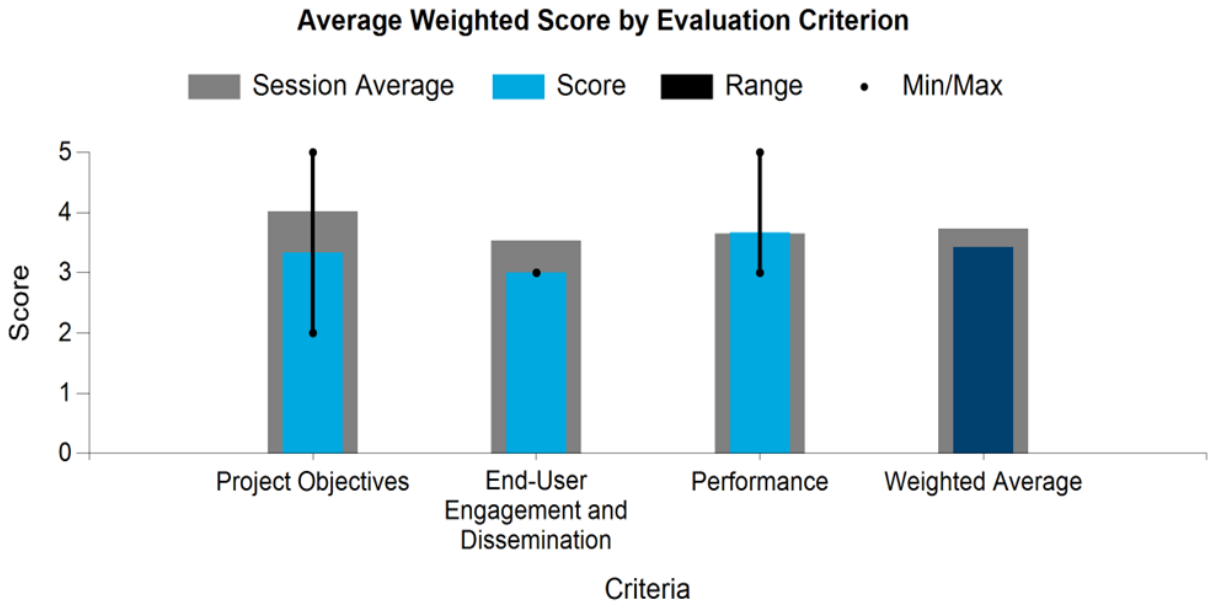
ORNL

WBS:	1.1.1.501
Presenter(s):	Scott DeNeale
Project Start Date:	10/01/2015
Planned Project End Date:	09/30/2018

Project Description

Small hydropower development is a complex and uncertain undertaking, with techno-economic and environmental features largely driven by site-specific considerations. Given existing technologies, there are limited opportunities for new, affordable hydropower growth. To address these challenges, the SMH Technology Acceleration project defines standardization, modularity, and environmental compatibility as three enabling principles of a low-cost, environmentally sustainable hydropower growth strategy.

The project promotes SMH technology acceleration as evidenced in its three core R&D tasks: Module R&D, SMH Facility R&D, and SMH for NPD Development. Together, the associated research activities aim to enable cost reductions and commercialization of new SMH technologies for both NPDs and new stream-reach development. Intended project outcomes directly integrate multiple social, ecosystem, and energy needs for new, small, low-impact hydropower deployment. In addition to core R&D, this project provides funding for ORNL's direct technical support to awardees under two FOAs: DE-FOA-0001836 (Facility Design Concepts for Standard Modular Hydropower Development) and DE-FOA-0002080 (Modular Technologies for Low-Head Hydropower Applications). Industry collaborators include Littoral Power Systems, Natel Energy, Percheron Power, and the University of Minnesota.



Aggregated Reviewer Comments

- The reviewer fails to see how these techniques will provide broad solutions for the industry. There are applications where repeatable generating units can be designed and deployed in groups where fewer larger units are not feasible, such as weirs and other broad, low-head dams. However, this project is so focused on the word "modular" that it has become myopic.

- The project has accomplished much in the identification of potential development opportunities at NPD facilities. The reviewer was able to briefly review some of the tools that have been developed, and they appear to be very useful for the identification of development opportunities. Prior to this peer review, the reviewer was not aware of the availability or usefulness of any of these tools. Since the reviewer is an active developer and an advocate of the development of hydropower potential at NPDs, they were surprised to not be aware of these study results and development tools. For this reason, the reviewer believes the outreach to the hydropower industry could be more effective and robust.
- The most significant and relevant part of this $3.9 million effort was the development of the NPD classification tools and dataset. Here, there was real progress with a tool that, if continued and covers the entire United States, will be very useful for developers and to bring the vision for NPDs into a more realistic focus. Of the 54,000 unpowered dams, analysis indicates that there are only around 1,000 worth developing. The work undertaken in tech support for the Littoral and Natel projects was no doubt good, and comments are provided under their respective topics.

National Conduit Resource Assessment

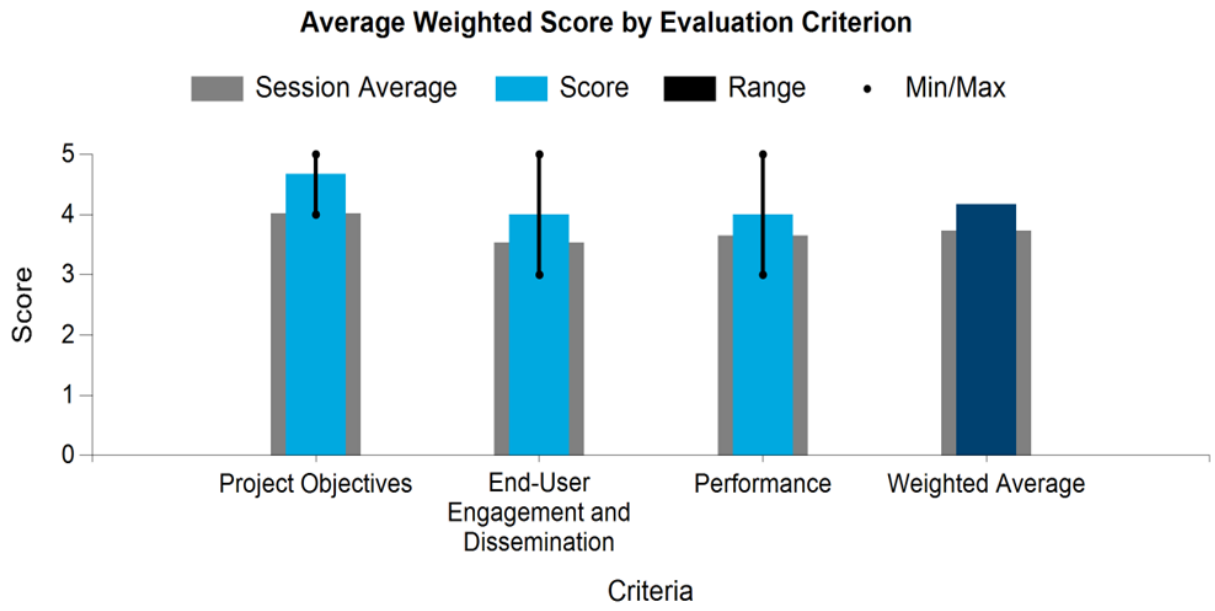
ORNL

WBS:	1.1.1.508
Presenter(s):	Shih-Chieh Kao
Project Start Date:	09/30/2020
Planned Project End Date:	09/30/2022

Project Description

Among various undeveloped hydropower resources, the potential from human-made water conduits (e.g., pipelines, aqueducts, irrigation ditches, water conveyance canals) has been estimated as being relatively small but having the highest development feasibility. This type of small hydropower development does not require the construction of new dams or impoundments, involves minimal environmental concerns, and entails reduced development timelines. It is eligible for net-metering in most states, yielding high value for the energy generated, and may qualify for an expedited 45-day regulatory approval process through the qualifying conduit approval process created by the Hydropower Regulatory Efficiency Act of 2013 and its amendments in the America's Water Infrastructure Act of 2018.

To quantify the national undeveloped conduit hydropower resource potential, a reconnaissance-level assessment is conducted for three main water sectors in the United States: municipal, agricultural, and industrial. The assessment leverages the best available data acquired through federal and state drinking water regulatory agencies, as well as novel remote sensing and feature detection techniques for systematic identification of national canal drop sites. The outcome of this project will be a publicly accessible hydropower resource assessment report that aggregates resource findings to both state and county levels to support future resource planning.



Aggregated Reviewer Comments

- This is an interesting project to assess the potential energy generation in conduits. The reviewer inquired what it serves. Whether the potential is 1 or 2 gigawatts does not matter. What is key is providing municipalities and other entities with the tools to be able to assess potential generation, technology choices, and associated costs. The reviewer recommends changing direction accordingly.
- The reviewer believes the study is a valuable first step to mobilize the potential for hydropower development in existing water conveyance infrastructure, although it will not offer specific identification of potential projects but will identify areas of the country (counties) that have potential. The reviewer believes that development of specific projects will likely happen in two general ways. One development implementation process will involve the infrastructure owner identifying the opportunity, carrying forth an evaluation, and hopefully completing construction and operation. This process would be facilitated by outreach to potential owners and operators. The reviewer identified several groups in California that could provide a forum for various owners to become aware of the opportunities in their system. This includes the Association of California Water Agencies, which represents 500 water agencies responsible for more than 90% of the water delivered in California; the California Rural Water Association, which represents more than 1,100 rural water systems; and the National Rural Water Association. A second process for development would involve private consulting firms or developers identifying potential projects and approaching project owners to develop the projects. The current study would be useful in this process to enable potential third-party development groups to identify general geographic areas of interest using the data provided for various counties in the Western United States. The current study provides valuable information for both development alternatives.
- The reviewer thinks the project may be using a definition of conduits that is too narrow. From the perspective of the FERC conduit exemption, consider including the vast canal system that exists in the Northern United States. Some of these are still in commercial use and, therefore, eligible for the exemption (check on what FERC allows as commercial use). Some are there just for recreation. Many have existing hydro in place, but many branches could be developed for new small hydro. The reviewer thinks that including relevant small hydro technologies that could be deployed would be an important add to the utility of this project. This type of project should also consider the economics. The reviewer believes that standardized approaches to construction and equipment are the only ones that will be cost effective because the price of power (and, therefore, the power purchase agreement) tends to be very low in the West where conduits are most prevalent. While the project considered the municipal water systems, the reviewer thinks there is even greater scope in analyzing the highly fragmented municipal water companies, most of which are close to 100 years old, are undercapitalized, and have never considered what hydro could do for them if they are close to a water source. Consolidation is happening across the country, and getting hydro into their vision of the future with all the long-term benefits is important. This does also require a good knowledge of what the various public utility commissions are planning by state as municipal water systems and policies are generally set by these commissions. Finally, water rights are key (in the West), and the mere fact that there is water there today does not mean that the water will always be there (witness the current drought). Where a conduit is located in a reservation or where Native American water rights exist, then there is a strong possibility that those rights are there in perpetuity and cannot be taken away.

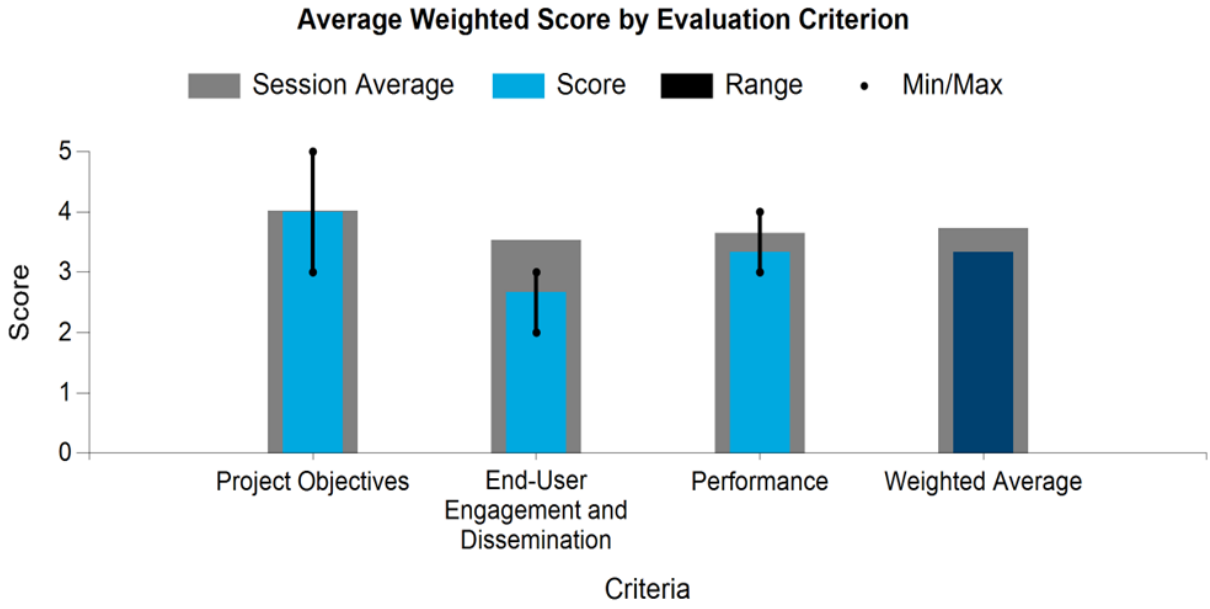
Small Hydro Interconnection Study

PNNL

WBS:	1.1.1.601
Presenter(s):	Alison Colotelo; Chris O'Reilley; Todd Wall; Hope Corsair
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2022

Project Description

Most new hydropower interconnections in the United States may be attributed to small hydropower, corresponding to distribution-level generators with nameplate capacities between 0.5 and 20 MW. Though these smaller projects hold significant growth potential for the industry, electrical interconnection has historically posed a significant impediment to development. To ease this obstacle and further inform small hydropower developers and utilities, this work assembles interconnection information from 290 interconnection applications, 151 interconnection technical studies, and state-by-state interconnection policies and protocols from across the United States. The products will present the findings in easy-to-use tools and guidelines to better equip stakeholders during the planning and interconnection phases of small hydropower projects.



Aggregated Reviewer Comments

- The reviewer recommends making sure the project is abreast of the current delays in the processing of connection applications at the independent system operators (ISOs). There should be an objective of identifying how these ISOs can be more responsive to small projects in approving interconnections.
- It is difficult to provide a specific evaluation on the work product that is still in process. It appears that the study did a reasonable job of evaluating interconnection requirements in different parts of the country. Interconnection is an increasingly difficult hurdle for small hydropower projects. This study could serve to provide the basis for regulatory reform on a nationwide basis. The study results should be specifically provided to organizations supporting renewable energy development such as NHA, wind supporters, and solar advocates. The goal would be to modernize and simplify the interconnection process for small power developers. In summary, this study provides an initial step in streamlining the interconnection procedures.

- This is a worthy and much-needed area for evaluation, and the reviewer looks forward to reading the report. It should serve as a good primer to interconnection by state. However, the reviewer inquired how deeply the report dives into the differences between system operators and then the distribution companies that operate within those systems. For example, in ISO New England, the distribution companies vary by state, and one would imagine they should all be similar, but that is not so. The reality is that most distribution companies do not understand hydro—be it the need for direct transfer trip, the impact of regenerative drives, or what a permanent magnetic generator is. They are used to the solar and wind world and tend to employ contractors who know even less. Having said that, these reports are only as good as the last update, so maybe consider a technical section, which should be pretty stable but allow for new technologies, and then a current requirements section that addresses lead times.

Integrated Water Power Resilience

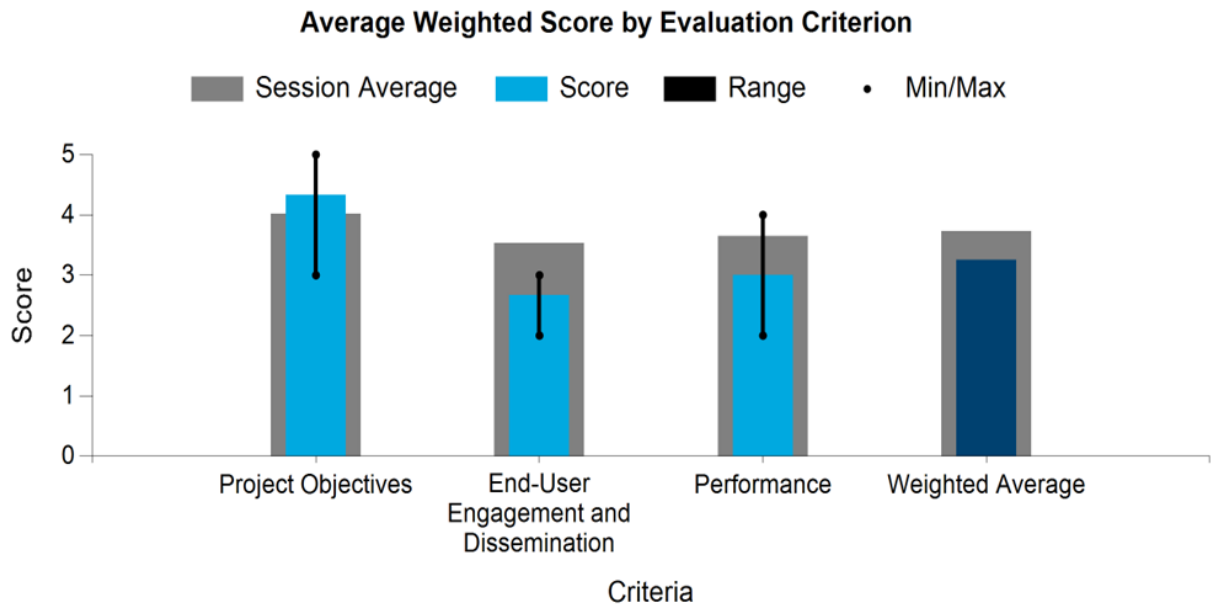
PNNL, INL

WBS:	1.1.1.606
Presenter(s):	Juliet Homer; Timothy McJunkin
Project Start Date:	12/01/2019
Planned Project End Date:	09/30/2021

Project Description

Water and power utilities are interdependent, subject to many of the same natural and human-made hazards, and critical to the well-being of communities and society. A wide range of compounding influences—such as increasing populations, aging infrastructure, natural disasters, cybersecurity threats, and climate change—increasingly threaten the ability of water and power systems to persist and continue to provide essential goods and services with acceptable levels of reliability and cost over the long term.

This project aims to improve the resilience of the nation's water supplies and power systems by working directly with industry partners to develop standard metrics and understanding of interdependencies and risks; compile and share best practices and develop useful tools and analysis for coordinated planning and operations for resilience; promote data development and sharing between water and power utilities; and increase efficiency, flexibility, and renewable energy development in both systems. Final products and outcomes will include a set of high-impact visuals, a cross-sector and cross-agency network of industry professionals advancing integrated resilience, an aggregation of best practices for risk assessments and integrated resilience planning considering climate change, an illustrative set of case studies, and analysis tools that support resilience assessments and planning from the electrical interconnect level to the county and community level.



Aggregated Reviewer Comments

- While the word "resiliency" dominated much of the presentation, the deliverables were not clear at all. Published papers telling utilities they need to create an integrated resource plan are okay, and suggestions on areas of study are helpful to them, but it does not seem that work has been done on solutions that can work.

- The current study and outreach effort are critical undertakings to prepare both the water and power industries for the unavoidable future uncertainties associated with climate change. The scope of this study is challenging since the concept of resiliency spans many different agencies and types of climatic uncertainties. The study team has done a good job at reaching out to many of the larger organizations to identify resiliency issues and to promote the development of mitigation strategies. It was noted in the verbal comments that water and power are often provided by smaller companies or municipalities that do not have the resources to conduct in-depth evaluations of potential resiliency issues. It is recommended that future work be corrected to develop programs for these types of organizations to allow them to economically and reasonably address potential resiliency issues without the expenditure of large portions of their revenue streams.
- The reviewer found it very difficult to understand the output of this project. There are lots of papers, but there is an insufficient summary of what the project is about and what it has produced that is tangible and implementable. It seems there was a good deal of output, but the examples in the presentation could not be read. It is the start of something bigger, but it is unclear. The reviewer is also unconvinced by the breath of outside company, agency, and state engagement. It is at the state level that this should be happening, and yet reviewers were only referred to the Massachusetts Department of Environmental Protection's work on one element of their climate resiliency work—the hydro turbine in their water supply system from the Quabbin Reservoir, the reviewer thinks. This is old news.

Cold Spray Process Development for In-Situ Repair and Mitigation of Cavitation Erosion

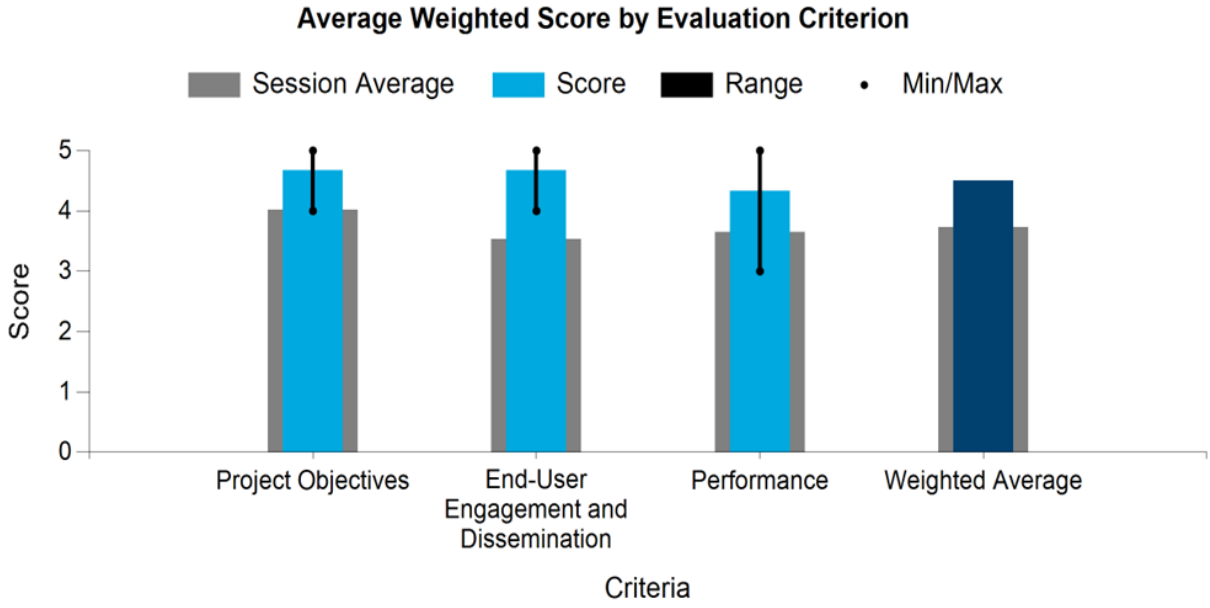
PNNL

WBS:	1.1.1.611
Presenter(s):	Chris Smith
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2022

Project Description

Cold spray is a solid-phase coating process primarily used for depositing metal onto other metallic surfaces. It can be used to repair or rebuild corroded or eroded surfaces and potentially to improve material properties. Cold spray has been demonstrated to be capable of creating surfaces with significantly improved cavitation erosion compared to the base material used in hydropower components and even more so compared to surfaces generated using current repair processes.

This project is focusing on developing a portable, capable cold spray process that can be applied manually and in situ for repair of hydropower hardware that has been damaged due to cavitation erosion.



Aggregated Reviewer Comments

- This is a terrific program of tremendous importance to the industry; well done. It appears the authors still have much to do to refine the application process and understand the impacts of the variables with which they are dealing. This includes robotic tools for learning the surfaces, along with identifying areas for repair and applying and finishing the cold spray repair. The reviewer recommends bringing a robotics partner on board, such as GE Labs, to work on this phase of the development.
- This project has a definable and real value for the successful operation of the existing hydropower installations in the United States. In addition to providing an accelerated process to address cavitation damage, the process will result in an increased resistance to future cavitation for both existing projects and for new turbine runners. It promises to be a game changer for addressing outages due to cavitation.

- This is another example of good, applied research leading to market-ready solutions. Having seen the extraordinary amount of high precision, multilayer welding that goes into repairing cavitation, this solution could be a great breakthrough. The reviewer likes the robotics (resulting in direct labor cost savings and consistency) and wonders if these coatings could be applied to new turbine runner manufacturing processes. The unions will not like it as the welder in the shop is considered to be the king. Of course, the aftermarket repair process seems excellent. Allowing for in-situ repair would allow for even greater O&M cost savings.

Irrigation Modernization (Scoping for Water Challenge)

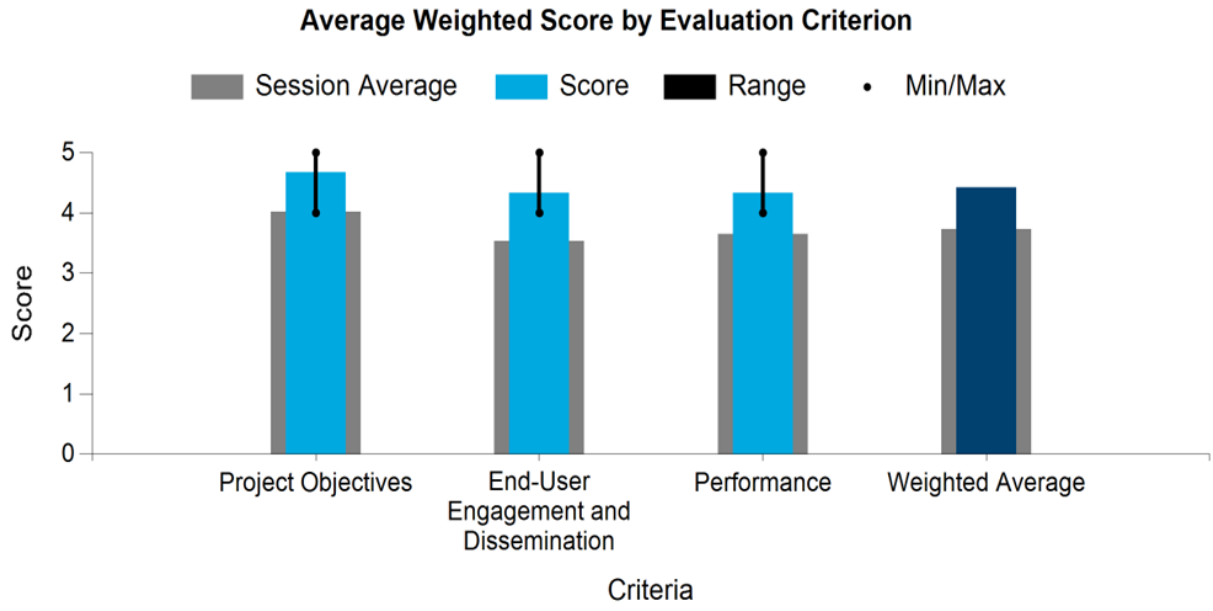
INL, PNNL

WBS:	1.1.3.101
Presenter(s):	Thomas Mosier
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2022

Project Description

Initial construction of most irrigation systems in the Western United States took place in the first half of the 1900s, funded largely by the federal government. Today, irrigation accounts for up to 80% of water use in the West. Irrigation system owners now represent a diverse but poorly resourced set of stakeholders. Irrigation infrastructure is also aging, risking efficient water delivery and threatening agricultural production. Irrigation modernization activities include projects that incorporate in-conduit hydropower to provide energy resilience. Traditionally, these activities have been expensive and difficult to quantify. This has led to a just-in-time approach to most modernization projects, resulting in missed opportunities to incorporate hydropower into existing systems.

The Irrigation Modernization project aims to lower the barrier to entry for irrigation stakeholders through two avenues. The first is by providing easy access to IrrigationViz, a pre-engineering, web-based application capable of comparing different irrigation modernization scenarios and their potential benefits and costs. The second is through stakeholder outreach, establishing communities of practice and identifying win-win scenarios where modernization can be incorporated into existing efforts. When successful, the Irrigation Modernization project will enable irrigation modernization activities and increase the deployment of renewable technologies in irrigation systems.



Aggregated Reviewer Comments

- Adequate irrigation is a worldwide problem that limits the ability of communities to be self-sufficient in the supply of food. Hence, projects like this can be part of the solution. It is appropriate that microgrids be central to this effort; remember mill wheels and diversions were common since humans used tools to farm and by definition are micro-grids. Thus, using energy, however derived (wind, solar, hydro, etc.), provides flexibility in terms of distance between the source and use of the power. Modeling these systems with alternatives and variables easily manipulated by prospective farmers or irrigation districts is going to make choosing the right infrastructure possible.
- The reviewer believes that the work products developed by this project have the potential to be an extremely valuable tool to both modernize irrigation systems and to capture the economic value provided by the addition of hydropower. The development of the IrrigationViz application will provide a systematic and easily usable tool for various irrigation districts to economically evaluate potential projects. The reviewer reviewed the application and was impressed with the format, even though it is a work in progress. In addition to partnering with agricultural groups, the outreach to existing irrigation districts for the development of potential projects is very valuable. The reviewer believes this project represents one of the more valuable contributions from the WPTO research effort.
- The reviewer very much liked the approach, which is obviously focused on one major irrigation project but sets the table for others. The reviewer would like to have seen more on the significance of integrating all renewable sources, especially microgrids, as this area is still much talked about but very few have been implemented from the reviewer's perspective. The reviewer recognizes the complexity of technologies, interconnection rules, and licensing, but these all have to be tackled. The presenter referred to the INL Net-Zero Microgrid project, and the reviewer inquired whether this could be a tie-in for a follow-on project. The reviewer would very much like to understand more of the work being done in the microgrid arena.

Cost Data Collection and Modeling for Hydropower

ORNL

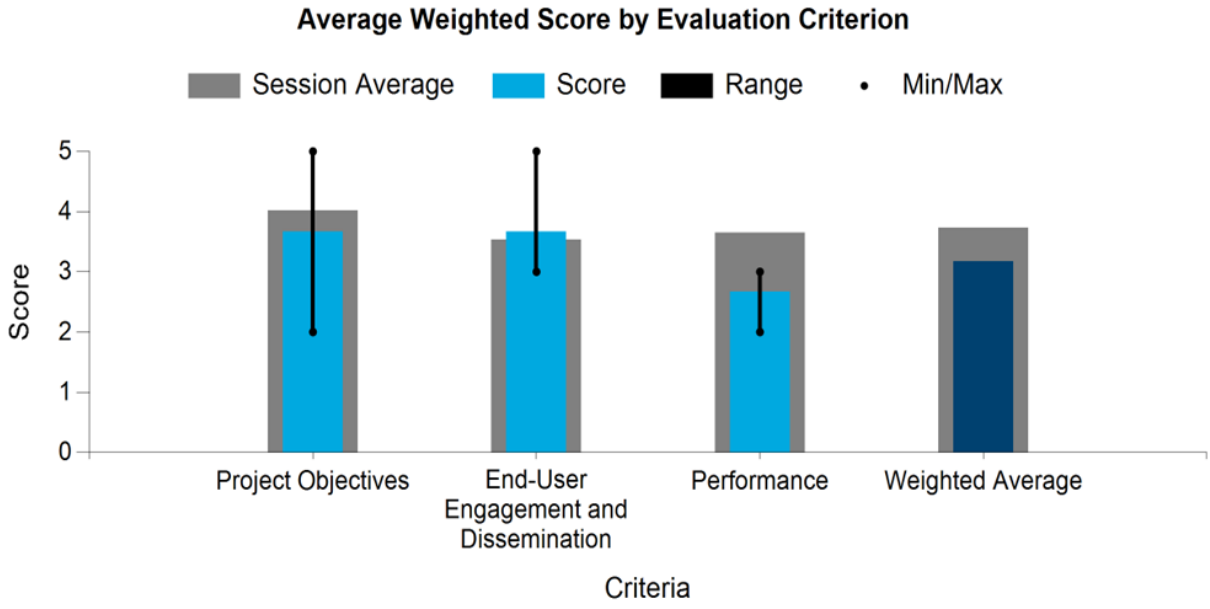
WBS:	1.5.1.507
Presenter(s):	Gbadebo Oladosu
Project Start Date:	10/01/2013
Planned Project End Date:	09/30/2021

Project Description

This project encompasses the data collection, modeling, and analysis of the costs and performance of hydropower plants in the United States. Thus, the project addresses the challenge of lack of access to information and metrics to support hydropower decision making. The project provides capabilities to track and quantify research activities' impacts on the economic competitiveness of hydropower technologies to address the challenge of limited opportunities for new, affordable hydropower growth given existing technologies.

The project has so far focused on NPDs and new stream development hydropower using multiple approaches to accomplish these objectives, including bottom-up analysis of hydropower projects, parametric models for use by hydropower stakeholders, and other activities.

The outputs of this project include improved LCOE baselines and reduction targets and updated datasets and knowledge on national hydropower costs (including environmental mitigation) for use by researchers and policymakers. These outputs are disseminated through technical reports, peer-reviewed publications, presentations, and interactions with hydropower stakeholders. The expected outcome of the project is to support improvements in decision-making processes and basin-wide management of river resources for multiple objectives through hydropower data availability and accessibility and publicly available analytical tools.



Aggregated Reviewer Comments

- This is a project that will really assist any new developers in evaluating and making key choices for projects. Much remains to be done, and there are several key facets that need to be addressed before this can be a reliable tool. This includes additional cost data from recent projects to be gathered through the establishment of nondisclosure agreements and the evaluation of system trends such as growth in annual flows. This is a key variable with project operating lifetimes of 100 years. Additional facets that need to be addressed include adding transmission interconnection costs such as interconnection lines and substations, O&M and other operating costs that affect the financial returns more than capital costs, and inflationary pressure on costs. The reviewer recommends that the authors engage a wider range of developers and system operators for data collection and review the models in detail.
- The development of reasonable cost estimates for hydroelectric projects invariably involves assumptions and potential inaccuracies throughout the process. This is clearly demonstrated by a review of hard money bids for hydroelectric projects that can often vary from contractor to contractor by 10% to 15%. A review of the capital costs developed by the project and included in the documenting report indicates that these estimates appear to be relatively high based upon comparison with actual, detailed engineering estimates. For example, the capital cost for the Overton project in 2019 was estimated to be $6,250 per kW. The Overton project is located at one of five very similar locks and dams on the Red River in Louisiana. A detailed engineering cost estimate for the very similar lock and dam located upstream of Overton indicated a direct capital cost of $3,522 per kW. This raises concerns regarding the accuracy of the estimating process. The capital cost for many of the projects identified in the report exceeded $10,000 per kW, which appears exceedingly high compared to recently completed projects. For example, the Red Rock project was $10,500 per kW, but the construction included several state-of-the-art geotechnical features such as a large secant wall and the world's tallest (approximately 100 feet high) diaphragm retaining wall. The discrepancy between the costs identified in the report and the actual known costs of projects led me to the "2" score. The reviewer believes this study has value to indicate the relative economics of the projects studied. However, the reviewer is concerned that the use of the proposed methods, which result in high capital costs, will serve to discourage developers at many sites.
- This is a critical project as the industry is generally dominated by large firms that do not often share their cost information. For the small hydro sector, there are so few developers that the situation is even more critical.

The Design and Development of a Composite Hydropower Turbine Runner

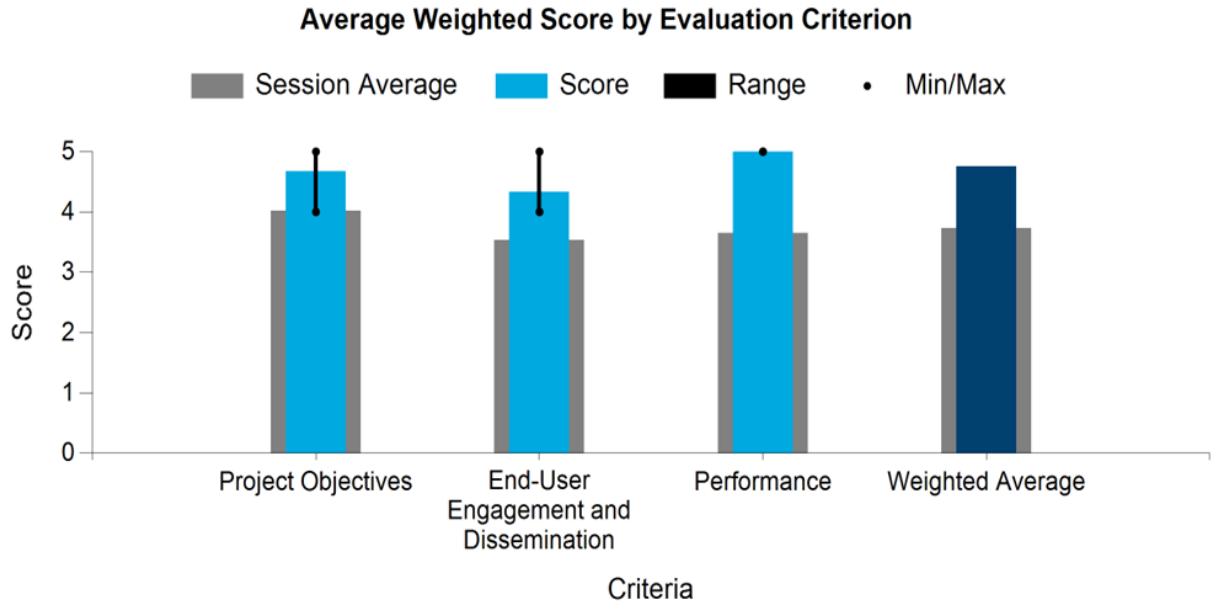
Composite Technology Development, Inc.

WBS:	EE0007248
Presenter(s):	Paul Fabian
Project Start Date:	07/01/2016
Planned Project End Date:	12/31/2021

Project Description

The overall goal of this project was to verify that composite materials are a reliable and economic alternative to traditional runner and flow guide materials and can provide designers with new design options that ultimately reduce operating costs and increase energy capture over the lifetime of the system.

During Phase One, multiple composite matrix systems and hard and soft coatings were evaluated for their ability to withstand the potential cavitation that greatly impacts the durability of hydro turbine runner blades. CTD-K08 resin and CTD-133 anti-cavitation coatings were identified as high-performance materials for these applications. In Phase Two, using a scaled hydro turbine design provided by a commercial partner, Composite Technology Development, Inc. designed, fabricated, and tested an all-composite hydro turbine runner blade for use in a scaled bulb hydro turbine simulator. This was fabricated for use in the 48-inch diameter water tunnel at Pennsylvania State University's Advanced Research Laboratory to simulate real-world turbine conditions. Mechanical bend testing confirmed the composite runner design performed as predicted by the finite element analysis. Following testing, a set of three composite runner blades was fabricated for testing in the Advanced Research Laboratory's hydro turbine simulator to verify the hydrodynamic performance. The composite runner set performed perfectly during all operational conditions with no indication of cavitation. This testing proved that advanced manufacturing methods and materials used in the composite turbine blades are viable candidates for use in hydro turbines.



Aggregated Reviewer Comments

- This is a fantastic program; well done. The reviewer recommends that the next steps need to include the feasibility of manufacturing with repeatable processes. This is critical to commercialization. Next steps also need to design blades using the strengths of the material rather than copying stainless steel.
- The project results clearly demonstrated that a composite turbine runner could be fabricated to have equal, if not sometimes better, characteristics than the stainless-steel runners currently manufactured and used. The question that the study did not answer was whether the composite runners provided an economic or performance advantage over current runners. In fairness, this question was not part of the ongoing research project. It, however, is an important issue that should be the focus of future investigations. If manufacturing processes can be developed to more economically manufacture turbine runners, it will obviously have a positive impact on the development of future hydro projects.
- This was a project, excellently conceived, which addressed a real, next-generation advance in turbine manufacturing. The presence of a leading turbine manufacturer and an expert in composite manufacturing resulted in an excellent result that could be taken to the next level and become a marketable product. While composites are commonplace in the aerospace industry, the hydro industry does not have the manufacturing volume to drive costs down the same curve. However, given that hydro turbine manufacturing is pretty much a bespoke industry and so much waste (that can be recycled) is produced and labor hours expended, it does seem that focused design on components that could be made out of composites (on the U.S. side) could be a long-term cost reduction driver both in materials and automation and, hopefully, less subject to supply-chain challenges.

Restoration Hydro: A Watershed Approach to Standard Modular New Hydropower

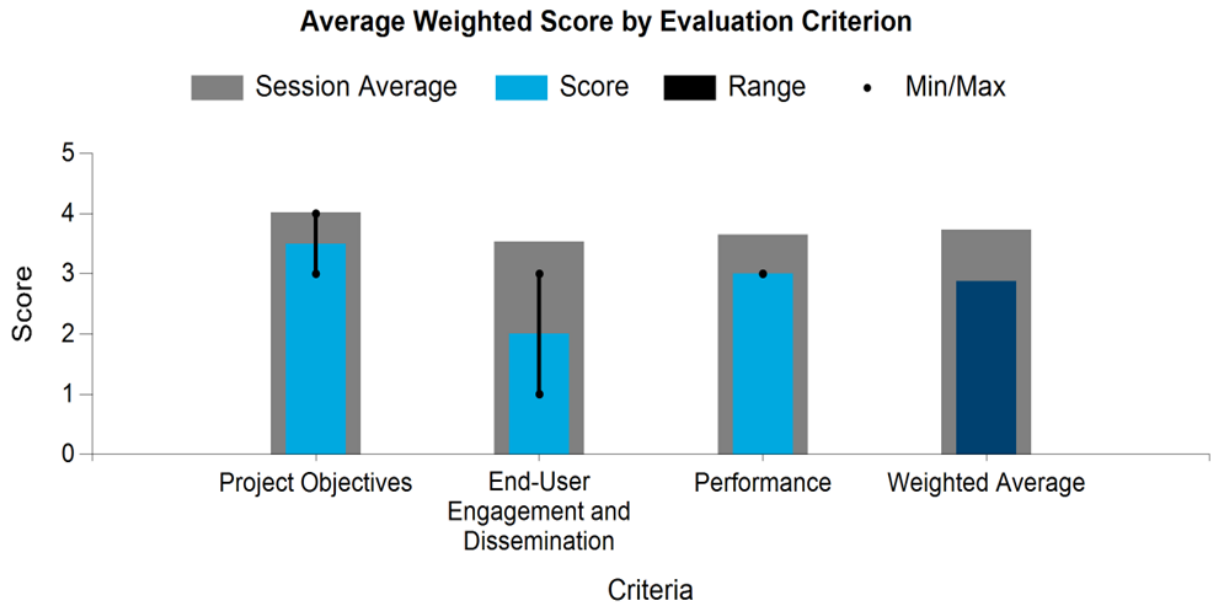
Natel Energy, Inc.

WBS:	EE0008777
Presenter(s):	Abe Schneider
Project Start Date:	08/01/2019
Planned Project End Date:	01/31/2022

Project Description

This project is building a blueprint for Restoration Hydro: A Watershed Approach to Standard Modular New Hydropower. The project builds upon the SMH Exemplary Design Envelope Specification in an effort to create a scalable, replicable facility design in which watershed restoration, safe water recreation, and cost-effective hydropower production are mutual outcomes. Restoration Hydropower envisions a future in which hydropower is river connecting, not river dividing.

This project is unique in its approach of hydropower engineers (from Natel Energy, Wells Engineering, and Small Hydro Consulting) working directly with watershed restoration engineers (from Natural Systems Design and the University of California, Berkeley, Environmental Systems Dynamics Lab) and whitewater recreation designers (from McLaughlin Whitewater Design/Merrick) in the creation of SMH facility designs, facilitated by ORNL. The project team evaluated opportunities for simultaneous ecosystem restoration and hydropower development potential and identified a new morphological feature—alluvial pockets in which a degraded, unconfined reach located upstream of a confined reach can be restored with improved, lateral hydraulic connectivity by the addition of a hydropower facility. Fish-safe turbines can enable simplification of facility operations while ensuring timely and effective downstream passage and are integrated into a scalable, submerged, modular powerhouse that can be constructed for less than $3,500 per kW.



Aggregated Reviewer Comments

- This is a logical follow-on program to SMH in an attempt to prove the SMH principles for river restoration. To meet that goal, the team selected an alluvial plain that agencies want reflooded. This is an admiral goal. However, the likelihood of this being repeated elsewhere is quite low, so this investment of public funds is not effective or useful. The researchers have not achieved their $3,500 per kW installed, and if there is not substantial potential volume of deployments expected, then this goal is out of reach.
- This was a very good presentation and was well explained. The concepts that Natel continues to develop are definitely innovative and visionary. The project does need to develop a total cost per kW as today it seems understated given quantities and costs including coffer dams, form work, structural steel, etc. The reviewer suspects the state agency costs will be significant in any project affecting wetlands. Certainly, in the East, the water source and floodplain approach would be challenged given flashy rivers, wetlands protection, and flood inundation concerns. The costs associated with FERC licensing, conditions, and FERC Dam Safety should be included.

Prefabricated Standard Modular Hydropower Installations for Low-Cost Small Hydropower

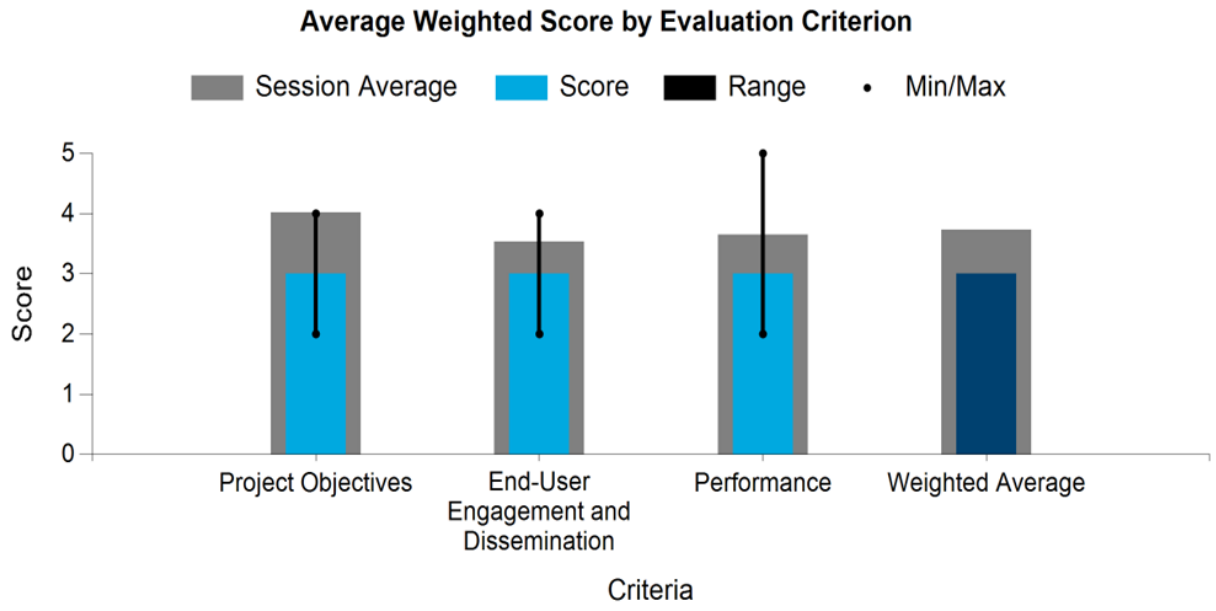
Littoral Power Systems Inc

WBS:	EE0008778
Presenter(s):	David Duquette
Project Start Date:	09/01/2019
Planned Project End Date:	06/30/2022

Project Description

Hydropower is an important renewable energy asset. It provides economic, renewable energy along with services that will help enable the clean energy transition. Currently, hydropower is lagging behind other renewables with respect to new project development in the United States because of cost and complexity. There is a better way to build. Using a set of intrinsically integrated, engineered modules, the process of hydropower development shifts to the selection and configuration of engineered equipment.

In this project, Littoral Power Systems selected sites, developed suitable modules to be used and configured for those sites, developed site designs, engaged experts to evaluate economic and environmental performance, and integrated that analysis into a design process. Littoral Power Systems can now use this process to select, configure, and install hydropower solutions, reducing time, cost, and risk compared to the traditional approach.



Aggregated Reviewer Comments

- Littoral has claimed that installations of its modular units have been accomplished, yet the reviewer cannot see where that is the case. While modularity is a nice buzzword, it will not inherently provide feasible and lower-cost solutions. Low-head NPDs are a good target for small, unitized units. Solutions for deployment need to be complete from hydraulic input through to generator terminals and be able to be located along a low-head dam using a siphon and anchoring scheme. The reviewer thinks this project has gone in the wrong direction.
- The project appears to have successfully accomplished all the goals identified at the beginning. In terms of outreach, the plan appears to solely focus on marketing of the turbine products. Activities such as publications in professional journals and participation in hydroelectric industry conferences represent additional outreach that could provide greater dissemination of the availability of the new modular technology.

- The project has had a long evolution and some interesting outcomes. Generally, there should be more real field examples of implementations. The reviewer inquired, for example, about where the I Modular is implemented, the river size, the output, and how it bears up to floods and flashy rivers. It seems that the applications are mostly for re-licensed projects, not new development in unpowered dams. It was unclear to the reviewer whether there had been FERC Dam Safety validation and U.S. Fish and Wildlife Service confirmation of no downstream harm to fish. Costs seem incomplete, and coffer dams would seem to be needed to provide for overtopping. The cost per kW seems low. It was unclear to the reviewer how LCOE and cost per kW (full-up costs, hard and soft) were calculated.

Development of a Modular Helical Fish Passage for Low-Head Applications

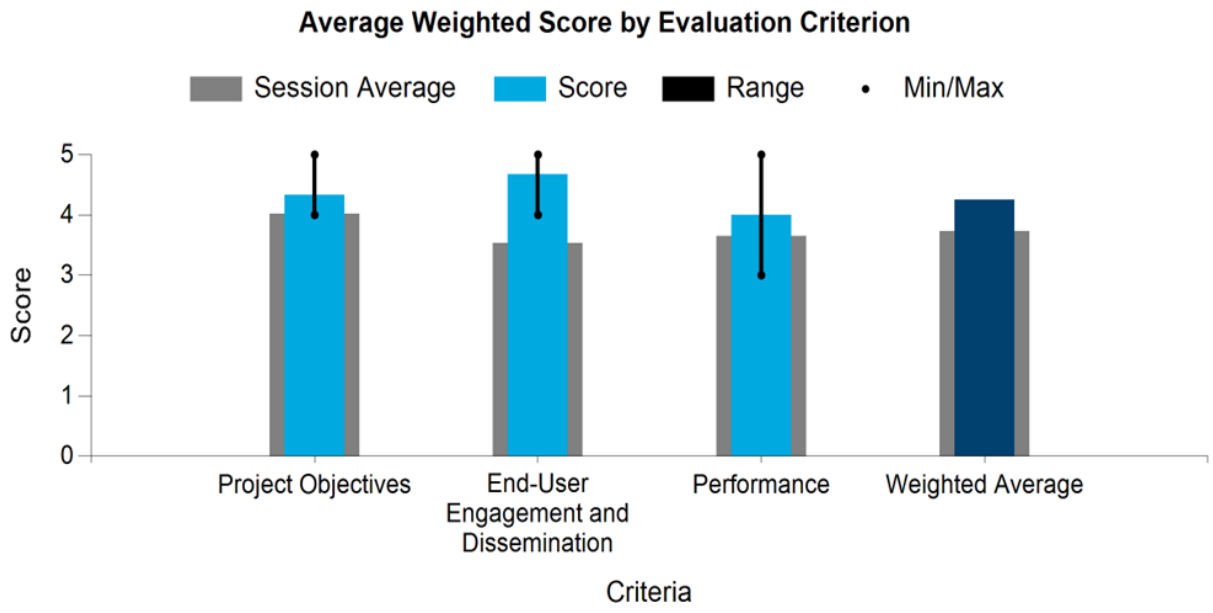
Percheron Power, LLC

WBS:	EE0008945
Presenter(s):	Jerry Straalsund
Project Start Date:	02/01/2020
Planned Project End Date:	09/30/2021

Project Description

This project aims to dramatically lower the cost of fish passage solutions and to manufacture components in the United States. It is focused on developing a new kind of bi-directional fish pass for low-head power plants and other barriers to migrating fish such as weirs, dams, culverts, and diversions. The modular device is based on Archimedes screw principles. The design is focused on optimizing the helix parameters (pitch, diameter, shape, number of flights, rotation speed, flow rate, etc.) for safe and efficient fish passage. Computational analyses of various designs offer an understanding of the hydraulic behavior and ensure appropriate conditions can be provided for fish when traveling both upstream and downstream through the device. Laboratory testing of scale models validates and further optimizes the designs prior to fabrication of a full-sized prototype. The prototype uses advanced manufacturing methods to produce modular, easily assembled components of inexpensive plastics and composite materials. Live fish testing with the full-sized prototype will be performed at PNNL's Aquatics Research Laboratory.

Once demonstrated, it is expected that this modular fish passage solution could be easily implemented at most any low-head site. It could be safer and quicker for fish to pass through, require a much smaller environmental footprint, have no sediment or trash accumulation, and provide at least an order of magnitude improvement in cost over conventional fish passes.



Aggregated Reviewer Comments

- This is a great project that can make a significant contribution to effective upstream fish transport. Clearly, much remains to be done to characterize the system variables and define the limits of its capabilities in length, slope, etc. Different species will need to be tried, especially the weaker ones.

- The proposed fish passage design is a potential game changer for many new and existing hydroelectric projects. The fact that the fish passage facility supports both upstream and downstream passage is impressive, and the fact that the center core provides attractive flows is very impressive and useful. Although the basic concept has been demonstrated to be effective, more work needs to be done to optimize the design and to allow the concept to be employed at a variety of different projects. Specifically, the effectiveness at different angles of the passage needs to be defined. If the passage facility can be angled parallel to the slope (of typical earth embankments), it will significantly decrease the cost of the support system for the passage facilities. Continued work should be undertaken to provide meaningful design configurations and to evaluate the limitations for the passage both in the angle and in the overall maximum head that can be utilized.
- This project has caught reviewers' attention. If it is feasible, manufacturable, and able to satisfy the agencies, then this will be a very valuable and cost-effective solution for low-head dams. Most new development in the East requires upstream and downstream fish passage regardless of whether there is a resident or migratory population. Frankly, fish passages are only needed during migratory periods in the East. The reviewer would be concerned about leaving a composite unit (lightweight, in the scheme of things) in a flashy or flood-prone river. Accordingly, apart from how the unit is secured in the river, consider having a lifting device to allow for removal of the unit off season. It is also worth double checking the species that can make it up a 26-degree slope.

Advanced Compact Generation Module with Fish Safe Runner Technology

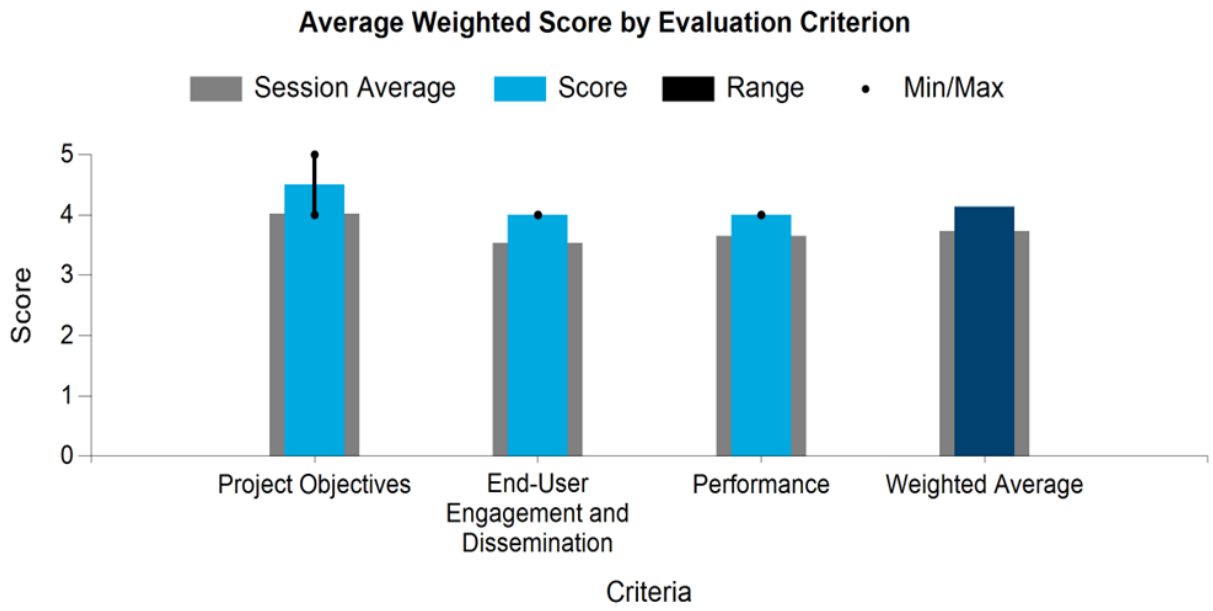
Natel Energy, Inc.

WBS:	EE0008946
Presenter(s):	Gregor Cadman; Sterling Watson
Project Start Date:	02/01/2020
Planned Project End Date:	09/30/2022

Project Description

This project centers on the development of a family of compact, RoR, overflow bay generation modules using fish-safe Natel turbines and based on ORNL's Exemplary Design Envelope Specification for SMH. In conjunction with module preliminary design, performance, and cost assessments, the project has focused on key validations of downstream fish passage safety and the maturation of advanced manufacturing methods for the unique fish-safe runner designs.

This project seeks to address the combination of environmental and cost challenges that limit new stream-reach development via minimal excavation and elimination of downstream exclusion without compromising generation performance. Combining downstream passage with turbine flow uniquely eliminates the need for exclusion, bypass, and guidance systems. Tests conducted within the project demonstrate the very high survival (more than 99%) necessary to minimize population impacts from distributed multi-site projects. Simultaneously, composite runner materials and methods have been assessed for high fatigue and environmental life. With pending publications of fish passage tests, the project team intends to open a door for the viability of through-turbine passage for low-head hydro and, generally, enable new or retrofit compact, low-cost, RoR development. The project team includes Natel Energy, Inc; PNNL; Kleinschmidt Group; and the ORNL Manufacturing Demonstration Facility.



Aggregated Reviewer Comments

- This is the best turbine design coming out of Natel to date. It is cleverly designed and, hopefully, it will perform as expected. The base generation module can be used in a wide range of weir and low-head dam applications. There remains much to be done to prove out the design in a real-world application. Areas such as high-head events, debris entrainment, foundation system, on-shore balance of plant design, multiunit management, and ice flows all require extensive design work and testing.

- The reviewer wonders if this technology is going to be effective with heads greater than 3 meters. The reviewer is unclear on what species dwell low in the riverbed or down at the level of the turbine. Clearly, this includes eels. The reviewer imagines that apart from the Natel-based tests, the U.S. Fish and Wildlife Service will need to see real life testing, which is in the plan, rather than bench testing. The reviewer inquired if arrays of fixed-blade turbines are able to maintain efficiency and also manage fish passage in low-flow periods. The reviewer also imagines the software routines and necessary sensors (flow, level, etc.) will become more complex as the arrays are scaled.

A Novel Sediment Passage Module Design for Support of Standard Modular Hydropower

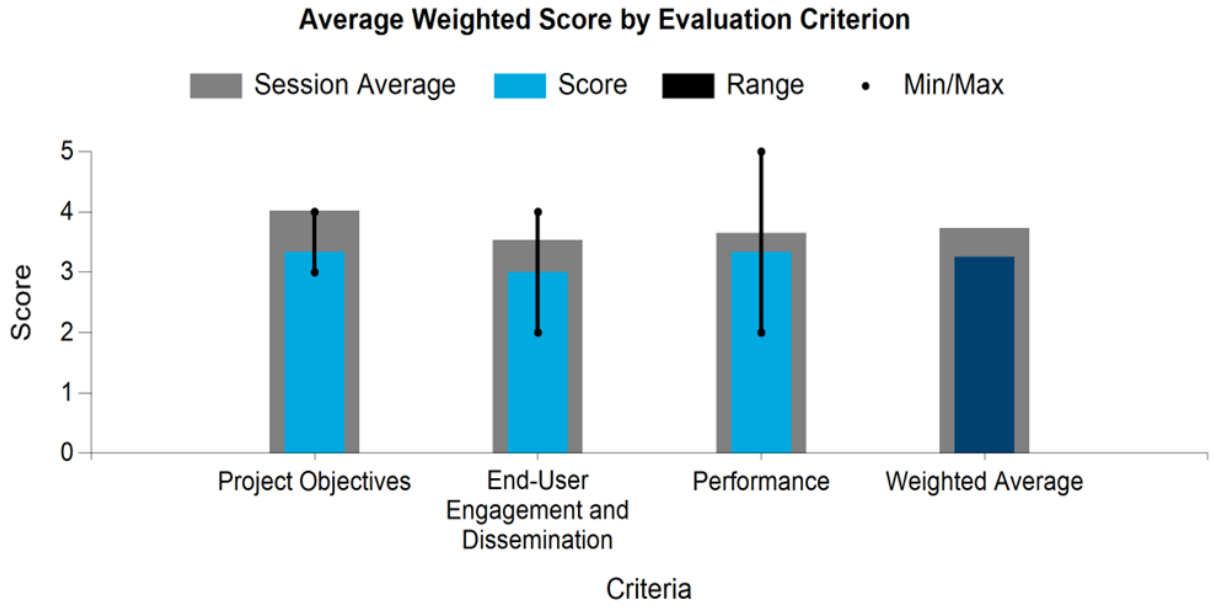
Regents of The University of Minnesota

WBS:	EE0008947
Presenter(s):	Jeffrey Marr
Project Start Date:	02/01/2020
Planned Project End Date:	04/30/2023

Project Description

WPTO is pursuing priority research areas to support the emerging frontier of next-generation hydropower. This includes the concept of SMH technologies, which are envisioned as scalable, stand-alone sub-systems of the complete hydropower system (power generation, fish passage, sediment passage, etc.) that serve to produce electric power while minimizing site-specific design. The SMH platform concept will support both existing NPDs and new stream-reach development.

This research project seeks to develop a sediment passage module for low head (less than 10 meters) dam sites. The technology is based on an approach called "hydrosuction," which uses head behind the dam to drive sediment into conveyance pipes at the river bottom and transport it downstream of the dam. The system under consideration is unique for several reasons. It uses an array of submerged, permeable vanes placed on the riverbed in strategic locations to "steer" sediment toward the suction intakes. It uses siphon inlets, each with multiple inlet points, to continually capture sand-sized bedload material and transport it out of the reservoir, and the natural water elevation drop across the dam provides the energy necessary to transport the sand. The system is designed to operate with minimal operator oversight, unlike active dredging. This report will provide an overview of the ongoing research, which is approximately 60% complete. The team will discuss design efforts on individual components, methods of design development and performance verification, and next steps in the project.



Aggregated Reviewer Comments

- This is a clever concept, but the reviewer is not convinced it is practical. When one compares it to a bulk-handling, barge-mounted system, one expects it to be more expensive and harder to maintain. The nozzles will become clogged. The presenter described it as a new stream-reach-based system, of which there may not be many, so it has to be able to handle a retrofit application if it is to be commercially viable.
- Sedimentation in upstream reservoirs is a significant, long-term problem that can impact both generation and recreation. The goal of identifying and developing methodology to transport sediment beyond the retaining data is a very worthwhile undertaking. Based upon the reviewer's view that many future, new stream developments are highly unlikely, the reviewer does not believe the proposed research will have a significant impact on the development of new hydropower potential. For this reason, the reviewer scored the initial question as a "two." The reviewer does believe that the research and study results could have a very beneficial impact for existing impoundments. The reviewer is aware of several projects that have settled with concerns and would be very interested in any new methodology to move existing and new sediments downstream of the impoundment. For this reason, the reviewer believes that continued research in this area could be very worthwhile in maintaining the generation and recreational benefits of existing projects.
- The main takeaway was that managing and maintaining an array of vacuum tubes in a riverbed will be costly and somewhat impractical. Fast-flowing, flashy, or severe flood-prone riverbeds will make this even harder. Downstream silt deposition and the impact on the streamflow will be difficult to model. In the Northeast or areas where there has been manufacturing historically, the other problem relates to disturbing environmentally challenged silt and materials that should not be passed downstream.

Prefabricated Zero Ascend Omnispecies (ZAO) Modular Fish Passage Modules Using Advanced Manufacturing Techniques

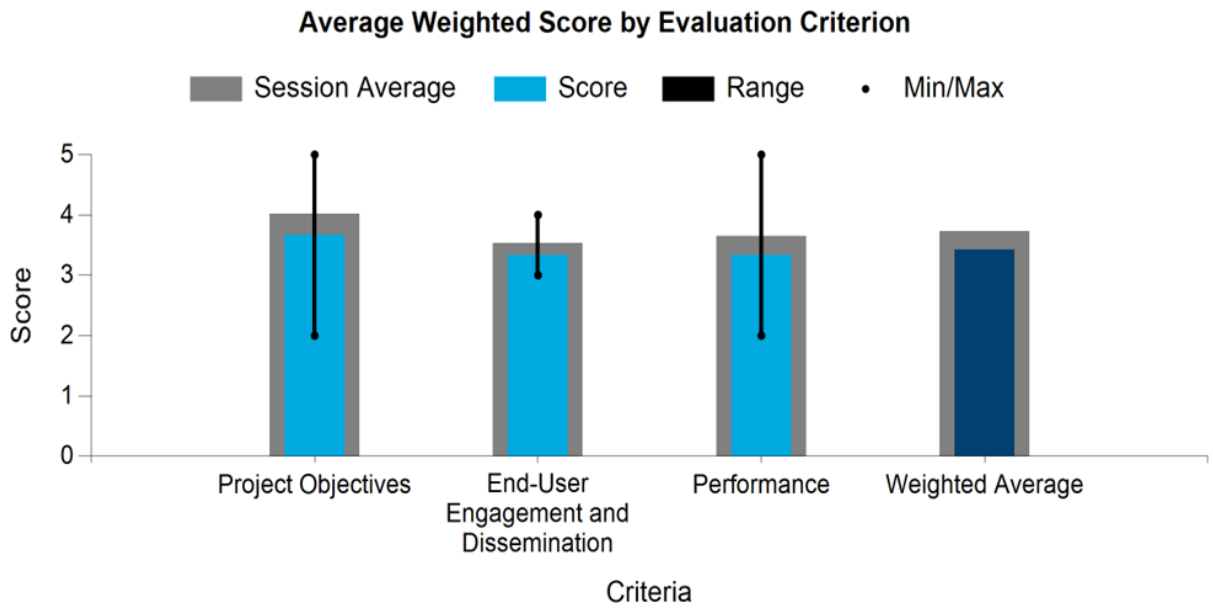
Littoral Power Systems Inc

WBS:	EE0008969
Presenter(s):	David Duquette
Project Start Date:	08/01/2020
Planned Project End Date:	10/31/2022

Project Description

Numerous hydropower facilities require cost-effective fish passage technology. The challenges are cost, attracting and passing both weak and strong swimmers, placing the entry in the path of the fish, and attracting fish especially in competition with turbine outflow. The zero ascend omnispecies fish passage attraction module, ZAO-Attractor™, addresses these challenges by integrating the successful Whooshh fish passage system into a unique, partially submerged, floating body shape with an adjustable entry that takes advantage of the turbine outflows for attraction rather than competing with them.

A successful ZAO-Attractor makes volitional, upstream attraction, and passage of weak (e.g., river herring) to strong (e.g., Atlantic salmon) fish available at a fraction of the cost of traditional approaches, making it affordable for low-impact and small hydro projects. It is a prefabricated system that can be assembled and set up in a matter of days. Each module has the capacity to pass up to 43,200 fish per day. Multiple modules can be deployed at a site for increased capacity. Modules can be moved to find the best place for fish entry. The modules can be removed and/or relocated, providing resilience against climate change. ZAO-Attractor requires no water from the head pond, leaving as much water as possible for energy generation.



Aggregated Reviewer Comments

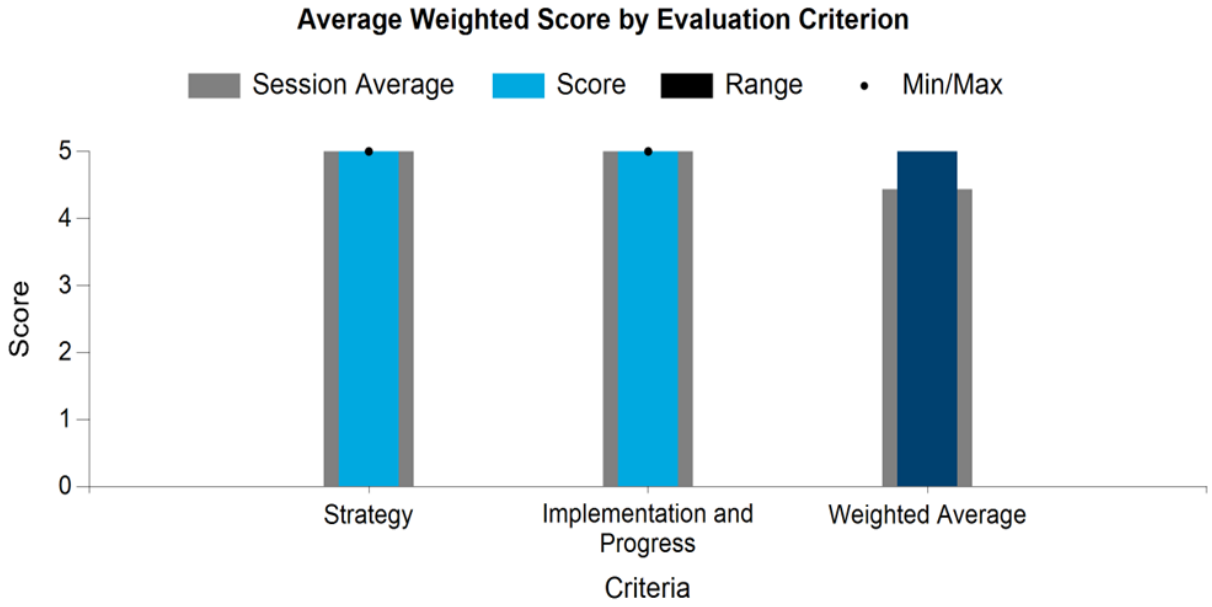
- This is a clever concept for fish attraction. The reviewer is concerned about the structure floating like a boat. Tethering in uncertain riverbed stability, high discharge flows, and varying depths will present considerable challenges. The reviewer is unclear why this cannot be a fixed-in-place unit.

- The proposed attraction facility appears to have been developed in a reasonable and systematic manner. The development included several industry partners that provided valuable input to the process. The project, however, did not include advisory groups from the regulatory arena. Since any fish passage facility or system will likely require regulatory approval, it would be very desirable to include regulatory representatives and experts in the evaluation and development process. Although the system provides an economical alternative to current fish passage and design, it appears that the use of this system is limited to warm-weather locations or seasonal periods in cold-weather environments. Whether this is a major factor in the overall effectiveness of this type of solution will need to be determined likely on a project-by-project basis. The state regulatory agencies, FERC, and U.S. Fish and Wildlife Service staff will likely have key inputs to these decisions. The use of this prototype facility for an actual project will be a valuable test and demonstration.
- The reviewer recommended considering flood impairment elements and inquired what is done with the unit in floods. Rigging and derigging the Whoosh and ZAO units will be a cost part of O&M. Some real scale models of the unit need to be developed and tested. Today, it looks too much like an Erector Set and would appear to have to be hidden in the depths of the river, which will also drive implementation costs. The reviewer doubts this is a solution for low head.

Grid Reliability, Resilience, and Integration (HydroWIRES)

Activity Area Evaluation

WBS:	1.2
Presenter(s):	Samuel Bockenhauer



Aggregated Reviewer Comments

- The overall impression of the HydroWIRES program is that it has evolved and performed very well since the last peer review. It has focused on developing mechanisms and funding research that aim to enhance hydropower performance to enable a flexible, reliable, and resilient grid. This could also enable hybrid power plants, meaning they use hydro as the main source to enable and increase generation from any other renewable energy source. The HydroWIRES program already funds several activities needed to achieve this, and it may be interesting to explore and identify R&D areas that would benefit from more funding to enable a hybrid plant. The program is very well managed and organized. It demonstrated that it has defined the strategy and works in accordance with the MYPP to meet its vision, mission, and intended outcomes. This is further supported by how the R&D projects all align with the program's priority areas and how they demonstrate adherence to the program's rationale. This is only achievable through effective communication that enables them to form the building blocks for the program. The FAST Commissioning Prize is a brilliant example of how the program leverages appropriate funding mechanisms to achieve outcomes. It was very interesting to learn more about how they have developed their approach and appear to have found success with great prize winners. The reviewer also finds that the program has extensive communication with an excellent understanding of the needs of the industry and other stakeholders. The program has successfully developed a strategy and funds research that enables it to address challenges that will benefit the industry and the value chain to end users. The reviewer believes the program will have a great impact on the sector, and it is on the path to address critical challenges. It could be of interest to also measure the impact of the program by identifying a suitable set of metrics. The program is very well organized, which is evident through how it balances its role as a public entity. The program is successfully managed with excellent accomplishments and results. The program demonstrates good stewardship of taxpayer funds by transparently communicating program priorities and resulting investments. Several of the R&D projects develop comprehensive datasets for their own modelling.

Several of these sets can probably be used for future research with other objectives, both individually and combined. This increases the value of the datasets and may require a more aligned approach in how the projects name and tag the same data points, variables, parameters, etc. The reviewer encourages WPTO to explore the possibilities for unified nomenclature for datasets.

- This program has fantastic outreach with very diverse stakeholders. There was a great summary of issues and gaps. All projects are pertinent and needed. The presentation was fantastic. The reviewer believes there was one project about hydro with other renewables and would like to see more unbiased comparisons/synergies/reporting on how they all work together, benefits pros and cons, and why all are needed. It would be great if this great research could also be simplified and targeted to educating U.S. citizens, students, etc. For example, the reviewer suggested explaining why they should be concerned about ancillary services and what it means to them.
- The HydroWIRES Initiative Research Roadmap laid out in clear detail the ways in which it will understand, enable, and improve hydropower and PSH's contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system. It defined four key challenges facing the industry and, from those, four focused research areas. Within the four research areas, 15 technical objectives were defined. Activities to address these objectives were presented, including the character of the activities (tool development, foundational understanding, etc.). The short-term, intermediate, and long-term results were identified as associated with each research area, and the rationales for each area and objective were described. The activities and projects were devised based on substantial input from industry and stakeholders and leverage appropriate funding mechanisms (financial assistance, prizes and competitions, national lab-led R&D, and a few others). Regarding implementation and progress, 25 projects funded by the HydroWIRES program were reviewed. Each project presentation documented an overview of the work conducted, the purpose of the work, its budget and approach, and directly connected the project objectives to the HydroWIRES program objectives. The progress and/or results of each project were also presented, including the relevance of outcomes and dissemination and tech transfer plans and accomplishments. Understanding that with the program's finite, albeit substantial budget, it is impossible to fund all of the most relevant technologies, tools, and studies, those receiving funding certainly are relevant and important. Based on the well-defined goals and objectives of the HydroWIRES program and the project presentations, it is clear that the program will very likely meet all of the performance goals and objectives set forth in the WPTO MYPP. The only areas that could use some improvement relate to dissemination and outreach of the results and tech transfer, and how to make the excellent project results continuously available and accessible to the community of stakeholders. In summary, the HydroWIRES program has evolved very well since its inception and initial review in 2019. The program is now very well defined, useful, and well run. It is a good and appropriate use of taxpayer dollars, and the program is effective and efficient in using those taxpayer dollars.

Project Evaluations

Value Drivers Quantification

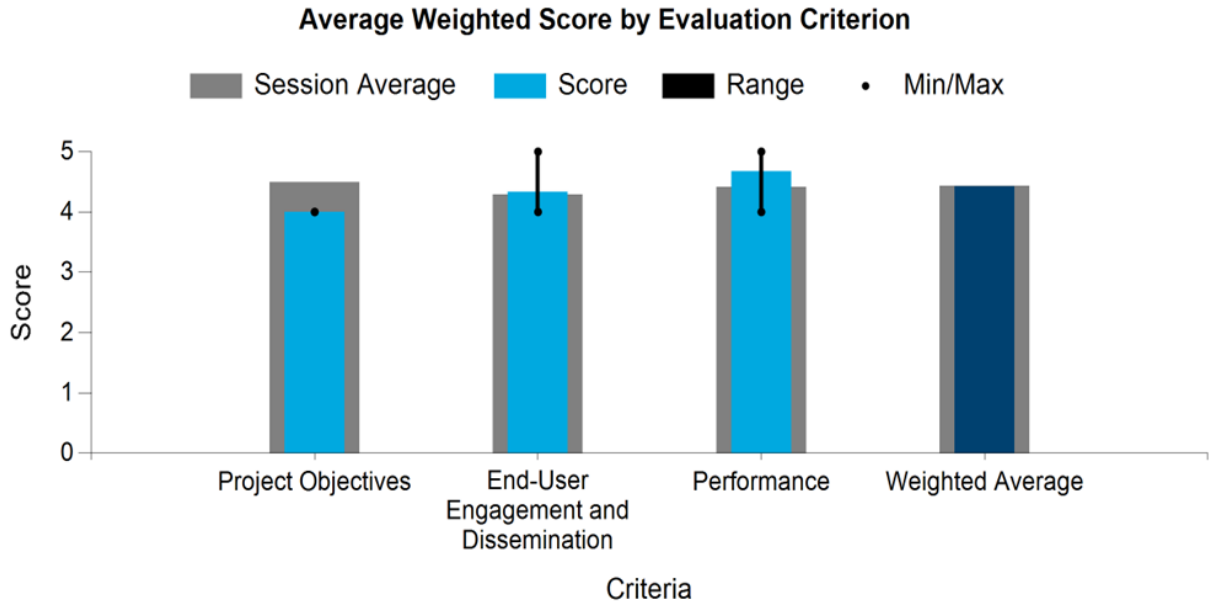
Argonne National Laboratory (Argonne), NREL, PNNL

WBS:	1.2.1.008
Presenter(s):	Todd Levin
Project Start Date:	09/01/2020
Planned Project End Date:	03/31/2022

Project Description

system-level value drivers for hydropower resources by analyzing historical electricity market data to identify system factors that have influenced energy prices, executing production cost models to simulate electricity prices under different system conditions, applying a custom statistical calibration tool to adjust modeled price distributions to account for system uncertainty, and applying a hydropower management tool to optimize plant operations in response to price signals and determine the system value provided by hydropower under different system conditions.

Intended outcomes include a framework for value driver quantification that is broadly applicable across the United States for various system conditions, along with an application of this framework across several regional case studies to identify the system- and plant-level drivers of hydropower value.



Aggregated Reviewer Comments

- The project objective responded well to WPTO's and HydroWIRES' mission. The tool and objective will have a high value for the industry, and it is the modeling that is particularly innovative. However, this also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required. This also increases the challenge of distilling the results to enable a wide audience. The project team identified a broad stakeholder group. It is good to observe that they have engaged a technical advisory group quarterly to present progress and findings and solicit feedback. When presenting, they elaborated more on their good dissemination plan and indicated they plan to make the raw data available. The results and accomplishments demonstrate good performance. However, the reviewer encourages the team to present more on project management as this is an integral part of performance evaluation. It is also of interest to

others to better understand how the team managed this type of project and if the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule and whether it progressed according to plan or what may have been a hindrance. The reviewer inquired if this is something that could normally be expected or if it was a one-time challenge. This type of knowledge is usually valuable to others conducting similar projects. The team presented a solid list of future work that could benefit from more information on timeline, decision gates, etc. It would also be interesting to learn more about why these topics were proposed.

- This is a really impressive project concept that is much needed. The team did nice work determining a way to quantify the hydro value drivers. The reviewer appreciated the work the team did identifying market enhancements needed for proper PSH valuation along with high-level market consideration recommendations. The technical advisory group was diversified and well represented. All the work is very relevant to current hydro industry shortfalls. The tools will be useful, helpful, and valuable to the industry. Details on how best to get the information out to the industry to those who will benefit most was lacking though.
- Regarding project objectives, this project's goal was to quantify the relative impact of different system-level value drivers for hydropower resources. A project management plan was not presented, but a project approach and timeline were. The timeline presented well-defined milestones but did not show go/no-go decision point or risks. The project approach flowchart was hard to decipher (e.g., the start was unclear). The reviewer suspects the oral presentation will clarify. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project team engaged with a technical advisory group quarterly to present progress and findings and solicit feedback, and the group members appear to be from relevant stakeholders. There is no specific tech transfer plan, but that is likely not needed for this project. Three journal articles and one technical report are planned. No presentations at industry events are planned but would be useful. Regarding performance, the project team has made significant progress toward achieving its objectives, and most of the expected outcomes have been completed. The project approach flowchart demonstrated sound R&D methodologies. Accomplishments have been achieved on schedule. The future work mentioned involved publications.

PSH-TES Tool

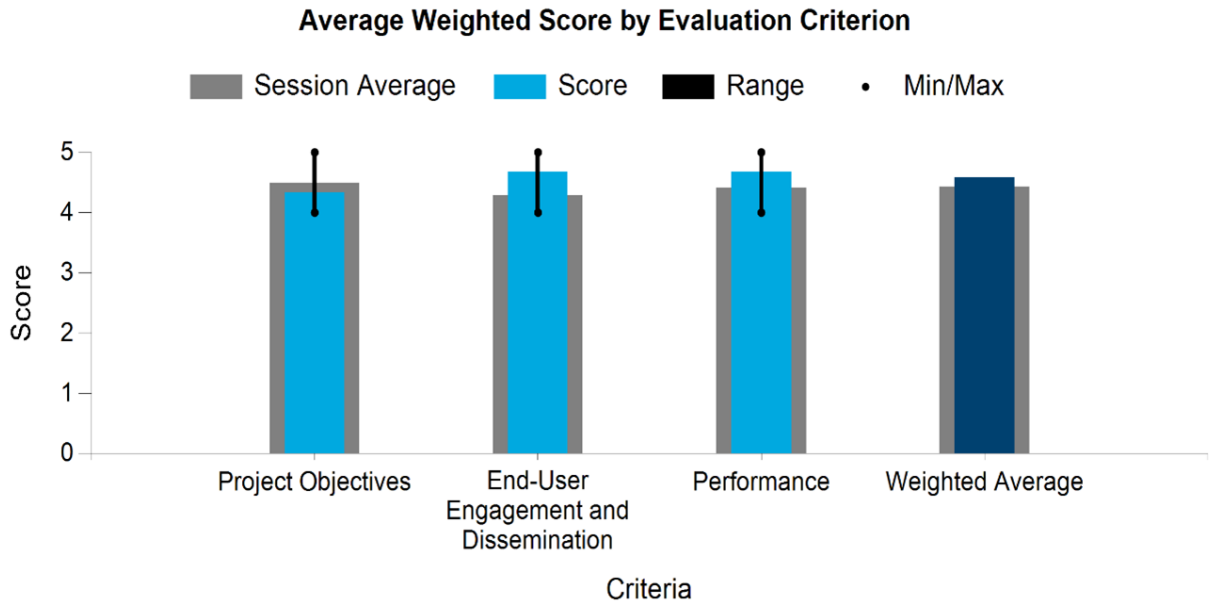
PNNL, Argonne

WBS:	1.2.1.606
Presenter(s):	Mark Weimar; Patrick Balducci
Project Start Date:	11/01/2018
Planned Project End Date:	09/30/2020

Project Description

PSH projects support various aspects of power system operations. However, determining the value of PSH projects and the many services and contributions to the electric grid they provide can be a challenge. To respond to this challenge, a five-laboratory consortium previously developed a PSH Techno-Economic Guidebook that defined extensive modeling approaches to evaluating the economic benefits of PSH projects. In addition, two case studies for potential PSH projects at Goldendale, Washington, and Banner Mountain, Wyoming, were undertaken to validate the approaches in the guidebook. Thus, the PSH Valuation Tool project was undertaken to develop a set of online tools that industry, regulators, and other stakeholders could use to evaluate new projects and additions to current PSH plants to determine the efficacy of their implementation.

During FY 2019 and FY 2020, the research team engaged in stakeholder discussions to determine the tool features that would offer the most significant impact to industry. The tool was developed to bring the guidebook to life. The web tool is a 15-step decision tree tool with a price-influencer approach and an embedded price-taker tool. The price-influencer approach allows prices to adjust as larger quantities of electricity flow onto the electric grid. The price-taker tool optimizes revenues subject to pumping and generating constraints across selected use cases for small projects (less than about 10 MW) that will not influence market prices. Both the price-influencer and price-taker tools can value bulk energy services, ancillary services, reliability and resilience, transmission infrastructure benefits, energy security benefits, and other indirect benefits. The tool also has an embedded benefit cost and financial tool and a multi-criteria decision analysis tool. In the 15th step, a report can be exported.



Aggregated Reviewer Comments

- The reviewer considers this project to be highly relevant for WPTO's mission, and it is a good continuation of the guidebook that the reviewer believes will be very useful for the industry in the United States and internationally. The project output and outcomes presented are good and supported by a well-written elaboration on the project's relevance. The reviewer encourages the team to elaborate more on the relevance of and plans to achieve the future outcomes to facilitate development and improve performance of future PSH facilities. They presented some information on project management, and it is good to read more details on budget with comments on delay and underspending. The accomplishments and results demonstrate good performance, and successful completion will yield meaningful short- and long-term outcomes. The reviewer recommends the team further detail their stakeholder and end-user strategy. The reviewer thinks it is good that the team has identified and queried stakeholders for relevant input, and it would be beneficial if representatives from this group are included in the review panel. They presented a broad definition of end users, and it may be beneficial to assess if they could start with a smaller group to build their user numbers. The team has started to disseminate the tool through workshops and to provide additional training through tutorials, etc. The reviewer also recommends that the team establish key performance indicators to demonstrate how they will attract, train, and retain users. They have a good presentation of future work, and it would be good if they also present a plan to complete these tasks. When presenting, the team shared that they have applied for funds to continue to fund, maintain, and develop this tool.
- The reviewer is very familiar with this project and thinks it is a great tool that is impressive, complete, and meaningful. It is great how the team solicited industry feedback before rollout. The reviewer cannot remember how many people were on the call, but it was significant. The reviewer hopes the team is keeping metrics on who and how many are using the tool. The reviewer inquired whether the team can tell where users get stuck so the tool can be improved. It was unclear to the reviewer how the team gets the word out about the tools. Suggestions for more outreach include having a "developers corner" on the FERC website under industries and hydropower that includes the tool, working with NHA to have a "developers corner" on their website where this tool could be included, and considering this approach with other associations. The reviewer imagines most original equipment manufacturers would consider placing this on their websites since most developers use their webpages for basic information on hydro equipment and projects. Most developers (independent power producers) would benefit a lot from this tool and do not have much technical depth, thus some of the inputs required may be difficult for them. For the above reasons, the reviewer wonders if it would make sense to develop a slim/easier/lighter version for independent power producers since they are developing 95% of the more than 90 proposed pumped storage projects.
- Regarding project objectives, the project created a PSH Valuation Tool that steps the user through a 15-step benefit-cost analysis process laid out in the PSH Valuation Guidebook. No project management plan was presented, though a timeline was provided. However, the timeline appeared to run from September 2020 to September 2021 and did not show tasks through the end of the project in September 2022. It was a confusing chart. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the report described a process where stakeholders were identified and queried for input for development of the valuation tool, and a tool review team was created. The project team has a good plan to engage industry and already has several meaningful disseminations. The report did not describe a tech transfer plan per se, but it did mention that it is creating a web-based valuation tool and that it is considering issues related to subscriptions, licensing, etc. Regarding performance, the project team has made very good progress and appears on track to complete the work. Insufficient details were provided to assess the soundness of the R&D methodologies, though the results presented suggests sound practices. Other than inconsequential delays and a Gantt chart that is not clearly presented, the project seems to be on track and hitting its milestones. A few items were listed as future work, and they seem consistent with the goals of the project.

HydroWIRES Topic B2: Improving the Representation of Hydrologic Processes and Reservoir Operations in Production Cost Models

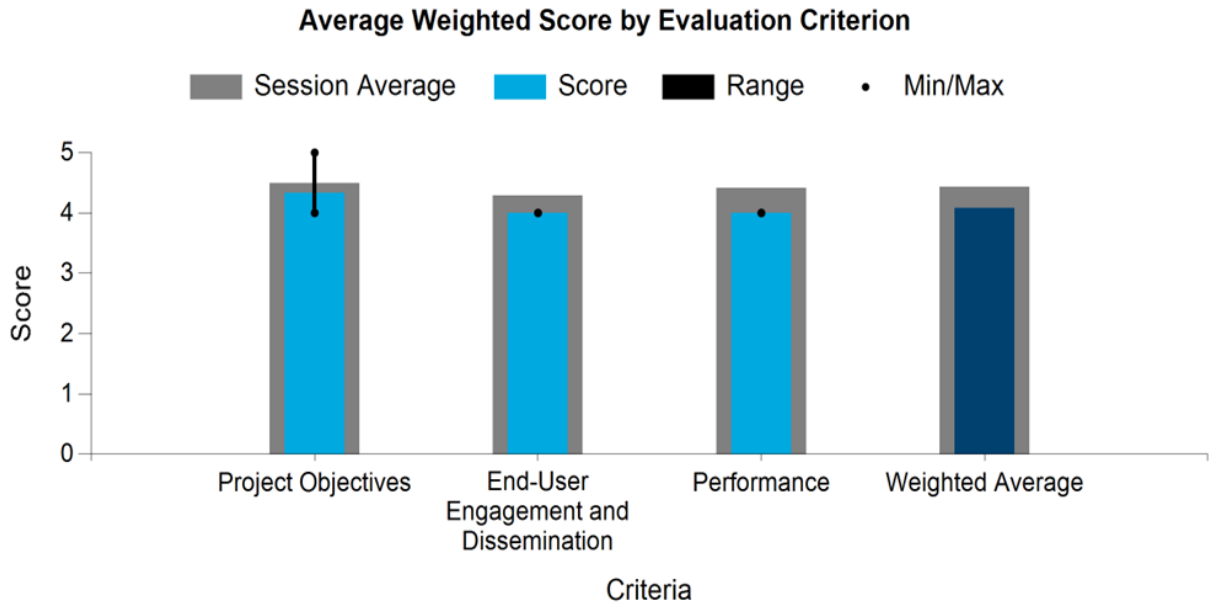
NREL, PNNL

WBS:	1.2.2.404
Presenter(s):	Greg Stark; Nathalie Voisin
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021

Project Description

Recent trends toward increased reliance on variable generation and emerging concerns about the impacts of climate and weather uncertainty on infrastructure systems have highlighted the growing need for improved hydropower modeling capabilities within grid operations models. To address this challenge, NREL is working with RTI International to develop an open-source modeling framework that enables the flexible specification of power system scheduling problems, including enhanced representation of water resource availability, hydropower constraints, and multi-stage stochastic programming capabilities. The platform combines the flexibility of NREL's Scalable Integrated Infrastructure Planning grid operations model with a generalized, river basin, decision-support system and network flow model, allowing optimization across both grid and river basin operations.

Demonstration use cases focus on research and enhanced planning in the water-energy nexus domain, including how to predict and make best use of water availability for hydropower production, discover trade-offs between water supply and hydropower generation, and predict and quantify the space-time dependencies and feedback connections between hydropower and variable generation (wind and solar), the water cycle, and other weather-related events.



Aggregated Reviewer Comments

- The project objective is highly relevant to WPTO's and HydroWIRES' mission. The objective and dataset will have a high value for the industry since it will provide a foundation that allows improved available flexibility and operational constraints as well as a template that can be used by commercial production cost modeling. This also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required to assess a plant's investment needs and costs. Furthermore, it may be beneficial to align parameters in this dataset with others from the HydroWIRES initiative. The team has a very good focus

on end-user engagement and dissemination. This is demonstrated by having already produced a substantial number of publications. They presented a good approach, and the reviewer considers this to be a high-performing project with good results and accomplishments. The presentation would benefit from increasing the focus on project management. This could enable others to learn more about how to conduct successful research programs. They have presented a good list for future work with a timeline. The reviewer encourages the team to start identifying solutions for how to maintain the dataset if that has not already been done.

- This is a great project. The reviewer appreciates the work on increasing the robustness of hydro models and that the team is coupling models. The team may also consider outreach to modeling companies used by the industry to make sure they incorporate this data. The team needs to think more about how it is going to best inform potential users since the team improved the model. Industry conferences are good, but the team has to make sure they are attended by potential users. Great work.
- Regarding project objectives, this project's goal is to improve hydropower's representation in power system models by actively coupling river basin (hydrologic) models with grid operations (production cost) models. No project management plan was presented, but milestones were presented on a basic timeline. No go/no-go decision points were listed, and risks were not mentioned. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. End-user engagement is light. This was addressed and explained during the peer review presentation. The project dissemination plan is also light, especially in terms of engaging the water power industry and users of production cost models. There is a no tech transfer plan to move the model (FLASH) to the broader community of users. Regarding performance, the project team appears to have made significant progress in developing the FLASH mode, but the model was not very well described. Insufficient details were provided to assess the soundness of the R&D methodologies, though the information provided suggests reasonable approaches were used. Except for a delay due to COVID, the project seems to be proceeding roughly as depicted on the timeline. Future work needed to complete the project was mentioned.

HydroWIRES Topic D1: CEM enhancements

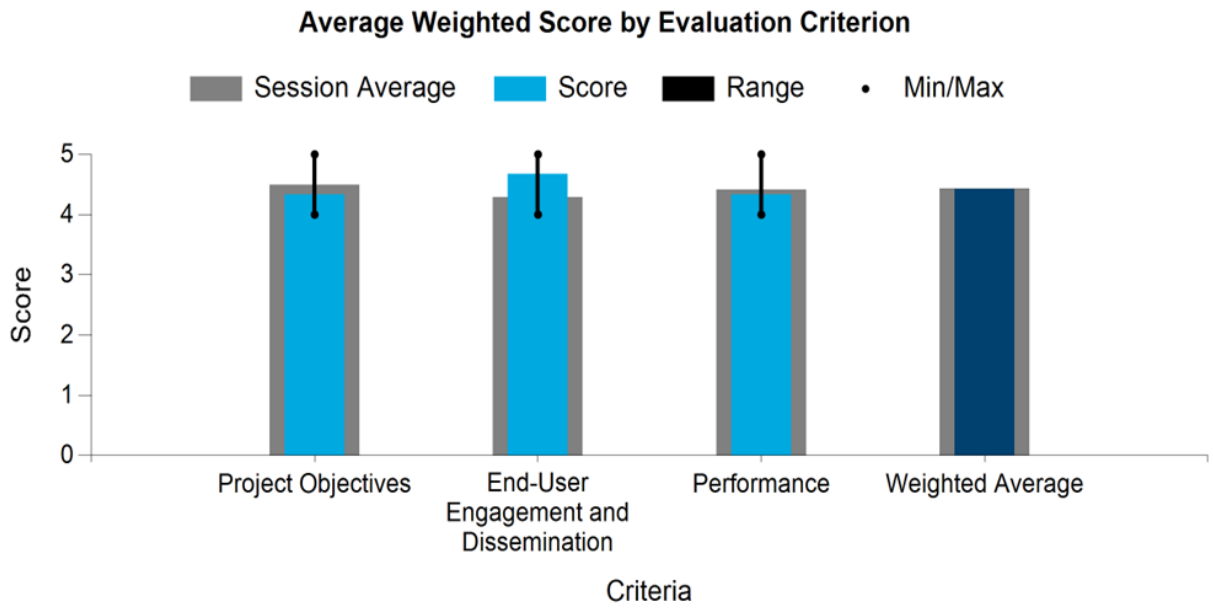
NREL

WBS:	1.2.2.405
Presenter(s):	Stuart Cohen
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021

Project Description

Long-term grid planning tools have difficulty representing detailed hydropower operating characteristics, which depend on technological specifications and water management practices and regulations. As a result, the value of hydropower is incompletely characterized, and the potential role of hydropower in the performance and resiliency of the future electric grid is not fully understood.

This work will fill that gap by developing new ways to represent hydropower resource, technology, and operational characteristics in electric sector capacity expansion models and implementing them in the open-source version of NREL's Regional Energy Deployment System model. This model is a well-established, national-scale, grid-planning tool used since 2003 by DOE and others to explore the evolution of the U.S. electric sector. Improvements will include a comprehensive national resource assessment for PSH and methods for modeling multiple hydropower technology categories characterized by technical, regulatory, and economic characteristics. The project will provide guiding principles and strategies for improving hydropower modeling in capacity expansion models and deliver a first-of-its kind, versatile PSH dataset. All data, code, and methods will be publicly available, allowing the industry to better identify the value of hydropower in the future electricity system and make more informed planning decisions.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since the project responds well to the challenge of limited access to the information necessary to support decision making by developing a dataset ready for analysis with an analysis method available publicly. The output and outcomes are well aligned with the objectives and have relevant applications for both short- and long-term perspectives. The team identified its end users, and there are many for a dataset and analysis methods like these. They engage stakeholders on an as-needed basis or in quarterly and report reviews. The reviewer encourages the team to involve stakeholders more actively in the process to ensure the project meets their needs. They have listed a number of dissemination activities that appear interesting, and the reviewer would appreciate a short description and link to these. The results and accomplishments demonstrate good performance. However, the reviewer encourages the team to present more on project management as this is an integral part of performance evaluation. It is also of interest to others to better understand how the team managed this type of project and if the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule and whether it progressed according to plan or what may have been a hindrance. The reviewer inquired if this is something that could normally be expected or if it was a one-time challenge. This type of knowledge is usually valuable to others conducting similar projects. The team presented an extensive list for future work that could benefit from more information on timeline, decision gates, etc. It would also be interesting to learn more about why these topics were proposed.
- The lack of robust PSH modeling has been a major issue facing the industry. For this reason, the reviewer appreciates the work this team is doing. The fact that the team's data will be integrated into the Regional Energy Deployment System model will provide more accurate information on the benefits and capabilities of PSH's ability, which, of course, has been lacking. The team's work will also provide a fairer representation when comparing hydro to other renewables. This is important because this database is used by the government for decision making and outreach. The reviewer agrees with the future work identified, and it is needed. Please continue outreach to others in the industry so they are aware of this project. Great job.
- Regarding project objectives, the purpose of this project was to develop new capacity expansion model capabilities and data to represent and understand hydropower and PSH flexibility, upgradeability, and deployment opportunities. No project management plan was presented, but some milestones and one go/no-go decision point were presented on the project timeline. Risks were not addressed. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, a diverse set of stakeholders were engaged, including several industry and national lab representatives. The project team interacted with industry stakeholders throughout the life of the project. A tech transfer plan was not articulated, though several useful forms of dissemination are planned (and occurring) that will lead to tech transfer. Regarding performance, the project team appears to have made significant progress toward achieving its objectives, and several accomplishments were mentioned. Insufficient details were provided to assess the soundness of the R&D methodologies, though the information that was provided suggests sound methods were employed. No Gantt chart (or similar) was provided for the project, so it was not possible to assess the schedule or challenges/delays. That said, the project is near completion and seems to have met its objectives. Several items were listed as future work, and they are consistent with the goals of the project.

HydroWIRES Topic A: Environment-Flexibility Win-Wins

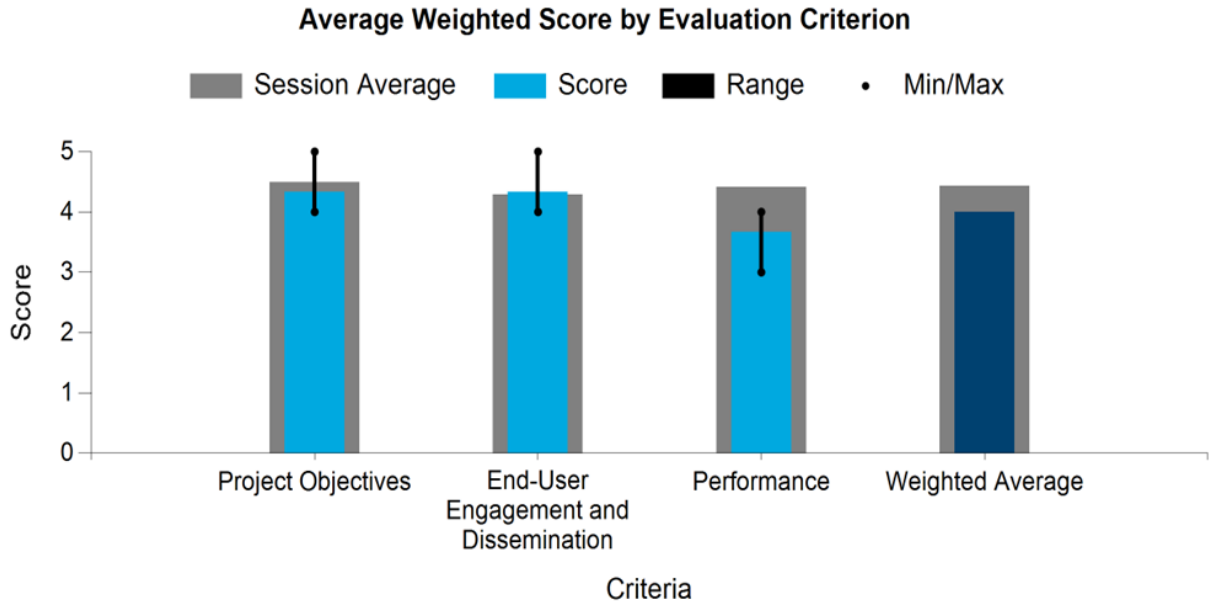
ORNL

WBS:	1.2.2.501
Presenter(s):	Brenda Pracheil
Project Start Date:	09/01/2020
Planned Project End Date:	03/31/2022

Project Description

The evolving role of hydropower to support increased contributions from variable renewable generation will change the way hydropower plants are operated and their environmental impacts as they are asked to ramp up and down and be available for generation if wind and solar are unavailable. The industry is just beginning to understand the role hydropower could play in the future grid and how interactions between power and environmental needs may point to research and policy gaps that need to be addressed as the grid decarbonizes.

Hydropower plants commonly have flow requirements created to protect biodiversity and ecosystem services provided by riverine ecosystems. However, it is currently not known whether or to what degree these flow requirements could limit the ability of hydropower to support more variable renewables in the power system. Moreover, climate change creates additional uncertainty and risk, affecting both power system reliability through increases in extreme weather and water stress that can affect ecosystems in a variety of ways. Therefore, there is a critical need to optimize trade-offs and co-design license requirements that address both environmental outcomes and power system needs at relevant scales. This project provides information that could be used by a cross-section of hydropower stakeholders involved in the FERC licensing process—such as hydropower operators, environmental and cultural resource interests, and state, federal, and tribal resource agencies—in the development of protection, mitigation, and enhancement measures for designing environmental and operational flows that create energy-environment win-wins.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since they focus on identifying win-win scenarios for hydropower and environmental solutions while keeping the objective of a reliable grid to enable the integration of variable renewable energy in mind. The reviewer thinks the team correctly addresses many of the relevant topics and found the discussion on ramp rates in an environmental context highly relevant and interesting. In the reviewer's opinion, hydropower is key for the energy transition on both system and environmental levels where it is important to find solutions to attenuate the flow due to fast up/down ramping of hydro and PSH. The reviewer thinks this research has accomplished much in terms of identifying constraints from many angles such as market, licensing, climate change, etc. The reviewer encourages the team to seek solutions in the design of hydro that can mitigate the environmental constraints for fast change in flow from the plants. The project outcomes and outputs support the project objectives and demonstrate accomplishments. The results and accomplishments demonstrate excellent performance. However, the presentation could benefit from an increased focus on project management, which is of interest to others to better understand how the team managed this type of project.
- This is the first time the reviewer is seeing a model that includes trade-offs between energy and environmental impacts for operators. The reviewer really likes it but struggles with how to actually quantify environmental benefits/impacts. On slide four, it would have been helpful to define milder impactive versus significantly. For example, the team could provide an example of what a significant environmental impact would be versus one mildly impactive. The reviewer looked at some of the other reports provided and sees that quantification of environmental impacts is not easily answered. The reviewer is hopeful the team's work will continue in this area. At any rate, the reviewer is very impressed with the work and looking forward to future results.
- This project sought to create conceptual and quantitative links between energy and the environment to find hydropower energy-environment win-wins. No project management plan was presented, though project milestones were shown on the project timeline. Go/no-go decision points and risks were not mentioned. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project involved a technical advisory group with members experienced in FERC hydropower licensing negotiations of environmental flow requirements. The members appear to be from relevant stakeholders. There is no tech transfer plan, though the project results will be disseminated in a project final report, peer-reviewed publications, and information available on HydroSource. Regarding performance, the project team completed the project and expects three publications (one published and two in review). The presentation infers that the objectives were achieved, but it is difficult to tell from the presentation. Insufficient details were provided to assess the soundness of the R&D methodologies, thought the outcomes suggest they were sound. No Gantt chart (or similar) was provided for the project, so it was not possible to assess the schedule or challenges/delays. It does appear that the project was finished on time. The future work discussion mentioned a follow-on project that will be initiated in October 2022.

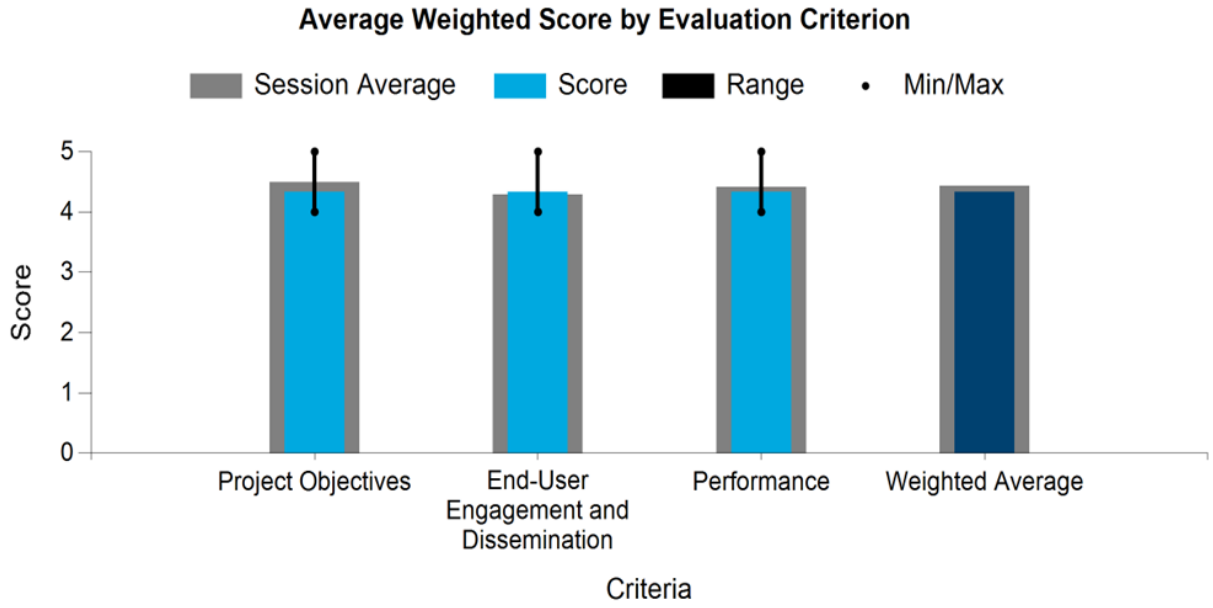
Hydropower Storage Capacity Dataset

ORNL

WBS:	1.2.2.504
Presenter(s):	Carly Hansen
Project Start Date:	09/01/2020
Planned Project End Date:	09/30/2021

Project Description

The Hydropower Energy Storage Capacity Dataset project documents and analyzes water storage patterns at existing hydropower facilities and translates this information into energy storage. In creating a national-scale dataset, this project brings together storage and facility characteristics from a variety of sources to describe boundary conditions and summarize patterns more consistently and comprehensively than was previously possible with any single dataset. The dataset provides a foundation for understanding potential resources that may support increasing storage needs of the evolving grid.



Aggregated Reviewer Comments

- The project objective responded well to WPTO's and HydroWIRES' mission. The objective and dataset will have a high value for the industry, and the aim to combine storage and facility characteristics at a national level is particularly innovative. This also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required to assess a plant's flexibility capabilities. The team included many relevant parameters, but the reviewer encourages them to evaluate if they could include parameters on reservoir surface area. In the reviewer's opinion, this could be valuable information to assess potential environmental impacts of flexible operation in reservoirs and if the reservoir is suited for it. For instance, large and frequent fluctuations in water levels may cause slope erosion and increase the risk of instabilities leading to landslides, etc. Furthermore, it may be beneficial to align flexibility metrics in this dataset with others from the HydroWIRES initiative. The team presented a good approach, and the reviewer considers this to be a high-performing project with good results and accomplishments. The presentation would benefit from increasing the focus on project management. This could help others learn more about how to conduct successful research

programs. The team presented a good list for future work, and the reviewer encourages the team to start identifying solutions for how to maintain the dataset if that has not already been done.

- The reviewer is grateful to see this work. It is so important to have correct data to make correct analyses, etc. The team's work synthesizing the data and documenting sources is also much needed. Working with data providers to set reasonable expectations on what the data can provide (resolutions, coverage, etc.) is a gap hydro has had to deal with. The reviewer likes that the team worked with other PIs and shared/communicated about the project to get their feedback. The reviewer inquired how the team can you get the word out about the dataset so others use it (since it is accurate). It would be great to work with an association (like NHA) and have them use the data in a press release, for example. The presenter stated that success will be measured by the number of projects using this data. The reviewer inquired if there is any way to facilitate them using it through outreach via a direct mail campaign, industry conferences, publications, etc. The reviewer recommends again working with associations to help with this. Great job on this project. It was much needed.
- The Hydropower Energy Storage Capacity Dataset project documents and analyzes water storage patterns at existing hydropower facilities and translates this information into energy storage. No project management plan was presented. A very general project timeline was provided, but the milestones shown do not match well with the four levels of map resolution presented in the approach. One go/no-go decision point was provided, but it was with regard to finalizing the scope of the dataset. Risks were not mentioned. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. The project team engaged stakeholders and end users in defining the expected outcomes for the dataset. End users were engaged in the data collection process when assembling the dataset. Dissemination is via three professional science conferences and an expected published report. No tech transfer plan is provided (or any overall strategy to get this information to the people who will use it), but the budget is modest, and there is no funding for much travel and dissemination. Regarding performance, the project team appears to have made good progress toward achieving its objectives with version one of the dataset published and version two due at the end of FY 2022. The methods employed seem appropriate to meet the stated objectives. No Gantt chart (or similar) was provided for the project, so it was not possible to assess the schedule or challenges/delays. Several items were listed as future work, and they seem consistent with the goals of the project, though quite general in nature.

HydroWIRES Topic B1: Enhancing the Representation of Conventional Hydropower Flexibility in Production Cost Models

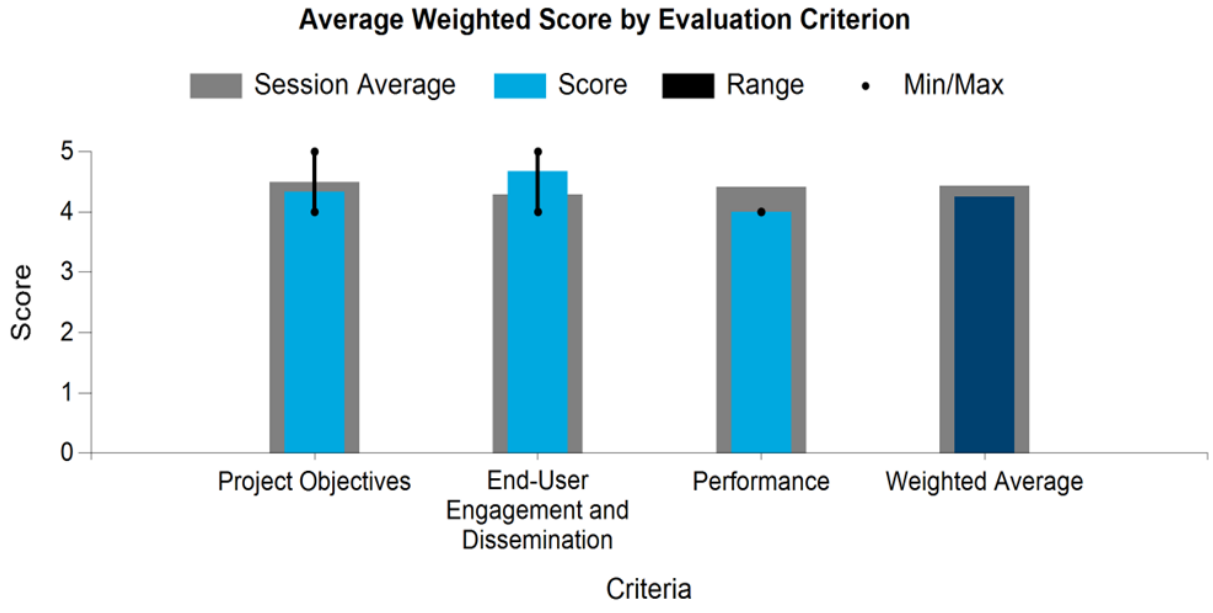
NREL, PNNL

WBS:	1.2.2.603
Presenter(s):	Greg Stark; Nathalie Voisin
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021

Project Description

U.S. institutional context leads to complex water management in which several water uses take priority over hydropower operations. Due to water management complexity, data availability, and computational tractability, the representation of hydropower in production cost models in support of reliability studies is limited to a combination of fixed hourly schedules from past observations and a monthly representation.

The team developed an approach for utilities to evaluate hydropower dispatch provided by reliability studies, quantify potential feasibility errors, and engage in a dialog between stakeholders to ensure power grid reliability. The team leveraged advances in large-scale hydrology modeling to enhance the current monthly representation to a weekly resolution with associated updates in the production cost model hydropower dispatch logic. The team also developed a proof-of-concept approach to translate complex hydraulic and market-driven hydropower operations into weekly hydro-economic surfaces to inform production cost model. Weekly hydropower datasets (generation and flexibility) spanning more than 20 years of water availability conditions were developed for more than 300 hydropower plants across the western United States. Evaluation of those datasets at the power grid scale confirms prior sensitivity of grid operations to water availability conditions while the change from monthly to weekly reduces wind and solar curtailment, which is a significant outcome in the evolving power grid to understand the value of hydropower in integrating those resources.



Aggregated Reviewer Comments

- The project objective responded well to WPTO's and HydroWIRES' mission. The objective and dataset will have a high value for the industry, and the aim to develop national-level data is particularly interesting. This also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required to assess a plant's investment needs and costs. Furthermore, it may be beneficial to align parameters in this dataset with others from the HydroWIRES initiative. The team has a very good focus on end-user engagement and dissemination. This is demonstrated by having already produced a substantial number of publications. The team presents a good approach, and the reviewer considers this to be a high-performing project with good results and accomplishments. The presentation would benefit from increasing the focus on project management. This could help others learn more about how to conduct successful research programs. The team presented a good list for future work with an indicative timeline. The reviewer encourages the team to start identifying solutions for how to maintain the dataset if that has not already been done.
- This is a much-needed research area focused on helping create more robust hydro datasets for use with reliability studies and realistic operations through water availability. Th team is including and evaluating market and regulatory impacts, which is great and much needed. It is great outreach to introduce datasets to commercial and open-source production cost model developers so what they have is more accurate and robust, and so is working with other interconnections. The reviewer is glad to see this research, which has been excellent to date, will continue. Great job.
- The objective of this project was to enhance the representation of conventional hydropower flexibility in production cost models. A project approach and timeline were provided, but there was no management plan. Key milestones were provided, but there were no go/no-go decision points. The project approach was hard to decipher from the slide provided; a verbal explanation will be needed to clarify. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. However, focused dissemination and some training on how to use and interpret the datasets may be needed. End-user engagement seems limited in this project. The project team has three disseminations in progress, and outreach and presentations to the water power industry are limited. There was no mention of a tech transfer plan per se, but the datasets produced have been connected with potential end users such as Energy Exemplar, Western Electricity Coordinating Council (WECC), Office of Electricity, and Office of Science. Regarding performance, the project is sunsetting and looks to have been completed on time and on budget. The project team implemented sound methodologies. Future work involves use of the datasets by appropriate (other) groups for whom it was intended (production cost model developers and users).

HydroWIRES Topic D3: Forecasting

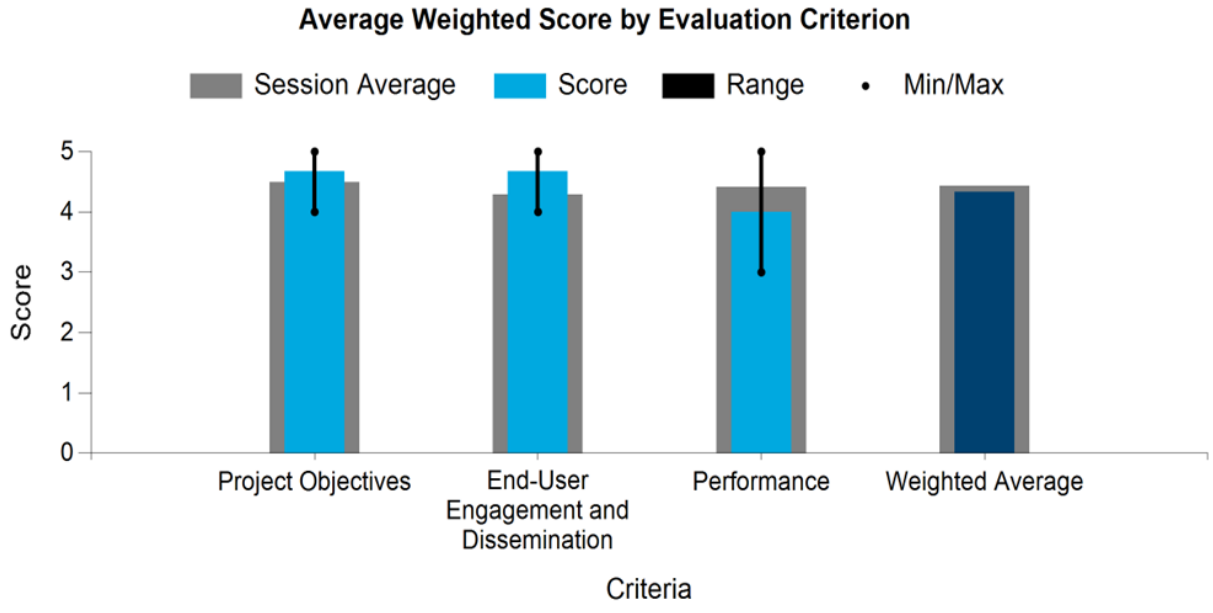
PNNL, INL

WBS:	1.2.2.604
Presenter(s):	Nathalie Voisin; Thomas Mosier
Project Start Date:	10/01/2019
Planned Project End Date:	09/20/2020

Project Description

Flow forecasts are used around the world to inform reservoir operations. A common practice for valuing climate service is to evaluate hydrometeorological forecasts according to their accuracy and quantification of uncertainty. For reservoir operations, a common practice is to evaluate how objectives are met and if, how much, and how often constraints are violated. While the needs for hydropower flexibility increases for the power grid, operations are perceived as constrained due to complex water management where many water uses take priority over hydropower. Another challenge is that storage is recognized as a value to the power grid but is not monetized because its value has not been quantified.

This project evaluated the sensitivity of bulk power system operations to flow forecast accuracy with the overarching objective to demonstrate the value of flow forecast beyond plant-scale revenues. With the western coastal interconnect as a case study, the team propagated medium-range flow forecasts onto hydropower generation forecasts all the way through bulk electric grid operations. The developed hydropower scheduling workflow allows quantifying the value of flow forecast for both independent producers and for integrated utilities and system operators, ultimately representing customers' wallets. A number of technical assistance projects have resulted from the project focused on pricing flow forecasts and supporting innovative scheduling for additional grid services. The workflow also informs new modeling approaches in academia to understand complex dependencies during compounded extreme events such as drought and heat waves.



Aggregated Reviewer Comments

- The project objective is highly relevant to WPTO's and HydroWIRES' mission. The objective and dataset will have a high value for the industry since it will provide a foundation that allows improved modeling of hydropower and hydrology. It is impressive that the team included forecasting for 85 locations. This also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required to assess a plant's investment needs and costs. Furthermore, it may be beneficial to align parameters in this dataset with others from the HydroWIRES initiative. The team has a very good focus on end-user engagement and dissemination. It is good to observe a list of measurable outputs. The team also presented a good timeline that show workstreams with decision gates. The team presented a good approach, and the reviewer considers this a good-performing project. It is good to observe that they decided to not go for some of the activities following the decision review meetings. The reviewer considers this a very good use of the intention of the project management plan and decision gates. The presentation would benefit from increasing the focus on project management. This could help others learn more about how to conduct successful research programs. The team presented a good list for future work with a timeline. The reviewer encourages the team to start identifying solutions for how to maintain the dataset if that has not already been done.
- This research project of quantifying non-monetized hydropower services is much needed and important to the industry. The presentation was well thought out and clear on the team's intentions. It is great that the team will be taking their findings and results and communicating them to software developers so they are aware of the current shortfalls. The team has an impressive industry committee; nice job. That the findings and research have the ability to reduce regional system costs by 10% is impressive in the Pacific Northwest. It really gives the research more credibility. The reviewer suggests including industry conferences, such as Clean Currents, in outreach. The reason being that this conference has technical, commercial, and C-suite decision makers attend, and it would be good for them to hear these accomplishments. The reviewer is glad this research will continue and looks forward to seeing the results.
- The purpose of this project was to investigate the value of flow forecasts to the power system. The presentation did an adequate job of justifying the changes to the project in dropping these forecast methods. A project approach and timeline were provided, but there was no management plan. Key milestones were provided on the timeline. Two of the original forecast tasks were not undertaken due to budget and timeline restrictions. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. The project involved adequate stakeholder engagement, including the U.S. Bureau of Reclamation, Brookfield Renewables, Tennessee Valley Authority, and Ontario Power Generation. There were several project meetings with stakeholders, and four presentations at industry meetings. The team is transferring outcomes via an SBIR project and a Centre for Energy Advancement through Technological Innovation Hydropower Operations and Planning Program flow forecast optimization project, and with WPTO. However, the plan for tech transfer is not clear. Regarding performance, the project produced some of the results initially intended but had to drop two important forecast methods: synthetic and physics based. The project team implemented sound methodologies and appeared to have a good approach. Some of the project objectives were met but not all. It appears the time required to complete the tasks was more than expected and beyond the modest budget of this project. The publication that was attached showed some useful results. Future work will be in a follow-on phase two project.

Scope Improvements to Power Flow and Stability Models

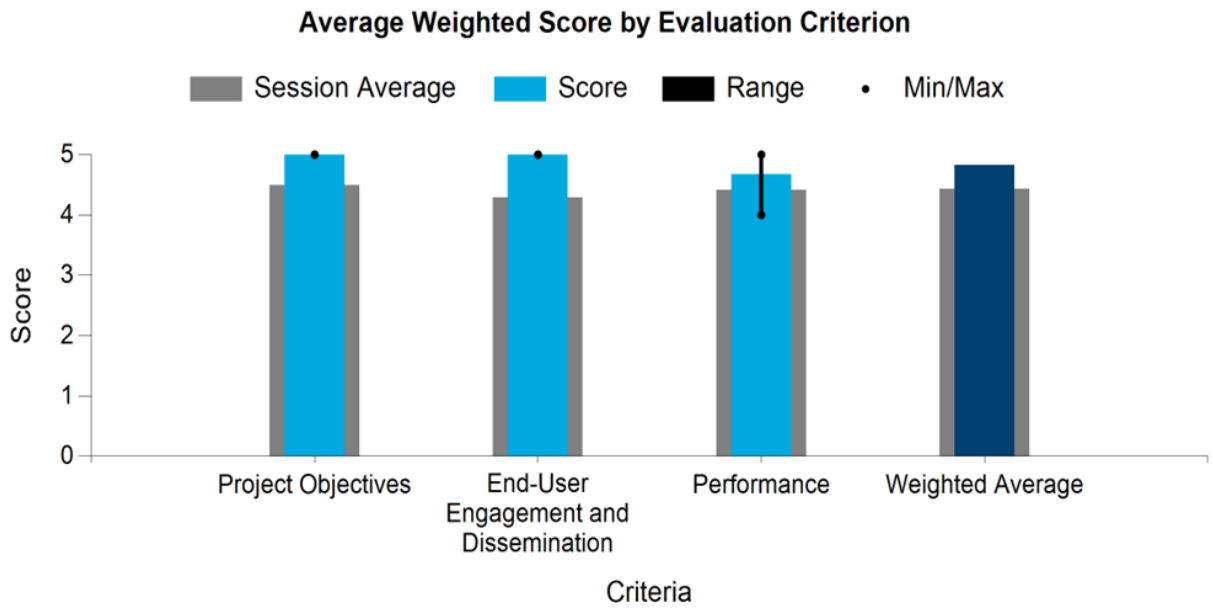
PNNL

WBS:	1.2.2.605
Presenter(s):	Slaven Kincic
Project Start Date:	09/01/2020
Planned Project End Date:	06/30/2021

Project Description

The project identifies hydropower misrepresentation in models used in power system operational and planning studies. Operational and planning system studies are a keystone of system reliability and decision making for system operation as well as for capital investments in electrical infrastructure. Hydro-based generation representation in the software and models used for operation and planning studies accounts for nominal water availability only, which leads to inaccurate results depending on water conditions in watersheds. Moreover, environmental constraints—such as maximum and minimum headwater elevation, minimum instantaneous flows, interdependencies among hydro plants, and others—are not represented in power system models. Identification and elimination of modeling gaps in hydropower plants can lead to more accurate evaluations of the contribution of hydropower to the resilience and reliability of the rapidly evolving power system.

During this project, the team heavily relied on interaction with the industry. The outcomes of this project are currently being leveraged to improve hydropower representation in the models used by WECC and its members for their reliability studies. In the long term, improving hydropower modeling will lead to more accurate power system studies and consequently help improve resiliency and reliability of power systems and emphasize the role of hydro in integrating other renewable resources.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since they focus on improving modeling of hydropower in the power system. The project outcomes and outputs support the project objectives and demonstrate accomplishments. The team presented a well-defined approach that demonstrates how they achieved their good results. This is supported by an excellent engagement strategy. The reviewer found the slides on industry feedback to be very interesting in terms of identifying the current status of and the need to improve modeling. It will be very interesting to observe what will be done in the extension of this project. The reviewer believes it will bring high value to the power system in the United States. The reviewer thinks this project could benefit from knowledge sharing and potential collaboration with Norway. The reviewer considers this to be a high-performing project and thinks the presentation could benefit from an increased focus on project management. The team elaborated on potential future work beyond the scope of this project, and it is great to observe that this project will be extended.
- This is a great research project. Hydro can really benefit from this project. The reviewer strongly agrees that most models are not robust enough for hydro. GE did outreach via webinars to stakeholders making decisions by way of models. They realized very few stakeholders actually understood the ability of the equipment because the models were developed using old technology (that is 25 to 50 years and older). The reviewer advises being sure to include the original equipment manufacturers in discussions. Working closely with the program vendors is also a great idea and would be a great way to get the word out to the industry. (They send out model improvements to their customers.) There are also several global experts on modeling the team should include in discussions. The teams of people the project team works with on this will be really important to the success of the project. The reviewer is glad this study is continuing. It is much needed.
- The project team investigated, evaluated, and prioritized modeling gaps of hydro generation representation in electrical models (power flow and dynamic models) that are used in power system operation and planning studies. This was a straightforward project, and the information presented provided sufficient information about the project management, timeline, and milestones. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. This project involved substantial stakeholder and end-user engagement, including input from communities at appropriate points in the project life cycle. A tech transfer plan was not part of this project, but the outcome did lead to an important and relevant follow-on project. Regarding performance, the project team appears to have made significant progress toward achieving its objectives, and several accomplishments were mentioned. Insufficient details were provided to assess the soundness of the R&D methodologies, though the information that was provided suggests they may be sound. No Gantt chart (or similar) was provided for the project, so it was not possible to assess the schedule or challenges/delays. Several items were listed as future work, and they seem consistent with the goals of the project.

Life Cycle Assessment of Storage Technologies

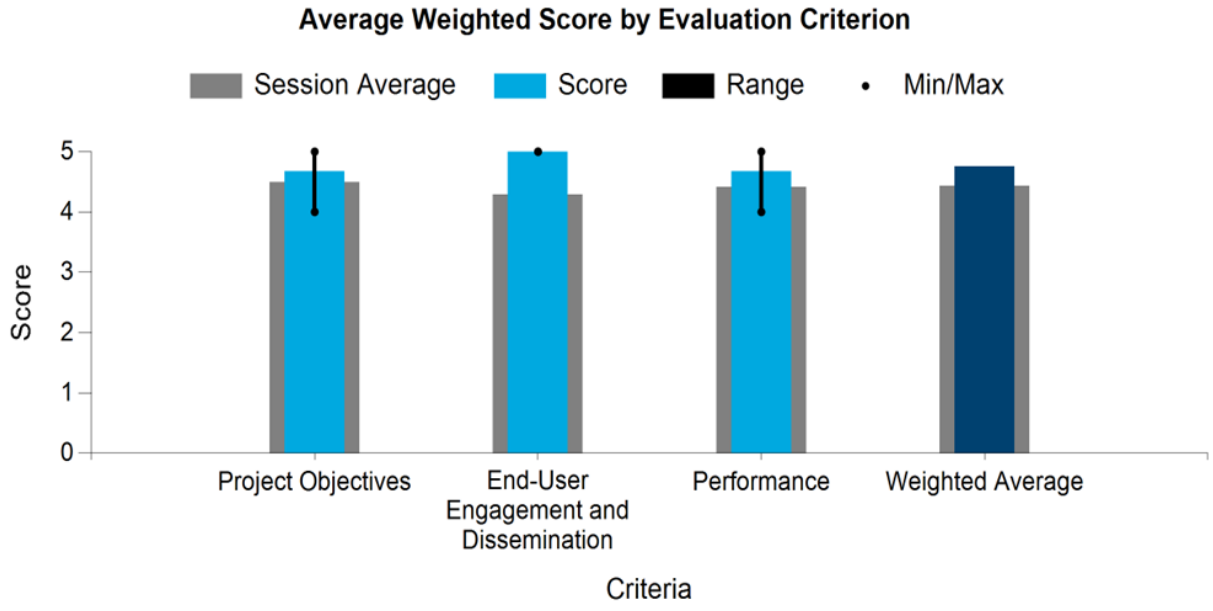
NREL

WBS:	1.2.3.405
Presenter(s):	Danny Inman; Greg Stark
Project Start Date:	09/15/2020
Planned Project End Date:	09/30/2022

Project Description

PSH is expected to be part of this solution to achieve U.S. clean energy targets because of its ability to provide grid flexibility and stability and enable the dispatching of variable renewable energy technologies. Despite PSH being a mature technology with a history of deployment dating back several decades, there is very little information on the greenhouse gas (GHG) implications of PSH as compared to other storage technologies.

The objective of this project is to perform a full life-cycle assessment of new PSH projects in the United States. This life-cycle assessment includes all project phases (resource extraction, construction, operation, maintenance, and end of life). Data used in this study are based on more than 30 potential PSH projects that are in preliminary planning phases and represent a wide range of potential closed-loop PSH systems in terms of location, technology, and capacity. The GHGs and energy return on investment from PSH will be compared to other storage technologies (e.g., stationary battery storage). Results from this project will improve the PSH community's and decision makers' understandings of the environmental impacts and sustainability of new PSH projects and how PSH compares to other storage technologies. The analysis framework (source code and data) will be made publicly available at the end of the project. In addition to reporting results for the base case, the team will perform a rigorous sensitivity analysis to identify the major drivers and understand the impacts of different configurations and future energy markets.



Aggregated Reviewer Comments

- The project is sunsetting and presents as a success. The reviewer considers the project objectives to be highly relevant for WPTO since they perform a full life-cycle assessment of new PSH. The reviewer thinks the fact that they include all project phases supports the objectives, and intended outcomes respond very well to WPTO's and HydroWIRES' mission. The reviewer thinks the results of this project will highly benefit the discussion on storage technology and will help guide decision making. The team presented a well-defined approach that demonstrates how they have achieved their good results. This is supported by an excellent engagement strategy with a technical review committee that comprised nine representatives from industry, government, and academia. Furthermore, the team presents an excellent dissemination plan, and it is good that the data and software will be made publicly available with guidance on how to use the tool. This work is also part of cross-DOE efforts, such as the Energy Storage Grand Challenge, that the team will use to disseminate this information and consider more comprehensive, multi-technology, life-cycle assessment studies.
- The reviewer liked the topic of this study. This is relevant and interesting research. The reviewer inquired why the team only looked at closed loop. The reviewer's concern is only a couple of these projects have done in-depth designs. Because of this, there could be significant changes after more engineering design work is done (such as doubling the size of the project). The reviewer is not sure how that could impact these findings. The reviewer realizes the majority of proposed U.S. PSH projects are closed loop, but many of the investor-owned utilities are now looking at open loop (due to the use of existing infrastructure originally built into the plants). The likelihood of an investor-owned utility being first to build a new PSH is strong. It was unclear to the reviewer if this will impact the conclusions. The reviewer inquired if the team considered including newly built PSH in Europe in this research and if that information would be relevant to the study. The outreach was great and impressive. The reviewer would have liked to see proposed next steps to continue the research.
- The project objective was to perform a full life-cycle assessment for GHGs and energy return on investment of new PSH projects in the United States. A project management plan was not provided, but the scope of the project was small and straightforward. There were no well-defined milestones, go/no-go decision points, or risks addressed. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. There was significant stakeholder and end-user engagement with industry and the International Forum on PSH. A technical review committee was formed and provided substantial input from relevant stakeholders. There is a tech transfer plan, though it is not articulated in any detail. Regarding performance, the project was completed on budget and appears to have been completed on time. Sound methodologies were employed to perform the life-cycle assessment.

HydroWIRES Topic C: Quantifying Reliability/Resilience

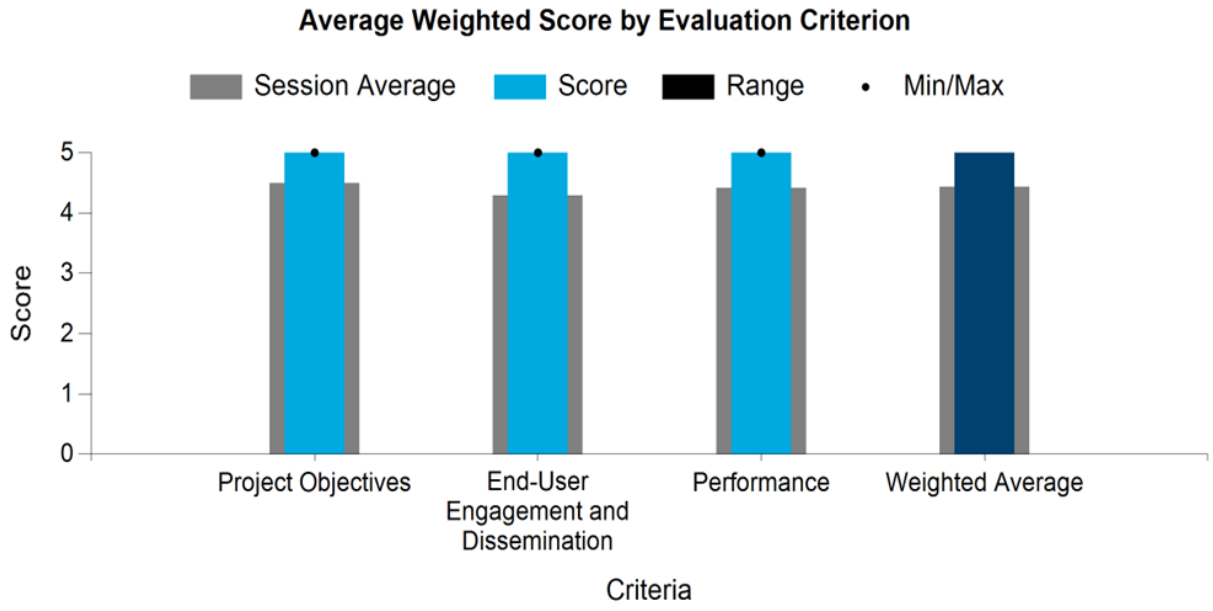
PNNL, Argonne, INL

WBS:	1.2.3.601
Presenter(s):	Abhishek Somani
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2020

Project Description

Hydropower facilities are often crucial in responding to extreme grid events due to their agility and flexibility. They can quickly change both their real and reactive power outputs to provide voltage support, inertial response, primary frequency response, and operating reserves. However, no standard practices exist to quantify the contributions of hydropower resources, especially for non-market and non-monetized grid services. This project was designed to identify tools, methods, models, and datasets to quantify hydropower's contributions to grid resilience.

The key outcomes of this project include a framework to quantify hydropower's contribution to grid resiliency in the Western Interconnection and application for the current generation mix. Models and tools used in this study are accessible to the hydropower community to support decision making for future operations. The longer-term outcome includes an improved understanding and quantification of hydropower's value to the power system and overall improved grid security made possible by utilizing hydropower's flexibility.



Aggregated Reviewer Comments

- The project objectives contribute to WPTO's and HydroWIRES' mission through quantifying benefits and value of hydropower for the system. The project outcomes and outputs support the project objectives. It is a very interesting outcome that the project team identified that hydropower constitutes 20% to 25% of capacity but contributes 30% to 60% of frequency response. Hydropower is also the largest contributor of voltage support. It is also good to observe that they obtain similar results in the simulations as in real-time data. They have presented a well-defined approach with a solid logic that demonstrates how they have achieved their good results. This is supported by an excellent engagement strategy. The reviewer considers this to be a high-performing project and thinks the presentation could benefit from an increased focus on project management.

This is of high value for others to learn and better understand how to execute a successful research program. They have not presented recommendations for future work, and it could be because they are not required to since the project is completed. However, the reviewer recommends the team do this as it will provide guidance for stakeholders and others who consider further developing the models. Please note that this comment is not considered in the scoring.

- The reviewer gave the project a perfect score. This is great work and a great research topic: extreme events and how hydro responds. This needs to be more recognized. The reviewer really liked the outreach to policymakers. The reviewer thinks that this was the only PI to do that. The reviewer likes the facts on hydro's contribution to ancillaries and hopes the team looks at other ancillaries as well for their contributions to the study. The reviewer is glad to see the project is continuing and looks forward to seeing the results.
- This project was designed to identify tools, methods, models, and datasets to quantify hydropower's contributions to grid resilience. A project approach and timeline were provided, but there was no management plan. Key milestones were provided, but there were no go/no-go decision points. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project involved a great deal of stakeholder engagement, including with the California Independent System Operator (CAISO), WECC, NERC, and USACE. The project team made several disseminations both to the water power industry and directly to some stakeholders. A paper produced from the project received the best paper award at Resilience Week 2020. There was no mention of a tech transfer plan, but the outcome has led to a follow-on project. Regarding performance, the project was completed on time and on budget. The project team implemented sound methodologies. Future work involves analyzing future extreme events and the role of hydropower in supporting grid resilience.

HydroWIRES Topic D2: Transmission/Storage Equivalence

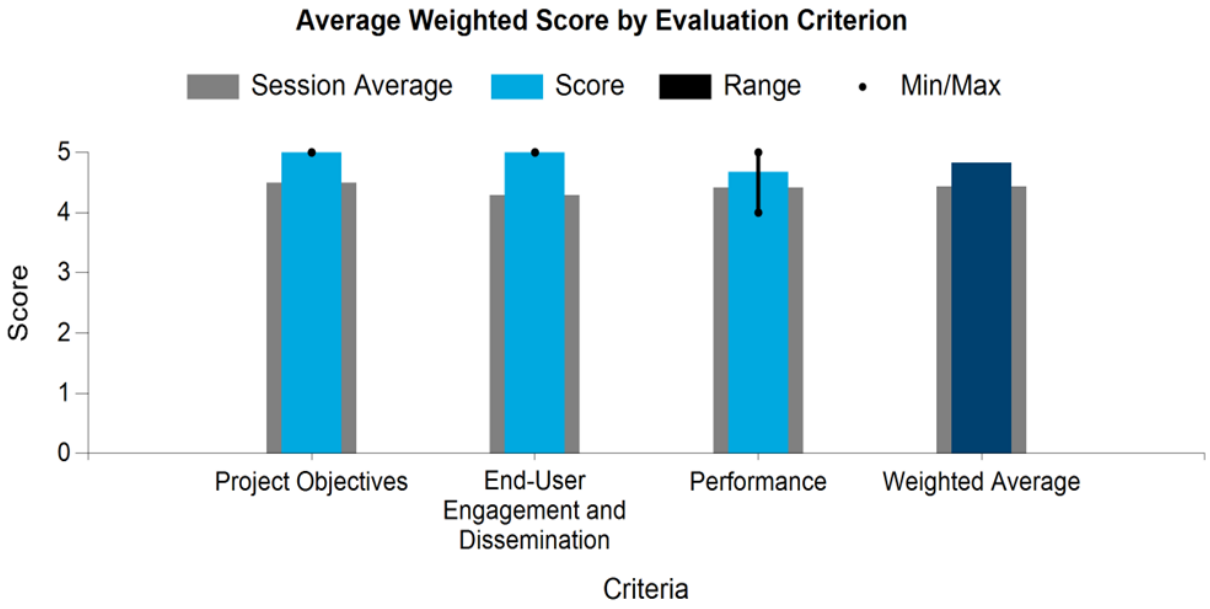
PNNL, Argonne

WBS:	1.2.3.602
Presenter(s):	Jeremy Twitchell; Zhi Zhou
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2021

Project Description

In 2017, FERC issued a policy statement that would allow PSH and other energy storage assets to provide both regulated transmission and competitive market functions, but regional market operators have struggled to implement enabling regulations. This project seeks to objectively inform regulatory proceedings on dual-use energy storage by developing a participation framework for dual-use storage assets and quantifying their potential value to the grid.

The outcome of this project is to identify the regulatory and operational challenges that impede the usage of storage for regulated transmission and competitive market function, potential solutions to those challenges, and the value of dual-use storage assets on the grid. The project team will achieve those outcomes through open-source models and publications: Transmission/Storage Equivalence Model (open-source models and journal publication), Participation Framework (open-source models and technical report), and Dual-use PSH Valuation (technical report).



Aggregated Reviewer Comments

- The project objectives contribute to WPTO's and HydroWIRES' mission through identifying regulatory and operational challenges that impede the use of storage for regulated transmission and competitive market function. The team presented a well-defined approach with a solid logic that demonstrates how they have achieved their good results. This is supported by an excellent engagement strategy. The reviewer considers this to be a high-performing project and thinks the presentation could benefit from an increased focus on project management. This is of high value for others to learn and better understand how to execute a successful research program. It is also good to note that this project received additional funding to extend and increase the scope of this study.

- This is a great topic. The project has achieved great results so far in a topic that has been discussed for years with no success. Please do not forget to include original equipment manufacturers in outreach. Design can be done differently, if needed, to optimize the dual-use scenario. Since this is such an important topic to the industry, the reviewer inquired where else the team could take this project if given additional funding. The reviewer would have liked to have seen more in-depth next steps. Otherwise, great job.
- FERC now allows PSH and other energy storage assets to provide both regulated transmission and competitive market functions. This project seeks to objectively inform regulatory proceedings on dual-use energy storage by developing a participation framework for dual-use storage assets and quantifying their potential value to the grid. No project management plan was presented, but a project approach and timeline were presented. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project team had significant engagement with grid operators, regulators, industry, developers, and other stakeholders. A modeling advisory group involved relevant stakeholders. The project outcomes have been disseminated at workshops for state regulators, at industry conferences, and via publication. There is no tech transfer plan per se, but the work led to a follow-up project. Regarding performance, the project team completed the project on time and under budget, so they added a few additional tasks. The results presented, combined with the approach, suggest sound R&D methods were applied. The timeline showed some key milestones, which appear to have been achieved. Future work was described in the context of a follow-on project.

Idaho Power ROR Hydropower and Battery Modeling

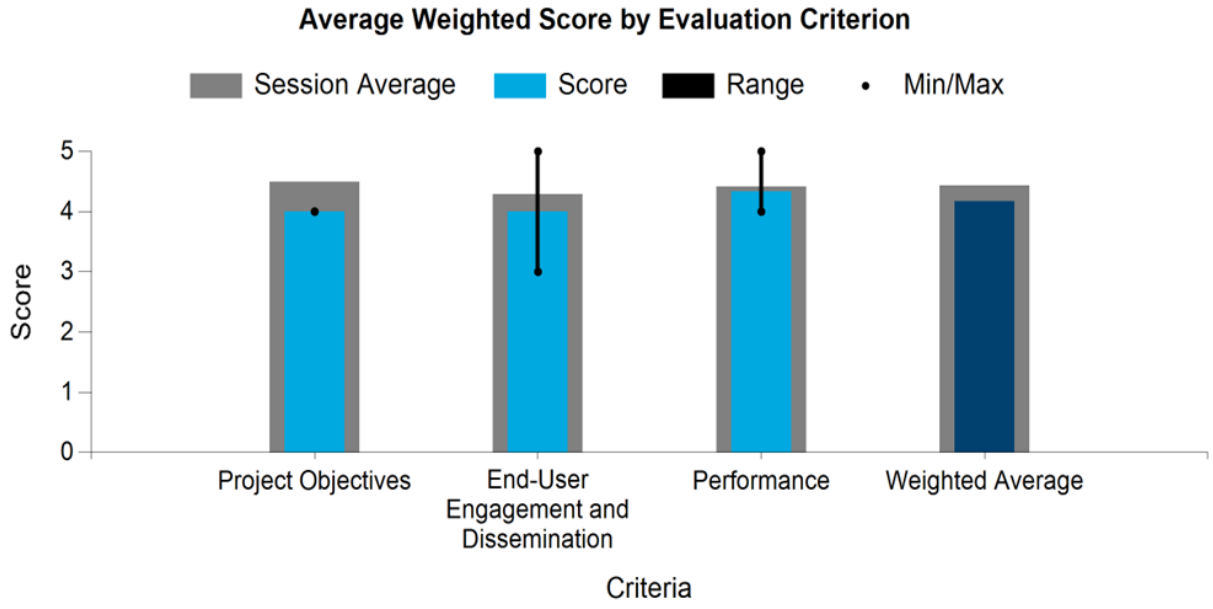
PNNL

WBS:	1.2.3.604
Presenter(s):	Feng Pan
Project Start Date:	09/01/2020
Planned Project End Date:	09/30/2022

Project Description

The project's objective is to assess the benefits of hybrid RoR hydroelectric generators and battery storage resources from a large power operator's, such as a vertically integrated utility or a system operator, perspective. Hybridization of resources can potentially provide dispatchable electricity and flexibility required to reach clean energy goals. All generating resources need to be accurately represented in power system operation to satisfy a list of physical, engineering, regulatory, and environment conditions unique to individual power operators. Energy storage and RoR hybrids have operating constraints different from conventional resources, making them more difficult to model in an optimization process. As a result, generic and simplified representations are generally used to solve for the commitment and dispatch for energy storage hybrids, which may lead to sub-optimal outcomes.

PNNL, working with Idaho Power Company, will develop an accurate hydro-generation and RoR and battery storage hybrid resource representation model to represent the new combination of resources in day-ahead planning. Models for siting and sizing energy storage for RoR will be developed to assess the benefit of RoR and energy storage hybrids. In this project, the proposed High-Performance Power-Grid Optimization–Hybrid System model will be developed to satisfy required modeling and operation constraints at a large utility scale to ensure the transition of the developed solution to industry.



Aggregated Reviewer Comments

- The project objectives are a great contribution to WPTO's and HydroWIRES' mission. It seeks to enhance the performance of RoR plants through investigating the benefits of operating RoR and battery storage as a hybrid generation source. They have a well-presented approach that supports the objectives and outcomes. The reviewer thinks they have a good focus on system evaluation of the benefits as well as on identifying necessary measures to be done at the plant level. The commercialization potential is large considering the number of RoRs around the globe and the apparent need to enhance their performance to better support the grid. This could greatly contribute to flexibility and reliability in the long term. They have engaged well with their selected partner with a good focus on technology transfer. This project could potentially have a good impact globally, and the reviewer encourages the team to evaluate how they could expand intended end-user groups and disseminate broadly. The reviewer considers this to be a good-performing project and thinks the presentation could benefit from an increased focus on project management. This is of high value for others to learn and better understand how to execute similar programs. This project may also benefit from sharing knowledge and potentially collaborating with X-FLEX in Europe and Vattenfall in Sweden, which both conduct similar research.
- This is a nice research project with a relevant and clear strategy. It has a strong project partner in working with Idaho Power. It was unclear to the reviewer whether it would have helped to work with other utilities in addition to Idaho Power to improve the tool or the increase the relevancy. The reviewer also inquired how the project team intends to communicate and rollout findings and benefits of the tool to the industry. Otherwise, great work and nice job.
- This project will support vertically integrated utilities to reach their clean energy goal by investigating the benefits of operating RoR and battery storage as a hybrid generation resource. No project management plan was presented, but the project approach was described with a project timeline and milestones. No go/no-go decision points have been identified, but the project plan seems reasonable and appropriate. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes, especially for Idaho Power Company. Regarding end-user engagement and dissemination, the project team has engaged and contracted with their primary end-user, Idaho Power Company. A potential weakness of the project is the lack of a dissemination plan for communicating results to the broader water power community. However, given the very small budget for this project, there are no resources for travel and dissemination. There is a no tech transfer plan other than adoption of the High-Performance Power-Grid Optimization–Hybrid System model by Idaho Power Company. Regarding performance, the project PI has made significant progress toward achieving the objectives. The methodologies employed to solve this problem are appropriate and sound. Accomplishments for the project appear to be tracking with the timeline, though it is difficult to tell from the information presented. Several items were listed as future work, and they seem consistent with the milestones listed for the project.

PSH Portfolio Evaluation and Innovation Study

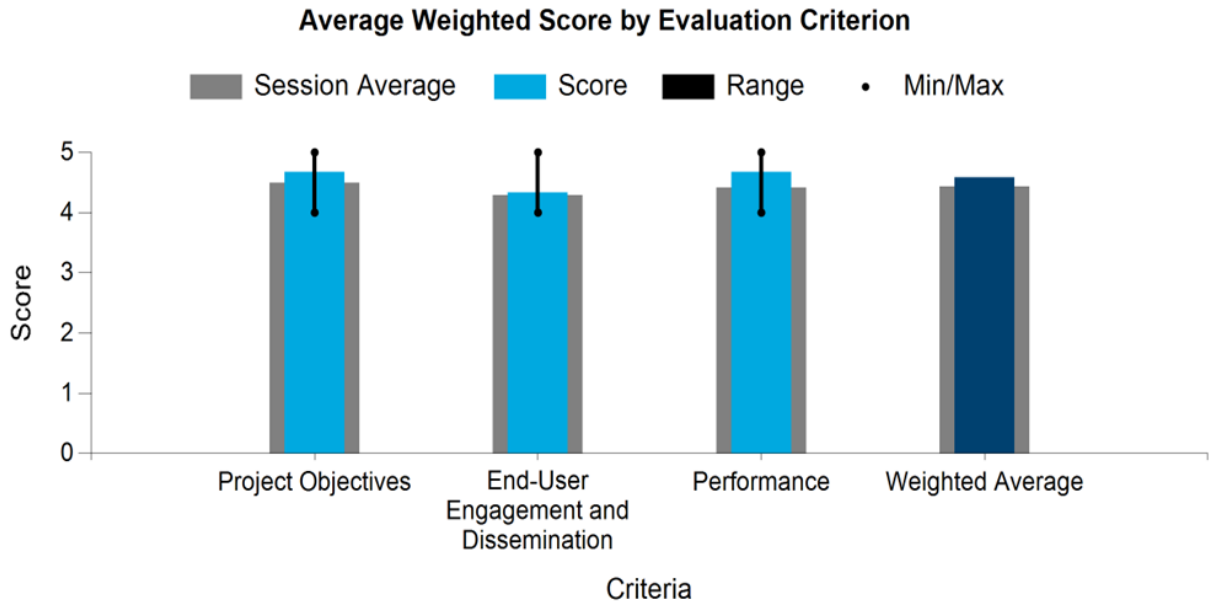
Argonne

WBS:	1.2.4.004
Presenter(s):	Vladimir Koritarov
Project Start Date:	09/01/2020
Planned Project End Date:	09/30/2021

Project Description

While PSH has been around for many years, the technology is still evolving. A significant amount of research is currently being conducted to develop new PSH designs and technologies that may have the potential to accelerate the development of new PSH projects.

The objective of this study was to provide a comprehensive review of the current state of PSH technology, the latest trends in PSH plant design and configurations, and an objective assessment of proposed new PSH concepts and technology innovations. The study provides a detailed review of 12 innovative PSH concepts and technologies, using a set of predefined evaluation criteria. The study also discusses potential ways to add PSH capabilities to existing hydropower plants, and innovative excavation and dam construction methods that could accelerate the construction of new PSH projects. The study supports the development and deployment of innovative PSH technologies by identifying and benchmarking the most promising new technologies that may be able to significantly reduce the cost, time, and risk for the development of new PSH projects. The key findings of the study are published in a HydroWIRES technical report and presented at industry conferences and other events.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since they aim to provide a comprehensive view of the current state of PSH technology, latest developments in design, and an objective assessment of concepts and innovations. The reviewer thinks they correctly address many of the relevant topics and use good evaluation criteria and metrics. This leads to a highly interesting evaluation of LCOE that can inform a broad range of stakeholders and enable informed decision making. The project outcomes and

outputs support the project objectives and demonstrate accomplishments. They provided more information on the risk assessment that is part of the project objectives when presenting. They shared they identified financial risk as the main one and only found limited technology risk. They presented a good plan for engagement and dissemination with a solid focus on technology development. The results and accomplishments demonstrate excellent performance. However, the presentation could benefit from an increased focus on project management. It is of interest for others to better understand how to manage this type of project. It is great to note that WPTO is actively developing new projects based on this one.

- This project was very interesting. Some of the levelized costs of storage are amazing with the various PSH technologies. The reviewer recommends in the future also taking into account technical risk. These same developers also reach out to the original equipment manufacturers and, as a result, perform deep technical dives. In this way, the team could also include this category. The presenter said that a targeted audience is lending and financial organizations. The reviewer agrees but wonders how the team intends to get the word out to these organizations. NHA does occasionally have finance summits, which could help. Bottom line, this project did a nice job and was very interesting.
- The objective of this project was to provide a comprehensive view of the current state of PSH technology, the latest trends in plant design and configurations, and an objective assessment of proposed new PSH concepts and technology innovations. A project approach and timeline with a few words about a management plan were provided. Key milestones and a go/no-go decision point were provided. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project involved a great deal of stakeholder engagement, including an external panel of reviewers. The project team made several disseminations to the water power industry and published a final report. There was mention of a tech transfer plan to help PSH innovators in advancing their technologies. Regarding performance, the project was completed on time and on budget. The project team implemented sound methodologies. Future work mentioned assisting companies in commercialization.

Integrated Hydropower and Energy Storage: Providing Essential Reliability and Ancillary Services Using Individual or Coordinated Hydropower Plants

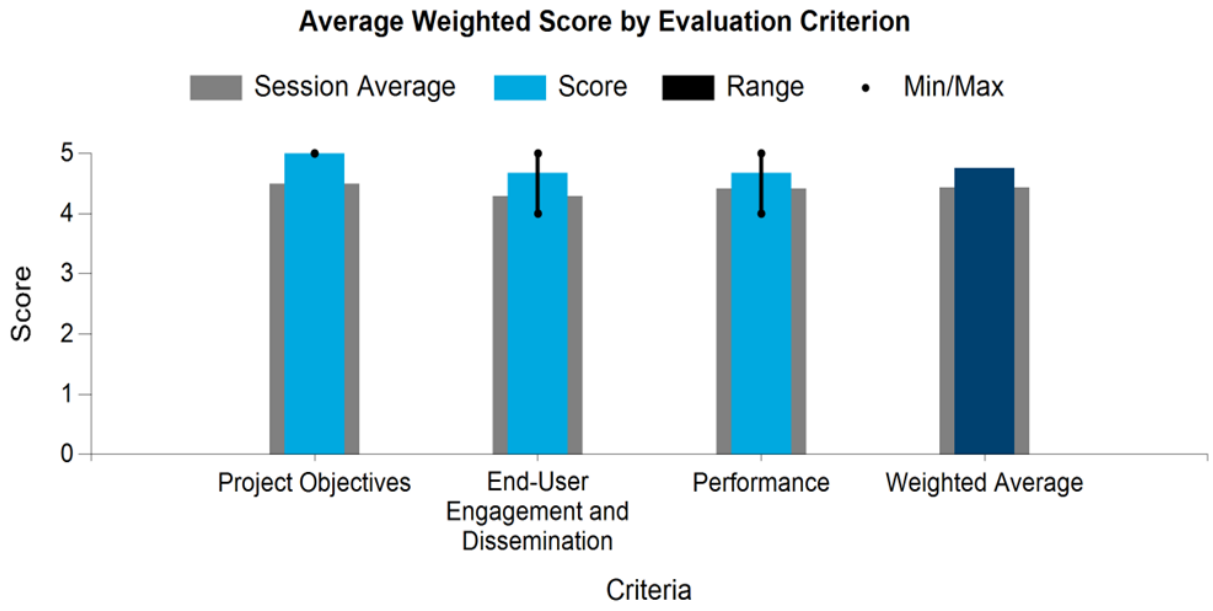
INL, NREL

WBS:	1.2.4.101
Presenter(s):	Vahan Gevorgian; Thomas Mosier
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021

Project Description

This project evaluated the feasibility and benefits of integrating hydropower plants and energy storage devices to enhance market participation and enable grid islanding. The approach is agnostic to the type and number of energy storage devices and hydropower generation assets used. The project team worked with Idaho Falls Power to demonstrate black start using their RoR hydropower plants and ultracapacitor energy storage system and developed a tool to recommend battery sizing for enhancing market participation in CAISO.

Intended outcomes included increasing competitiveness of hydropower plants as electricity markets evolve to favor higher amounts of flexibility. The status quo is that hydropower plant owners feel a high degree of uncertainty about the value proposition of hybridization. This work helps them take the first step. Another outcome was to enable small hydropower plants to provide black start and grid islanding capabilities to local critical loads. The status quo is that diesel generators are typically used for initial black start and then small hydropower plants are brought online. This approach enables black start without diesel generators.



Aggregated Reviewer Comments

- The reviewer considers this project to be highly relevant as the potential of small hydropower and how it can potentially contribute to flexible, reliable, and stable grids should not be underestimated. In addition to these advantages, they have a short construction time and low environmental impact, are easy to design, and can melt into the landscape. The downside is high LCOE such that it may be challenging to identify economically viable sites, but there is good potential to develop and construct in bundles. They present a good approach with a focus on both market participation and black start with ultracapacitor support. The reviewer considers this

to be a high-performing project with good results and accomplishments, and the presentation would benefit from increasing focus on project management. This could enable others to learn more on how to conduct successful research programs. One interesting finding from small hydro in Norway is that governor parameters are not adjusted for a site and are set to "standard manufacturing values." This is okay with a few in the same grid area but could potentially cause big problems when there are too many of them. Statnett, the Norwegian transmission system operator, tested this on a full scale on an islanded grid. These findings support the relevance of this research project.

- This is a very interesting project. The interviews by Energy I-Corps of 75 people across the industry provided great feedback. The project certainly met the intent of the HydroWIRES Program. There were also great research topics covering black start and valuation of hybridization. The future work in making the model more robust, such as taking into account location and specific plant criteria, will make the tool even more valuable. The reviewer liked that the team demonstrated black start capability first in the lab and then at a real plant. There was a great rollout and communication plan. This project was really impressive and had great results that will be a great tool for the industry.
- This project evaluated the feasibility and benefits of integrating hydropower plants and energy storage devices to enhance market participation and enable grid islanding. There were two main outcomes: the team conducted a field demonstration with Idaho Falls Power to demonstrate black start using their RoR hydropower plants and ultracapacitor energy storage system and developed a tool to recommend battery sizing for enhancing market participation in CAISO. A project approach and timeline were provided, but there was no management plan. Key milestones were provided, but there were no go/no-go decision points. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project involved a great deal of stakeholder engagement, including CAISO, WECC, NERC, and USACE end users via 75 interviews (conducted by Energy I-Corps) and through engagement with the project partner, Idaho Falls Power. The project team made several disseminations, primarily via the Institute of Electrical and Electronics Engineers (IEEE) or lab or journal publications. More dissemination directly to the water power industry would have been beneficial. There was no mention of a tech transfer plan, but the models developed were posted on GitHub and provided to Idaho Falls Power. Regarding performance, the project was completed on time and on budget. The project team implemented sound methodologies and produced outcomes that, due to their complexity, would have been very difficult for a utility to do. No future work was mentioned since the project is complete.

FAST Commissioning Prize for Pumped Storage Hydropower

NREL, WPTO

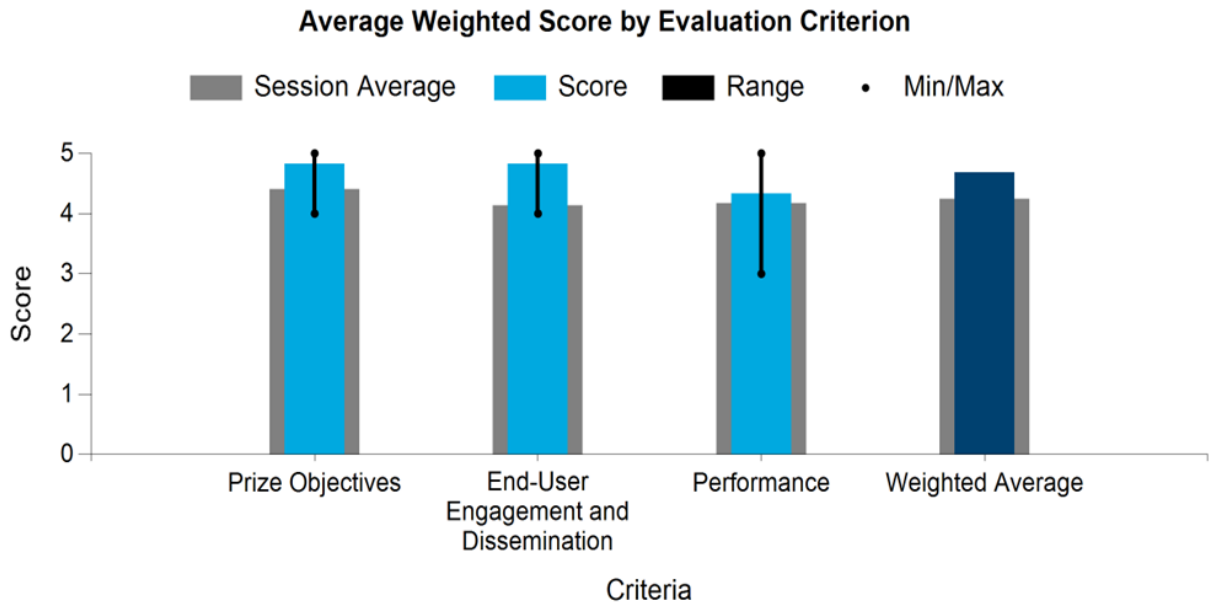
WBS:	1.2.4.403
Presenter(s):	Corey Vezina; Tessa Greco
Project Start Date:	10/01/2018
Planned Project End Date:	12/31/2019

Project Description

The Furthering Advancements to Shorten Time (FAST) Commissioning for PSH Prize aimed to reduce the time, cost, and risk required to commission PSH projects by crowdsourcing ideas via a three-stage prize. This prize was WPTO's first hydropower prize and, as a result, was viewed as a pilot application of the prize model for the hydropower program. By explicitly seeking concept solutions for cost, time, and risk reduction for PSH facilities, the FAST Prize directly addressed stated intermediate and long-term outcomes noted in the "untapped potential for hydro and pumped storage to support a rapidly evolving grid" challenge.

A three-stage prize (concept, incubate, and pitch) encouraged broad participation from a range of stakeholders and contributors not already engaged in hydropower and PSH. Prizes are an excellent way to leverage funding and historical expertise to procure innovative and entrepreneurial solutions to energy issues. The FAST Prize introduced innovative solutions to drive down costs, timelines, and risks of PSH by engaging a nationwide problem-solving community.

PSH is a largely untapped resource that can be used to balance variable renewable energy generation sources. By initiating this important topic via a prize mechanism, WPTO sought to identify solutions for bolstering a more reliable and resilient grid.



Aggregated Reviewer Comments

- The results of this research program speak for themselves, and the reviewer rates it as a great success as reflected by the scoring. The reviewer also appreciates the innovative approach that encourages creativity to identify solutions for PSH. The reviewer also thinks it is very good the solutions presented by three of four winners are also applicable for conventional hydropower plants. The presentation focuses on accomplishments

and results, and the reviewer encourages the team to present more information on project management in the future. When presenting, they informed more about their different approaches and how they established good collaboration between the labs through good organization and clear assignment of responsibilities. It was also interesting to learn that they had adopted several different models in the past and that they consider it more successful with this three-stage approach with down selection ending with a pitch contest. The reviewer also appreciates the focus on selecting commercially viable solutions. In summary, the project demonstrates good adherence to strategy and excellent performance.

- There is a clear connection to the program mission and objectives. The multi-part engagement strategy is well explained and detailed. The scientific merit of the winners is unclear based on the presentation and written materials.
- The reviewer was a judge for this prize so was involved from start to finish. The reviewer thought it was a great, really creative concept, and several applicants displayed very innovative approaches. Involving the labs to expand their research was a fantastic idea. The process was well managed and soliciting judges' feedback in the middle of the process was a great idea so that course corrections could be made. Great job. The reviewer hopes to see more of these in the future.
- The team had strong messaging around objectives (e.g., reducing commission time, cost, and risk) for PSH projects. The reviewer appreciated the fact they leveraged learning and achievements and adopted several models, specifically in the water prize program. Working with national labs seemed to add significant benefit to the program and the tech's journey to commercialization. For this prize, they have done a better job of matching objectives to outcomes. This prize program is a robust model for prize administration and the coordination between the labs is laudatory. This model seems adaptable to other prize programs. It is a best practice to have teams supply technical reports. The external engagement strategy incorporated the successful use of networks. The reviewer appreciates the investment this prize program made in voucher support ($400,000). The reviewer believes that this adds so much value to the prize program and to those that win the support. It is good to have this untethered investment in the winners.
- This project seems to be ongoing. It is difficult to judge how successful the prize will be at this point.
- The FAST Commissioning for PSH Prize aimed to reduce the time, cost, and risk required to commission PSH projects by crowdsourcing ideas via a three-stage prize. This topic is directly related to the WPTO's mission. Though not mentioned in detail, due to its successful completion as the first prize competition, the project appeared to have a good management plan. A timeline and approach were presented with defined milestones. Go/no-go decision points were not mentioned. The project's expected outputs of injecting innovation into a well-established industry were met. The project's outcomes of establishing a prize methodology is a useful short-term outcome. Whether or not the prizes themselves will yield useful short-term outcomes remains to be seen. Regarding end-user engagement and dissemination, a technical review committee was engaged, a strategic outreach and promotion network was created, and the prize was advertised. The prize team engaged with the water power industry and attempted to reach a wide audience of potential applicants. A report and an executive summary on a baseline analysis for PSH as well as the identification of opportunities to focus on the sought-after innovation areas was provided. To assist in commercialization, $400,000 of in-kind voucher support was included with the prizes. Regarding performance, the prize competition produced some innovative ideas, and it appears the team putting the prize competition together gave appropriate incentives to the competitors and the prize recipients used sound methods in conceiving of their innovations. This was the first rendition of a prize, and therefore the team had to create all the processes and materials needed. It looks like they did a good job.

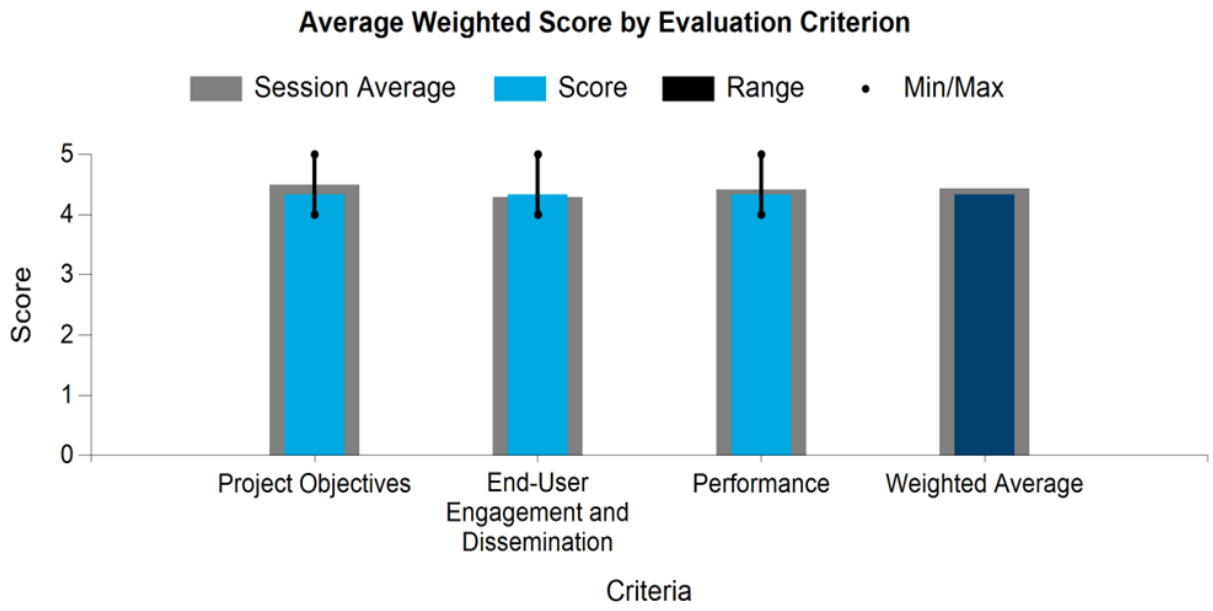
Hydropower Plant Controller Prototyping Using Remote Hardware in the Loop

NREL

WBS:	1.2.4.404
Presenter(s):	Mayank Panwar
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2021

Project Description

Real-time prototyping of hydropower plant controls is important for reducing the cost and risk of field deployment. This project will collect design and operational data from actual hydro plants and use a physics-informed machine learning approach for real-time emulation of hydropower plants, including hydro turbine and hydrodynamics. The data-driven models will be interfaced with digital, real-time simulation at NREL's Flatirons campus for hardware-in-the-loop testing of the governor hardware device or controller-hardware in the loop. The proposed approach will also establish the connectivity-based remote controller-hardware in the loop testing capability using real-time data streams from an actual hydro plant. This integrated hydro-plant emulation with controller-hardware in the loop will be used to prototype hydro-governor controls and eventually provide an opportunity to test hydropower integrated with various technologies (conventional and renewable generation, energy conversion, etc.) as hardware in the loop.



Aggregated Reviewer Comments

- The project is complete and presents as a success. The reviewer considers the project objectives to be highly relevant for WPTO since they focus on real-time prototyping of hydropower plant controls. The project outcomes and outputs support the project objectives through streaming data and testing in the lab. They present an excellent approach with physics-informed machine learning, and it is particularly good to note that they include turbine and penstock dynamics. This demonstrates that they have engaged and involved stakeholders, and they have published results in highly relevant forums. The reviewer considers this to be a high-performing project, and the presentation would benefit from increasing focus on project management. This could enable others to learn more about how to conduct successful research programs. When presenting, the team elaborated more on potential future work beyond the scope of this project. It is great to learn that they will transform this from a seedling project to a larger R&D project.

- The team did a good job on their project. The results were amazing, and the team had a good partner with Cordova. The team did a lot with a small budget, so good job with that. The presenter stated the design modification and prototyping of hydro controls can be costly and introduces unnecessary risk during field deployment and commissioning. The reviewer would have liked to see a quantification/identification of these risks. Congratulations on the results/research being used for the HydroWIRES Hydro Emulation project at NREL. Again, great work.
- This project's goals were to use a data-driven approach for hydropower plant controller prototyping using remote hardware in the loop. A project approach and timeline were provided, but there was no management plan. Key milestones were provided, but there were no go/no-go decision points. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. One aspect of the project summary and outcomes that would be useful to address is why this is important. It seems inherently useful to develop controls for a hydropower plant and test remotely with hardware in the loop prior to implementing, but it was unclear to the reviewer why this is an improvement over the traditional method. Regarding end-user engagement and dissemination, the project involved a stakeholder engagement in a few ways: by partnering with Cordova Electric Coop, through an industry advisory board, and via engagement with the University of South-Eastern Norway. The project has made two disseminations, but no high-visibility publications or reports at the project end were mentioned. (These would be useful.) However, the budget for this project is small and does not include sufficient funds for conference travel or journal publication. There was no mention of a tech transfer plan. Regarding performance, good progress is being made on the project, but it does seem to be running behind schedule. The project team has implemented sound methodologies that are state of the art. Future work was mentioned in the next steps and future work slides but without specifying key milestones and go/no-go decision points. The items mentioned are consistent with the project objectives and timeline.

Geomechanical Pumped Storage

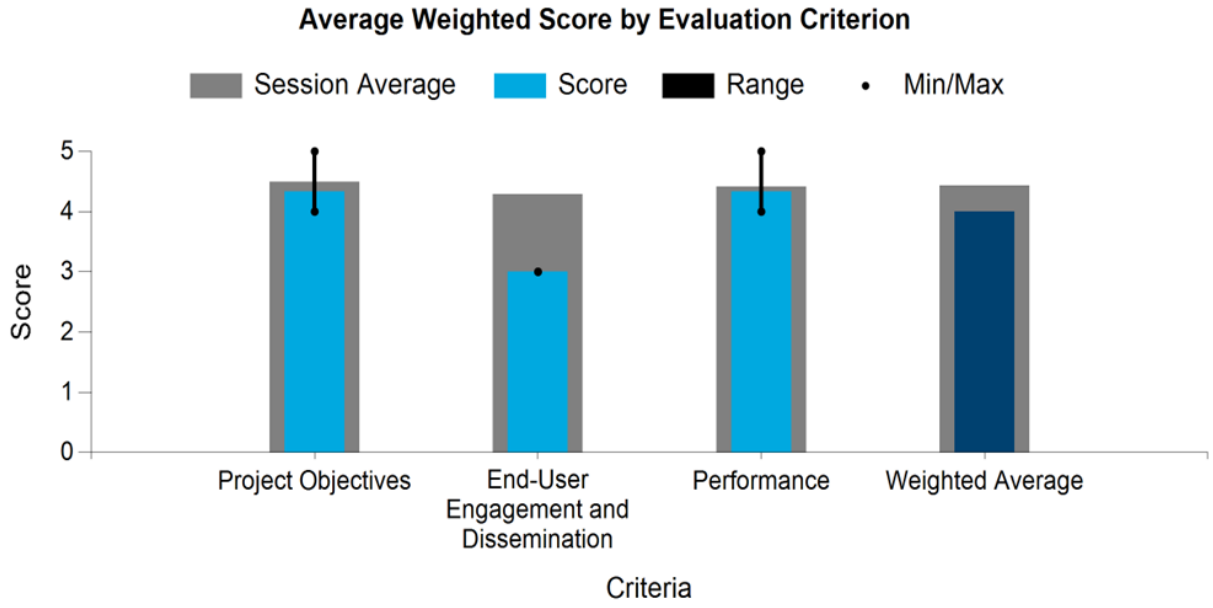
Quidnet Energy Inc.

WBS:	EE0008780
Presenter(s):	Howard Schmidt
Project Start Date:	08/01/2019
Planned Project End Date:	01/31/2022

Project Description

The Geomechanical Pumped Storage project seeks to develop and test a versatile injector-generator prototype for high-head applications. The injector-generator comprises a novel combination of known mechanical elements (modern plunger pump and early water engine technologies) to realize a bidirectional hydraulic platform with high efficiency and attractive cost metrics.

The project supports WPTO's HydroWIRES Initiative with an innovative solution for improved grid service capabilities. The injector-generator is particularly applicable to geomechanical pumped storage, a new PSH modality. A homologous design series resulting from this work supports granular deployment in the 0.5 MW to 10 MW range for sub-surface energy storage requiring durations longer than 10 hours. Injector-generator modules could also affordably support co-generation from adventitious, geopressured fluids and small scale PSH sites with simpler, two-level facility designs. The specific outcomes of this project are to produce a 0.5 MW to 10MW homologous design series capable of operating at 700 to 3,000 pounds per square inch, as well as a small-scale prototype to characterize performance with the goal of achieving mechanical efficiencies better than alternative reversible rotodynamic machines, targeting greater than 95% mechanical efficiency in both the pumping and generation modes. The project will also generate a manufacturing plan to achieve less than $100 per kW injector-generator manufacturing cost at scale in the long term.



Aggregated Reviewer Comments

- The project objective responded well to WPTO's and HydroWIRES' mission. It is a very interesting project seeking to develop new technology to enable a geomechanical hydropower plant. The opportunities to scale up and build plants with storage is large (1 terawatt), and there is a potential they will succeed in developing this. The design allows for a standalone plant to support and enable a stable grid and even more so if they

build a distributed system with multiple plants. It could potentially support the grid even further. It is apparent the project has identified end users with agreements already in place with a customer as well as a wide range of applications. The accomplishments made so far demonstrate good progress and management of the project. The reviewer encourages the team to present more on project management as this is an integral part to performance evaluation. It is also of interest to others to better understand how to manage this type of project and if the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule. The team presented an extensive list for future work that could benefit from more information on timeline, decision gates, etc. During their presentation, they elaborated more on the main challenges related to fluid dynamics, controlling, and propagation. It would also be interesting to understand how this is addressed in future work.

- This is an interesting concept and technology. The goals of greater than 95% mechanical efficiency and targeted cost per kW are impressive. Since no cavern development is needed, project costs will certainly be considerably reduced as well as project risk. The reviewer likes that the technology under development can also be applied to other areas. The presentation, strategy, and future work required were clear and well thought out. If it proves out with the numbers and efficiencies as it scales up, this will be an impressive product. Outreach was limited. The reviewer suggests presenting at general hydro industry conferences.
- The project contributes to WPTO's mission to advance R&D, testing, and commercialization of next-generation hydropower and pumped storage systems for a flexible, reliable grid. The goal of this project is to design, build, and test a prototype geomechanical pumped storage unit with higher efficiency that current PSH technologies. No project management plan was presented, and there were no well-defined milestones, go/no-go decision points, or risks addressed. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project team did not mention any dissemination or outreach. It appears most of their work has been technical to this point. They have engaged with Quidnet Energy, a company with whom they anticipate doing their first field tests. The company has existing intellectual property and added new intellectual property as part of the project. The tech transfer plan appears to be through customer contacts. Regarding performance, the project team appears to have made significant progress toward achieving its objectives; several accomplishments were mentioned. Based upon the material presented, the work plan and methods appear sound. The accomplishments are in line with the proposed work. The plan for the work, however, was not well described. It is not clear what the specific outcome of the project will be—whether it is a working bench model, a field demonstration with Quidnet Energy, etc. The future work mentioned seems reasonable for the last year of the project.

Modeling and Optimizing Pumped Storage in a Multi-Stage, Large-Scale Electricity Market Under Portfolio Evolution

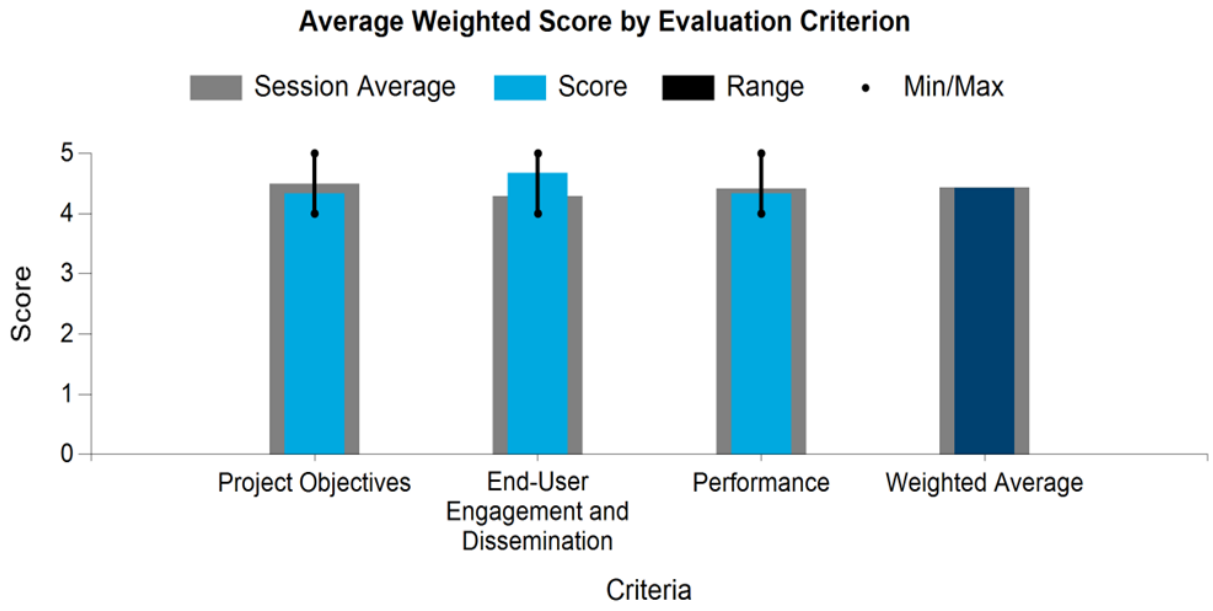
University of Missouri System

WBS:	EE0008781
Presenter(s):	Rui Bo
Project Start Date:	08/01/2019
Planned Project End Date:	08/31/2021

Project Description

To leverage the fast-ramping capability of resources to provide great value to the grid, electricity system operators such as the Midcontinent Independent System Operator (MISO) continue to evolve their approaches for integrating energy storage resources, including PSH, into electricity markets. This project aims to develop a prototype, enhanced PSH model and evaluation tool in the multi-stage market-clearing process, considering PSH's unique characteristics to better align underlying PSH capabilities with evolving grid needs. This includes the need for more frequent and larger cycling to manage variability and uncertainty from renewables. Challenges arise in modeling and optimizing these energy-limited resources across multiple market-clearing processes and planning studies with uncertainties and imperfect information.

The project is carried out in collaboration with industry partners representing all PSH owners in MISO's footprint. The project uses industry-grade tools and models and realistic data to study, evaluate, and quantify opportunities to improve market design. This project will enable greater utilization of PSH flexibility and facilitate a deeper market penetration of renewable and/or distributed energy resources. MISO is considering incorporating the developed models from this project into production in the future, pending further extensive tests, stakeholder process, and prioritization.



Aggregated Reviewer Comments

- The project is complete and presents as a success. The reviewer considers the project objectives to be highly relevant for WPTO since they focus on PSH for a flexible and reliable grid to enable the integration of variable renewable energy. The reviewer also thinks this focus on market design and efforts to value the opportunity to withhold energy is of great importance for how to enable reliable power supply in the future. The project outcomes and outputs support the project objectives through developing a scalable mathematical model. It is very interesting to note that MISO is considering incorporating the developed models into production in the future. It is understandable that they first require a proof of concept to identify the economic viability of the model before doing so. It is also good to note that the models are published in journals that are publicly available, and the reviewer encourages the team to provide guidance for others to adopt them. This demonstrates that they have engaged and involved stakeholders, and they have published results in highly relevant forums. The reviewer considers this to be a high-performing project, and it would also be good if the team would present more on project management. It is evident that they have completed the project on schedule since they have been granted a six-month, no-cost extension. This also indicates that the budget was sufficient. When presenting, the team elaborated more on potential future work beyond the scope of this project, such as more testing for the intra-day scenario. These were very interesting ideas, and the reviewer encourages them to find a suitable format to share with other interested parties. It is also useful information for those who may be interested in adopting and further developing the model. Please note that this comment is not reflected in the scoring.
- This is a great project—impressive. The work on modeling and optimizing pumped storage in a multi-stage, large-scale electricity market is needed. The reviewer appreciated that these models would be scalable for large-scale markets and power grid. This project had a strong team considering three were major investor-owned utilities. The reviewer liked that the team partnered with both academia and end users for this project. It is great that the team developed models and simulations with real, large-scale market data. There were impressive results with up to a 97% increase in PSH profit in day-ahead markets. The fact that MISO is considering using the model brings real credibility to this work. Outreach was outstanding. Great job. However, the reviewer was disappointed to not see next steps. The reviewer hopes the team will be continuing its research in this area.
- The purpose of this project was to develop a prototype, enhanced PSH model in the multi-stage market-clearing process considering unique characteristics of PSH and leveraging its fast-ramping capability to provide great value to the grid. A table showing the project milestones was presented. Since the project is finished, all milestones have been met. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, stakeholder engagement was primarily with their project partner, MISO, and three PSH owners that formed an advisory group. The report mentions some dissemination through peer-reviewed journal publications and via technical conferences but does not provide any details. As for tech transfer, MISO is considering incorporation of the models that were developed. Regarding performance, the project team achieved its objectives, and the project is complete. The R&D methodologies were sound and appropriate. Though it is difficult to tell from the materials presented, it appears the project was completed on time. Future work was not mentioned.

Value and Role of Pumped Storage Hydro Under High Variable Renewables

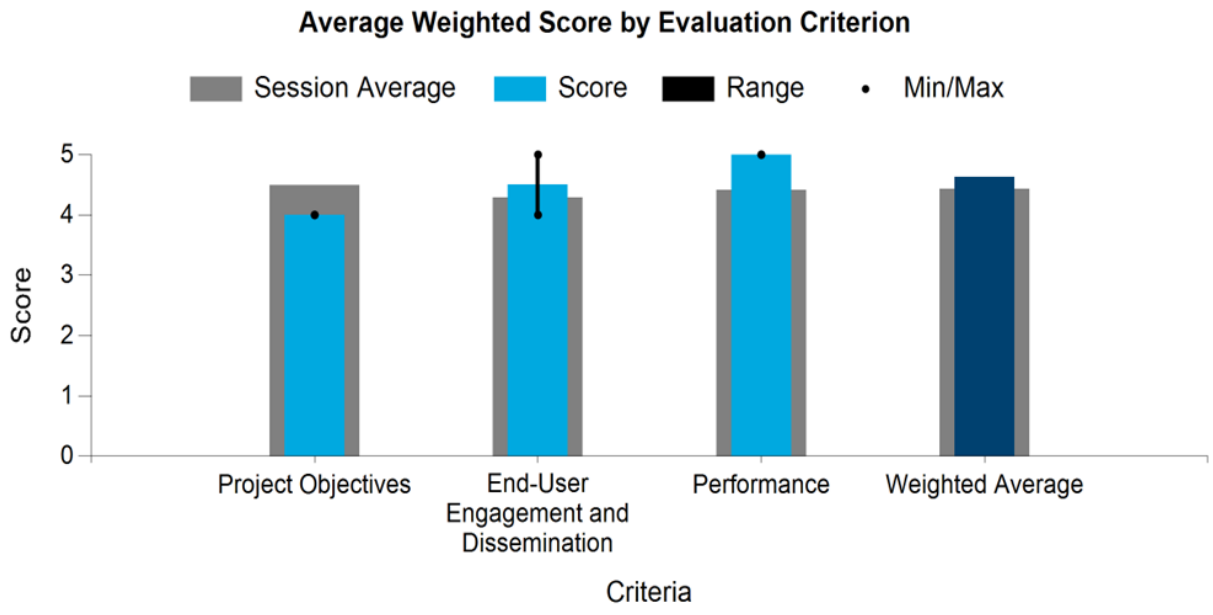
General Electric Company

WBS:	EE0008782
Presenter(s):	Christina Bisceglia
Project Start Date:	09/01/2019
Planned Project End Date:	02/28/2021

Project Description

PSH can accommodate the intermittency and seasonality of variable renewable energy resources such as solar and wind power. New PSH plants in areas with recently increased wind and solar capacity are expected to improve grid reliability while reducing the need for new fossil-fueled generation.

This project aims to overcome a range of market barriers for PSH by helping stakeholders understand the benefits of PSH that are not well understood or quantified by demonstrating the capability of new variable-speed PSH technologies and by helping developers improve PSH revenues with the development of a new PSH scheduling tool. The study is particularly intended for utilities, public utility commissions, developers, and regional planner organizations as it explores the values and impacts of PSH, specifically in high-renewable penetration systems. Intended outcomes from this project aim to develop a PSH scheduling tool to co-optimize energy and ancillary services, analyze and quantify the potential value of PSH under different system conditions, develop a set of variable-speed PSH models for transmission planners, investigate the dynamic capability of variable-speed PSH and assess its impact on grid frequency response and transient stability, and investigate PSH contributions to resource adequacy.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since they focus on PSH for a flexible and reliable grid to enable integration of variable renewable energy. The reviewer appreciates the focus on accurate representation and system value of hydropower and PSH. The team presents a good approach with a sound logic and red line throughout. They also present a good and well-reasoned method that demonstrates how to reach the objectives. It builds up under the relevance of the outcome as they use

real operation data from PSH facilities in developing, calibrating, and validating their model. This will allow for a greater understanding of the value of both existing and potential PSH. The reviewer would like to highlight the team's good focus on how this research can be applied and further developed in the future as they state they will provide a framework for others. The reviewer considers this to be a good-performing project, but the presentation could have an increased focus on project management. The team completed the project on schedule since they have been granted a six-month, no-cost extension. The cost came in slightly less than budget, and they plan to continue to disseminate the results after project completion. This is also of high value for others to learn and better understand how to execute a successful research program. The reviewer encourages the team to present more information on risks and mitigations, challenges encountered during execution, and lessons learned. The project has identified end users and engaged with relevant stakeholders, and they plan to continue collaboration with New York Independent System Operator (NYISO) and Duke. The final report is underway, and it is good to note that they intend to summarize this in a white paper for the IEEE conference. They have not presented recommendations for future work, and it could be because they are not required to since the project is completed. However, the reviewer recommends the team do this as it will provide guidance for stakeholders and others who consider further developing the models. Please note that this comment is not considered in the scoring.

- The purpose of this project was to demonstrate the value and role of PSH, and in particular variable-speed PSH, under high renewable energy. No project management plan was presented, but a project timeline with well-defined milestones and a go/no-go decision point (i.e., a critical performance review) was provided. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. This project appeared like a useful extension of the General Electric tools for addressing PSH, but the method, though appropriate, was not very innovative nor easily transferrable to non-General Electric tools. Regarding end-user engagement and dissemination, stakeholder engagement appeared to occur through presentations at several industry workshops or meetings. The engagement was satisfactory. Engagement of stakeholders happened at a variety of different meetings, including at least one hydro-specific meeting (NHA's Clean Currents in 2021). The commercialization plan will likely occur through General Electric's normal marketing of its services. Regarding performance, the project is complete and successfully met its objectives. The project team used sound methodologies in their research plan. The project was accomplished in a timely manner. Since the project is complete, no future work was mentioned.

Predicting Unique Market Pumped Storage Significance (PUMPSS)

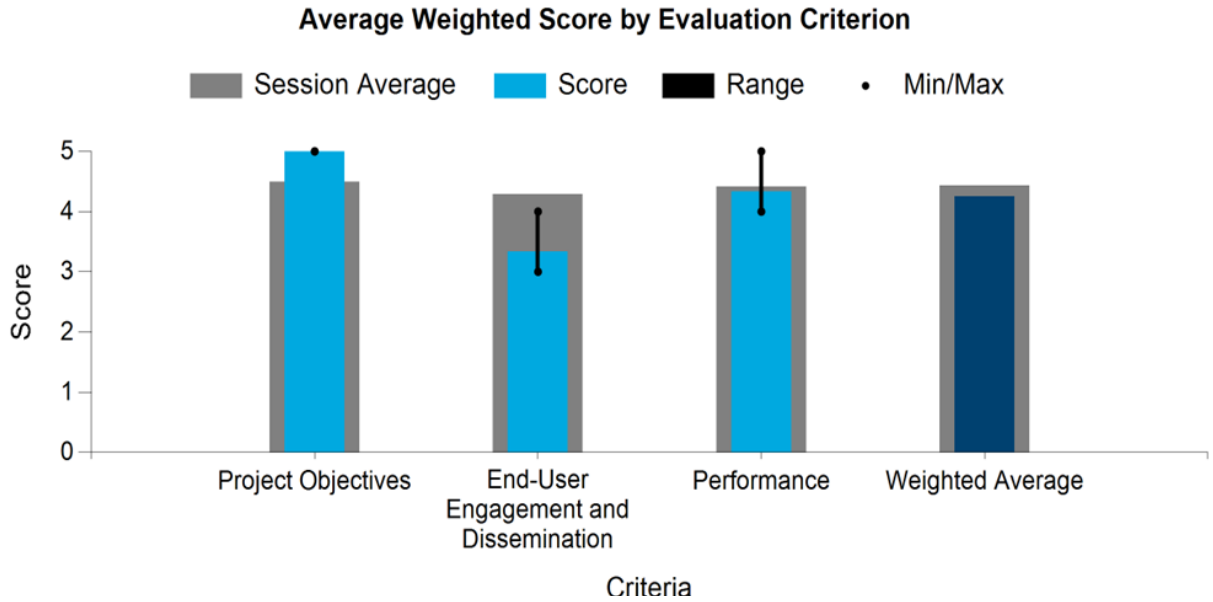
Electric Power Research Institute, Inc. (EPRI)

WBS:	EE0008783
Presenter(s):	Aidan Tuohy
Project Start Date:	08/01/2019
Planned Project End Date:	01/31/2022

Project Description

This project aims to demonstrate a new methodology to value PSH's contribution in multiple systems over a range of variable renewable energy penetration scenarios using real-world operating conditions from PSH facilities. Advanced production cost modeling provides greater accuracy on aspects like treatment of uncertainty, inclusion of multiple decision steps from weeks ahead to real time, and treatment of reserve requirements and provision from PSH. This increases understanding of the value of existing and potential PSH in those systems, various PSH technologies across regions, and individual services and attributes.

Benchmarked cases for the existing Duke Energy Carolinas and NYISO systems were developed, followed by future resource mixes with high and medium renewable penetration for those regions based on planned resource additions and the presence of battery storage and nuclear resources. A case study matrix was developed to determine specific issues to study that show value for PSH. This included operational assumptions, storage duration, fuel prices, and market design sensitivities. Key results were the cost savings due to presence of PSH with increasing value in both regions as variable renewable energy increases. The savings were more noticeable in the Duke system for several reasons including the specific resource mix and PSH characteristics. Extensive sensitivity analysis shows the value PSH can bring increases if different operational practices were used. Technology upgrade options were also examined.



Aggregated Reviewer Comments

- The reviewer considers the project objectives to be highly relevant for WPTO since they focus on PSH for a flexible and reliable grid to enable integration of variable renewable energy. The reviewer appreciates the focus on accurate representation and system value of hydropower and PSH. The team presents a good approach with a sound logic and red line throughout. They also present a good and well-reasoned method that demonstrates how to reach the objectives. It builds up under the relevance of the outcome as they use

real operation data from PSH facilities in developing, calibrating, and validating their model. This will allow for a greater understanding of the value of both existing and potential PSH. The reviewer would like to highlight the team's good focus on how this research can be applied and further developed in the future as they state they will provide a framework for others. The reviewer considers this to be a good-performing project, but the presentation could have an increased focus on project management. The team completed the project on schedule since they have been granted a six-month, no-cost extension. The cost came in slightly less than budget, and they plan to continue to disseminate the results after project completion. This is also of high value for others to learn and better understand how to execute a successful research program. The reviewer encourages the team to present more information on risks and mitigations, challenges encountered during execution, and lessons learned. The project identified end users and engaged with relevant stakeholders, and they plan to continue collaboration with NYISO and Duke. The final report is underway, and it is good to note that they intend to summarize this in a white paper for the IEEE conference.

- This is a great project. The team certainly met the intent of the DOE objective for identifying untapped potential for PSH. As the team is aware, this work has great relevance to what the industry is dealing with right now, especially Duke and what to do with variable renewable energy versus pumped storage and how to value it. That the team is developing a more robust, state-of-the art evaluation tool for pump storage will help identify the impact and value on the grid. The reviewer liked that the team will be identifying key PSH value drivers and giving guidance to other regions that it did not work with on this project. The industry engagement was strong. The reviewer recommends that the team present at Hydro Industry since this work is so relevant and much needed. The reviewer is very impressed with this work and hopes that this will continue because there is great benefit in what the team is doing. The reviewer wishes recommended next steps were included in the presentation.
- This project developed a framework to investigate the value PSH provides to the grid currently and in the future as the resource mix decarbonizes. No project management plan was presented since the project is complete. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project team engaged stakeholders and end users through direct project work with EPRI, Duke, New York Power Authority, and NYISO. The project was discussed with EPRI member utilities. There is a tech transfer plan via one to two conference papers and a discussion with EPRI utilities, but it is not clear that this will be very effective. Regarding performance, the project team completed the project successfully. Based upon the information presented, it appears the project team implemented sound R&D methodologies. The project was completed on time with approved variances. Future work was not discussed.

Hydropower Flexibility Framework

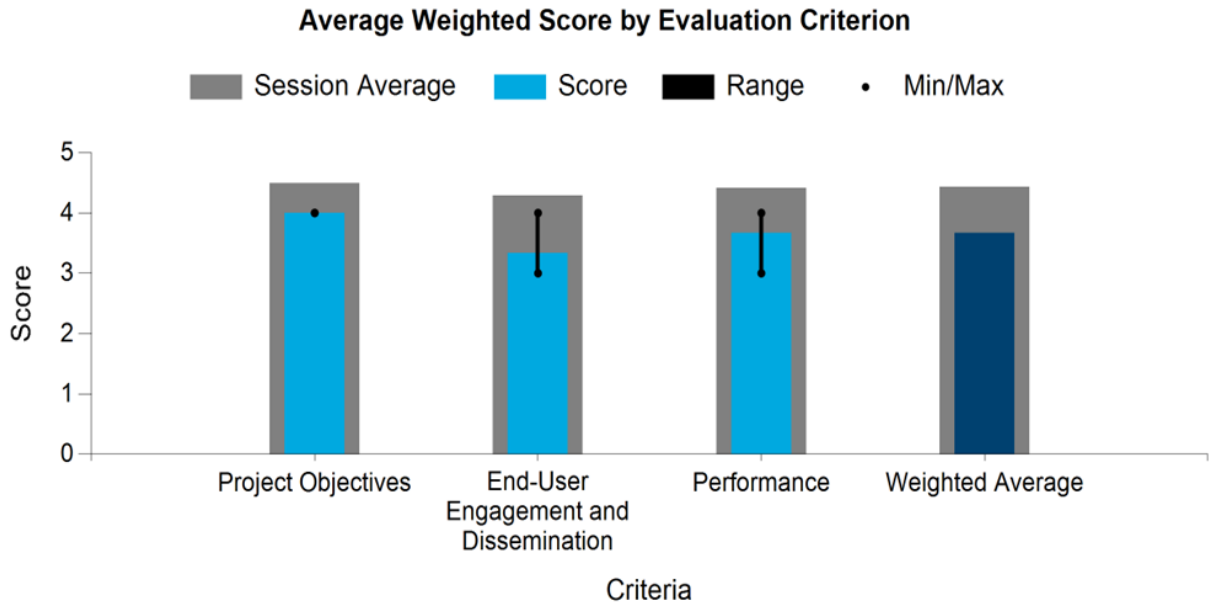
EPRI

WBS:	EE0008941
Presenter(s):	Francisco Kuljevan
Project Start Date:	02/01/2020
Planned Project End Date:	02/28/2023

Project Description

The Hydropower Flexibility Framework intends to develop an industry-recognized methodology and framework for calculating the flexibility that hydropower assets can provide, demonstrate the validity of the approaches and the viability of comprehensive application across the fleet, and establish a platform for future flexibility assessments. This quantification relies on a systematic and detailed understanding of hydropower plants' capabilities and constraints, a directory of flexible services needed by the power system, and a model capable of co-optimizing a solution while accounting for these factors.

The Hydropower Flexibility Framework aims to better understand and capitalize upon opportunities for hydroelectric power plants by integrating water schedules, energy generation and ancillary services (regulation and spinning reserve), unit and reservoir characteristics, and minimum flow requirements to support hydropower owners and operators in making informed, asset-level decisions. The overarching outcome is to provide an organizing framework to evaluate the effects of hydroelectric power plants' capabilities and constraints on the various types of flexible operations and services that could potentially be supplied along with the generation of clean energy and to enable more appropriate decision making for investments in plant equipment.



Aggregated Reviewer Comments

- The project objective responded well to WPTO's and HydroWIRES' mission. The tool and objective will have a high value for the industry, and it is the modeling of ancillary services that is particularly innovative. However, this also increases the complexity as it is necessary to include many parameters, and careful selection of each parameter is required to assess a plant's flexibility capabilities. The team has included many relevant parameters, but the reviewer encourages them to evaluate if they could include parameters on waterway

characteristics and unit inertia. In the reviewer's opinion, these are key in understanding a plant's performance and dynamic behavior and may be more applicable for all turbine types than pressure pulsations, which is a hydraulic phenomenon limited to submerged turbines. Many plants indicate good performance when assessing the unit characteristics, but the waterway limits performance because of poor design. This can occur for all head ranges, penstock lengths, etc. The team supplemented information on their end-user engagement when presenting. It is good to observe that they have engaged a large group (utility and independent system operator: Southern Company, New York Power Authority, CAISO, and U.S. Bureau of Reclamation; power unit: Voith Hydro, American Hydro, HDR, EPRI, and Mercury Governor Group; and optimization and operations: PSR, Polaris System Optimization, and USACE). The reviewer encourages the team to define a key performance indicator and quantify at the end of the project. The test case presents promising results as the schedules were consistent. It is especially interesting to note that the forecast analyses had greatest improvement for low flow since this could potentially yield the highest benefit in planning terms. Furthermore, it would be interesting to see how this could be used on a fleet of hydropower plants. The results and accomplishments demonstrate good performance. However, the reviewer encourages the team to present more on project management as this is an integral part to performance evaluation. It is also of interest to others to better understand how to manage this type of project and whether the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule and if it progressed according to plan or what may have been a hindrance, including whether that could be something one could normally expect or if it was a one-time challenge. Usually, this type of knowledge is also valuable to others conducting similar projects. The team presented a solid list for future work that could benefit from more information on timeline, decision gates, etc. It would also be interesting to learn more about why these topics were proposed.

- This is an interesting topic. The reviewer agrees with the importance of the methodology the team is developing for calculating hydropower flexibility. This development and issuance of a flexible services directory was needed and important for the industry. It was good that the team validated its model by comparing it to actual results. The reviewer liked that they were able to quantify the results in test case one for low-flow summer months of 5.5% improvement, which gives the research credibility. It is clear the direction the team is taking for the future. It would have been nice to know who was on the technical advisory team and to have a more detailed rollout plan on how the team intends to communicate findings.
- The Hydropower Flexibility Framework project contributes to WPTO's mission to advance R&D, testing, and commercialization of next-generation hydropower and pumped storage systems for a flexible, reliable grid. This project seeks to define, apply, and disseminate a flexibility framework that will help hydro plant operators understand the flexibility inherent in their plant to optimize energy, regulation, and spinning reserves. No project management plan was presented, and there were no well-defined milestones, go/no-go decision points, or risks addressed. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the report described a skilled and diverse technical advisory group comprised of ISOs, utilities, research organizations, and technology developers that are actively guiding the technical approach to quantify hydropower's flexibility, but no further details of the group were provided. The technical advisory group members appear to be from relevant stakeholders. There is a tech transfer plan, though it is not articulated in any detail. Regarding performance, the project team appears to have made significant progress toward achieving its objectives, and several accomplishments were mentioned. Insufficient details were provided to assess the soundness of the R&D methodologies, though the information that was provided suggests they may be. No Gantt chart (or similar) was provided for the project, so it was not possible to assess the schedule or challenges/delays. Several items were listed as future work, and they seem consistent with the goals of the project.

Increasing Operational Flexibility of Francis Turbines at Low-Head Sites through Analytical and Empirical Solutions

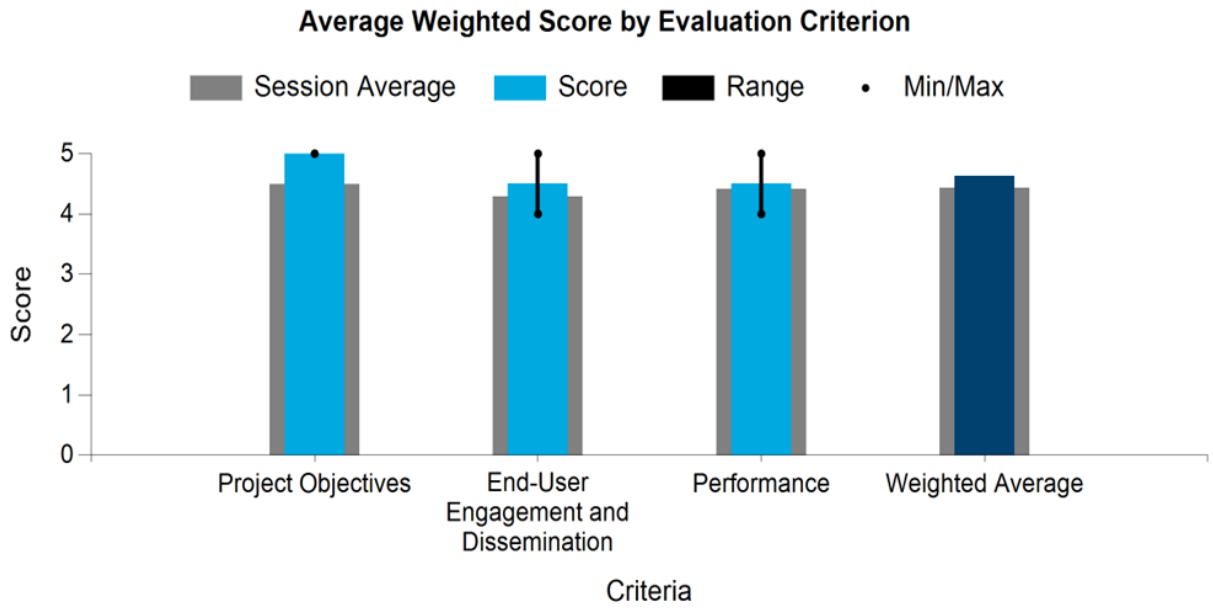
General Electric Company

WBS:	EE0008942
Presenter(s):	Guillaume Rudelle
Project Start Date:	03/01/2020
Planned Project End Date:	02/28/2022

Project Description

This project aims to demonstrate the untapped flexibility potential of the low-head Francis hydropower fleet and the methodology to tackle it through an extension of the usual turbine operating range. This increased flexibility will enable these plants to generate power over a wider operating range and to contribute to grid system resilience and reliability.

The proposed approach based on analytical and empirical solutions will be implemented for demonstration on the High Rock hydropower facility operated by Eagle Creek Renewable Energy. Then a grid simulation will evaluate the impact of hydro fleet additional flexible capabilities on frequency response of the WECC grid on a typical worst-case scenario.



Aggregated Reviewer Comments

- The project objectives respond very well to WPTO's mission as it seeks to extend the operating range and improve the flexibility of low-head Francis turbines. In terms of turbine performance, this is the opposite regular performance since it entails regulating a large inertia and slow speed. This means that they are commonly known for being good baseload machines that generate power at a set megawatt (i.e., are less capable of responding and balancing fast frequency fluctuations). The reviewer considers the potential impact high because there are many low-head Francis turbine plants that will benefit from this upgrade, and there is a large potential for new plants. This will also increase the value of the plant as it will generate more electricity compared to traditional designs. During their presentation, the team elaborated more on the impact COVID had on both progress and budget. The main reason was because they developed special tools that were increasingly difficult to procure, and there was slow progress with the site measurement campaign as it was

problematic to travel to site. On top of this, they experienced unfavorable weather conditions during their first measurement campaign and had to do a second. They were granted a no-cost extension and covered the budget increase themselves. They have started to disseminate the results of the project according to a well-developed plan. Furthermore, the reviewer agrees with the team that support from the HydroWIRES initiative would be impactful. The reviewer considers this to have a high potential for commercialization, and they aim to develop a lighter execution model to enable use on any site. The project is in its final phase, boasts it is globally successful, and has achieved its goals. This is supported by the incredible increase of operating range at the High Rock site, its quantification of grid impact through estimating frequency response, and planned reports. Information on how the project has helped guide operating strategies at High Rock is not explicitly written but demonstrated with hill charts. The results and accomplishments demonstrate excellent performance. The reviewer encourages the team to present more on project management as this is an integral part to performance evaluation. It is also of interest to others to better understand how to manage this type of project and whether the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule and whether it progressed according to plan or what may have been a hindrance, including whether it could be something one could normally expect or if it was a one-time challenge. Usually, this type of knowledge is also valuable to others conducting similar projects.

- The low-head, operational flexibility Francis turbine project contributes to WPTO's mission to advance R&D, testing, and commercialization of next-generation hydropower and pumped storage systems for a flexible, reliable grid. This project sought to demonstrate an increase in operational flexibility on a low-head Francis turbine but air injection on a new impeller design. It then extrapolated the results to predict its positive impact on a frequency disturbance on the WECC grid. The project is sunsetting, and it appears to have met all of its objectives. The project's outcomes have led to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project engaged with the High Rock 39.6 MW hydro power plant in North Carolina. It has also had two conference disseminations during FY 2021 and two planned in FY 2022. The technical advisory group members appear to be from relevant stakeholders. There is a tech transfer plan. Through dissemination and advertising, General Electric will market these turbine upgrades. Regarding performance, the project team appears to have completed the objectives of the project. Insufficient details were provided to assess the soundness of the R&D methodologies, though the outcomes of the project suggest they were sound. The project timeline showed the major achievements and described challenges mitigated with a six-month extension and additional General Electric cost share. Future work was described and is consistent with the goals and timeline of the project.

Identifying Hydropower Operational Flexibilities in Presence of Streamflow and Net-Load Uncertainty

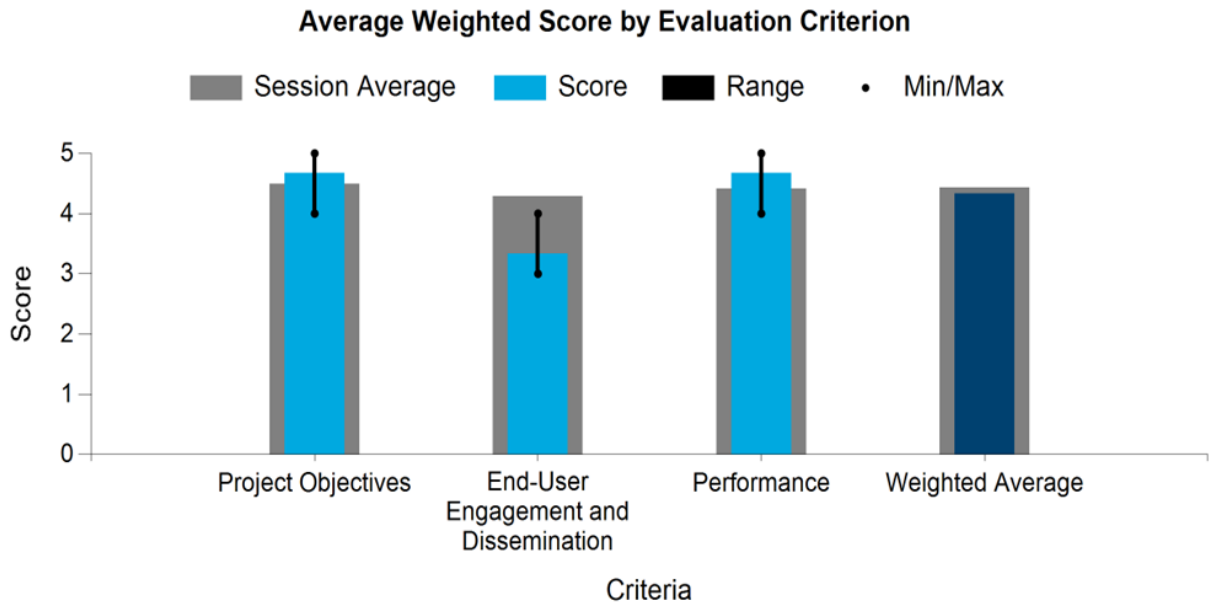
University of California, Irvine

WBS:	EE0008943
Presenter(s):	Bita Analui; Soroosh Sorooshia
Project Start Date:	07/01/2020
Planned Project End Date:	06/30/2023

Project Description

Flexibility in a hydropower plant refers to its capability to schedule the optimal timing of power production to provide reserves and respond quickly to changing power system needs. This is an important value to help integrate high penetration levels of variable generation into the grid system. Despite the importance of hydropower generation, many reservoirs, especially in the United States, must serve multiple purposes, which often predominate electricity production. Constraints on such systems include environmental objectives, flood control, water supply, recreation, etc. Although there is close coordination to ensure that various hydro constraints are not violated, there is great potential to understand how this existing coordination could be improved to provide more efficient and flexible operations. One way to identify these hydropower operational flexibility potentials is to understand how the system responds to the underlying uncertainties with respect to system constraints.

In this project, the team describes the flexibility of an operating hydropower facility by capturing uncertainty in both water and power systems and formulating the hydropower operation as a multi-stage stochastic optimization problem. The proposed optimization approach is generic enough to support short- to seasonal-term operations and planning decision horizons and scales from daily to weekly to monthly decisions. The Missouri River Mainstream Reservoir System consisting of six reservoirs serves as the case study. The aggregate installed capacity of all powerplants in the Missouri River Mainstream exceeds 2,500 MW with an annual generation of more than 9,300 gigawatt-hours.



Aggregated Reviewer Comments

- The project objective is highly relevant for the HydroWIRES and WPTO mission as it explores untapped potential in the challenging interaction between the grid and hydropower plants. The project's expected outcomes and outputs are highly relevant since they aim to develop a decision framework and quantify flexibility. To do so, they have modeled a range of options using a scenario tree. Then the variance of the distributions of optimal solutions provides the quantified flexibility in terms of how much water a plant in the cascade can release for generation. They develop a very interesting and complex mathematical model that will be highly optimized for the cascade under research. It also means that commercialization of this model will be limited, and the reviewer encourages them to engage and involve the intended user to the degree possible. The reviewer recommends the team assess the potential to use this approach on other cascades. It is understandable that the intended user, USACE, would need to extensively test the model to verify its applicability and to ensure that it does not add any risk to the operation. The results and accomplishments demonstrate good performance with a very interesting approach. The team has presented a good project timeline that is split into activities and shows decisions gates and relevant milestones. The reviewer encourages them to present a few comments to the timeline, budget, and risk in the next review. This will enable the review team to better evaluate project management. This is also valuable knowledge to share with others. The team has presented an extensive list for future work that could benefit from more information on timeline, decision gates, etc. It would also be interesting to learn more about why these topics were proposed.
- The reviewer really likes this topic that accounts for and identifies optimal trade-offs among multiple operational, environmental, and regulatory constraints that hydro operators have to deal with. No other renewable has such complexity. The concept and research will facilitate and improve these complex decisions being made. The project presentation was clear and concise. Progress and accomplishments to date were very informative and well laid out. That the team has developed this concept and plan to apply it in a real operational system is great. The reviewer realizes the team picked the largest hydro asset owner in the United States, so kudos to the team, but nearly all hydro owners are struggling with these same issues. The reviewer recommends in the future the team consider diversifying outreach with investor-owned utilities and independent power producers.
- The project contributes to WPTO's mission to advance R&D, testing, and commercialization of next-generation hydropower and pumped storage systems for a flexible, reliable grid. In this project, the flexibility of an operating hydropower facility is described by capturing uncertainties in both water and power systems and formulating the operations as a multi-stage stochastic optimization problem. The approach applies to operations and planning decision horizons from short to seasonal term. No project management plan was presented, and there were no well-defined milestones, go/no-go decision points, or risks addressed. The project's expected outcomes will be useful and relevant and lead to meaningful short-term outcomes. Regarding end-user engagement and dissemination, the project team has one poster publication and other informal dissemination. It is not clear if the dissemination plan will include water power conferences or publications where the work may have its greatest impact. There is no tech transfer plan provided. It appears that the intended tech transfer will primarily be to USACE. Regarding performance, the project team appears to have made significant progress toward achieving its objectives, and several accomplishments were mentioned. Based upon the material presented, the research plan and methods appear sound. The accomplishments are in line with the proposed work plan, and the project timeline and go/no-go decision points are appropriate. The future work mentioned is in alignment with the work plan.

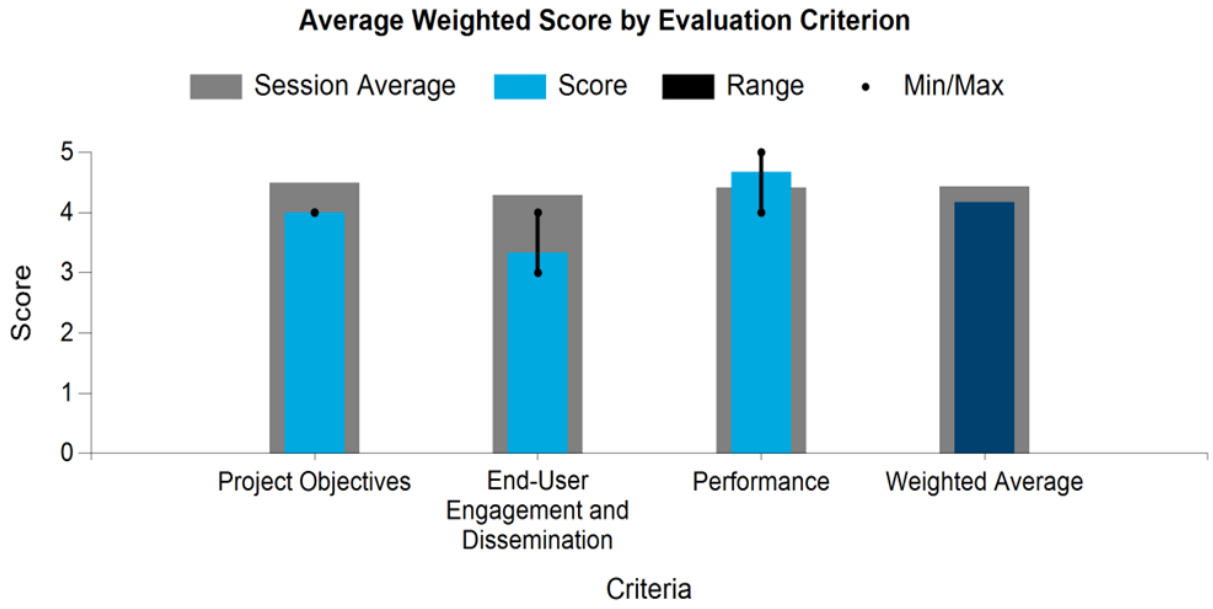
Exploring Multidimensional Spatial-Temporal Hydropower Operational Flexibilities by Modeling and Optimizing Water-Constrained Cascading Hydroelectric

Stevens Institute of Technology (Inc)

WBS:	EE0008944
Presenter(s):	Lei Wu
Project Start Date:	04/01/2020
Planned Project End Date:	05/31/2023

Project Description

Existing heuristic operation practices of cascading hydroelectric systems may predate renewable integration and prohibit fully utilizing systems' inherent flexibilities in providing valuable grid services. This project explores enhanced water inflow forecasting models and advanced modeling and data-driven optimization approaches to maximize the value of these resource-limited assets in providing four-dimension, enhanced operational flexibilities—when, what reservoir, which hydro turbine, and how much water to be discharged and stored—through the development of accurate water inflow forecasts to guide short-term operations and long-term reservoir draft-and-fill cycles and rigorous models of physical and operating characteristics to explore inherent flexibility against uncertainties and information imperfectness.



Aggregated Reviewer Comments

- The reviewer considers the project objectives, outputs, and outcomes to be highly relevant for WPTO as they focus on increasing and optimizing electricity generation from existing assets through improving modeling and forecasting of the potential in the cascade. This is very relevant and applicable for utilities, and it is good that the model incorporates weather forecasting in addition to hydrology and other relevant parameters. It would be interesting to observe how they may adapt the forecasting model and algorithms to other cascades. In the reviewer's opinion, the project team has a strong focus on end-user engagement and could increase their focus on disseminating findings through workshops, publications, and presentations. The results and accomplishments demonstrate acceptable performance. The project is currently behind schedule, but they present a reasonable plan for accelerating work. However, they note that they may ask for a no-cost extension later. The reviewer encourages the team to present more on project management as this is an integral part

to performance evaluation. It is also of interest for others to better understand how to manage this type of project and whether the team had sufficient budget or required an increase and why. It is also of interest to better understand the project schedule and whether it progressed according to plan or what may have been a hindrance, including whether that could be something one could normally expect or if it was a one-time challenge. Usually, this type of knowledge is also valuable to others conducting similar projects. The team has presented an extensive list for future work that could benefit from more information on timeline, decision gates, etc. It would also be interesting to understand why these topics were proposed.

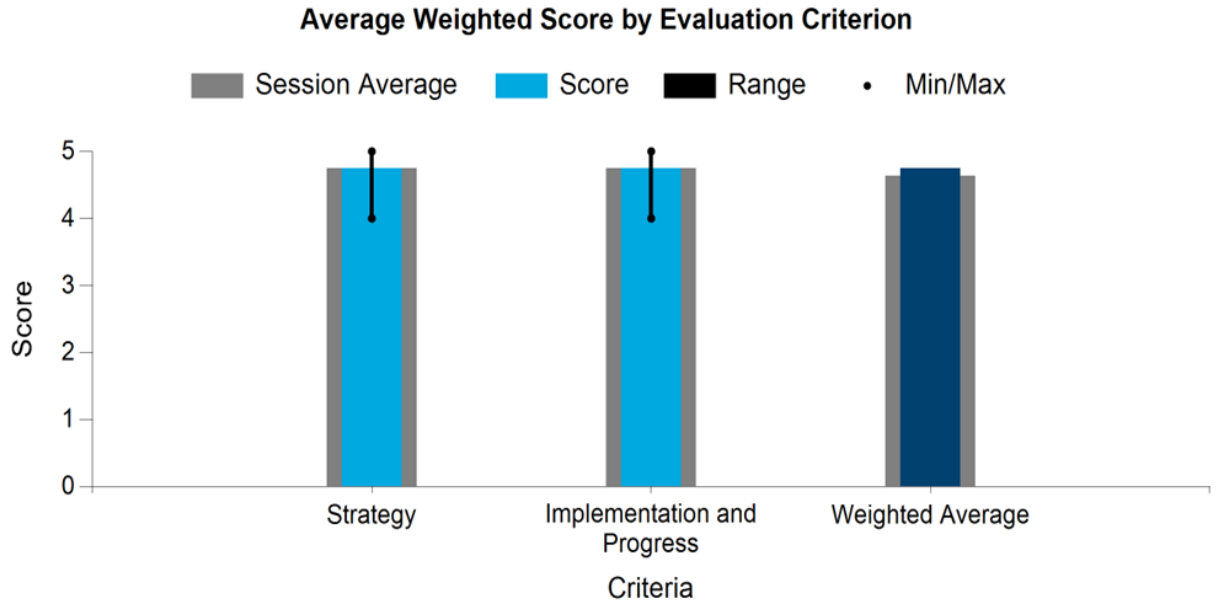
- The reviewer liked the concept. One of the major industry concerns has been the robustness of models used for hydro as compared to other renewables. The team tackled a great concern in the research, which was with models using old, overly conservative data and then performed simulation via actual Portland General Electric data. The reviewer liked the approach and outcome. Well done. The reviewer suggests in the future getting a more diversified audience for outreach. Since operators and generation owners are targeted users, the reviewer recommends the NHA conference and Northwest Hydroelectric Association conferences, which many generators attend. The reviewer can get advance participant lists, which could help the team.
- The project contributes to WPTO's mission to advance R&D, testing, and commercialization of next-generation hydropower and pumped storage systems for a flexible, reliable grid. This project seeks to employ enhanced water inflow forecasting models and advanced modeling and data-driven optimization approaches to increase the value and use of the hydro resource in an electrical system with high renewables. The project team presented a detailed Gantt chart and appears to be on schedule and to have it its first set of milestones. The project's outcomes have already produced some meaningful short-term outcomes. From the presentation, the project looked good but not easily adapted to other sites. Regarding end-user engagement and dissemination, the project has had good engagement with Portland General Electric, the owner of the hydropower projects where the modeling and numerical techniques are being applied. Three journal articles, one conference paper, and three presentations have already occurred during the project, so outreach is good. A specific plan for tech transfer is not provided beyond the normal channels of academic publication. That seems appropriate given the project team. Regarding performance, the project team has made good progress and appears to be close to the predicted schedule for completing the project. The R&D methodologies appear sound and appropriate. Future work was described and is consistent with the goals and timeline of the project. Key go/no-go decision points do not appear to be part of the project work plan.

Fleet Modernization, Maintenance, and Cybersecurity

Activity Area Evaluation

WPTO

WBS:	1.3
Presenter(s):	Kyle DeSomber



Aggregated Reviewer Comments

- The presenter did a wonderful job explaining the activity area and the strategy of how the projects fit together, especially with the figure on slide 14. His understanding of stakeholder needs and challenges was clear. The activity area is closely aligned with the MYPP objectives and looks likely to fulfill all of the MYPP 2021–2025 Key Results and Performance Goals. Regarding whether the program leverages the appropriate funding mechanisms and whether it funds the most relevant studies, the reviewer did not see enough information to determine whether these were true (not that the reviewer is yearning for a lengthy discussion of funding mechanisms). The studies that were funded do seem relevant, but the reviewer would have to see all the studies that were not funded to say they were the most relevant. (The reviewer apologized if they are getting hung up on unintended details with the wording.) The projects are diverse and complement each other but seemed a bit light on the maintenance side. This might have been due to funding constraints or a lack of relevant studies being proposed. HFI was a great project, but the reviewer thinks there is room for more (around baselining maintenance costs or benchmarking plant outage causes) while still maintaining diversity among projects.
- The activity area presentation was very well put together to provide insight into the program, the projects within the program, and details showing how the program activities linked and complemented each other within the program area. The lead did a really good job answering questions and addressing comments following the presentation and has a solid handle on the industry, the benefits that may be realized from the projects, the challenges associated with the projects, and the requirements set by the MYPP. The primary weaknesses noted in the program are likely the result of streamlining the activity area presentation. The moderator outlined the work to be reviewed and noted additional calls for papers that were released recently in the activity area. However, reviewers did not hear what other projects may have been deferred in the activity area or what projects were in the queue and how they ranked the projects against each other. The reviewers discussed this

and believed that this analysis is covered in the MYPP process, so it is outside the limits of the review. As a result, the fact that reviewers did not review projects outside of the review area is not perceived as a detriment to the scoring for the activity area.

- The program's three focus areas—maintenance, digitalization, and cybersecurity—align well with the MYPP vision and mission statements for the Fleet Modernization, Maintenance, and Cybersecurity Activity Area. The MYPP, figure 21 (Sub-Activity 3.2 Maintenance Research Priorities) indicates efforts to develop first-generation condition sensors, but this activity does not appear to be included in the current program. It is stated that development of wear-and-fatigue models is now starting and that it seeks to cover critical hydropower components while avoiding one-off models that do not translate across the industry. This is an exciting but also very challenging task. For example, the reviewer would consider the generator stator winding a critical hydropower component, representing a significant maintenance cost, and replacement (rewinding of the generator) decisions and timing are still associated with much uncertainty. The reviewer sees a great challenge in being able to develop an accurate model of as complex and varied a system as a generator stator winding that is not a one-off model. If it is doable, it would represent a major step forward in generator predictive/smart maintenance. It appears that the cybersecurity R&D work builds on cybersecurity work completed during the last two to three years. However, in the fleet modernization and maintenance areas, it is not clear to what extent future work builds on past work, except that the digital twin project description indicates that a feasibility study was completed in FY 2021. Regarding funding mechanisms (slides 10 and 11), it appears that all funding comes from government. It is not clear if industry and academia or prizes/competitions are part of any of the funding. Also, funding is explained for development of wear-and-fatigue models and for cybersecurity research but does not more broadly cover the maintenance and digitalization activity areas.
- Regarding strengths, the presenter did a great job showing the correlation of the various initiatives and projects between one another. There were no real weakness. One recommendation will be to continue to show at the project level how the outcome of a project complements other projects under this activity area. Another feedback will be to look for opportunities to promote work under the activity area within the hydro industry. Leverage industry groups for opportunities to partner with the projects, solicit feedback, and utilize the project outputs.

Project Evaluations

Digital Twin

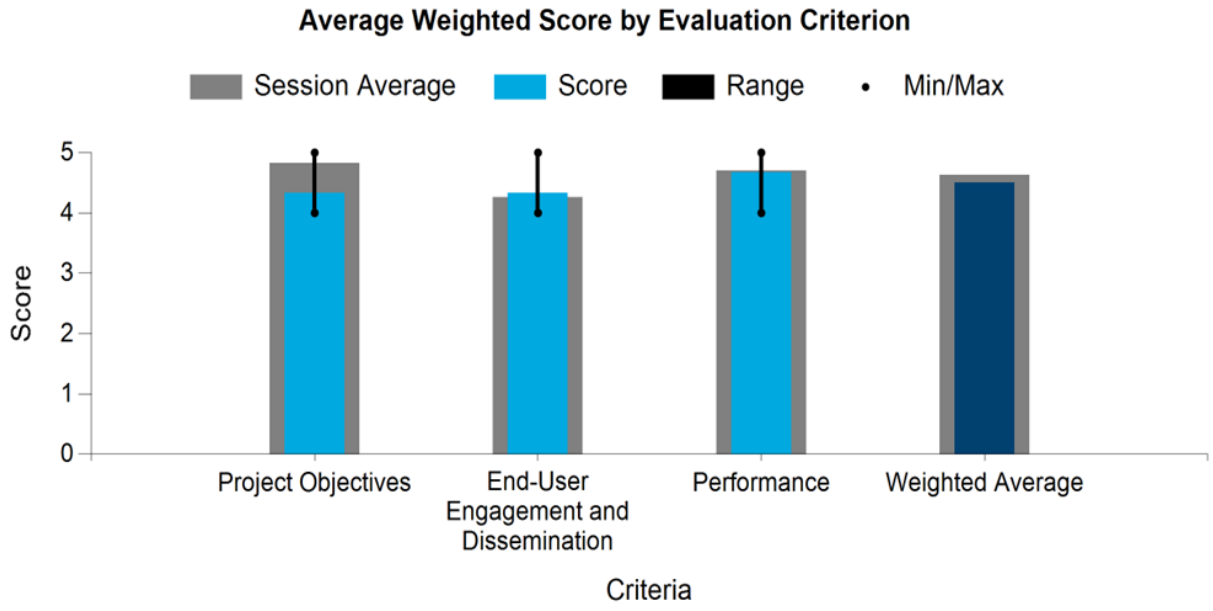
PNNL, ORNL

WBS:	1.3.1.601
Presenter(s):	Osman Ahmed; Hong Wang
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2021

Project Description

Hydropower operations are becoming more complex and demanding as hydropower strives to provide grid reliability and resiliency in the face of variable renewable energy production as solar and wind installations continue to expand. As the electric power grid prioritizes reliability, resiliency, and value amidst an evolving mix of variable renewable and baseload assets, hydropower technology will require the integration and full benefit of the best available and future advancements in sensors, data and control systems, analytics, simulation, optimization, and computing capabilities to remain competitive. This need is referred to as the Hydropower Digitalization Challenge.

ORNL and PNNL have been working together on a four-year project to design, develop, prototype, and demonstrate an open platform digital twin for hydropower systems to help address the hydropower digitalization challenge. The digital twin is a virtual platform that mimics the behavior of a real plant, allowing utilities, end users, original equipment manufacturers, and others to extract deep insights from the real system and enhancing operational performance through simulations and predictive or prescriptive analytics. With its novel open platform, the digital twin will be affordable to own and operate. It is expected that, at the project's completion, the hydropower industry shall fully understand how the digital twin can play a vital role in modernizing plant operation and improving overall plant operational performance, creating the necessary market pull for the digital twin.



Aggregated Reviewer Comments

- Digital twin was specifically called out in the MYPP, so it is hard to get more aligned than that. This one was particularly fascinating, and there is a lot behind the scenes that the reviewer is sure would take years to really understand, so their comments should be taken with a grain of salt. Regarding the last bullet under project objectives, the reviewer's impression is that the meaningful short-term benefits to end users would be trying out scenarios with the cyber-surrogate aspect of digital twin (which the reviewer does not recall being presented by this project, but mentioned during a discussion on Friday) and making operations decisions at the plant level using the twin to roughly or generically estimate start-stop wear and tear on units in energy imbalance market or in response to grid dynamics. The reviewer does not foresee short-term benefits from a one-dimensional model at the level of detail where the end user would see financial benefits from being able to shift from scheduled to predictive maintenance (e.g., individual unit condition, shaft alignment, history of fatigue stresses, vibrations, bearing temperatures, known pitfalls of particular designs of components, and maintenance history). The reviewer would love to be proven wrong about that at the FY 2024 deliverable.
- This is a very complicated project with much technical detail that has a high potential to create a new way that hydropower plant owners and operators will use existing technology on a broad scale at their plants. The project team did a great job of outlining the project objectives, timeline, and costs incurred to date. The project has set measurable go/no-go steps and is progressing through them well. The team did a good job emphasizing the strengths and weaknesses of their model, and they are doing a good job of getting engagement through outreach through their stakeholder group, checking in with industry conferences, and their planned outreach with the Norwegian laboratory. Regarding strengths, this is a very complex project that appears to be progressing according to the provided schedule and budget, and the objectives are in line with the requirements outlined in the MYPP. The investigators are very motivated on this project and passionate about their work and sharing their findings. They are reaching across the industry to multiple stakeholders to help them develop the technology with much input on the process. To that end, the reviewer really appreciates the work that the investigators are doing with the Norwegian laboratory to take the project from the tabletop to a prototype application. They did a great job explaining how this prototype application will help the team validate and tune their algorithms, validate their calculations, and test the machine learning software they developed. Real-world calibration and validation are a very important part of the project and have a whole host of benefits. Regarding weaknesses, given the detailed nature of the project, the concept of creating an open-source tool for hydropower owners and operators to utilize to analyze their plant operations in real time seems to be as equal of a challenge as the creation of the digital twin tool itself. Most utilities will not be able to or interested in connecting real-time plant data to a third-party, cloud-based tool that is termed open source. Although a cloud-based tool is fantastic for validation, many utility cybersecurity requirements limit their ability to connect to existing vendor data acquisition systems for vibration or partial discharge monitoring programs. In order to get more value from the end product, it would be beneficial during the next phases of this project for the project team to set up workshops with the participating industry partners to further define and validate the application for the end user. For example, the reviewer inquired if it would be possible for the project to investigate if they could outline and develop a tool that a utility or hydropower owner could download and install behind their own firewall to use and maintain in house.
- WPTO's MYPP includes broad focus on digitalization of the hydropower fleet, and the development of a digital twin hydropower model addresses this focus. This is outlined in slide three. Potential risks in the project development are not discussed and included. A strong point is the creation of an approximately 20-representative industry advisory group, which helps with end-user engagement and shows a good understanding of project beneficiaries and the importance of dissemination of results. Slide nine also includes a stated plan for reaching out to underrepresented groups in the next couple of years. The project performers demonstrate a good understanding of the project's potential benefits; however, they did not lay out a plan for commercialization of the new technology. Collaboration with external academia and research institutions

(Norwegian University of Science and Technology, Norway) is a strong point because the development builds on work accomplished by others, avoiding reinvention of the wheel. It appears from slides six and seven that project objectives are being met on schedule, assuming that stated milestones on September 30, 2022, are being met. There is no discussion of any COVID-19 issues. The digital twin approach, if successful, could be a great tool to facilitate better predictive maintenance decisions and thus reduce O&M costs for turbines, generators, and auxiliary systems. As far as generators are concerned, a generator rewind (replacement of the generator stator winding and possibly the core) is usually based on electrical tests, service time, and engineering judgement but is still associated with a fair amount of uncertainty as far as timing is concerned. Because a stator rewind is the highest cost maintenance activity for generators, the timing can represent significant capital losses if it is performed prematurely or, if a generator were to fail before a scheduled rewind, it would result in additional capital losses because of an extended outage time. A significant challenge as far as the generator goes is to develop a model of the complex physics involved that would accurately describe wear and tear, including stator winding and core, as a function of operating conditions and parameters. It is generally accepted that increases in dispatch variability, i.e., more frequent start/stops and increased thermal cycling, lead to increased wear and tear. For example, the generator stator winding is significantly impacted by thermal cycling, but there are a large number of variables involved (type of insulation system, age, operating temperatures, design, build/installation quality, etc.) that impact the correlation between operating scenarios and winding degradation and aging. There has been much focus and research in this area during the last couple of decades, and a literature study to assess results and progress might provide useful input to the current project. (Also, contrary to conventional wisdom, the reviewer believes some research, possibly from the Centre for Energy Advancement through Technological Innovation, has demonstrated a weak correlation between thermal cycling and accelerated stator winding aging for some generators.) The reviewer is excited to see what tools will be made available to the industry as a result of this project.

Hydropower Fleet Intelligence

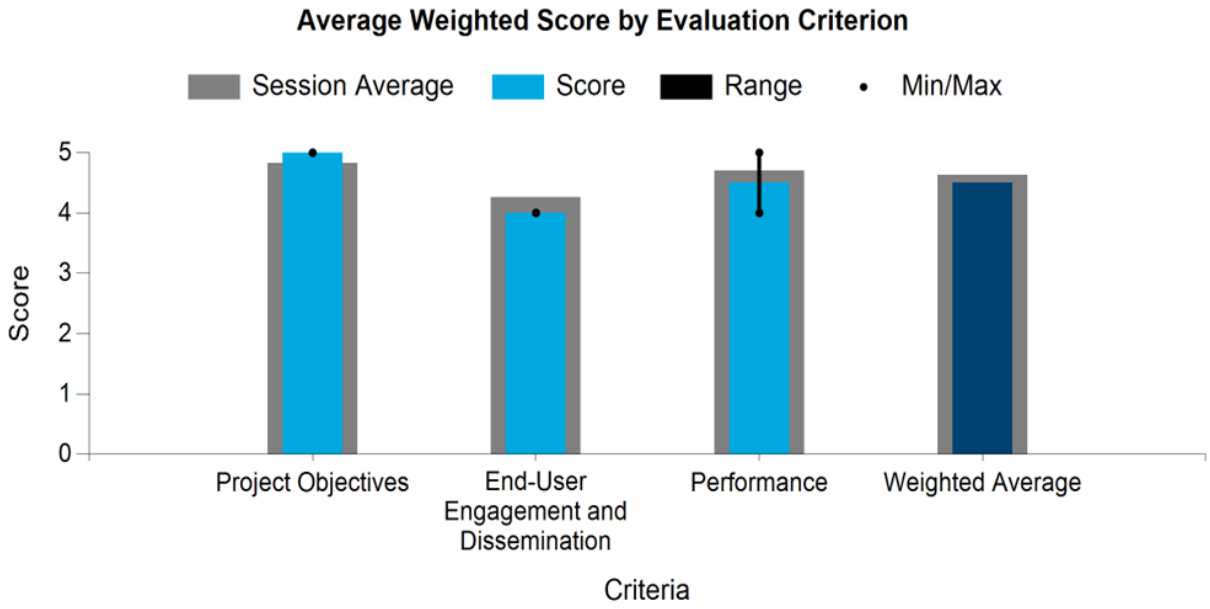
ORNL

WBS:	1.3.2.504
Presenter(s):	Pradeep Ramuhalli
Project Start Date:	10/01/2014
Planned Project End Date:	09/30/2020

Project Description

The HFI project is developing and demonstrating standard processes to make data-driven decisions on O&M for cost-effective hydropower generating unit asset management under evolving contexts. A primary challenge is maintaining cost competitiveness, reliability, and security of existing hydropower assets given the age of the fleet. The project is focused on developing tools to align, correlate, and analyze disparate national- and plant-scale datasets and providing actionable information to U.S. hydropower operators for optimizing O&M decisions. The project is also developing formal processes for verifying data availability and sufficiency and mechanisms for benchmarking and aggregating data from disparate sources. It is also developing and evaluating analysis methods for condition-based asset reliability assessment to support predictive maintenance strategies, assessing digitalization technology, and developing best practices for integration with hydropower facilities. The tools and methods developed under the project are being made available to stakeholders for evaluation and use.

Expected products and outcomes include a data-driven method for assessing dispatch variability impact on hydropower O&M costs, a formal process for assessing hydropower data sufficiency, and software tools (algorithms) for hydropower data analysis to quantify asset condition and reliability and to enhance and coordinate disparate cost, condition, operation, and reliability information to improve hydropower value and reliability. The project outputs are expected to enable better understanding of correlations and dependencies between reliability, efficiency, and O&M performance, and enhance hydropower asset managers' capabilities to optimize facility management for greatest benefit and value.



Aggregated Reviewer Comments

- This was one of the best projects as far as meaningful benefits to end users in the short term. The reviewer liked that plants with any level of digitalization could start to use this tool. This was also the only project the reviewer remembers specifically mentioning how they could dovetail with other projects (digital twin and wear/fatigue data) to the benefit of the overall activity area. It was unclear to the reviewer how a plant would be able to actually implement the Python scripts. The flexibility is key, but to the reviewer, it seemed there might be a few steps missing between the project deliverable and successful deployment in plants of this tool. Maybe the FY 2022–2023 facility and fleet-scale data models will iron out those details, or maybe this would be a non-issue to a programmer or supervisory control and data acquisition expert. (The reviewer is mechanical.)
- This is a very interesting and technically challenging project that has a potential to help utilities significantly advance their asset management processes and maintenance practices and manage risk at their facilities. The project has progressed in accordance with their project schedule and is within budget and in line with the MYPP. It was great to see that there has been much work to engage with industry stakeholders and several presentations at industry conferences to gather feedback and engagement. Regarding strengths, this is a very complex project that touches almost all aspects of hydropower owner and operator datasets. There has been fantastic engagement across the industry and stakeholder engagement. The project has completed much work to successfully identify the required and available datasets most hydro owners and operators have and used this data to successfully build the HydroSource database. The HydroSource database can be used not only by this project but by other related projects that WPTO undertakes today and into the future. The software modules for detailed calculations based on the datasets are currently under development in accordance with the project schedule. It is good to see the project has identified several diverse and complementary outputs of this project, which can be implemented directly by hydropower owners and operators when complete. Regarding weaknesses, the use case and adoption of the software models when created is as important as the creation of the model itself. There appears to be a lack of end-user engagement as to the best way to package the identified deliverable of the software modules. As discussed during the Q&A section of the peer review, most if not all hydropower owners and operators should be able to apply at least one piece of the software tool if engaged and interested in the deliverable. As such, it was recommended by one reviewer to structure the deliverable as a series of Python scripts and a user guide to allow the hydro owners and operators to apply one or all software tools in house based on their configuration of databases in the way that makes the most sense for them. However, it is recommended to host a workshop with their participating utilities, possibly at a utility conference, to further define the best deliverable for quick adoption by the industry and to further validate the best way to package the software module deliverable for implementation by the hydropower fleet.
- The project aims to create correlations between big data from component- to plant-level sources with decisions on O&M activities, including cost impacts of hydropower flexible operations to support the electric grid. The reviewer views this as a very ambitious undertaking because of the many moving parts and variables involved, and it will be very interesting to see the tools for the industry and results of the project. The project management plan (slide seven) does not include discussion of potential risks. The budget for FY 2022 is not included. A better description or vision of actual user-friendly tools to be developed for hydropower operators would have been nice. There is currently only an indication of a variety of data models that are being developed. End-user engagement and dissemination plans are strong, but there is no stated plan for commercialization of products.
- Regarding strengths, this project has the potential to help the industry to better understand the need for data and how data can help decision making. Regarding weaknesses, more end-user engagement is needed when it comes to helping the industry understand what they can do with existing data. Helping them organize data will help build confidence in the project's potential as well as provide utilities with the business case to invest in gathering more data.

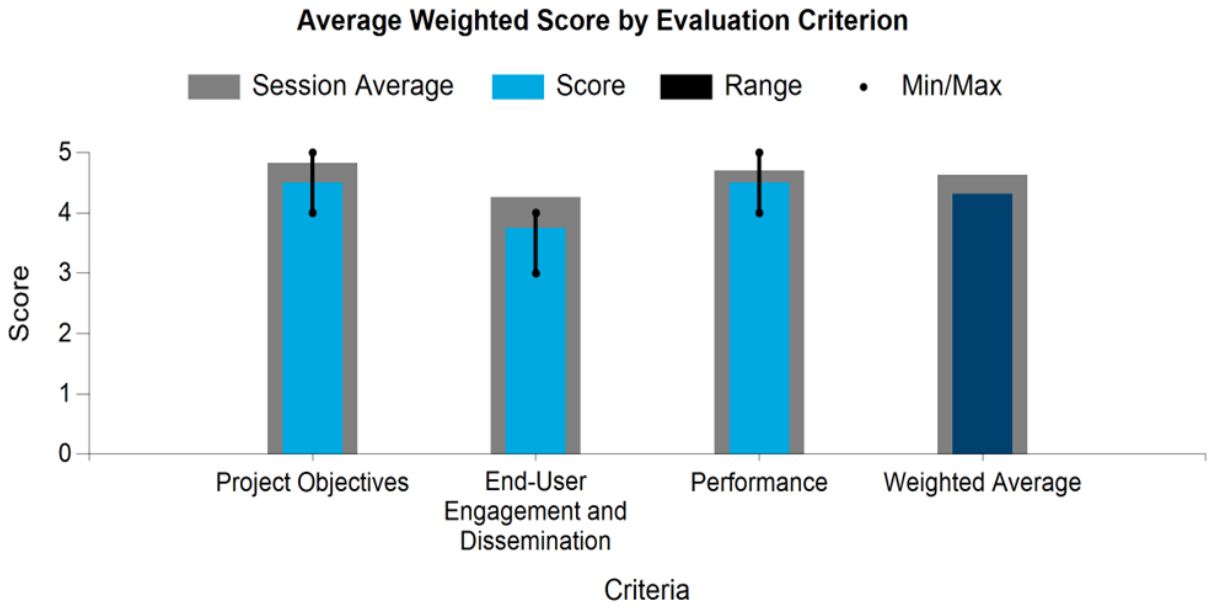
Cybersecurity Value-at-Risk Framework

NREL, Argonne

WBS:	1.3.3.402
Presenter(s):	Anuj Sanghvi; Vladimir Koritarov
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023

Project Description

Hydropower plants need tools for assessing the value of cybersecurity while making critical decisions on plant investments in cybersecurity and risk mitigation. The Cybersecurity Value-at-Risk Framework will provide an industry-accessible, self-guided, automated tool for hydropower stakeholders to identify best practices for their systems and provide guidance for management through a quantitative scoring mechanism to inform effective cybersecurity investment decision making and planning.



Aggregated Reviewer Comments

- This seemed like a useful and cost-effective project that is well aligned with the goals of the MYPP and activity area. The reviewer thinks the FY 2023 expansion for site-specific attributes with the option to tailor assessment and valuation would be key to providing real benefits across the board for hydropower plants. The team is doing a lot of end-user engagement. Trying to anticipate every factor that each unique hydropower plant might want would be extremely difficult and messy and doomed to miss something regardless. Some projects value fish passage above hydropower, some have black-start capability and are more valuable targets for that reason, some might be targeted as tourist attractions, some provide drinking water, some do more to help incorporate wind into the grid, and some might be so remote that few of the common concerns apply. The reviewer is sure the team has many factors included in the tool, but there will always be something to customize. The customizable aspect of the tool would not have to be as user-friendly as the main menu.
- This project developed a tool that allows a user to determine the risk and/or vulnerability of their hydro facility to cybersecurity threats. The work was based off of another project in this area that has already been completed and seamlessly ties into the MYPP cybersecurity focus area. The project output, when complete, should be able to be used by any utility to review the threats to their plant almost immediately. Regarding

strengths, the tool, though not demonstrated during the peer review, appeared to have much sensitivity for the hydro user to set sensitivities for the owner's risk tolerance, facility criticality adjustments, etc. These inputs are essential to ensure the user has the ability to ensure they install the best available controls for their company, reasonably available control technology, or lowest achievable risk technology. This tool should be hosted publicly and adjusted and maintained as new threats are determined or standards implemented. Regarding weaknesses, this tool should be able to be applied to any facility, no matter what size. However, the tool as is may not provide as much benefit to the larger or fully integrated utilities that may have an entire department dedicated to monitoring and hardening their facilities, transmission grid, and customer data from cybersecurity threats. That being said, during the Q&A session, the investigator did mention a potential for future work to modify the tool to allow for a fully integrated utility to audit all of their facilities to look for differences between the facilities and log recommendations for one project against the next. Another limitation is the scalability for a utility to use this tool to audit their substations, customer data vulnerabilities, etc. If the tool is expanded into these areas, the department and NREL would likely get more value and adoption of the tool across the industry sector.

- Project objectives and outcomes are clearly defined, and they align well with WPTO's MYPP. Potential project risks are not discussed, and a project budget for FY 2022 is not clearly shown. In the project timeline slide, using actual fiscal years instead of FY-1, FY-2, etc., would improve readability and correlation with the project budget slide. It was unclear to the reviewer if this project should include results from the already completed project "Hydropower Cyber-Physical Reference Framework," which classifies plants into nine types. The plan for end-user engagement and dissemination is good, including partners and advisors, but there is no plan outlined for commercialization of developed products. It is difficult to correlate the project timeline (slide five) with the accomplishments and progress list (slides eight and nine). More consistent use of terms and designations would help improve clarity of progress versus timeline.
- Regarding strengths, developing a tool that provides a framework for assessing cybersecurity risks for a utility and helping prioritize investment could be something utilities could use. Regarding weaknesses, the reviewer recommends engaging with more and more diverse end users. Adding the ability for utilities to provide input for risk appetite will be something that will help utilities customize the tool to their use. Another suggestion is to incorporate NERC and other compliance requirements into the tool such that it provides not only risk assessment but also a way for utilities to audit their compliance program and manage risk around compliance.

Hydropower Cyber-Physical Reference Framework

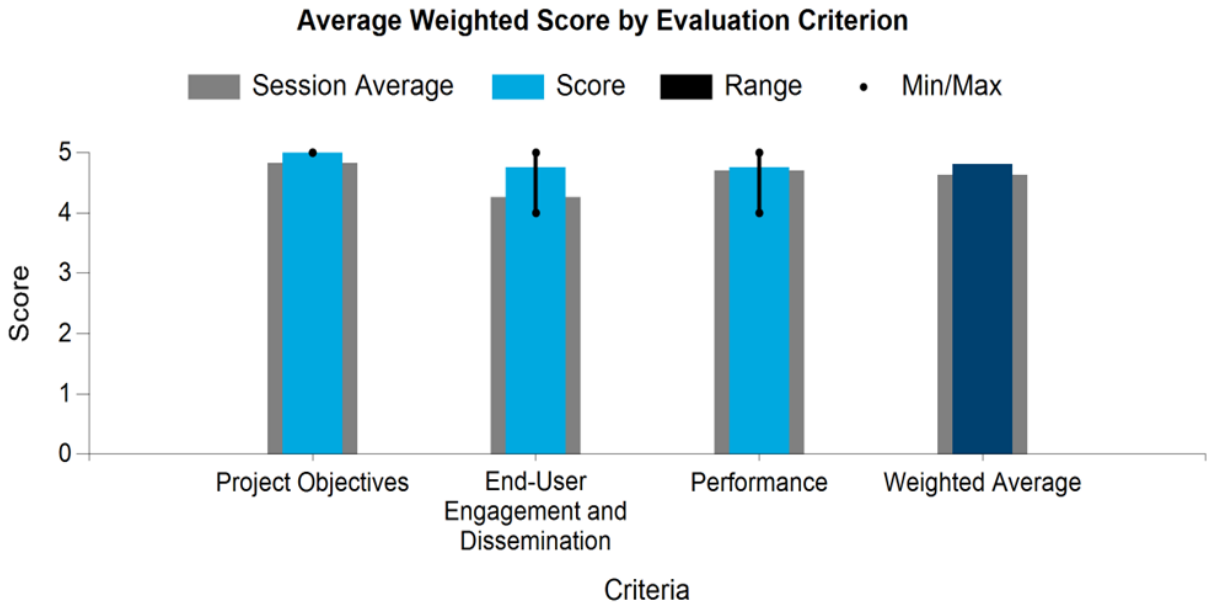
PNNL, Argonne, NREL

WBS:	1.3.3.602
Presenter(s):	Ken Ham; Vladimir Koritarov; Michael Ingram
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2020

Project Description

WPTO funded PNNL, Argonne, and NREL to develop a typology to characterize the variety and pervasiveness of cyber-physical configurations across the nation's hydropower fleet. Outreach to plant operators returned configurations for 275 hydropower plants or approximately 12% of the fleet.

Components (operational and information technology), systems, and connections among systems differed among plants according to function, age, position in the river cascade, and other factors, producing nine distinct cyber-physical configuration types labeled A through I. These types were differentiated by how pervasive data and control connections were among components and how frequently control signals paired with data signals in a feedback loop. The flow of data and control within each type implies what cybersecurity vulnerabilities may exist and the most effective mitigation actions. A self-assessment approach allows plant operators to type their plants and link to the lessons learned and best practices information. The cyber-physical typology reinforces the idea that hydropower facilities vary widely, but it also highlights useful similarities in how their components interact. These groups help address fleet-wide cybersecurity needs by identifying a reasonable number of configuration types that share risks, vulnerabilities, and potential mitigations.



Aggregated Reviewer Comments

- This project is aligned with the MYPP and activity area and addresses a current challenge being faced by end users trying to scope and program cybersecurity work. The reviewer will be keeping an eye out for conference presentations and the report. The reviewer would like to understand the connection diagrams better. The reviewer does not recall that reviewers mentioned this project in particular on Friday in the context of projects that would give benefits in the short term, and they should have. This will be providing end-user benefits in

the very short term, more and more as the results are disseminated as mentioned on the future work slide. The reviewer just noticed in future work that the team mentioned supporting the roadmap project also in this activity area—good call.

- This project brought industry stakeholders together to develop common frameworks of data transfer within common plant configurations so that other departments, government sectors, etc., can develop standard processes or requirements for protecting the equipment at their facilities. This project is already complete and is presently adding value to the program. Regarding strengths, the project investigator noted that they had achieved a response from 13% of the facilities in the United States. Based on this reviewer's experience running R&D projects in the energy sector, this is a remarkable rate of response from the industry. The methods and means for getting such a high response rate could be a model for other similar projects in the WPTO program. No weaknesses were identified.
- Commercialization was not discussed, but the project appears to be intended to support future R&D in the cybersecurity area and is, therefore, not intended for commercialization as a standalone product. The response rate to the questionnaire was impressive, reaching about 13% of the nation's hydropower plants. The graphics included in slides 10, 11, and 12 are difficult to grasp, but this is probably a moot point because the project is already completed. Also, the graphics are likely explained in the report.
- Attaining a high response rate across the hydro industry is commendable. It will be good for other projects to see what sort of strategy was used and take some lessons learned.

Hydropower Cybersecurity Risk/State of Fleet

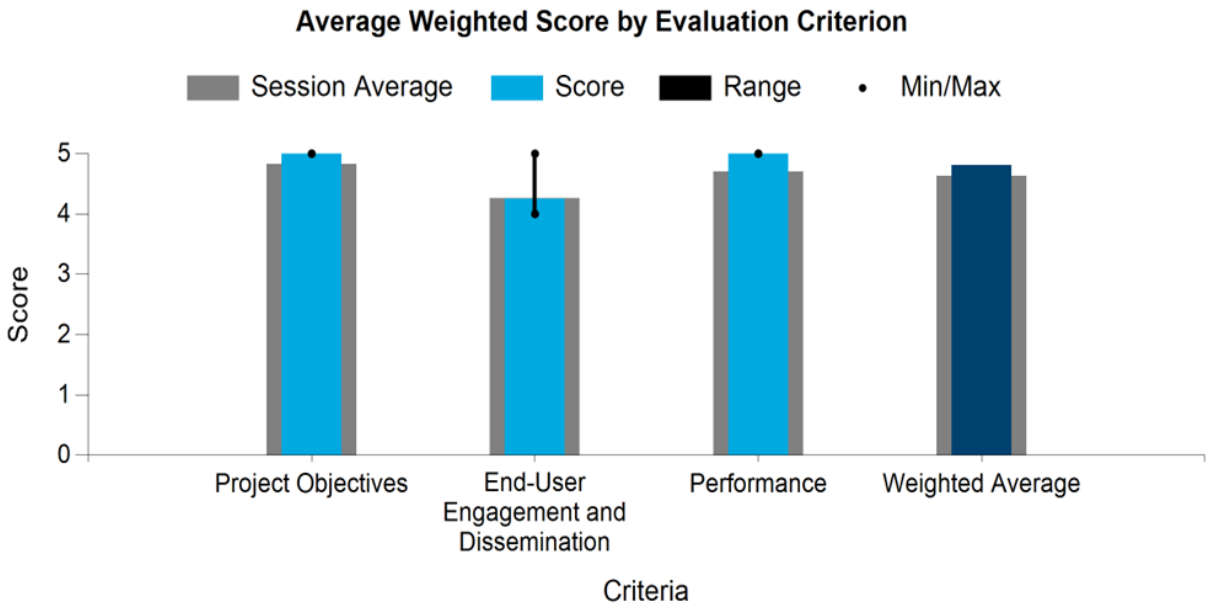
PNNL

WBS:	1.3.3.603
Presenter(s):	Marie Whyatt
Project Start Date:	10/01/2020
Planned Project End Date:	12/31/2021

Project Description

The project focused on researching and painting a picture of hydropower's cybersecurity state along with current and emerging identified threats and gaps for the coming decade. The project team used that knowledge to prioritize threats and gaps, survey known and emerging solutions, and recommend near-, mid-, and long-term R&D investments. The goal was to discern where WPTO ought best to invest R&D funds for highest impact and to truly "move the needle" in hydropower cybersecurity.

The project vision statement was the following: "Within 10 years, the U.S. hydropower fleet shall be conspicuously modernized, well-maintained, and a cybersecure source of value for the nation."



Aggregated Reviewer Comments

- This is a small detail, but it would be helpful to reviewers to have the name of the presentation document and abstract more closely match the project name in the agenda. This project is well aligned with clear short-term benefits and seemed to have exactly the right people executing and supporting it.
- This project was completed in 2021 within budget and schedule. The project evaluated the cybersecurity landscape for hydropower plants (first six months) and then built a roadmap for WPTO to continue research based on the threats and/or gaps identified in common cybersecurity threats for the next 10 years. The recommendations were broken down into recommendations for WPTO R&D investments in cybersecurity for 0–3-, 4–6- and 7–10-year horizons. The tenants of these recommendations are already adding value back to the industry and currently being used by WPTO, the Department of Homeland Security, and utilities. The

reviewers appreciated the investigators' knowledge and passion in this space and the thoroughness of their work to engage and appreciate the nature of hydropower. The investigators engaged with multiple stakeholders across the hydropower, cybersecurity, and compliance sectors to really understand the cybersecurity issues that face the hydropower industry today and into the future. The challenges for hydropower facilities are different in nature than those of natural gas facilities, for example, because hydro plants are all different designs, configurations, and eras of equipment. Some have technologies dating back over a century, and others are quite new and modern. In addition, the way hydropower is operated varies significantly across the sector—some are ramping and starting and stopping as part of ancillary services and/or energy imbalance market and may in the future allow a third party like a system operator to switch a breaker for them, which can create a host of cyberthreats that do not currently exist. This paper considered the risks across the entire sector, which is no small task.

- These comments may be moot points because the project was successfully completed in FY 2021. The project was intended to be a tool for guiding WPTO research in the cybersecurity area and aligns well with WPTO's mission statement. The project appears to lack industry participation and input and was executed mainly with PNNL staff with minimal, if any, input from industry. Validation of results ("sanity checking") appears to have been minimal (conferences and lunch and learn both through the Northwest Hydroelectric Association). The training guide that followed the project appears as a valuable tool for small hydropower plant operators. Because of the continually changing cybersecurity landscape, it is believed that updates to the guide/tool will be required on a regular basis for it to remain relevant. Because of this, commercialization of the product should be considered.
- It is great to see that the project involved looking at other industry sectors as the cybersecurity risk state for hydropower was reviewed.

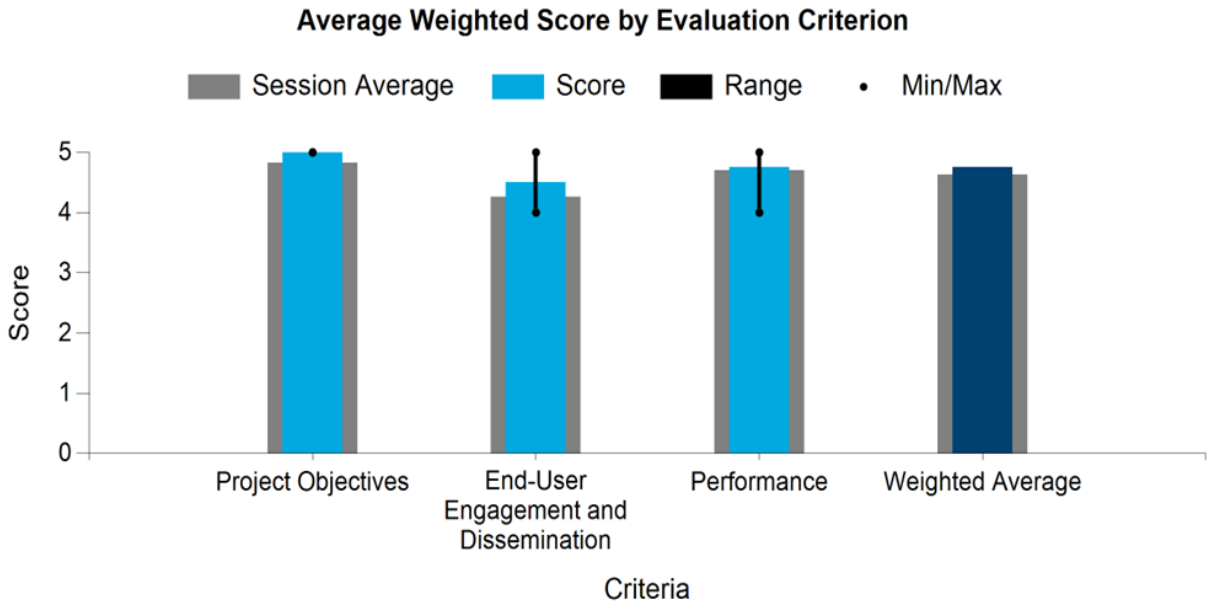
Hydropower Fleet Cybersecurity Response and Recovery

PNNL

WBS:	1.5.1.601
Presenter(s):	Darlene Thorsen
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2020

Project Description

This project aligned cybersecurity and emergency response frameworks into a consolidated, quick-reference flipbook of steps to be taken during an incident at a small or moderate-sized hydropower plant. This effort color codes and standardizes the steps a hydropower plant operator needs to take, along with required regulatory steps to enable a plant to validate a cyber event and return to normal operations quickly. The flipbook tool has been evaluated, shared, and exercised at national and international industry conferences as well as by federal and state organizations involved in energy-sector cybersecurity and emergency response.



Aggregated Reviewer Comments

- The reviewer appreciated this project being sent out to reviewers. This is one of the projects that the reviewer thinks could provide really practical short-term benefits to end users, and, as far as the reviewer is aware, this is the only project trying to answer the question of how exactly to respond and recover after an attack versus defending from an attack in the first place. Arguably, the question of how to respond and recover is more urgent because there will always be a chink in the armor someplace, cybersecurity measures take time and money and an attack could happen before they are in place, and regardless of defensive measures, questions will still arise after an attempted cyberattack is recognized. The reviewer hopes to hear of the results. If the flipbook is found to be of practical use in an exercise and/or updated using feedback from the exercise, that will be very persuasive.
- This project focused on the creation of a guidebook or flipbook that is focused on small to moderate organizations to address cybersecurity protections and will help an owner recover from an event if a threat is present. The book may also be used to identify protections for the user's system from events that may

occur at their facilities, on their electric grid, and/or for their customers' data. The investigators explained how they worked through the various standards and requirements so that the utilities do not have to. The final deliverable is already complete and submitted to WPTO. It is available to the public, adding value to the hydropower community. The reviewers appreciated the strong, knowledgeable team that was awarded this project. Their knowledge and passion in this area was very apparent. One point of particular note that the reviewers appreciated was the "required notifications" pieces of the guidebook. Where the book notes if a breach of cyber data is present, the guidebook provides links to Federal Emergency Management Agency and Federal Bureau of Investigation intake forms along with QR codes, where applicable, so a user under stress may provide timely notifications to the federal agencies in accordance with the required standards.

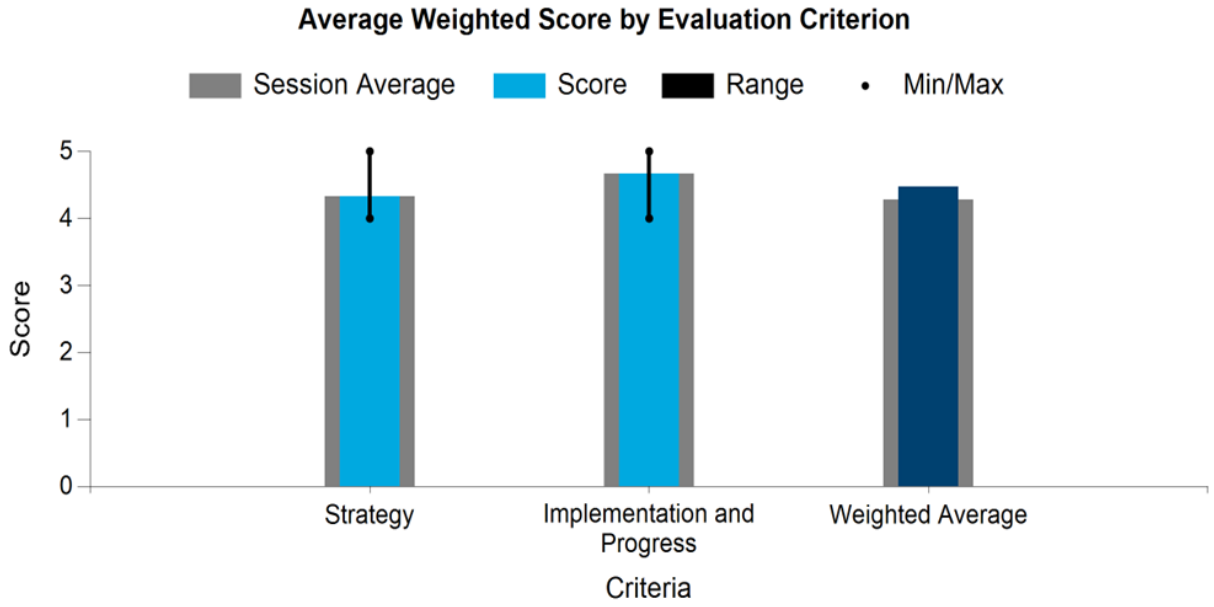
- These comments may be moot points because the project was successfully completed in FY 2019. It sounds from the presentation that the guide is completed, but the slide on future work seems to indicate that it is still to be validated and needs updating. Please clarify the status of the guide. It appears that for this tool to remain relevant and up to date, regular updates would be required. Because of this, commercialization of the tool should be considered.
- This is a good project with a deliverable that will be useful for small to mid-size organizations. Hopefully the product gets promoted and used by the industry. Great work by the project team.

Environmental and Hydrologic Systems Science

Activity Area Evaluation

WPTO

WBS:	1.4
Presenter(s):	Dana McCoskey



Aggregated Reviewer Comments

- The programs and projects in this portfolio are well matched with the strategic goals and objectives of the MYPP. The work is high quality and will be valuable. The department will just need to ensure that the work is carried forward, either through the next stage of research (methane) or through commercialization (shad tags) and that the work is communicated broadly and effectively so that the full value of the findings will be put to the highest and best use.
- The overview did a good job of walking reviewers through goals and priorities for the MYPP. The communication approach seems to incorporate a range of options improving the ability to both receive input and disseminate information. Research programs seemed focused on new, innovative approaches with very little attention to economic feasibility for implementation. There needs to be a continued emphasis on ensuring members of industry, academia, resource agencies, and nongovernmental organizations are involved in the process to ensure results are applicable and inclusive to needs across hydropower.
- Regarding strategy, the overall strategy for the two major program areas and most of the programs that fall within each seems very good. However, much of the stakeholder engagement and outreach that was done initially to inform the strategy is now more than five years old. Things change quickly (particularly as it relates to climate change), and it would be useful to have an overall strategy that is perhaps a bit more flexible and can be modified based on periodic feedback from and focused check-ins with stakeholders. Perhaps this is being done, but it was hard for the reviewer to tell from the presentation update. Regarding progress, it appears as if good progress has been made on most elements of the program. The reviewer rated progress and implementation a five, but it was a bit hard to tell from the presentation exactly what activities/modules had been completed and how well the original implementation schedule has or has not been achieved or modified. Overall, the reviewer thinks this part of the program appears well organized and well directed. The reviewer encourages WPTO to make sure enough attention is paid within each of the program elements to getting

the message out and making the program research results available and well distributed within not just the hydropower community but also within academic institutions that may be doing research in some of the areas and who could make use of the results. Finally, regarding the presentations for each of the individual program elements, for the next peer review, the reviewer strongly recommends that the presentations focus as much or more on the results to date of the research activity and maybe not quite so much on progress made relative to the original schedule. Also, peer reviewers should be given more time to ask presenters questions and have more frequent breaks for notetaking, etc. There was so much information presented that it was hard to keep up and keep track.

Project Evaluations

A Real-Time and Autonomous Water Quality Monitoring System

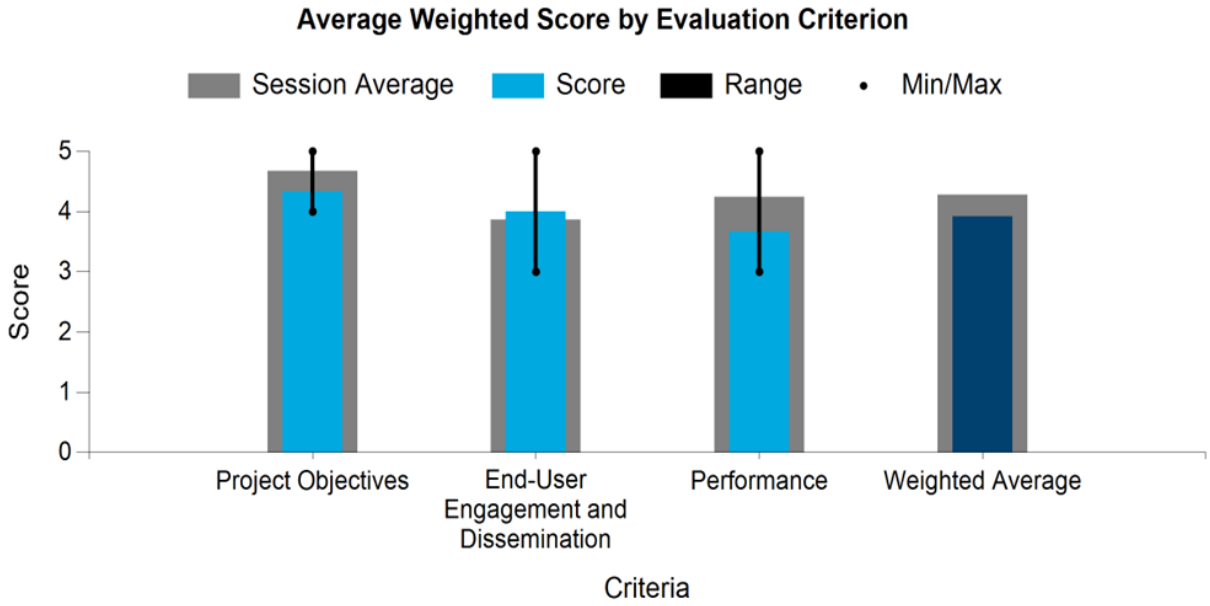
PNNL

WBS:	1.3.1.608
Presenter(s):	Daniel Deng
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021

Project Description

PNNL is developing an enhanced, real-time, and autonomous water quality monitoring system to allow for improved measurement in challenging locations (e.g., around turbine intakes and in the tailraces of dams). This system reduces risks to workers, enables greater spatial coverage of measurements, and improves communication between the sensor and dam operators. It incorporates a remotely operated vehicle as the mobile monitoring platform, a dissolved oxygen sensor for monitoring water quality, a tether management system, a solar mobile docking platform for suppling power to the remotely operated vehicle, and a web-based, graphical user interface for data post-processing and visualization.

Commercialization and widespread use of improved environmental monitoring technologies can help hydropower owner/operators and other stakeholders better understand complex issues, implement mitigation solutions or real-time operational changes to reduce or avoid impacts, and potentially increase generation or system flexibility. These efforts can also help operators successfully manage extreme events such as droughts and/or heatwaves, which can lead to low river dissolved oxygen levels in particular. Information is also useful to understanding longer-term hydrologic variations and increasing the long-term resiliency of America's river ecosystems.



Aggregated Reviewer Comments

- The project is on point with regard to the MYPP and objectives. It is a reasonable step forward and developing new technologies is an appropriate role for WPTO and the labs. Water quality monitoring is important and needs improvements in cost, methodology, timeliness, etc. The work has certainly moved forward. The rovers are exciting. The reviewer gave a three mostly because it needs to keep moving forward. Datasets need to be

expanded. Commercialization needs to be thought out. More use cases need to be demonstrated. The reviewer looks forward to the research continuing.

- Improved methods for water quality data collection are necessary across the hydro industry. This project's adaptability to different environments both upstream and downstream will allow for greater use of the product. Project implementation of the technology will provide operators the necessary information for maximizing profits with flows and meeting FERC requirements in place for water quality standards. The team has presented preliminary results and has a plan in place for additional outreach. The obvious constraint for the project is the lack of field testing and data. In order to become a standard in the industry, rigorous testing needs to be in place to ensure function, cost effectiveness, and quality are present. Additionally, a comparison to current technologies (including O&M costs) would be helpful. This is an excellent start to the project, and the reviewer looks forward to updates and additional field-testing results.
- This is an interesting and potentially very useful project. The reviewer appreciates that the project focus was on a subject that many hydropower owners have to deal with—water quality monitoring. The goals and objectives for the project seem sound and well thought out. However, there were a few things that WPTO should consider. The automated water quality monitor (rover) and systems were a great idea and translated into a working system that was deployed as pilot project. That is great. The presentation should have focused a bit more on how well the monitor worked in the pilot setting and what problems were encountered. (The reviewer is sure there were some.) Also, going forward, the project needs to compare the cost of designing and building one of the autonomous rovers compared to conventional water quality monitoring costs. Also, a focus on rover maintenance requirements will be important to understanding if this new tool will be a practical and cost-effective replacement for traditional water quality monitoring systems. In short, the project should focus now on what needs to be done to demonstrate that the automated system is a practical alternative to traditional water quality monitoring. It will also be very important that the program results be made available to the public and that steps are taken to increase awareness. The program should also focus on finding a way to make the technical and design information on the automated system available to the public. Perhaps a final design and operational manual would be a good ultimate product for this project.

Shad Tag Development

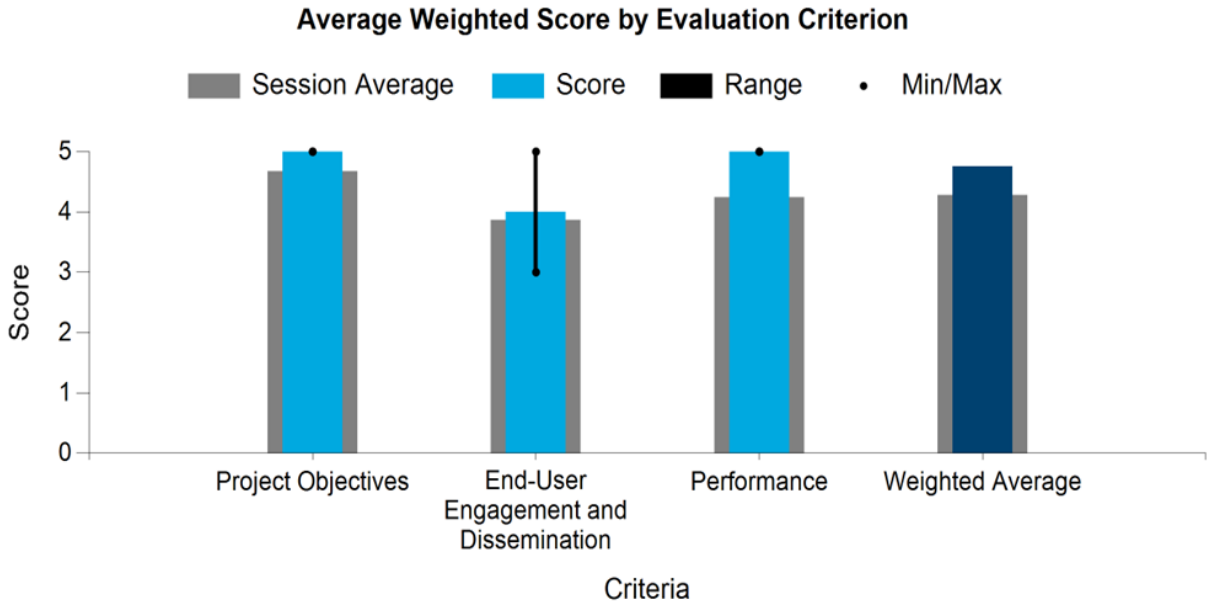
PNNL

WBS:	1.4.1.604
Presenter(s):	Daniel Deng
Project Start Date:	04/01/2020
Planned Project End Date:	03/31/2023

Project Description

American shad (Alosa sapidissima) is a migratory fish native to a large range across the East Coast of the United States. In many rivers where shad are present, they must pass upstream and downstream of hydropower facilities multiple times to complete their life cycle. American shad are an economically valuable fishery, but their populations have been declining throughout their historic range. More than 100 U.S. hydropower facilities with a total capacity of more than 4 gigawatts will have expiring FERC licenses over the next 10 years and are within the native range of American shad. As a part of the FERC hydropower license process, fish passage and mitigation measures for American shad will be routinely and rigorously reviewed by federal agencies and stakeholders.

PNNL is developing a revolutionary acoustic transmitter that can be used to study the behavior and survival of sensitive species, such as juvenile American shad, to inform hydropower mitigation and species management. The ability to implant acoustic transmitters and track the movements of species and life stages of fish that have never been studied before at this level of detail would greatly advance understanding of fish migration timing and behaviors, habitat use, fishway use and performance, and survival rates at hydropower facilities. This would result in more informed management decisions regarding new and existing hydroelectric facilities and better designs of new hydropower systems that minimize or avoid environmental impacts.



Aggregated Reviewer Comments

- This work is well situated in the MYPP and its goals and has advanced well. The key for more use within the industry is commercialization. Another important step will be robust studies of passage and migration using the tag. The positive reception of the work and anxiousness for access to the tags speak for the fact that this is filling a need. Now it needs to get out there.

- There is strong demand across the industry for fish tracking technologies, specifically for the collection of data for various life stages relevant to upstream and downstream passage at hydropower facilities. Researchers for the project have made great progress with studies, including observing a high survival rate and low fall back compared with other technologies currently available on the market. The reviewer's recommendations include involving resource agencies in the development of pilot field studies to better measure performance in the field.
- This is a very good project. It is focused, well thought out, reflective of an industry need, and timely. The mission is clear, and the implementation seems very good with excellent progress made toward the final product. The presentation could have benefited from a little more information about the results of test applications of the shad tag. The reviewer is unclear on whether it worked well and if signal, battery life, etc., were what was expected. It was also unclear to the reviewer if the size was manageable for the juvenile shad. Some of this was presented, but the reviewer thinks the peer review panel might have benefited from hearing a bit more. Going forward, the focus should be on disseminating the results of the R&D, the pilot projects (testing) that was done, and the tag effectiveness. Also, it is not clear how PNNL will make the tag or tag technology available to users or commercial developers. Clearly there is interest and demand, and so this should be the next priority for the project. Well done.

Fish Protection Prize

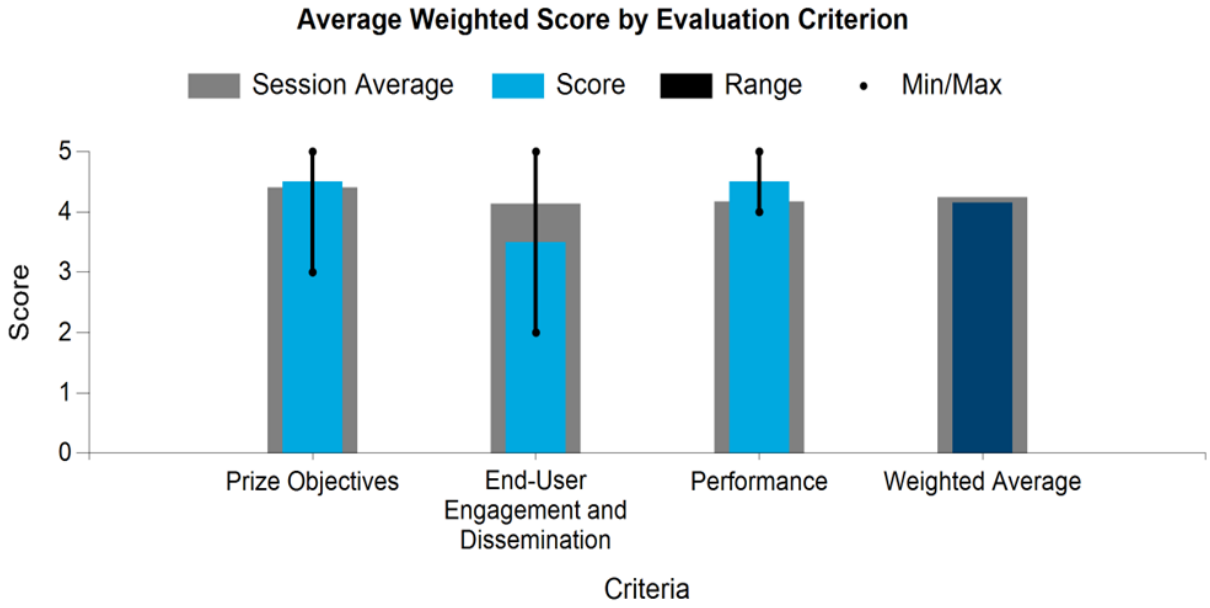
NREL, WPTO

WBS:	1.4.1.611
Presenter(s):	Dana McCoskey; Tessa Greco
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2020

Project Description

The Fish Protection Prize sought new solutions, designs, and strategies to prevent fish from swimming into water infrastructure, such as water diversions and pipes and intakes at hydropower dams. WPTO collaborated with the U.S. Bureau of Reclamation on the prize to inspire innovators to compete for $700,000 of cash prizes and voucher support.

The development of water resource infrastructure and operational criteria must conform to federal and state regulations that protect the environment and public health and safety. One specific environmental concern is the movement of aquatic species, most notably fish, out of natural habitats and into unnatural environments, which may result in injuries or mortality. This movement is referred to as "entrainment." The Fish Protection Prize offered opportunities to reduce entrainment at diversions and intakes to promote more sustainable and reliable water resource systems. This prize built on the initial Fish Exclusion Prize, run by the U.S. Bureau of Reclamation from March to December 2019. This next three-staged prize asked participants to share their innovative approach—along with a design and research plan—for keeping fish away from water diversions and intakes. The prize consisted of three stages that provided the structure and resources needed to move methods for protecting fish from water diversions and intakes from concept to design to prototype and field-tested systems.



Aggregated Reviewer Comments

- The prize team's project management plan was unclear in the written materials and presentation. There was a schedule that included some milestones, but the critical go/no-go decision point and adequate methods for addressing potential risks were somewhat unclear. The prize has a sound stakeholder and/or end-user engagement strategy working with a community of stakeholders. The connection between the prize team and specific water power industry stakeholders or end users at appropriate points in the project life cycle (e.g., establishing an advisory group, assessing end-user needs, communicating progress/preliminary results, and/or disseminating final results, tools, and data) was unclear. The prize's technology transfer and/or commercialization plan for concepts created in the prize was unclear. The projects selected made appropriate progress toward addressing the prize objectives. The project performers coordinated via vouchers with national lab partners to implement sound R&D methodologies and demonstrated the results needed to meet the prize objectives.
- This prize included practical objectives, a healthy prize package, and meaningful voucher support for the winners. The reviewer appreciates the intention to field "radical new ideas" and new solutions to improve fish exclusion technology. A strength of the program included the approach and design and the fact that the team built on the lessons learned from the Fish Exclusion Prize. The three-stage approach worked well, and the team's direct involvement with the winners is laudatory. It was smart to include a pitch contest.
- Given the resources available, this project had great results. While there is still plenty to do, there is good progress with clear benefits should the technologies be successful.
- The reviewer knows they are being tough on stakeholder outreach and engagement, especially with the prizes. Communication strategies should be shared in more detail. The winning ideas will advance the technology forward, so that was exciting to see. It would be great to get some non-industry winners included.
- This was an excellent concept with quality prize recipients and applicants. It was unclear how winners were scored and selected. It was also unclear if WPTO has practices in place to ensure consistency through sharing of information after the completion of the prize. There seems to be a disconnect with this program and universities. A strong recommendation would be to establish relationships within the academic systems to ensure researchers' involvement and not just industry-led technologies.
- The reviewer likes the prize concept. It seems like a good way to effectively spend fewer dollars to bring interesting concepts forward into an R&D phase. The reviewer is not familiar with how these prize programs work, so they did not fully understand some of the details of the Fish Protection Prize program, particularly related to how prizes were judged and awarded. The reviewer would like to see more educational institutions be awarded one of these prizes. The reviewer does not think WPTO is getting the most for the dollar when the prizes go to commercial firms/organizations. If the prizes went to educational organizations, there would be the combined benefit of advancing the research on a particular solution as well as the educational advantages conferred on the receiving institution or team. Also, the reviewer again emphasizes the importance of disseminating information about a particular prize concept, like the Fish Protection Prize, within the relevant water power industry stakeholders or end users at appropriate points in the project life cycle. The reviewer also thinks the project should focus on how the resulting technology or product would be transferred to a broader audience to widen the potential for development of commercial applications.

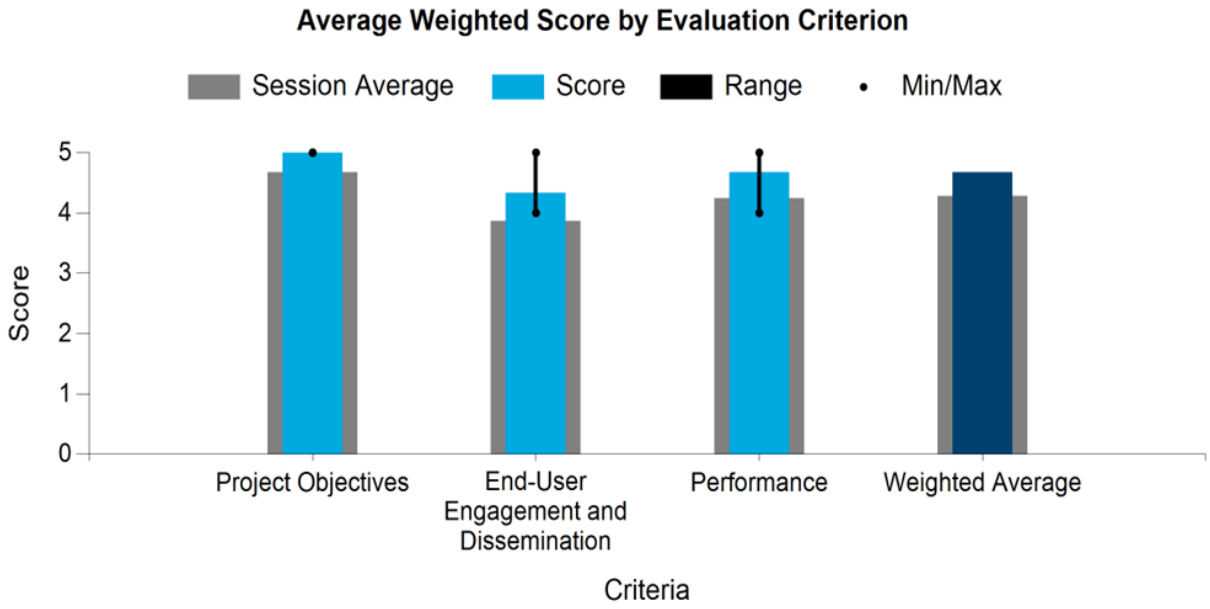
GMLC Water Risk for the Bulk Power System: Asset to Grid Impacts

NREL, ORNL

WBS:	1.4.2.402
Presenter(s):	Ariel Miara
Project Start Date:	06/29/2020
Planned Project End Date:	05/31/2021

Project Description

There is no standardized, consistent mechanism for utilities and other stakeholders to understand how evolving, predictive climate and hydrologic science can be translated to evaluate the various potential climate- and water-related risks of power grid assets and the implications to planning decisions. Based on this need, the project's two overarching research goals are to execute a state-of-the-art, multi-model framework to assess climate-water impacts and risks to the grid, including sensitivities to varying hydrologic drivers and infrastructure futures, and to create a visualization platform using data and model results from the climate-water risk assessments that enables stakeholders to better understand and evaluate climate-water risks to individual assets and systems. Importantly, both the analyses and visualization platform will be designed and developed based on stakeholder engagement, building on prior successful efforts by the team, and close coordination with industry and researchers to ensure relevance and value of the analyses and visualization platform.



Aggregated Reviewer Comments

- This is a critical project that will help with adaptation and water management. They have done a great job at involving stakeholders, adding them into the workflow, and incorporating what they are learning from them. The progress is great. There is a great plan for beta testing and usability.
- This is an extremely useful and timely tool for use across the industry. Stakeholder engagement is outlined within the work plan but is not as clearly defined for dissemination of information. The use of visualizations for climate change seems to be an effective approach to messaging and widely applicable. As with all other projects involving models, a key question remains as to how to maintain the tool's effectiveness over time. Basin-wide planning tools that incorporate increased resiliency in aquatic ecosystems along with grid resiliency will provide improved decision making for water resources. The reviewer is looking forward to the release of the tool.

- This is an important and exciting project. Clearly, climate change and its effect on hydrology have serious implications for hydropower projects and grid reliability. The reviewer's only caution is to keep the model focused on the climate-water-hydropower side of the problem and not on the grid needs-infrastructure demand side. Climate change will have other effects on grid reliability beyond the potential contribution of hydropower, but this research and the model should stay focused on the climate-water side. That alone will be a complex problem. The project goals are sound. Creating a model and then providing a good platform for the model will allow the resulting model to be used to evaluate climate-water risks. However, again, the model and its use will only be as good as the effort that is made to make people aware of the model and provide them with clear instructions on how to locate and use it. The reviewer presumes that integration of this project with the HydroWIRES program will help with that. The reviewer really thinks the key for the potential success of this tool is going to be involving the regional transmission organizations and ISOs. The reviewer suggests that WPTO make every effort to take the prototype model (even in its development stages) to the regional transmission organizations and get periodic feedback from them as the model continues to be developed and tested. They are the experts here. The team should find a way to involve them and use their expertise to create a truly useful modeling tool.

Methane Emissions

ORNL

WBS:	1.4.2.501
Presenter(s):	Natalie Griffiths
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2023

Project Description

Hydropower reservoirs, like all inland waters, emit GHGs (including carbon dioxide and methane) to the atmosphere. However, estimates of GHG emissions from all reservoirs (including hydropower) are highly uncertain and range from 0.14% to 6.6% of global GHG emissions. Characterizing uncertainty in GHG emissions from reservoirs has been identified by WPTO as an important first step in identifying and mitigating risk from high-emitting reservoirs.

This project is utilizing a coupled modeling-measurement approach to reduce uncertainty in GHG emission estimates, particularly methane, both within individual hydropower reservoirs and across reservoirs in the United States. Development and validation of novel, in-situ GHG measurement technologies combined with comprehensive, statistically based monitoring designs informed by GHG emission models are critical components of this project. The short-term outcome will be a reduction in the uncertainty in GHG emission estimates from U.S. hydropower reservoirs that will arise from the analysis of field measurements, model assessments, and data syntheses efforts as well as the development and use of novel measurement technologies. Accurate quantification of GHG fluxes is paramount for the hydropower industry to assess its role in decarbonization and because GHG emissions may be considered when evaluating hydropower's status as a form of renewable energy.

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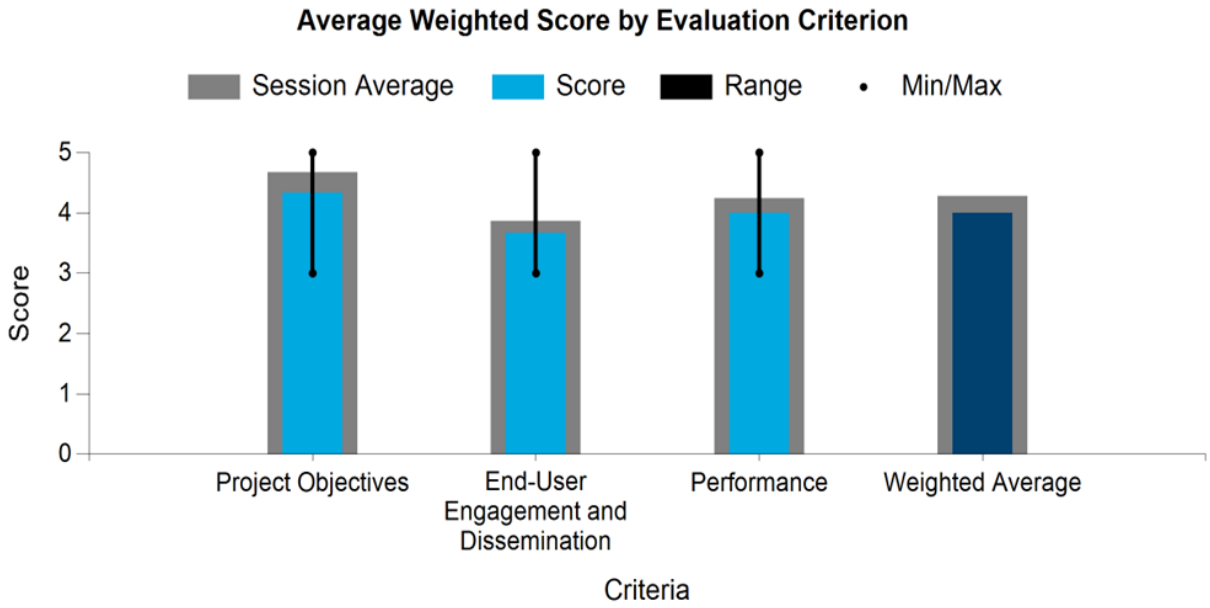


Aggregated Reviewer Comments

- This is critical work for WPTO to do and take the lead on. This addresses concerns that reach beyond industry into the whole hydro community. Actual data is truly necessary in this area because without it, people use whatever is at hand to make their own cases rather than letting comprehensive data direct policy. Although there are some in the industry that do not necessarily yet see the value of this work, it is one of the most important projects that the environmental nongovernmental organization community is keeping track of. The

work is detailed and great. It needs to be clear how this phase of work (concentrating on the U.S. Southeast) translates (or does not) to other regions of the United States. Context will be key. Extractability will also be key. There will be a need for another round of funding to take the research all the way to where it needs to be. The presenter outlined those future years of work well. The only criticism is that the recognized stakeholders did not include policymakers and environmental nongovernmental organizations specifically but should.

- Additional tools such as this are necessary to understand the hydropower industry's role in GHG emissions through the use of reservoirs. Pumped storage continues to be a growing part of the industry, and better access to information pertaining to localized emissions data can help planners on all levels, including city, state, and federal, to consider value and trade-offs of development within a region or watershed. An attempt to engage all stakeholders with interest in GHG emissions should be made; this needs to include elected officials, regulatory bodies, and nongovernmental organizations. The tool seems to be in early stages with a focus on the southeast that is not necessarily applicable across the United States. The project needs broader use of the tool and more refined methods of determining hydropower's part in reservoir emissions versus other purposes.
- The reviewer has several concerns with this project and hopes that they just do not understand it. If the reviewer has it wrong, then their primary comment would be that the presentation was not oriented to someone new to the project, and so the information conveyed about the project should be revisited to make sure it is a little clearer as to the need for the project and what exactly the project is intended to do in support of the hydropower community. The reviewer's concerns are based on the project as they understand it. The project has a goal of creating a good model for estimating GHG emissions from hydropower reservoirs. The reviewer understands that the International Hydropower Association (IHA) already has such a model, and it is unclear how this new WPTO-sponsored model will differ or be better than the IHA model. In fact, based on the response the reviewer got to their question about the model, the reviewer thinks they understood that the model being used for this project is the IHA model, so it is not clear to the reviewer what changes or enhancements will be made to that model to make it better suited for U.S. hydropower project GHG estimation. The deployment of new monitoring techniques of new GHG emissions is apparently going to occur in the Southeast United States. If the goal is to develop a tool that will allow hydropower owners to better estimate their project's GHG emissions, the tool must incorporate or be calibrated to data, information, and measurements that have been taken throughout the United States, not just in one particular region. In short, the product of this research must be useable throughout the United States. Hydropower project reservoirs are often multi-purpose reservoirs that may also be used for water supply, irrigation, flood control, etc. This project seems more intent on improving the estimation of GHG emissions rather than estimating GHG emissions from hydropower reservoirs, and then separating out the portion of the emission that is directly a result of hydropower operations, not operation of the reservoir for other purposes or from what GHG emission would be naturally from a similarly sized and located natural water body (lake). This is critically important as the emissions from hydropower reservoirs may not all be related to the actual operation of the project for electric generation. Finally, the impetus for this research project seems a little off target. Most hydropower project owners in the United States would rather not have another model that estimates GHG emissions from their reservoirs unless that model is aimed at separating just the effects of the power generation operations (see the comment above). In the reviewer's opinion, a much more important topic related to GHG emissions would be a model or tool that allows an estimate of the net GHG emissions associated with a particular project that is a comparison of GHG emissions from a hydropower reservoir as a result of only its hydropower operations, as compared to the GHG emissions from the electric generation sources that would most likely replace those megawatts. To the reviewer, that is a tool that is totally missing in the GHG/climate change/hydropower discussion. There may be GHG emissions from hydropower reservoirs/operations, but the reviewer asked how those compare to the emissions from the next most likely source(s) of replacement generation. The reviewer suggests this research project consider pivoting to address this need.

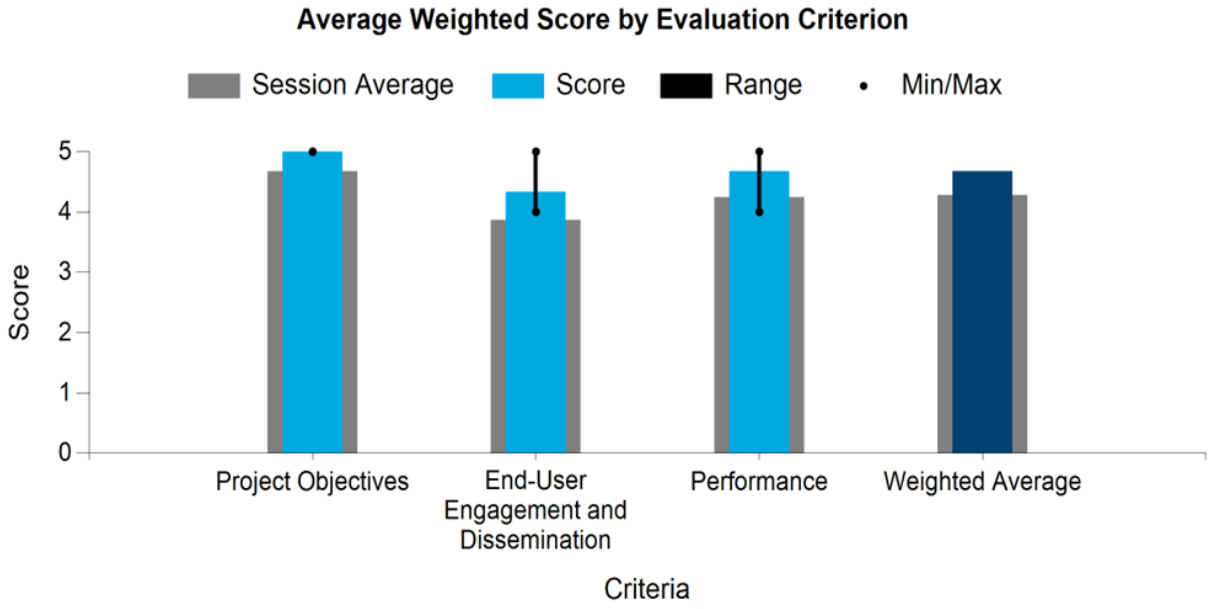
Hydro Fleet Database Development and Analyses (HydroSource)

ORNL

WBS:	1.5.1.502
Presenter(s):	Debjani Singh
Project Start Date:	10/01/2014
Planned Project End Date:	09/30/2020

Project Description

HydroSource is a comprehensive, unique, national water-energy digital platform that accomplishes data stewardship and dissemination for U.S. hydropower stakeholders. The HydroSource digital platform consists of hydropower-related datasets, data models, visualizations, and analytics tools that support and enable hydropower R&D. Hydropower operators and developers, governments (federal agencies, resource agencies, and decision makers in federal, state, and local jurisdictions), nongovernmental organizations, academia, policy leaders, and the public use HydroSource to inform policy decisions, increase transparency in hydropower projects and information, support science-based analysis, enable robust research, consider new project development, develop new tools for data-driven environmental assessment, and inform strategic environmental permitting and mitigation.



Aggregated Reviewer Comments

- HydroSource is a much needed and useful website. Making this information accessible and organized is important. The reviewer's only concern relates to making sure that the communications plan is robust and that the tool is easy to find. It should pop up in searches for "hydropower" or "hydropower development" or even "water use" or "water data," etc. The reviewer inquired if there is a university dissemination instrument that could help let institutions know that it exists. This is a great project.
- This is a great undertaking to provide a centralized database benefiting users across industry, resource agencies, and the public. The greatest challenge is marketing the tool to users and the long-term maintenance to keep the project relevant and data up to date. Several opportunities were identified during the review to include making the page a default on Google for searches and getting the word out through universities for communication.

- HydroSource is an excellent program for bringing together all sorts of hydropower data and databases and putting them all in one place for use by researchers and the public. WPTO needs to continue to keep the databases and information sources available through HydroSource up to date; continue to review the HydroSource webpage from the perspective of a new user to make sure it is clear about what data sources are available and how to easily access and manipulate the data (with particular attention to the ability to download datasets and use offline); provide easy-to-use instructions on how to use and access the HydroSource databases; and work to keep getting the message out about the availability and use of the HydroSource database and tools. Anything WPTO can do to continue to spread the word among potential users beyond the immediate hydropower community would be helpful. The reviewer would particularly like to see more effort put into information for academic institutions about HydroSource so the data can get into the hands of students and researchers within academia. The team should spread the word among engineering organizations as well. Finally, when the reviewer searches "hydropower data" or "US hydropower data," the HydroSource webpage come up as about the sixth to eighth entry. The reviewer recommends seeing what can be done to move that up to one or two. The reviewer also recommended checking the DOE website and making sure that getting from the homepage to the hydropower page to a link to HydroSource is easy and obvious.

FERC eLibrary

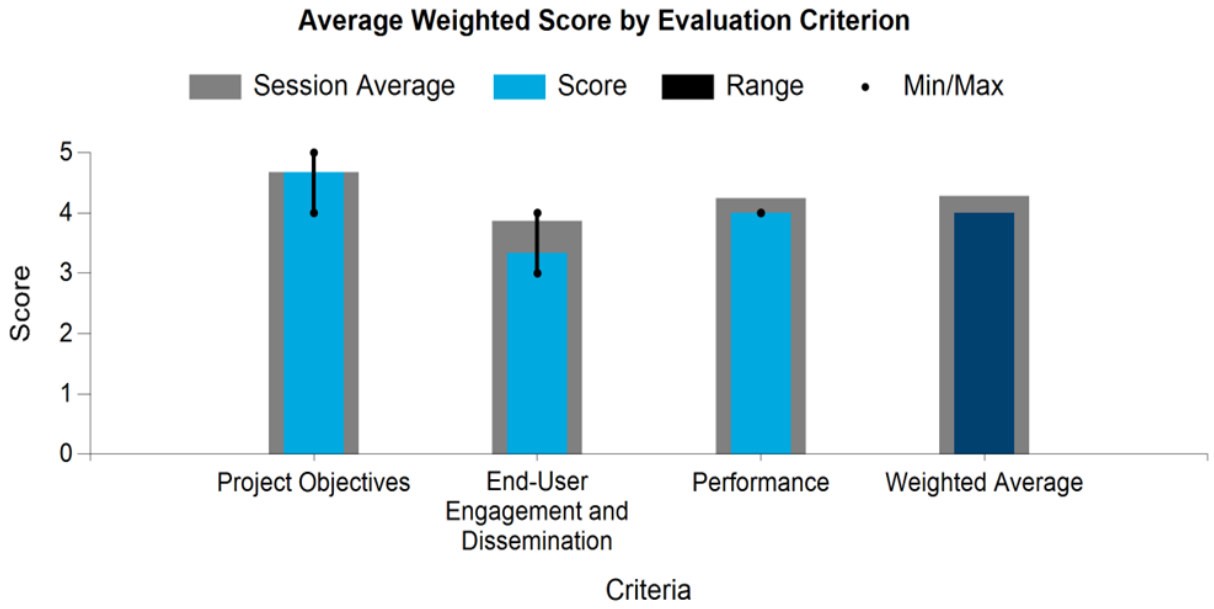
PNNL

WBS:	1.5.1.605
Presenter(s):	Bo Saulsbury; James Bradford
Project Start Date:	10/01/2020
Planned Project End Date:	09/30/2021

Project Description

FERC's eLibrary is an online records information system that contains documents for the four industries FERC regulates. The system is especially useful for the hydropower community. However, eLibrary users, including FERC staff, express frustration with the difficulty of finding and accessing relevant documents due to the poor usability and data tagging.

This project seeks to improve the process of finding and accessing hydropower documents and information within the eLibrary system by analyzing and improving FERC data tagging and quality and by creating an alternate eLibrary tool specific to FERC hydropower data. The project approach follows a typical user-centered design process. First, the team studies and models the workflows of users attempting to find specific documents or classes of documents within eLibrary. Second, they design and develop an alternative eLibrary search tool, targeted at facilitating the identified user workflows. Third, they release and test the new tool in comparison to the original eLibrary, making iterative improvements based on feedback. When completed, this publicly available tool will make it easier for users to find and access documents and information within FERC's existing eLibrary system without altering the system itself. Such improved access to documents and information will help streamline the FERC environmental review and licensing process, thereby increasing hydropower capacity by catalyzing the development of sustainable hydropower.



Aggregated Reviewer Comments

- Although reviewers were not able to see a demonstration, it appears that the work will have a positive impact on the public at-large's ability to access and find information in the FERC eLibrary. This is an important step toward leveling the playing field for everyday users and those that are only participating in a single project's licensing activities. The reviewers all look forward to being beta users. This tool needs to have a prominent

place to live and easy access to finding it. Hopefully, a link from the FERC website itself will be possible. If not, the communications plan needs to be robust and the tool needs to be very easy to find, even if that means paid placement on Google searches.

- There is a clear nexus with this project and a current need of both industry and resource agencies. Improved access to information through the FERC online library could streamline review processes by reducing delays caused by lack of access or inefficient access, causing extended search times. The project has progressed on the provided timeline, but a final product and marketing plan did not seem to be clear. It was not clear from the documentation provided if industry or stakeholders using the FERC online resources have been directly engaged in the development of tagging and searching tools to better capture the needs of these communities of users. Additionally, the end product does not have a clear path for broad use with the only identified outreach and marketing tools identified as WPTO and PNNL.
- The reviewer thinks the idea and need for this project are well supported. Nobody likes eLibrary or finds it easy to search. However, the reviewer has two major concerns/questions. First, the reviewer thinks it is odd that this eLibrary search tool will not actually search FERC's eLibrary, but instead will search a separate, parallel database. The reviewer is not sure they can articulate all their questions/concerns about this, but there seems to be a lot of potential problems with this approach, not the least of which is creating a separate database that may or may not accurately reflect the info officially filed with FERC and available on eLibrary. The reviewer is not saying such a tool will not still be useful, but it would certainly have to be provided to users with a serious word of caution about the database it is searching since it will not actually be searching eLibrary. The reviewer's second comment is about making this tool available to people who are actually searching eLibrary. If the tool is intended to be used by a wide array of folks searching eLibrary, then it seems that some link to the tool or reference to the tool should appear on or be made available on FERC's eLibrary webpage. Otherwise, the reviewer is not sure how the tool will get widely known or used. Finally, because of the reviewer's first two comments, their final comment is that it seems imperative that WPTO be engaging with FERC about this tool development—and more than just asking FERC staff if they need a better search tool. Close coordination between FERC and DOE is needed, or the reviewer sees some potential difficulties ahead for transitioning this project from the development to implementation phase. The reviewer thinks they are stating the obvious when suggesting that this project seems to be doing FERC's work for them. The reviewer suspects that is not the impression WPTO wants to give.

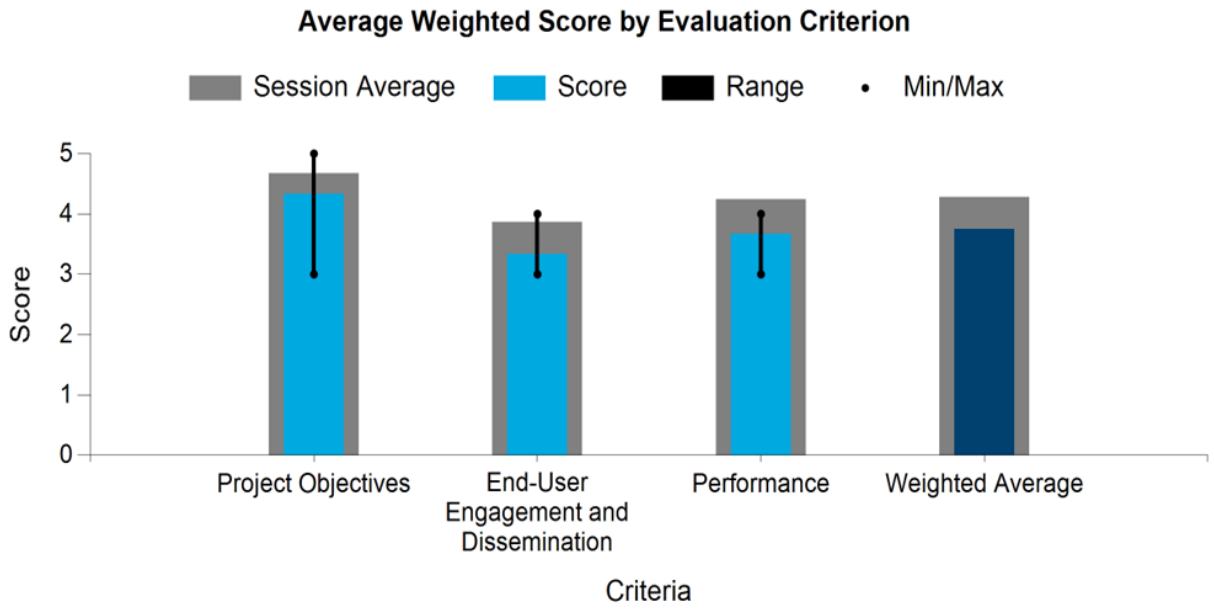
Demonstrating Value of River Data Aggregation and Visualization Capabilities

PNNL

WBS:	1.5.1.606
Presenter(s):	Kyle Larson
Project Start Date:	06/28/2019
Planned Project End Date:	09/30/2021

Project Description

Easier access to diverse types of river data is needed to facilitate basin-wide approaches to multi-objective river management and streamline regulatory processes. This scoping project seeks to help inform future WPTO involvement in activities aimed at improving access to river data by gaining a better understanding about factors affecting accessibility and usability of river data, identifying related initiatives being undertaken by other agencies and organizations, and demonstrating the benefits of accessible data through a series of data stories based on complex river management scenarios in the United States. Through these activities, the project also hopes to build broader interest in the topic among the community of river data users and producers.



Aggregated Reviewer Comments

- This is an important project. The work is great thus far but is limited in applicability since it has focused on anecdotal stories and has not quite reached the point of broad-based applicability. It was helpful to understand that part of the project's objective was to inform WPTO strategy, which it will in no doubt do. The project team needs to do more outreach. It sounded like dissemination of the work was left to a few select audiences to disseminate. It was unclear to the reviewer if they were aware that was their task.
- The most beneficial component of this project seems to be the stakeholder engagement. The reviewer did not see a clear path for addressing data access issues or a nexus with industry/resource agency involvement at hydropower facilities.
- This is another good project that has the potential to bring useful data and information to a broad spectrum of users in a useable and flexible format. The data and visualization aspects of the tool are impressive and could be very useful in many applications. However, to get there, once the database/tool is ready to go, it will

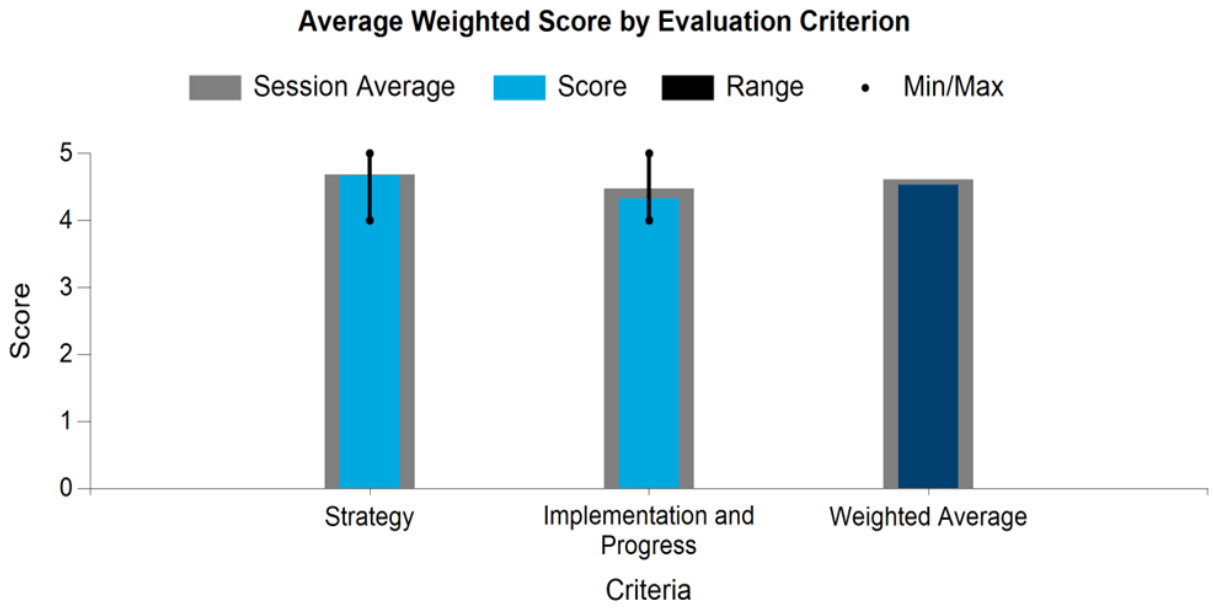
be critically important to get the word out about the availability of the tool, its capabilities, where to find/access it, and how to make it "dance." By that, the reviewer means providing end users with easy-to-understand information on how they can access and effectively utilize the tool. Also, it would be important to include a feature that would allow users to download data or information from the tool, including visual representations of the data and resources being searched or researched. The reviewer recommends the team keep thinking about ways to make people aware of the database/tool and work toward developing easy-to-find information, links, and pathways to get to the tool and help users understand how to use it effectively.

Hydropower Data Access, Analytics, and Workforce Development

Activity Area Evaluation

WPTO

WBS:	1.5
Presenter(s):	Corey Vezina; Allison Johnson



Aggregated Reviewer Comments

- This is great work that is vital to our industry for further project and workforce development. HydroSource is a cool tool to use to search information, data, and opportunities. However, the reviewer is concerned that there is no clear mechanism for correcting omissions, updating status, and editing data. Workforce development and education is a great program that is moving forward at a good pace. This effort is focused on creating high-level awareness of the industry and opportunities for employment. The next phase needs to delve deeper into education through joint planning between PNNL, NHA, the Hydropower Foundation, and the National Energy Education Development Project with direct WPTO funding of the team, its outreach, and the supply of educational materials. Beyond that, in cooperation with industry, the reviewer recommends developing training facilities for craft trades and internships for graduate levels.
- As indicated by the score, the reviewer believes that the program is achieving good results in a diverse number of areas. The reviewer was particularly impressed with the HydroSource portal, which provides one source for permitting and valuable pieces of information. The reviewer recommends that work on this portal continue and the scope be expanded as necessary to capture results of the many studies being developed by the various national laboratories. The information on the workforce provided valuable background for the STEM program, which the reviewer believes is doing a very good job. Overall, these programs are capturing valuable information that will be useful for regulators, developers, and all participants in the hydroelectric area.
- This is the first comprehensive costing project the reviewer has seen from WPTO in recent years. It does confirm much of what developers of new small hydro on existing unpowered dams are experiencing, and the results are realistic. While the focus has been on lakes and locks/dams, it would be good to see similar data for pure RoR, low-head dams. Much of the study material appears to be for the Midwest, and there is a need to compile similar information for the Northeast. The FERC and state licensing processes need unending attention as these agencies and their unfortunate process times and requirements are a real barrier to development of small-scale hydro. Even with the 10 MW exemption, this is still a one-size-fits-all approach that FERC and the

states take. Beware that each state applies its own interpretation. On the workforce front, the outreach to colleges and universities is excellent, although having looked through those that applied, there is not much diversity (in size, rank, etc.). The reviewer thinks the awards need to be higher than presented. Also, the time at which WPTO solicited was (the reviewer believes) at the end of April/May when most schools have their minds on exams/graduation. WPTO should launch this to hit the academic year or the January session when colleges are often looking for off-curricula projects. Nonetheless, this is a good effort. The reviewer also thinks the industry should know which hydro firms hire from which institutions. This should be an annual survey and worked in conjunction with NHA. Finally, every year hydro firms hire summer interns, and the industry should know who is hiring who and from where. These may just be the future entrants/leaders needed.

- Overall, the projects are good choices and logical steps to improve access to quality data related to hydropower. The work is aligned with goals and objectives. The key to this work's effectiveness, however, will be in making sure people know HydroSource exists, is a great resource, and is easy to use. Communication is key. Workforce development is also looking into the right areas in terms of identifying what the needs are and the tools for filling the coming gap. There were questions about whether the research is inclusive in what it considers a hydropower-relevant field. Certainly, colleges and universities have moved quickly ahead in terms of majors that are directly related to the field. In many cases, they are ahead of where the industry is. The reviewer wondered whether that is because there is insufficient coursework for future hydropower workers, or because hydropower has fallen behind in how it looks at its own operations. It is critical that WPTO find an industry partner for this work. It should be owned by industry. The reviewer suggests that the Hydropower Foundation is the best fit, but it needs resources to staff up and take the lead. As it is independent from an industry advocacy group, it is better situated to present a wider degree of programs to the full spectrum of stakeholders in the hydropower community.
- A subsequent presentation covered details from the report, but this presentation did not get into specific questions from reviewers. Understanding and predicting the need for early recruitment based on data on the current workforce age and workloads in the next decade is a great approach to addressing workforce challenges. Clarifying specific areas within hydropower facing retirements would be necessary to fully utilize this report. Additionally, a breakdown of degrees considered to be in line with hydropower needs would be helpful. Some attention should be paid to how this program measures success as well. This was touched on in the discussion after the presentation but not with enough time to follow up.
- The strategy for this program seems a bit unclear, and the program seems to suffer a bit from being spread perhaps too thinly across the three primary areas (data access, data analytics, and workforce development). The program would probably benefit from WPTO trying to better focus the three distinct areas into a more cohesive set of goals or strategy. This also seems to result in the program resources being scattered thinly across a number of different initiatives, thereby reducing the overall effectiveness of the program. The collegiate competition is a great idea, and the reviewer thinks that should be expanded and/or supplemented with a broader reach for the competition and a scholarship program. The workforce development goal would benefit from both. Expanding reach into the education community will also help. More effort should be put into reaching more students about available opportunities. It sounds like this important program is supported by only a very small budget. (The reviewer thinks the presenter said 2%.) The reviewer would recommend expanding funding support for these important hydro education and workforce development programs. Data access is really important, and the reviewer thinks this is a terrific program area. However, to be effective, the data access elements of the program really need to strive to get the word out. It does little good to make the available data accessible if people still do not know the data exists and where they can find it. WPTO should emphasize communication and marketing throughout this program area—get the data into the hands of the people who are most likely to use, and increase communications about data availability and access within the educational community where most researchers reside (as students, graduate students, fellows, and professors). From the presentation, the reviewer had a hard time really determining how and what progress has been made relative to the original program schedule. It seems that good progress has been made in most areas, but the reviewer suggests that in future updates and peer reviews, more detail is provided about progress with program elements relative to the schedule. If there are reasons why progress has been delayed, those should be explained as well.

Project Evaluations

STEM/Workforce

NREL

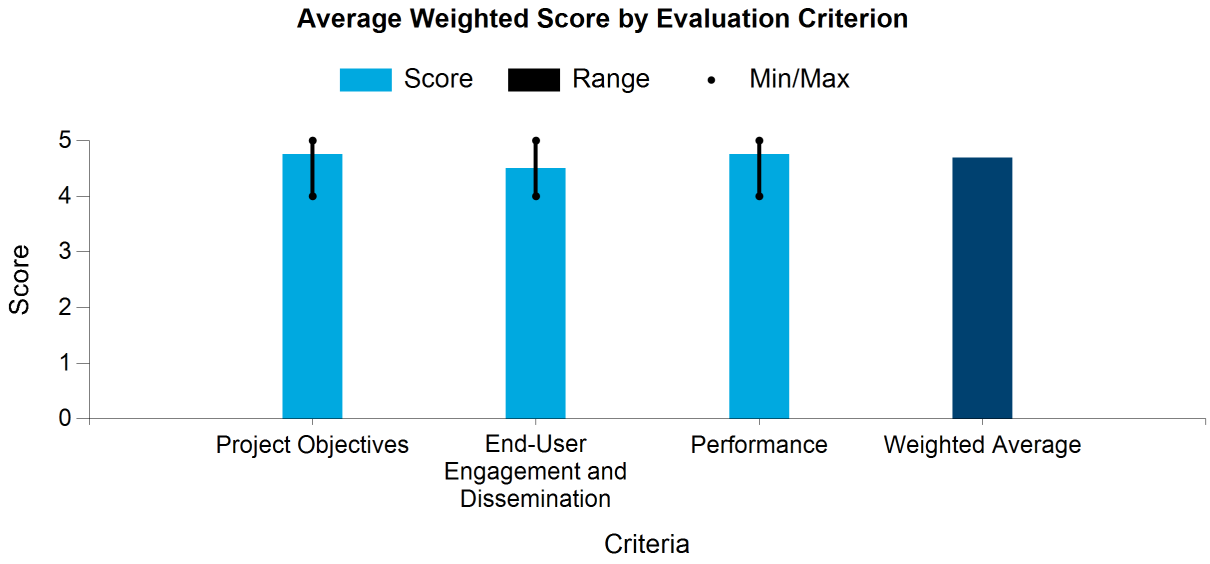
WBS:	1.4.2.403
Presenter(s):	Elise DeGeorge
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2020

Project Description

As interest in renewable energy grows, water power technologies will continue to play a robust and growing role. However, the industry needs new talent to spur innovation and to support industry needs.

NREL has a long track record of working to address educational needs across the renewable energy spectrum. Leveraging this track record, this project brought the Hydropower STEM Portal to water power stakeholders with information from a multitude of sectors and partnerships with the Hydropower Foundation, the National Energy Education Development Project, and others. The team has also sought to integrate activities with the Bonneville Environmental Foundation to increase dissemination opportunities and interfaces. The purpose of the portal is to be a one-stop shop for information geared toward inspiring the next-generation water power professional.

NREL also leverages experience engaging with stakeholders to understand barriers to technology adoption to identify issues and drivers, provide feedback to the R&D community, work to clarify misperceptions, and inform decisions to facilitate market adoption. The outcome of this work is a more successful and diverse water power industry based on a motivated and better-trained workforce.



Aggregated Reviewer Comments

- The project objectives, engagement with representative end users during the project, and performance were all excellent. Looking at slides 9, 12, and 13, in particular, this project has done a lot to engage end users and disseminate outputs, but the reviewer does not think they would have come across the portal outside of being a reviewer. The reviewer did use the STEM for Hydropower Portal to find some hydropower engineering courses in which they would be interested. The reviewer also forwarded a link to a coworker's niece, who is still in high school and asked about working in hydropower and being an engineer versus a mechanic. In particular, the reviewer advised her to check out the Career Pathways page with lots of short day-in-the-life videos from diverse career tracks. The reviewer heard another mention reaching out to the Society of Women Engineers, which is great. The reviewer recommends also reaching out to the Society of American Military Engineers (the Portland chapter has a lot of USACE folks), the IEEE (hydroelectric power subcommittee), and the American Society of Mechanical Engineers (hydropower technical committee). The reviewer thinks there are lots of engineers who would be happy to pass on a helpful link to a young student, just like they did.
- After reviewing the presentation and much of the referenced material, the reviewer is greatly impressed at the overall organization and outreach from this program. The STEM portal is particularly impressive as are the videos of the daily lives of various participants in the hydro industry. The reviewer is currently on an advisory board for the engineering department at their alma mater and will share much of this material with them. In addition to providing a basis for new workforce members, this provides valuable information and credibility to the general public for the hydropower industry. This undertaking needs to be continued.
- Regarding this project's strengths, much of the three-pronged approach makes a lot of sense and is presented in a good way. The Marine Energy STEM Portal contains helpful information and is presented nicely. Conducting a school survey is an excellent first step to figure out the baseline of educational offerings. The outputs and planned future work are all well thought out and strategic. In particular, working with industry is planned and needs to be the center point of this effort. It is good that effort is made to redress the lack of representation by women and minority groups in the traditionally white and male-dominated hydropower industry. Regarding minor weaknesses, it is not clear how much the program is involved in workforce and education efforts at the EERE level, at DOE, and with other U.S. government offices. There are a number of missing ingredients from other EERE, DOE, and U.S. government resources and industry information. It may be that more is being done, but in 18 slides, this is not evident. For example, consider connecting with other key U.S. government resources, like U.S. Department of Labor resources such as the Renewable Energy Competency Model. (Note that this identifies skills needed until one reaches water.) The National Science Foundation is a key funding organization for Ph.D. students to work on hydropower issues. It is not evident that this is happening. While the Hydropower STEM Portal is nicely done and well laid out, there is nothing about efforts to work with other EERE renewable energy programs to present a common renewable energy approach to workforce. This is especially important in the K-12 space as effort should be on getting kids interested in renewable energy and providing information about marine and hydropower as part of that as a secondary concern. It is excellent that there is an advisory committee advising DOE on workforce development issues for hydropower, but the charter seems more focused on education than on workforce development opportunities. There is also not enough information to know if coordination is happening between industry players and undergraduate clubs, such as the Society of Women Engineers and other relevant clubs that university students look to for career information and active engagement. There was a mention of creating internships, which is critical to recruiting new talent, but more are needed. The most evident weakness is there does not seem to be enough of a concerted effort to meet a larger swath of students where they are beyond those involved in the Hydropower Collegiate Competition and internships/fellowships. Industry needs to adopt a more coordinated, dedicated, and strategic effort to attract and recruit new talent given how long they have been aware of impending retirements. It would be good to look more holistically and strategically at hydropower workforce issues from a student/potential employee perspective. While the collegiate competition is likely to be a fantastic competition and opportunity, the students who are able to participate are at the whim of those higher ed institutions that

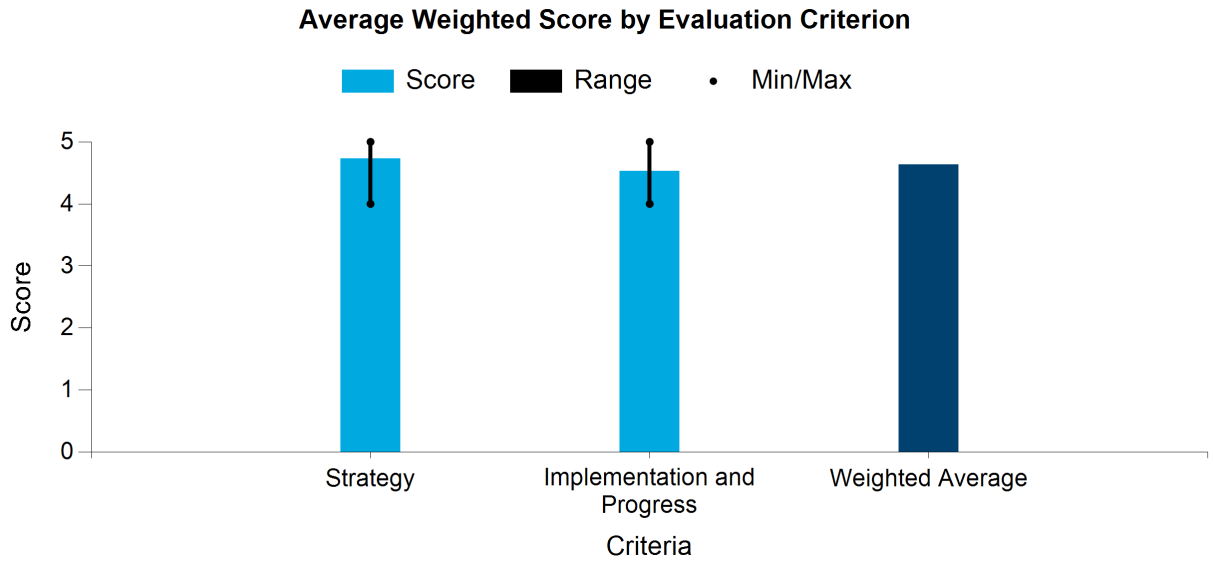
have the bandwidth and interest in participating, so it is critical to be mindful that undergraduate and graduate students at other institutions should be apprised of opportunities to learn about water energy jobs. A lot of new majors (such as environmental science, materials science engineering, environmental engineering, and biological science) would have the skills to work in hydro and marine energy but are not aware of opportunities or necessarily need to take courses being developed. Also, some of these majors are majority female and could be a good way to deal with DEI issues.

- Excellent work instituting a plan to address workforce issues identified in the larger data and analytics section. The outcomes track new hires and new students in the hydropower industry. Attention needs to be paid to degrees categorized as a path to hydro as this can look very different across industry and resource agencies. The reviewer also recommends including a broader approach to outreach for university involvement and a goal for diversity and inclusion standards across the industry.

Marine Energy Program Evaluation

WPTO

WBS:	2
Presenter(s):	Tim Ramsey



Aggregated Reviewer Comments

- Regarding the strategy, the program has a defined strategy that reflects both the needs of the industry and the stakeholders and challenges faced. The key results from each of the four activities—especially around testing of devices both in the lab and on site and improving regulatory efficiencies—are key to move the industry forward. Focusing on the Data Access, Analytics, and Workforce Development projects, while all the projects are very impressive with useful outputs being produced, at the moment there is not enough evidence that these projects have resulted in improved regulatory efficiencies or reduced uncertainty around environmental impacts. However, this might be due to the early stages of the projects given that all the tools have a huge potential to streamline permitting and licensing if widely used by developers and regulators. Specific on the Workforce Development projects, it is unclear if the program will attract people who do not have a previous interest in the area or knowledge of the field. It would be useful to clarify with whom the resources are being shared. Overall, the program priorities, investments, and outcomes were clearly communicated. The technologies, tools, and studies funded do achieve the stated outcomes from the MYPP; however, the reviewer found it hard to judge if these are the most relevant projects or if they will have the greatest impact, especially on the long term.
- The MYPP is an excellent and well-written document that clearly sets out the strategy of the WPTO with a rational plan to deliver its goals in the short and longer term. The wider requirements of successful technology development are considered (such as the requirement for suitable testing facilities) and objectives set out to deliver on these requirements as well. The strategy is clearly being delivered by a passionate and capable team that appears adaptable and reasonable when dealing with project teams to ensure the optimal outputs for the industry. The reviewer also emphasized funding of at-sea demonstration of technologies will be vitally important moving forward and takes significant funding. The only way to deliver this will be through significant

funding opportunities. If WPTO funds are constrained, then there will need to be some selection of leading technologies for funding. It will be important to ensure sufficient funds are allocated if maximum benefit is to be realized. Significantly limiting funding has the potential to curtail deployments and, in the worst cases, lead to health, safety, and environment concerns during deployments as cheaper, more risky options are selected instead of the safest. When larger-scale at-sea deployments commence, there needs to be visibility of expected onward opportunities and financial support (if needed) through the so-called valley of death—if this is not in place there is a very real danger that good technologies fall away and the potential benefits of previous funding are lowered. Where projects are in the program for a long time, this could be symptomatic of the fact that funding for growth toward larger-scale testing is not currently available, and projects are therefore crafted that fit funding availability until such time as other funds become available. It may be important to engage with these companies to understand their "money no object" plans, and then see how that would fit with the wider program aims and if assistance is possible. Short-term, staged funding can be problematic for companies as it is a never-ending cycle of project application and raising. More longer-term funding will enable companies to have a less meandering route through technology development and will enable them to concentrate on the technology development itself. It would be great to see longer-term funding pathways being developed (with funding gates, if necessary, to ensure projects are delivering according to plan). This would give confidence to the developers and potential investors that continued funding assistance would be available through the technology development stage. Collaborations are key—at the moment there are predominantly full wave, tidal, and current energy converter (CEC) systems being developed and funded rather than smaller, focused projects that could focus on enabling technologies that will also be an integral part of the onwards success of the industry. There are many potential opportunities for collaborations in this space that could deliver real benefits to the industry. It may also be a great way to get technology transfer into the industry (industry doing funded projects on a specific component or system that is of need to a developer). Although valuable projects, the reviewer felt that some projects within the technology-specific workstream would sit better within the foundational R&D stream. If only limited funds are available for each stream, then this may be more important than it otherwise may seem. A number of projects could potentially benefit from linking in with previous international developers or expertise that relates to similar concepts. Leveraging this expertise could provide some projects with an initial boost and overall deliver better value and more developed technology quicker.

- The strategy is in line with the MYPP. There are probably some ways to improve funding mechanisms. On the implementation side, it seems that sometimes the selection for funding some technologies is not very clear. Where technologies have been tested or tried before, the rationale on the reason to return to the technology should be carefully considered. The reviewer also notes some focus on common technologies could favor a wider set of technologies.
- The WPTO is doing a superb job of identifying and funding a suite of initiatives from technology development and device testing to workforce development, data sharing, and public engagement that are collectively advancing the implementation of marine renewable energy in the United States. Moreover, the innovations supported through the WPTO have implications on a global scale, and advances facilitated through this program have worldwide applications for the sustainable transition to renewable sources of marine energy. As this program moves forward, it would be wise for the program to promote opportunities for funded projects to engage with end-users and regulators, and where possible, to advocate for the publication of research findings in peer-reviewed journals. This will add credibility to funded projects and provide regulators the protection they need from public scrutiny for permitted projects (i.e., risk reduction for regulators due to the scientific peer-review process).
- The Marine Energy Program is clearly structured and has a strong MYPP, which addresses many of the key issues affecting the development of wave and hydrokinetic energy conversion systems. The Foundational program provides a good opportunity for blue skies thinking and the investigation of oddball ideas that may have a significant impact (or may not). This is a critical part of any research, development, and demonstration

program, and the WPTO should continue to fund such activities. The focus on co-design for energy converters and the development of underpinning software tools is excellent and is world leading. In particular, the development of open-source software tools and models is to be commended and must be continued. Of particular concern was the limited number of stakeholders engaged with the program. Only three wave energy companies and one MHK company are involved in foundational R&D, and these companies are often the only stakeholder representatives in a project. Wider stakeholder engagement is critical so lessons learned are shared widely, enabling the overall development of the sector. Another concern is that there are clear linkages and synergies between projects with the risk that work is duplicated or opportunities missed as each team is working in a silo. The reviewer strongly recommends that DOE organizes intra-project events to share progress and discuss common issues. This was achieved in the UK through the Supergen program, where the funders made it a condition of funding that university research teams worked closely with each other. Similar things have been done with companies receiving funding from Wave Energy Scotland. Everyone benefits from this approach, which also ensures better value for money for the taxpayer. Furthermore, project teams must be encouraged to engage with the international community, leveraging learning and accelerating development by considering a broader range of options/decision needs. The reviewer also expressed concern that foundational technology and component development projects are not considering the impact of the real ocean environment (multidirectional waves, wind driven, ocean and tidal currents, turbulence, etc.) as part of a co-design approach, and this leads to weaknesses in designing and expensive lessons being learned at sea. Testing must be performed on the bench or at scale in hydrodynamic laboratories before putting steel in the ocean. An excellent maxim is that you should not go to sea until you believe you have nothing to learn by doing so! (You will still learn a lot.) Tests need to simulate the real environmental conditions with multidirectional, multispectral waves, sheared and turbulent ocean and tidal currents, etc. Back-to-back power take-off (PTO) test rigs need to be driven by realistic "software-in-the-loop" models, while hydrodynamic tests need to be performed in facilities able to create "realistic" conditions. At the FloWave facility in Edinburgh, a lot of work was done to synthesize a library of sea conditions representative of both survival and production seas at the European Marine Energy Centre (EMEC) wave site. These are now part of the standard testing required by Wave Energy Scotland/Europe Wave. They include mixed seas with ocean swell mixed with local, wind-driven storm seas. If additional facilities need to be added to the TEAMER program network to achieve this, it should be done. It may be much better value to fund access to international facilities such as FloWave rather than to build your own $15 million facility. At-sea testing at specific test sites should only be mandated when the test site is ready and fully able to accept devices for test. DOE should work with test sites and their local port and harbor facilities to ensure that there are adequate berth and laying down areas available to accommodate devices during test programs. This will encourage the development of local supply chains to support developers coming to test.

- This is a wide ranging and connected program of research and innovation, which connects foundational research through to demonstration and standards development, as well as curriculum, skills, and workforce development. Both utility-scale and niche applications for marine energy research are explored. Public engagement and dissemination are considered highly important throughout the program, and there is an impressive level of ambition. It would be useful to consider how to engage a more cross-disciplinary approach to the R&D as the challenges of marine energy development will require marine science as well as engineering in order to develop technology solutions in harmony with nature. Furthermore, some of the biggest challenges in the energy transition are bringing people along with the next technologies and behaviors, and so social scientists have a valuable role in helping design projects that can achieve public acceptance and adoption.
- The WPTO Marine Energy Program overall is doing a very good job in planning and implementing marine energy within the United States. The planning and design for implementation of marine energy is well thought out and appears to be working in a positive direction. The reviewer was extremely impressed with the organization, efficiency, and smooth running of the peer review process. All staff were well versed in the topic areas and kept the presentations and review process running on time and effective for all involved.

- A well-balanced program with good breadth and depth in all areas. Excellent management of the overall program by committed WPTO staff and leadership. Consideration should be given if the program can sustain its current breadth as its technologies initiatives require more funding and WPTO staff management time as they mature in scale and TRL.
- The presenter gave a very useful, high-level overview of the program, its vision, and mission. The program is very broad in scope, nurturing a number of interlinked technologies. It seemed during later review events that they were not as clearly connected to the broader scope, or they did not realize/display that connection. This may have led to some projects viewing their efforts overly narrowly. (The reviewer specifically referenced the cables project, which has equal applications for offshore wind as for offshore waves and could seek broader stakeholders/inputs. The reviewer cited additional examples, such as some of the smaller kW units that could more broadly assist offshore needs or pumps designed for a particular need, but noted there could be many others.) The reviewer noted a graphic showing reviewers what they were about to see mapped out on a strategic continuum would be helpful, and it might also be helpful to the PIs in how they view their efforts. PIs could benefit from better seeing the interlinkages between their projects.
- The Marine Energy Program is a comprehensive and impressive approach to addressing the needs and the challenges of fostering development of the marine energy sector for the United States. Given the urgency for development of decarbonized sources of energy, distributed energy production, and the nascent state of the marine energy sector, the Marine Energy Program is profoundly important. This reviewer has been very impressed with all aspects of the Marine Energy Program, and well-crafted documents articulated the need and justification for the program and the vision, contributions, and accomplishments of the funded projects. The quality of the execution of the projects is encouraging. The reviewer strongly recommends the development of a series of workshops to help bring the results of the breadth and depth of this work to researchers, developers, and regulators who are not actively a part of the network formed by those within projects funded by WPTO. The advantages of such a series of workshops include the potential to accelerate uptake and commercial viability, reduce time to permitting, and build a wider understanding of the transferability of the technologies and methodologies tested and developed. The work of the program is vitally important.
- The vision outlined in the presentation is clear and provides a forward-thinking methodology. The commitment to DEI is impactful, and the team should be commended for their dedication. TEAMER is great! It is a way to utilize and smartly use multiple resources from numerical modeling to experimental testing. The goal of disseminating results and reducing "time to water" is a challenging but much needed step to advance the marine energy sector. With the rapid growth of the blue economy, the reviewer suggests more engagement with industry and K-16 to train the workforce needed to meet future demand. Many K-16 students are unaware of marine-based renewable energy; most are only aware of solar and wind.
- The Marine Energy Program is well run and successfully addressing the objectives of the MYPP. The overview presented by the program manager demonstrated an understanding of these objectives and the needs of the industry and stakeholders, and clearly communicated the rationale and strategy for the program. This rationale and strategy were subsequently demonstrated in the variety of projects presented in the course of the peer review. The program is appropriately funding the many different areas of technology that require development for marine energy to be successful. For example, the program funds sensor development for measuring the environmental effects of marine energy devices as well as the development of the marine energy devices themselves. The former will assist regulators in judging permit applications for the latter. Individual projects are monitored by WPTO staff to ensure that taxpayer funds are properly spent and schedules and milestones are followed as closely as practical. Inevitable delays, principally due to field tests facilities, are handled in an open and professional manner. As stated above, the program is funding technologies that address the many steps needed—such as planning, designing, and manufacturing (including material selection)—in the development of a marine energy device, control hardware to work with PTO mechanisms, and assistance in the testing of prototypes in laboratory and field test sites. This testing assistance is accomplished through several

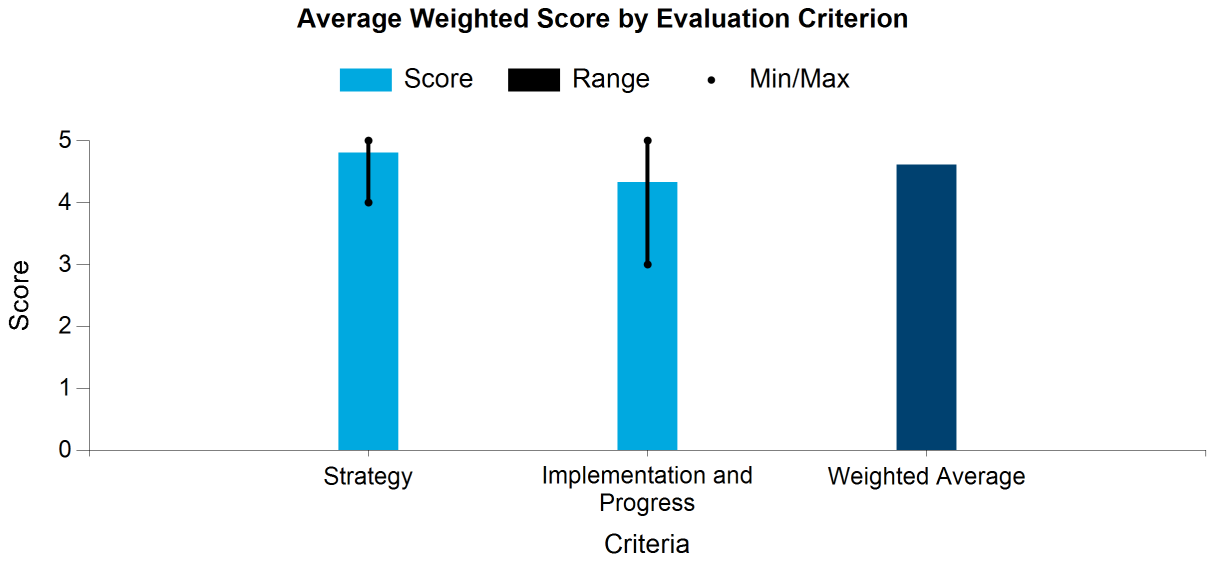
projects, specifically Triton, TEAMER, National Lab and University Collaboration for MHK Instrumentation and Data Processing Tools, NMREC Infrastructure Upgrades, and PacWave. These efforts, many of which make very effective use of leveraged funds from other sources, provide significant aid to marine energy device developers by supplementing their in-house expertise and making test facilities available, thereby accelerating the development and eventual deployment of renewable marine energy.

- The Marine Energy Program being delivered by the WPTO is a diverse range of projects, each of which will enable and accelerate the development of marine energy. The Reducing Barriers to Testing Activity Area panel looked closely at the projects to ascertain if they would enable access to open-water, grid-connected testing facilities, support environmental monitoring, and provide technologies, tools, and data collection to understand potential environmental risks. The projects were largely of a very high caliber with good range of scope in all areas, and there appeared to be a good degree of collaboration and consideration of the projects as part of a program. The work was very focused on wave energy and impact assessment. This is reflective of the prominent industry in the United States and the available test facilities already in place. It is apparent, however, that there should be a review of the investments to ensure all blue economic potential end users have the ability to benefit, where practicable. There may be multiple end users, not simply marine energy, that could benefit from the innovation and research, as well as the infrastructure investment taking place. The program, if fully successful, could yield extensive facilities and information of use to the sector, and this should be as broadly disseminated as possible within the domestic research, industry, and end-user communities but also internationally.
- The work done to date has been excellent. There is a great focus on and understanding of the industry. The reviewer was impressed with how the team helps companies focus their energy and planning and, at the same time, pushes them along the development pathway. The willingness to explore the different tech has been admirable; it is important to allow blue-sky and creative solutions be investigated. The planning is well structured, and the growth in scale in the programs is very clear and helps to converge the industry toward some defined standard ranges and sizes, if not yet to designs. The access to these programs and the kinds of proposals that are considered shows that there is a fair process that opens up this kind of funding to a wide audience and gives small developers a chance to build their designs. The funding that can be accessed by companies that have been previously supported is critical for companies to get to the TRL that will allow them to attract investment. In the private sector, investment in emerging tech is almost nonexistent, and the ability to apply for public funds ensures creative, innovative technology development is ongoing during leaner times.
- This was a great presentation. Year-long field tests through a year's worth of wave conditions is an excellent idea. The reviewer recommends considering more direct engagement with coastal communities (perhaps by establishing little offices), city-run incubator programs, university tech development offices, etc., who often try to shop creative ideas to the wrong groups of people. The reviewer thought that perhaps some of the ideas that come out of such interactions could bear more fruit than keeping the same old tried-and-tested designs funded through years until they report measurable success. The reviewer noted there is value in such success, too. However, the reviewer suspected ideas that originate on the ground could more easily attract private investors and make quicker progress through technological and logistical hurdles. The reviewer also requested the consideration of their comments on the resource characterization project presented by Levi Kilcher on behalf of NREL, PNNL, and Sandia.

Powering the Blue Economy Evaluation

WPTO

WBS:	2.2.5
Presenter(s):	Tessa Greco



Aggregated Reviewer Comments

- The PBE program has a clear, long-term strategy, strategic approaches, and future direction that reflect an understanding of the industry needs. The near-term demonstration opportunities presented are brilliant and closely tied to the program's strategic direction. The reviewer was impressed with the usage of wave power for desalinization and was not aware of the project before. Understanding the effect of marine renewables on coastal communities is key to avoid any potential conflicts between sea-users, thus seeing programs such as the National Sea Grant Office collaboration being created is fantastic. Similar, using the renewable energy for aquaculture and powering ocean research will open new market opportunities. Overall, the funding opportunities align with near-term PBE opportunities.
- The PBE Initiative is an excellent way to develop water power technologies in markets where the cost is not a great barrier. Lessons learned here in smaller-scale deployments will no doubt have applicability to larger wave energy technology developments. Focus on this initiative shows an understanding of how technology development at a smaller scale (or with fewer constraints on cost) can occur and feed into wider goals. The rationale for the PBE Initiative is well set out and being delivered by a very capable team. Some of the projects focusing on the PBE Initiative would benefit from additional support with end-user engagement to quantify the problem and requirements.
- The strategy seems to target the best entry points (local communities without access to the electricity grid and aquaculture), but it would be interesting to quantify the impact and the time to impact in the blue economy on a large scale. Also, the successful implementation of marine energy in these areas will be dependent on the reliability of the systems (or strategy to keep the marine energy supply reliable). The implementation has been successful in mobilizing parts of society to marine energy. The use of prizes and competitions were useful, but the reviewer expressed concern with the support for cooperation with technology developers and the impression that the problems highlighted in the prize contest are the only aspects to overcome.

- The PBE Initiative is a well-conceived and strategic approach for integrating with and meeting industrial partners' and end users' needs in the marine energy sector. This initiative supports the WPTO strategy and mission and works with partners to develop solutions to address energy challenges facing partners in the private and public sectors. The establishment of prizes and financial support for entrepreneurs pursuing novel innovations at small businesses is key for developing new technologies that can ensure a sustainable transition to renewable sources of energy from the marine environment. The R&D being facilitated through this program are cutting edge and require ongoing support. The program is also making great strides toward reducing barriers to device testing in situ. A future focus on access to data, workforce development, and innovative analytic approaches is forward thinking and will help ensure the success of marine renewable energy technologies in the future.
- PBE is encouraging an appropriate route to market for developers with devices being designed and tested at small scale for niche applications (desalination, ocean observation, aquaculture, off-grid communities, etc.) where energy commands a much higher price than grid power or where existing small-scale diesel generation can be displaced. This is a very important route and enables developers to learn by doing much more cost effectively than can be done at grid scale. As with the broader MHK program, stakeholder engagement is poor and needs to be much wider. There are strong opportunities in this area for collaborating with other DOE and NOAA programs (including hydrogen), and these should be explored. EMEC has shown that combining tidal energy with onshore wind allows curtailed electricity (the local grid is very weak) to be used to manufacture hydrogen cost effectively, and this could be used for a number of applications (including ferries, road transport, aviation and renewable heat). The Waves to Water program is an excellent example of what can be achieved, though it should be remembered that traditional desalination, potable water treatment, and wastewater treatment are very energy intensive processes that, like hydrogen production, can be used to shift electricity demand patterns. Local communities will be very interested in this work and should participate as stakeholders. It is important that the wider supply chain is engaged with. The reviewer expressed concern that in the dynamic export cable project the research team was working with a wave energy developer and not with a cable manufacturer. This led to real problems with the supply of cable and the loss of some critical parts of the project's work program. Had they been working with a cable manufacturer with a large potential market (wave, floating wind, autonomous vehicle charging platforms, etc.), much more could have been achieved. Finally, at-sea testing should only be undertaken when developers believe they have nothing to learn by doing the sea trial. Devices must be tested in the lab (using hydrodynamic labs and back-to-back PTO test systems) under realistic conditions before going to sea. This will be much more cost effective for the program and will lead to much less disappointment.
- PBE is an important strand of the WPTO program. It will assist with the development of marine energy through targeting high-value markets that will benefit from marine energy in order for them to be decarbonized. It is also an important route for marine energy technology to be tried and tested at smaller scale before being developed further and demonstrated at grid scale. Thus, the applications being investigated through the PBE program are valuable in their own right and also as part of the pathway to cost reduction for utility-scale marine energy development. The combination of foundational research, industry partnership innovation funding, and prizes is a good mix and provides opportunity and involvement of different stakeholder groups within the landscape. The dissemination and public engagement should continue to be a strong part of this.
- The PBE program is well thought out, and I particularly like the kilowatts to gigawatts thinking. PBE does an excellent job looking at each step in the needs and process for marine energy from small-scale and local community needs and concerns/impacts to R&D with developers and research institutions. With the growing of marine energy and the blue economy, the addition to the PBE organizational structure of a PBE ambassador and PBE administration and coordination offices should provide good support and control for the growth of PBE in the future. The collaboration with other federal agencies, industry, national labs, and involved communities is a key part for success of PBE.

- A well-balanced program with good breadth and depth in all PBE areas. Excellent management of the overall program by committed WPTO staff and leadership. Consideration should be given if the PBE Initiative can also be funded from other sources (i.e., end users from the oil and gas, defense, autonomous underwater vehicle sectors). Consideration should also be given to ensure there are synergies between PBE and utility scales of devices.
- The presenter gave a very useful, high-level overview of the program, its vision, and mission. The program is very broad in scope, nurturing a number of interlinked technologies. It seemed during later review events that they were not as clearly connected to the broader scope, or they did not realize/display that connection. This may have led to some projects viewing their efforts overly narrowly (The reviewer specifically referenced the cables project, which has equal applications for offshore wind as for offshore waves and could seek broader stakeholders/inputs. The reviewer cited additional examples, such as some of the smaller kW units that could more broadly assist offshore needs or pumps designed for a particular need, but noted there could be many others.) The reviewer noted a graphic showing reviewers what they were about to see mapped out on a strategic continuum would be helpful, and it might also be helpful to the PIs in how they view their efforts. PIs could benefit from better seeing the interlinkages between their projects.
- PBE has articulated a well-defined strategy to meet the needs—both broad (e.g., grid-scale) and specific (e.g., targeted needs of aquaculture or desalination)—within the PBE concept. Informing the PBE strategy is an understanding as demonstrated by the synthesis provided in the 2019 report and the collaborations across DOE offices and other federal agencies. The challenges are an innovative approach to identifying the projects deserved of funding.
- The attempt to engage small businesses though SBIR awards, competitions, and monetary prizes is a great idea. There is a broad range of applications listed for the blue economy, and this should really broaden and expand the much needed future workforce. It would be great for the team to identify the need to engage industry as next steps. The reviewer also recommended engagement with K-16, even if just for awareness.
- The PBE activity area is well run and successfully addressing the objectives of the MYPP. The diversity of the projects that it has chosen to fund demonstrates that the WPTO staff in charge of the activity understands the challenges of the industry and stakeholders. It is likely to achieve its goals and objectives based on the success of its current projects and the plans for future projects.
- Marine energy has a key role to play in developing the blue economy. While the eight areas for potential marine energy application (ocean observation, underwater vehicle charging, aquaculture, algae farming, underwater mining, desalination, and powering isolated communities) will certainly be part of the economic development of marine energy, the sector is still at an early technical stage of development and, therefore, it may not be commercial to apply marine technology to these areas yet. Focus should be, at this stage, on a program that accelerates and de-risks scaling and innovation in marine energy to reduce costs. At-scale deployments, including of larger devices and arrays, will be critical to ensuring the technology becomes economic and can fully support these novel applications. The marine energy industry can see a unique and diverse application of kinetic energy devices in a broad range of environments, and this reflects the diversity in the technology types. Large-scale convergence of technology solutions, as has been done in wind energy, is unlikely due to the nature of the resource form which kinetic energy is extracted. The program aims, at this stage, are aligned within the sector, but there should be continuous review and engagement with technologies and potential end users or applications to ensure funding is focused on the correct stage and application of the marine technologies it is supporting.
- The goals of the program are clear, and the kinds of work done are meeting those goals. This is a wonderful program. The early stage and, in particular, the prizes encourage development and participation in the ocean energy space. The opportunity for outreach is high with this program. The marine market focus is a good use of funds at this scale. Desalination and island grids are applications that benefit greatly from this kind of funding

and are often places for the training of highly qualified persons. This kind of funding will attract researchers with new and innovative ideas. While the reviewer believes that a large-scale commercial project is necessary for the industry at this point in marine energy development, they also fully support these types of programs and are excited about the wide impact they can have. This one is particularly well designed and the clarity is exceptional.

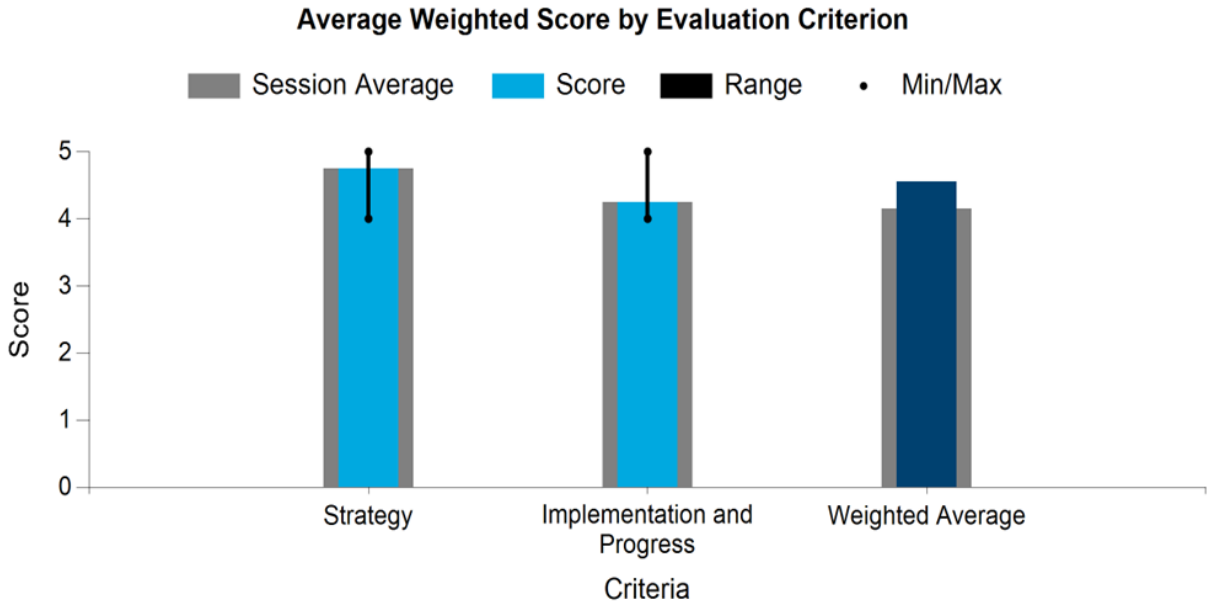
- Excellent work and excellent presentation. The reviewer believes the PBE program is one of the great major developments to emerge from DOE's engagement in water power. This is one area where the reviewer sees a merger of interests between what people on the ground need and DOE's priorities. The reviewer encourages continuing this program regardless of whether or not it turns out to make it easier to transition the conversion technologies to utility-scale operation.

Foundational R&D

Activity Area Evaluation

WPTO

WBS:	2.1
Presenter(s):	William McShane



Aggregated Reviewer Comments

- The Foundational R&D program is well thought out and has been carefully constructed against the needs of the sector. The reviewer welcomed the strong focus on co-design methodologies, which are very important for devices (particularly wave and MHK) that are subjected to a complex environment with forces created by wave action, tidal and ocean currents, shear profiles, wind-driven currents, and large-scale turbulent structures. If these water power technologies are to succeed in power generation or in other applications such as desalination, they must be both reliable and cost effective. Increasing reliability and availability drives down costs, reducing LCOE. Evidence from the fixed offshore wind industry in the UK and Europe has shown that a strong focus on driving down O&M costs is also needed. Co-design should make this possible, but perhaps WPTO needs to be firmer on this requirement with project proposers. The projects developing WEC optimization and modeling tools (particularly WEC-Sim) are delivering world-leading tools and are an area of which WPTO should be extremely proud. They are a major and important output of the foundational R&D work and should be continued. While ongoing development of WEC-Sim may not need the same level of resource, it is critical that the software is supported and maintained in the long term and that training and promotion of the tool set continues. The reviewer expressed no doubt that the national labs are capable of doing this—noting that they have with other software tools for flow visualization (Sandia) and wind energy (NREL)—but is unsure of the funding mechanisms. The seedling and sapling program is a strength, and it should be the roll of a foundational R&D program to look at wacky ideas and encourage blue sky thinking. One key area of concern is that much of the work in the water power program is focusing on what is an international grand challenge. There is a risk that funded work is duplicating (or worse, ignoring) work done elsewhere and, thus, WPTO is not ensuring best value for the taxpayer. Stronger international articulation would be beneficial across the whole water power program with projects able to draw on experts and technology developers in other countries (to

share learning and help to develop a domestic market) or to allow access to world-leading and unique test facilities and to gain experience from working with long-established test sites. One project specific point that needs careful consideration is that testing of a device had been held up by delays at the Hawaii wave test site while the infrastructure at the site was updated. It is less than ideal that risks owned by the test site should be passed onto a developer or a demonstration project, especially when this causes significant problems at the local port. WPTO should be wary of mandating testing at a particular location as a condition of funding if the test site is not ready to accept the device. It is also important that the test site works closely with the local community to build relationships and that they strive to have laying down areas and berths where developers can store equipment while it is either waiting to be deployed or waiting for repair prior to redeployment. As EMEC says, the point of field testing is not to succeed but to fail. If we do not fail (sometimes), we do not learn. Finally, it is clear that WPTO has been working closely with project teams to help them deal with COVID-related delays and other problems. One presenter told reviewers WPTO has been extremely helpful in supporting their project so far, indicating WPTO has been positive and responsive to requests and has been a pleasure to work with. WPTO should be very proud of this positive feedback; many funding agencies around the world would not get such praise.

- This is an impressive program for supporting research in marine renewable energy, and there are good examples of impact over a sustained period and very broad range (e.g., the software development and support WEC-Sim, which has a very wide user base internationally). The focus of the research program is well aligned with the needs of the sector, and it is clear there is strong consultation in developing the research themes to be addressed. It would be good to see more of the industry, both device developers and supply chain, involved in the foundational research projects. There appear to be a few, and they are often involved in more than one project. There is quite some variation in the level of dissemination and public engagement embarked on by the different projects within this grouping. Some have excellent engagement and dissemination outputs openly available, whereas others appear not to have engaged outside of the project team or published their findings. Many of the projects have clear linkages and would benefit from collaboration or sharing of findings during the projects; this could be facilitated through workshops where all projects present to one another under nondisclosure agreements, if necessary, so they can find identify areas of complementary work or where it makes sense to share effort in order to achieve more. There is also a linkage with other areas of net-zero-related research, such as energy integration, hydrogen and other storage, and offshore wind; opportunities for joint funding of projects with other offices could be explored. In addition, further efforts to connect with and jointly fund research programs internationally would be recommended.
- The reviewer asked if there is a clear plan/trajectory for probable destinations of projects with various energy ratings and noted this could help broaden the field of stakeholders. The reviewer asked if there has been any thought to co-locating offshore wind fields with marine energy sites, noting this might also be a resource mapping issue, if they are not good for both. The reviewer noted this might help with some of the permitting issues of which the reviewer is aware.
- This component of the program is being managed in a thoughtful, methodical way and appears to be consistent with the MYPP. The seedling/sapling program is particularly praiseworthy and could ideally build a vibrant community of researchers within the national labs who can collaborate freely. The reviewer recommends the team perhaps also consider opening up the seedling programs to university-led collaborations with national labs.

Project Evaluations

Fatigue and Structural Load Analysis and Control for Variable Geometry Wave Energy Converters

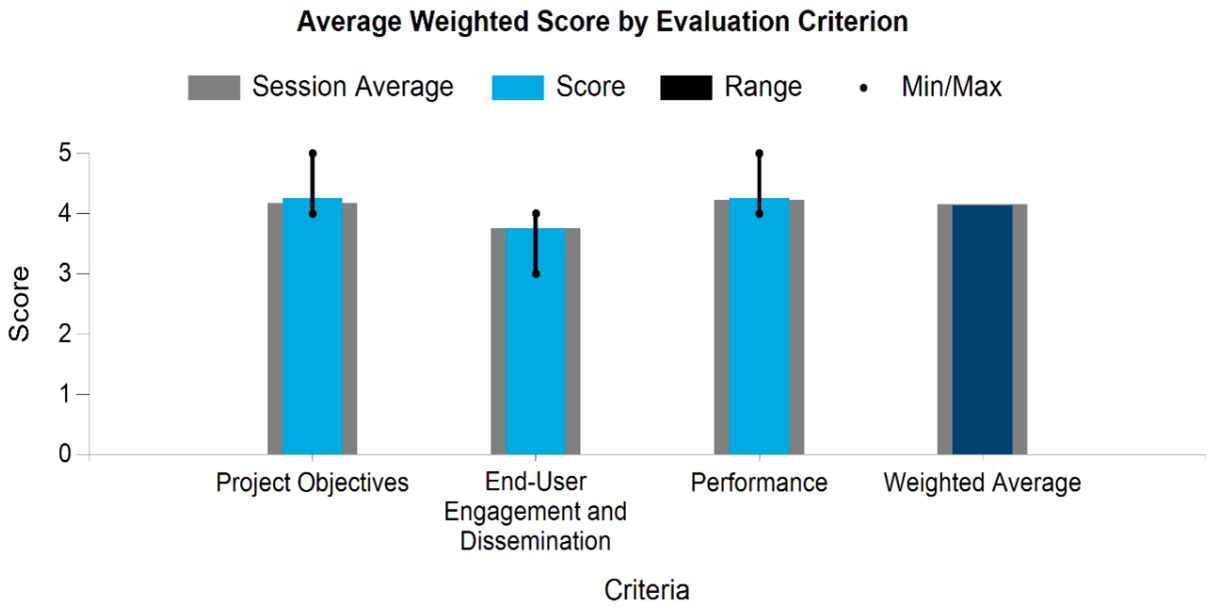
NREL

WBS:	2.1.2.403
Presenter(s):	Nathan Tom
Project Start Date:	08/01/2018
Planned Project End Date:	07/31/2022

Project Description

This research effort is a four-year, two-phase project designed to develop the next-generation control strategies for variable-geometry wave energy converters (VGWECs). VGWECs are designed such that their shape can be adjusted to reduce the forces the waves place on the WEC structure. For example, VGWECs create windows for waves to pass through so wave energy devices do not bear the full force of the ocean's power. This project aims to create a paradigm shift in WEC design by providing the option to control both wave hydrodynamics (to reduce wave pressure through shape change) and the PTO. The VGWEC control strategies expected to result from this project will maximize power, offer additional load-shedding capabilities (and thus help to reduce costs), and lower peak-to-average power ratios. The additional load shedding capability provided by shape-changing variable-geometry is expected to reduce the device structural mass and extend the sea states in which the device can operate. This is accomplished by limiting peak loading, which can help reduce LCOE.

This project aims to reduce the LCOE through a structural optimization to reduce the required WEC steel thickness, which is directly coupled to capital costs. This optimization is only possible if greater control over peak loads is enabled by the hydrodynamic load control provided by the variable-geometry concept. In this project, there will be an attempt to incorporate the structural flexibility in the hydrodynamic models so that the structural stress can be analyzed to determine the location and magnitude of peak stress concentrations.



Aggregated Reviewer Comments

- This is an interesting piece of work that is considering varying the geometry of a WEC as part of the control strategy. While a lot of work had been done with good quality modeling of the different geometries, it was difficult to see how this work addressed the fatigue and structural load analysis part of the project as there was more concentration on the control aspects. That said, the work is excellent and shows promises in the ability to use geometric control. Maguire and Ingram ("On Geometric Design Considerations and Control Methodologies for Absorbing Wavemakers," Coastal Engineering, Vol. 58, no. 2, 135-142, 2011. DOI: 10.1016/j.coastaleng.2010.09.002.) showed that this could give a broad range of absorption characteristics for wave makers by using geometric design for one frequency and spring/damping control at a different one. To do this, geometry needs to build into the motion equations for the WEC and to look at changes in the spring, mass, and damping forces with changing geometry. The reviewer cannot see that the same extension of the resonant frequencies should not also be possible. Unfortunately, many of these effects are non-linear, and the weakness of the linear theory will need to be considered. The reviewer noted that the experimental program will use fixed but changeable WEC geometries (following the approach used by Quoceant in the Wave Energy Scotland Novel Wave Energy Convertor competition). While this works well, one needs a wave tank with excellent repeatability and must be aware that the response of the flexible structure to wave loading will not be modeled. To cope with flexibility, WEC-Sim may need to be modified. This is an excellent foundational R&D project and has good dissemination of results.
- This is a very interesting project that is well aligned with the objectives of the program and with potential for disruptive technology and step change in LCOE. A structured process is followed, and results are assessed at each stage: three types of VGWEC investigated and one down-selected for wave tank testing. There is some delay in the research program, but no cost extension required, and the second phase of the project to complete wave tank testing is now underway, as is the hardware in the loop testing. The results are disseminated through appropriate channels to academia and WEC developers, and a patent application underway. The investigators may be interested in studies carried out by Quoceant in a Pelamis-type study.
- The reviewer inquired how this approach handles a wide range of sea conditions and about the expected limits on the inflation mechanism. It would have been good to see more information on the design selection process, and how it changed the flow dynamics. Some hydrodynamical modeling would have been good to see. It would be useful to increase industry engagement; even though it is early there may be considerable interest in this design.
- Good work overall. Larger pictures and a clearer explanation of the three geometries would be helpful. It was not clear how work performed represents the title of the project. The reviewer inquired about the time constants for the shape change process in the chosen design and how much power would be needed to (reactive and resistive) bring about the shape changes.

Next Generation WEC PTO Co-Design

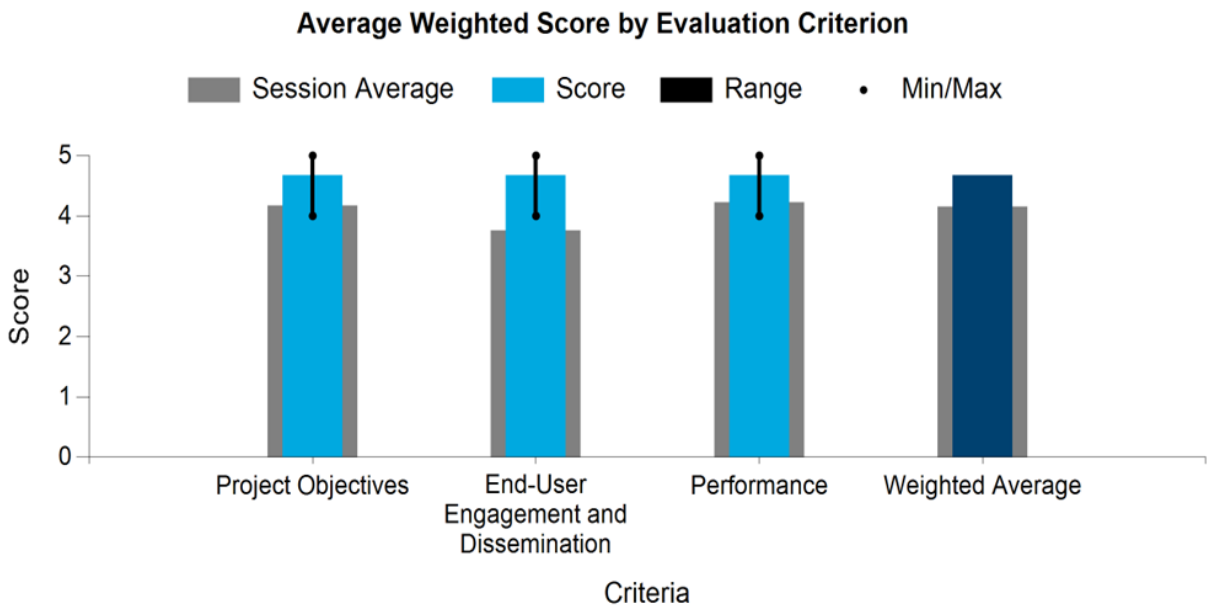
Sandia

WBS:	2.1.2.705
Presenter(s):	Ryan Coe
Project Start Date:	10/01/2019
Planned Project End Date:	09/30/2022

Project Description

WECs are unique from other existing energy generation technologies. Instead of converting relatively steady input mechanical energy that fluctuates about some mean (e.g., wind, nuclear, hydroelectric), WECs must absorb a purely oscillatory energy input. This unique quality necessitates the usage of advanced control to maximize energy generation and minimize LCOE. Control strategies can be used to shape the dynamic response of a WEC to achieve resonance and increase energy absorption by as much as 200%. However, WECs comprise complex hydrodynamic, mechanical, electrical, and sometimes hydraulic subsystems, all of which must be properly designed to be capable of efficiently implementing a control strategy in order to reap the benefits of advanced control.

This issue of designing the dynamic WEC system, of which the PTO and control systems are central components, to minimize LCOE is the central focus of this project. The project team applies impedance matching principles within a co-design framework to the holistic WEC system. This method of WEC PTO and control system design is being developed in a device-agnostic manner, enabling industry developers and researchers to apply the method to their own devices and produce dramatically better performing WECs.



Aggregated Reviewer Comments

- The importance of co-design for the development of WECs and other complex technologies is clear, and this project has been showcasing the approach and developing the tools required. It is a very impressive piece of work that is making excellent use of the open-source model to disseminate the software being developed. The use of control strategies that allow the full WEC PTO to be optimized and not just the hydrodynamic properties (as has been done in the past) are an important step forward. The industrial and academic outreach is strong with International Conference on Ocean, Offshore and Arctic Engineering workshops and a raft of papers

alongside the software repository. It was not clear from the presentation which devices it had been tested with, and this raises the question as to whether the stakeholder group is wide enough.

- This project focused on the development of a co-design wave to wire model and impedance matching framework for co-design, which could have significant impact on the WEC sector. A good number of co-design research papers have been published, and there is a strong level of public engagement and workshop activities. The open-source WEC-Sim and MATLAB code for co-design released through GitHub will be extremely valuable to the WEC community. The co-design methodology has been demonstrated for the Monterey Bay WEC project, and there is strong industry collaboration.
- The presenter provided excellent context, and the co-design idea seems to fit a deep need. Outreach so far is excellent, and it is good to see that the project has been demonstrated in more than just the Monterey Bay Aquarium Research Institute's WEC. The reviewer recommended further device/location testing to help expand utility.

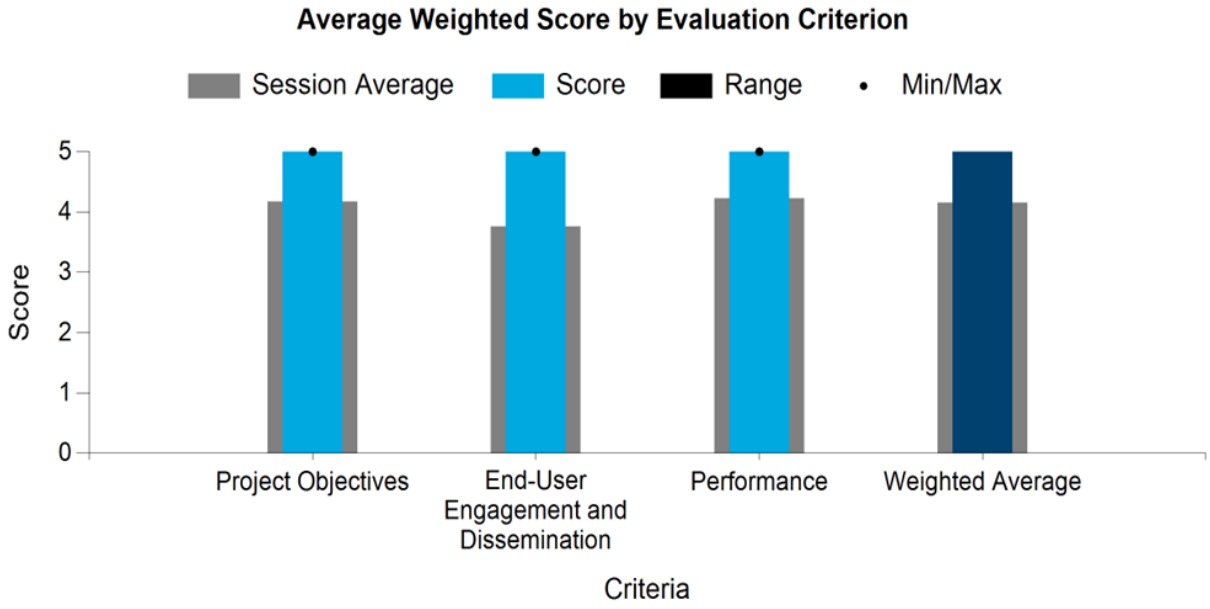
Wave Energy Converter Modeling

NREL, Sandia

WBS:	2.1.3.401
Presenter(s):	Dave Ogden; Kelley Ruehl
Project Start Date:	10/01/2014
Planned Project End Date:	09/30/2021

Project Description

WEC-Sim is an open-source software for simulating WECs. The software is developed in MATLAB/Simulink using the multibody dynamics solver Simscape Multibody. WEC-Sim has the ability to model devices comprised of bodies, joints, PTO systems, and mooring systems. WEC-Sim can model both rigid bodies and flexible bodies with generalized body modes. Simulations are performed in the time-domain by solving the governing WEC equations of motion in the six Cartesian degrees-of-freedom, plus any number of user-defined modes. The WEC-Sim Applications repository contains a wide variety of scenarios that WEC-Sim can be used to model, including desalination, mooring dynamics, nonlinear hydrodynamic bodies, passive yawing, batch simulations, and others. The software is flexible and can be adapted to many scenarios within the wave energy industry.



Aggregated Reviewer Comments

- The development pathway for the WEC-Sim tools continues to deliver outstanding progress and builds a strong user community. The team is making excellent use of the open-source software model and should be proud of their international recognition and software development prizes. Indeed, WPTO should also be celebrating this world-leading achievement. The use of a licensing model that allows WEC developers to hold private copies of the code with bespoke modules containing intellectual property-sensitive models is exactly what is needed by the sector. The reviewer hopes that the fact that WEC-Sim is being developed by national labs means that their project has longevity and that there will be continued support for the maintenance and support of the tool set once the development funding ceases.
- This is an excellent and impactful initiative; WEC-SIM software is widely used throughout the world and relied on for design of WECs and floating structures. The developments proposed for interoperability with the solvers is good. The reviewer also recommends pursuing international collaborations and interaction.

- The reviewer inquired about the plan for testing with other devices. The reviewer also encourages continuing to ensure this is compatible with other tools being developed, having found that a framework for tools and coupling their outputs is a key to long-lasting use.
- Excellent work. The reviewer inquired whether the project team is currently working with commercial 3D CAD/3D printing software makers. If not, that could be a path worth exploring.

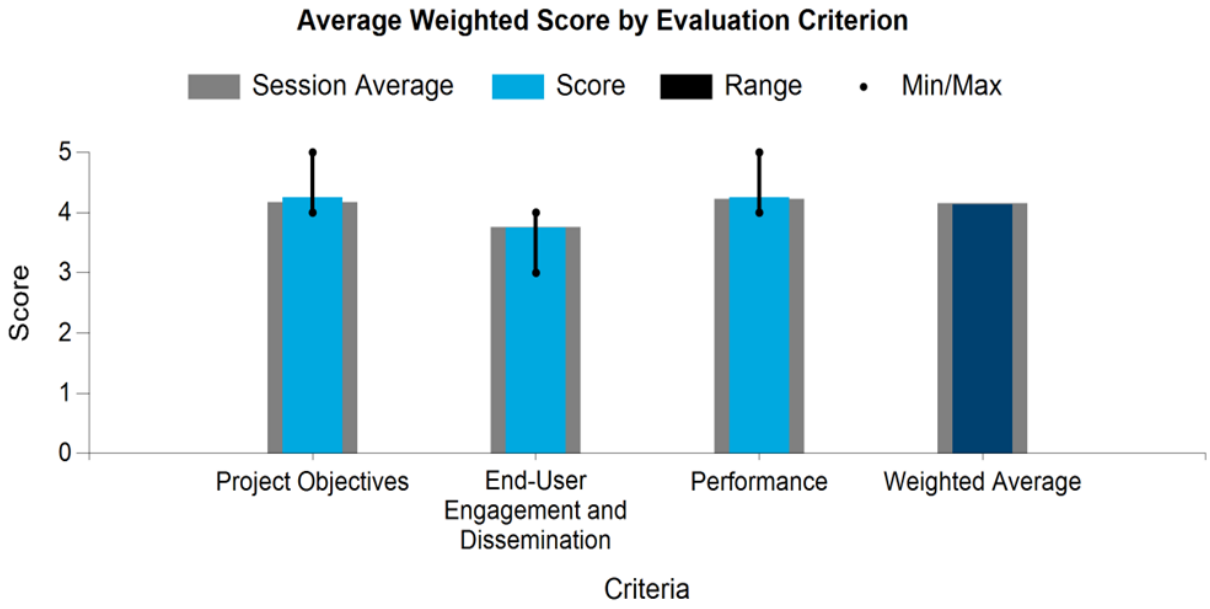
WEC Array Power Management and Output Simulation Tool

NREL

WBS:	2.1.3.404
Presenter(s):	Toan Tran
Project Start Date:	08/01/2018
Planned Project End Date:	09/30/2020

Project Description

An array of WEC devices have variations in power output due to the chaotic nature of waves. Eliminating or mitigating power fluctuations is important for reducing the integration impacts of WEC plants in both distribution and transmission grids and in standalone, isolated power systems. Reduced variability of WEC-generated power in combination with energy storage or power management control at each WEC and at the array level will help increase hosting capacity of distribution feeders for this type of variable renewable generation and minimize electric losses. The use of modeling tools to simulate the resource environment, device dynamics, and utility power system response, along with the development of an interface for an array controller can help to reduce risks and risk perception, gain key stakeholder acceptance, and enable developers to design effective and compatible energy plants with arrays of WEC devices. The project will create a publicly accessible numerical modeling framework to empower the wave energy sector to design projects of various scales (from kilowatts to hundreds of megawatt) that are optimized on a plant performance basis and compatible with different power systems and wave conditions. The framework will integrate with WEC-Sim, a wave environment model (SWAN-FUNWAVE), and relevant established electrical analysis tools to model the grid system and interconnection and optimize power output and power management for the WEC array.



Aggregated Reviewer Comments

- This is a very important piece of work and an excellent addition to the WEC-Sim suite. It is critical for the future development of grid-connected WECs and those supplying islanded communities. In these cases, the frequency and power levels in the grid will have a direct impact on the control of the individual WECs and may (under certain cabling arrangements) lead to changes in the performance of the individual WECs as their PTO forces change due to frequency synchronization. It is disappointing that the model is currently only wave to wire when a bi-directional model is needed in reality (see Kiprakis, A., Nambiar, A., Forehand, D., & Wallace, R. (2009).

Modelling Arrays of Wave Energy Converters Connected to Weak Rural Electricity Networks. In Proceedings First International Conference on Sustainable Power Generation and Supply https://doi.org/10.1109/SUPERGEN.2009.5348024). The reviewer was unsure about the extension of the model to energy systems including battery storage, wind, solar, and diesel generation, etc. Such modeling with the connection of a wave farm to a grid is normally done using tools, such as Power World, that model the grid dynamics and provide power quality information and include the effect of frequency on connected generators. Extending the model in this direction is somewhat of a red herring and could be a displacement activity when it would be better to couple the array tool to existing power system tools.

- This is a good project integrating WEC array modeling and power management. The project achieved further development of WEC-Sim numerical modeling code to develop wave-to-wire modeling for WEC arrays and includes energy yield modeling and storage integration to further develop numerical modeling tools for WEC farm design. An advisory board is in place to help steer the project, and a good number of research publications have been developed. The code is made available in the public domain through GitHub and will be a highly valuable resource for project developers.
- This is very consistent with other tools, and it is good to see the grid integration and storage. The reviewer recommended planning for further model coupling with power grid models onshore for further use.
- It would be good to discuss what device developers are learning from the project team's work. The reviewer inquired about the developer questions the project team is addressing.

WEC Design Optimization

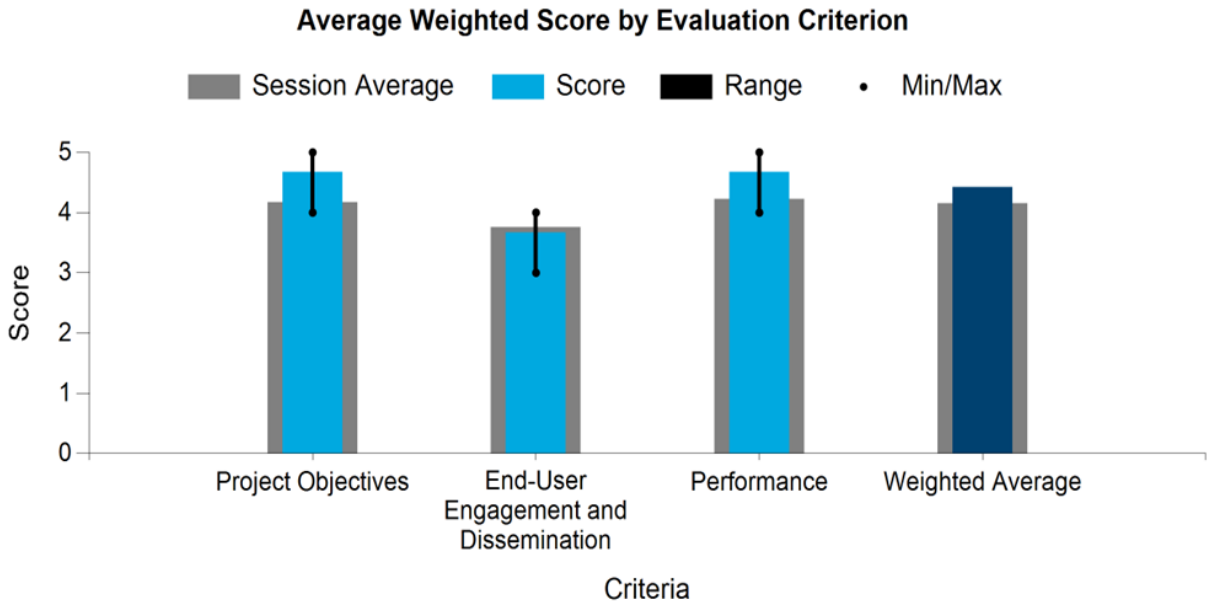
Sandia

WBS:	2.1.3.704
Presenter(s):	Ryan Coe
Project Start Date:	07/01/2018
Planned Project End Date:	09/30/2023

Project Description

For aircraft design, light materials and reliable mechanical systems are critical to a viable design. For wind turbines, longer blades are now being paired with relatively smaller generators to maximize capacity factor. For WECs, these fundamental concepts, which are well understood in other fields, are only beginning to become clear at best. Given the relatively immature nature of WEC design, having a tool with which to perform rapid and holistic design studies is crucial. To address this problem in the past, developers have used brute force approaches, e.g., in which high-dimension matrices of time-domain simulations are run to find the best combination of controller tunings, hull shape, mooring system, PTO components, etc.

WecOptTool has grown out of Sandia's WEC dynamics and controls work as a means of addressing these practical design questions in both internal and industry collaboration projects. A crucial aspect of WecOptTool is the utilization of a pseudo-spectral solution method that efficiently handles nonlinearities, lends itself to a co-design framework, and allows for both unstructured ("numerical optimal") and structured controllers. Written in Python and developed on GitHub, WecOptTool is entirely open-source and free. WecOptTool is already providing direct benefit to industry developers and will continue to deliver deeper insights to a broader audience moving forward.



Aggregated Reviewer Comments

- It is good to see that a tool that complements WEC-Sim has been developed (also using the open-source model) to develop a fast, frequency domain optimizer for the co-design of WECs. Uptake of the software is excellent given that it has only been available for a year. It was also nice to hear that it had been applied to a real device and improvements were identified. The dissemination of the tool is good but could be much better. The reviewer thinks the team has been working with a very small pool of technology developers when working with the wider community would be even more beneficial. The reviewer is certain that there is work on existing

WEC geometries and controllers (which are not under commercial development) that could be used as test cases and would form a strong basis for publicizing and disseminating the tools set. The reviewer also thinks there is a need for stronger interaction with academic researchers, many of whom are looking at novel control systems for WECs and could make excellent use of such an optimization tool.

- This project develops an open-source design tool for WEC optimization and the numerical tool is made available through GitHub. The aims and objectives align well with the program. The results indicate a reliable fast optimization tool that will be very useful for WEC and PTO optimization for developers. Some more information on the validation work would be helpful and on the research, papers published, and dissemination activities planned.
- The project team could give more detail about connections to partners and stakeholder outreach. It is good to have a consistent framework of tools, and the modeling speed increase is laudable. The reviewer inquired about papers published and references.

Wave Energy Converter Interlink Umbilical Cables Design Requirements, Best Practices, and Recommended Design Improvements

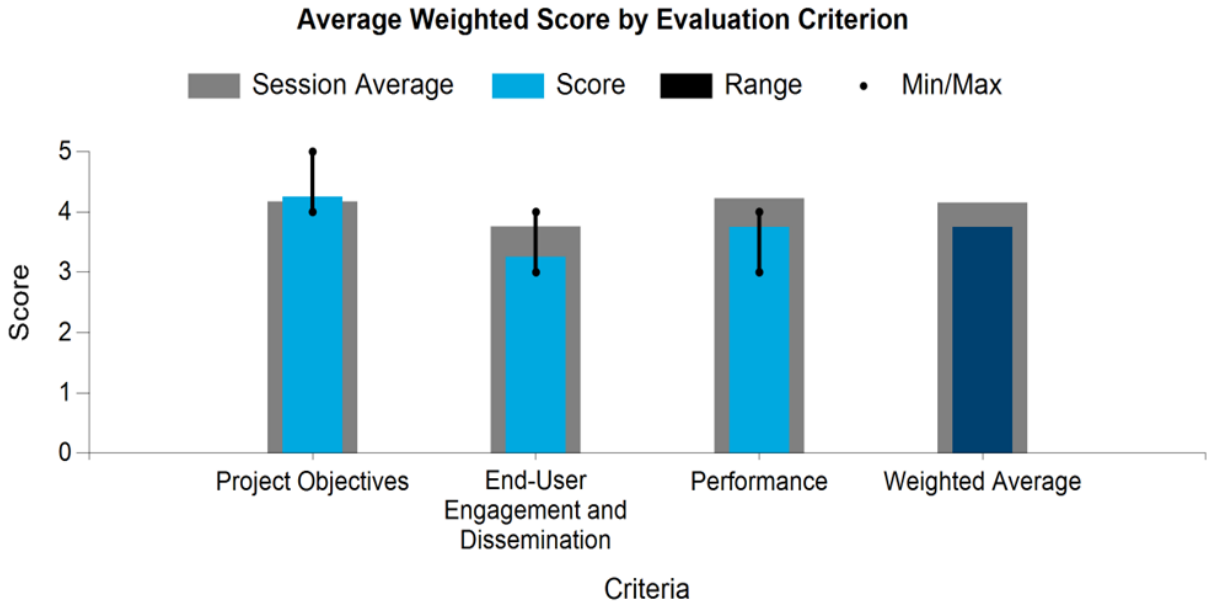
PNNL

WBS:	2.1.4.404
Presenter(s):	Leo Fifield
Project Start Date:	08/01/2018
Planned Project End Date:	09/30/2019

Project Description

This project, led by PNNL and NREL in partnership with offshore cable experts Delmar Systems Inc. and the University of Southampton, aims to accelerate the development and reduce LCOE of commercial wave energy systems by empowering the design and utilization of robust and cost-effective medium-voltage power and communication umbilical cables that connect floating WECs to subsea transmission lines.

This project is utilizing accepted industry practices from offshore wind, oil, and gas and existing software tools (WEC-Sim, OrcaFlex, COMSOL) to evaluate the life-cycle mechanical and electrical performance of interlink umbilical cables, define expected requirements, and make suggested improvements based on techno-economic evaluation. Targeted goals of future work include validation of simulated umbilical cable performance with experimental lab testing and connection with cable manufacturers to advance design, longevity, and WEC cost savings potential.



Aggregated Reviewer Comments

- This project looked at the design of medium-voltage WEC export cables and has developed a multi-physics model to assess cable performance. The results obtained are very important and show that cable designs must account for the motion of the WEC or they will fail very quickly. This work is widely applicable and has implications for WECs, floating MHK turbines, and floating offshore wind systems. The reviewer was surprised the team has been working with a WEC developer and not with a cable manufacturer. A cable manufacturer would have been able to provide an example medium-voltage dynamic cable sample with drawings and support and information on modifications that could be made to cable designs. This would have saved a lot of problems as a DOE-funded project (supported by WPTO) would have a lot more traction with a cable manufacturer than a WEC designer would. If this work is continuing, the reviewer strongly advises getting a cable manufacturer on

board as soon as practicable. There have clearly been issues with the project resulting in experimental tests not being undertaken. This must not detract from the fantastic work done in model development. It would be interesting to see this work extended to included vortex-induced vibration on the dynamic cable (alongside wave-induced motion). Many deployment sites have oceanic- and wind-driven currents that can induce such effects.

- It is a shame that experiments at Southampton were completed due to COVID and delays. The project lacks experiment validation but is otherwise a very good project with engagement with end users and development of a design tool for umbilicals including hydrodynamics, structural response, and electrical performance. Finite element analysis was carried out for the complex cable composite structure. There was good collaboration with WEC developers, but the reviewer recommends that the project team engage with a cable supplier.
- It was unclear to the reviewer whether the presenter mentioned the sources of the cables, and the reviewer asked whether there will be testing with more cables, which would increase the applicability. The reviewer asked if the project team accessed via the WEC or via a cable manufacturer, which would have provided some very different perspective on the cables. (The manufacturer might have said, "Don't use that one. These are better for your purpose.") The reviewer also noted not to dismiss the issue of the sea states versus depth. That said, it is definitely of benefit to do such a thorough, integrative physics project, and it seems this would be of equal benefit to offshore wind installations.
- This project reflects good work overall with good attention to detail. The cable installer and cable user involvement in this work is good but having a cable manufacturer on board would help. The reviewer was unclear on whether the project team considered dynamic coupling between cable oscillations and the magnetic fields generated by current passing through the cable. This could become an issue when converter motions are large and/or there are vortex-induced oscillations that bring parts of the cable closer together than they are meant to be.

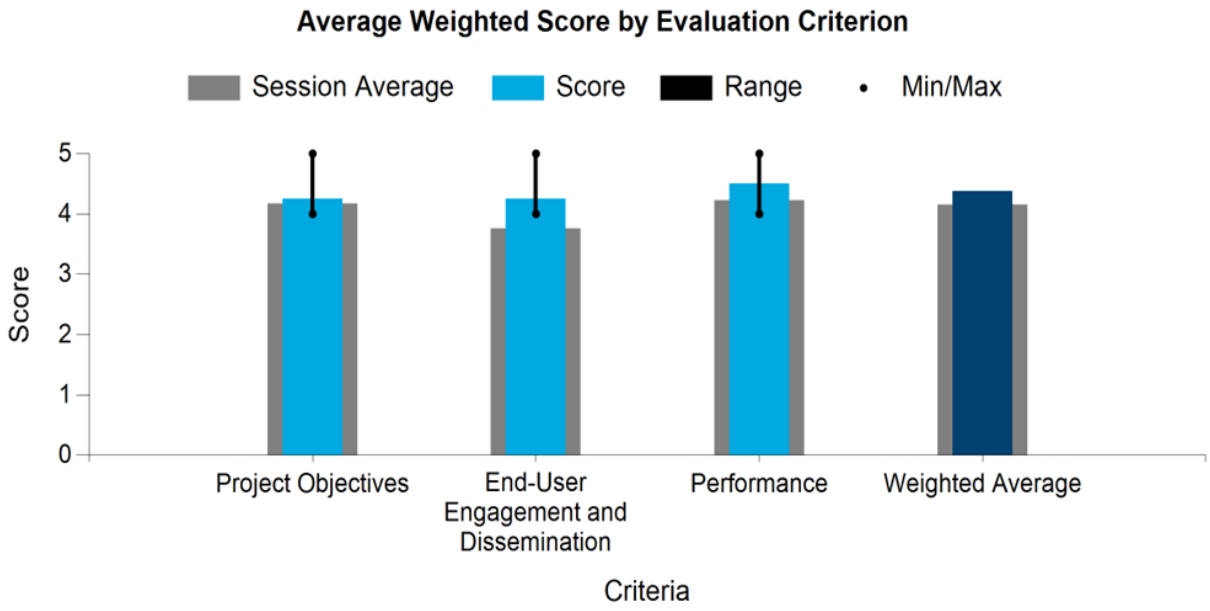
Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme

NREL, PNNL, Sandia

WBS:	2.1.5.401
Presenter(s):	Levi Kilcher; Vincent Neary; Zhaoqing Yang
Project Start Date:	10/01/2015
Planned Project End Date:	09/30/2020

Project Description

The Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme project, commonly known as the Marine Energy Resource Characterization project, is designed to generate and disseminate resource data needed for marine energy device design and project siting and to quantify the high-level marine energy opportunity for decision makers. The project has been a collaboration between NREL, PNNL, and Sandia since 2016. Without this project, high-quality datasets that can be used to assess resource opportunities would not be available. The project combines the institutional resources of the three labs to deliver coordinated and consistent results that leverage the expertise across the labs. The data the project generates is disseminated in several formats to maximize impact—from the Marine Energy Atlas for the public to cloud-hosted data APIs for researchers who need efficient access to the detailed underlying data.



Aggregated Reviewer Comments

- This resource characterization project is an extremely important piece of work. In particular, the compilation of marine energy atlases within a GIS framework provides an extremely valuable tool for both the assessment of the overall resource potential and the determination of potential sites for deployment. While this work is critical for the wave energy and MHK sectors, it is equally important for offshore wind, particularly floating systems, and for other marine users. The combination of high-resolution, met-ocean modeling and accurate field measurements is of significant value, and it is important that (as is being done) this data is made publicly available. It is clear that the team has worked with developers and the wider community to identify metrics for the marine energy atlas that are meaningful for developers. The ability of the tool to take a power matrix and to provide (omni directional?) estimates of power production is extremely useful. Given that this is built within GIS environment, it would be extremely valuable if the tool set could include other constraint information

(bathymetry, navigational routes, distances to ports, sea-bed slope, exclusion areas, etc.) to allow a multi-criteria site selection to be performed. This was done in Europe by the MARINA Platform project (see Craddena et al (2016) multi-criteria site selection for offshore renewable energy platforms, Renewable Energy, https://doi.org/10.1016/j.renene.2015.10.035) and allowed decisions to be made on the basis of estimated LCOE for different technologies. In tidal energy, the reviewer suggests being careful about simply providing current speed and turbulence intensity. Work in the RealTide project and data from the EMEC tidal site have shown that significant loads on MHK turbines can be created through wave action and that the turbulence is highly anisotropic with very large-scale structures that affect loading. The reviewer is aware measurements made by PNNL at U.S. tidal sites show similar tenancies. Gross simplifications to average turbulence intensity and length scale risk badly misleading developers and causing either very high safety factors or machines that fail quickly. Wave current interactions are also very important for both technologies. This work has also shown that the turbulence spectra used by codes such as TidalBladed and TurbSim, which are essentially marinized wind spectra, are a gross simplification at best and just plain wrong at worst. Consequently, the reviewer is very concerned that there is not enough knowledge to be able to embark on a tidal site classification system of the type proposed. The reviewer has similar concerns for WECs where almost every machine has different characteristics and, consequently, there is not enough knowledge about likely technologies to classify sites in a meaningful way. One final observation is that it is known that the third generation spectral models (WAM3 and WaveWatch3) used in met-ocean codes perform very poorly under certain conditions and cannot account for many non-linear wave interactions that can be important at energetic sites. These models still owe much to the first generation approximations used to estimate wave conditions for the D-Day landings but now have lots and lots of correction factors added into them. The reviewer is certain a discussion with NOAA on open ocean wave modeling would be very instructive.

- This is a large and ambitious project focused on impactful wave resource characterization at commercially promising sites using various data collection campaigns and mapping through a layered GIS model. The project also aims to develop classification of different WEC types for standardization, although this may be premature. The data collected and collated is open-source information and utilizes existing modeling resource and data. This is a hugely valuable dataset that will be well used by the sector in the years to come. The project also includes a capacity factor mapping tool. There is an opportunity to include GIS layers of bathymetry, site characterization, other marine users, ecology etc. There is strong engagement with potential users through webinars and webpages and a significant list of research publications.
- Thank you for the excellent talk; it is good to know this level of planning is occurring. The reviewer is reassured that they are using NOAA wind data to force the wave modeling and appropriate wave/tide models for the high resolutions. The team should be aware that site characteristics may change suddenly and episodically with conditions not contained within the Climate Forecast System Reanalysis historical datasets.
- Excellent work on resource characterization.

Demonstration of an Advanced Multi-Mode Point Absorber for Wave Energy Conversion

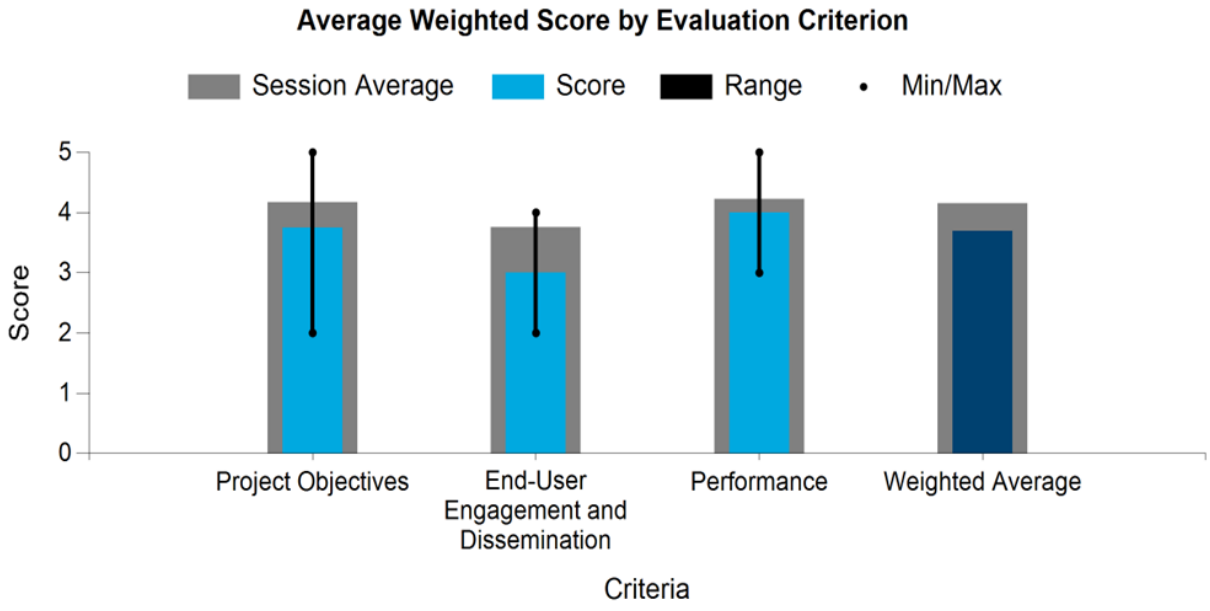
Oscilla Power, Inc.

WBS:	EE0007819
Presenter(s):	Tim Mundon
Project Start Date:	01/01/2017
Planned Project End Date:	09/30/2022

Project Description

The purpose of this project is to design, construct, deploy, and prove the performance of the 100 kW Triton C. The Triton C (for Community) is a two-body, multi-mode WEC that shares the same general architecture as Oscilla's larger 1 MW Triton. At its basic level, the Triton-C comprises a ring-shaped reaction structure that hangs below a surface expression via three tendons. Wave action on the float generates relative motion between these two bodies, which can then be converted to electrical power by the drivetrains. The Triton C was developed with the goal of providing power to remote communities or facilities; however, Oscilla has also seen demand for this system to provide power at sea for high-power PBE applications. The Triton C has been developed with a long travel rotary drivetrain that allows a system of its (relatively) small physical size to operate in fully energetic waves and an improved self-deploying installation approach that allows the system to be deployed quickly and simply with low-cost vessels.

The Triton-C has been constructed and launched and is currently waiting in Honolulu Harbor for the U.S. Navy's WETS to be made ready for its installation. It is provisionally expected to be towed to the site in August 2022 once infrastructure work is complete. When installed, the system will be connected to the Hawaiian Electric Company grid. During its deployment, the Triton-C will also be acting as a testbed to evaluate other technologies and initiatives, such as advanced control techniques developed for Oscilla by Sandia, the Adaptable Environmental Monitoring Platform developed by the University of Washington, and an offshore emergency radio system for the state of Hawaii.



Aggregated Reviewer Comments

- This project has managed to achieve a lot during the COVID pandemic, and the ability to manufacture and ship a prototype WEC to site is a major achievement. The reviewer is concerned that the WEC has remained undeployed, and while this is due to the wave test site not being ready, the reviewer is surprised that the WEC

has been left in the water rather than removed to a laying up area. Being in the water for 12 months without being in operation could lead to significant problems when the device is moved to the test site. Developers working at the one quarter-scale EMEC test sites normally remove their devices from the water in between deployments. Given that this is a foundational R&D project, the reviewer is concerned that their dissemination of project results is rather weak. While this is probably due to a strong commercial focus, it is important that as much general learning from the project as possible is made available to others.

- The project objectives contribute very well to WPTO's mission. The aim is to demonstrate the WEC and novel technologies within it and to take it to commercialization. Good progress has been made, though there are some delays in deployment at the test site, partly COVID related. There is no management plan or risk table in the presentation, and the team should consider how project objectives might be achieved if other delays or issues are experienced. Many issues have been resolved in the construction and a patent granted. Dissemination plans appear limited, and it is not clear what has been shared so far.
- This project might be ready for discussions with specific users to broaden consideration of possible local factors (e.g., size needed, access for repair, and site usage). That would also help motivate a local harbor to be supportive of real-life delays. Harbors have long-term plans they need to accommodate; hopefully, they would be able to help flex calendars if they prioritize this higher. The reviewer was unclear on how this device handles extreme conditions or sudden changes in conditions (e.g., rogue waves and other outliers). It is one thing to show power rating at max, but it would also be beneficial to show expected power rating dependent on sites.
- The team has done a great job under very difficult conditions. The name plate power rating appears to be 100 kW. Absent any discussion of actual conversion performance, it was hard to see how well the device actually performs. The reviewer notes that a point absorber is typically an axisymmetric body that radiates equally in all directions when oscillating in heave. It is also very much smaller than the wavelengths it is designed for.

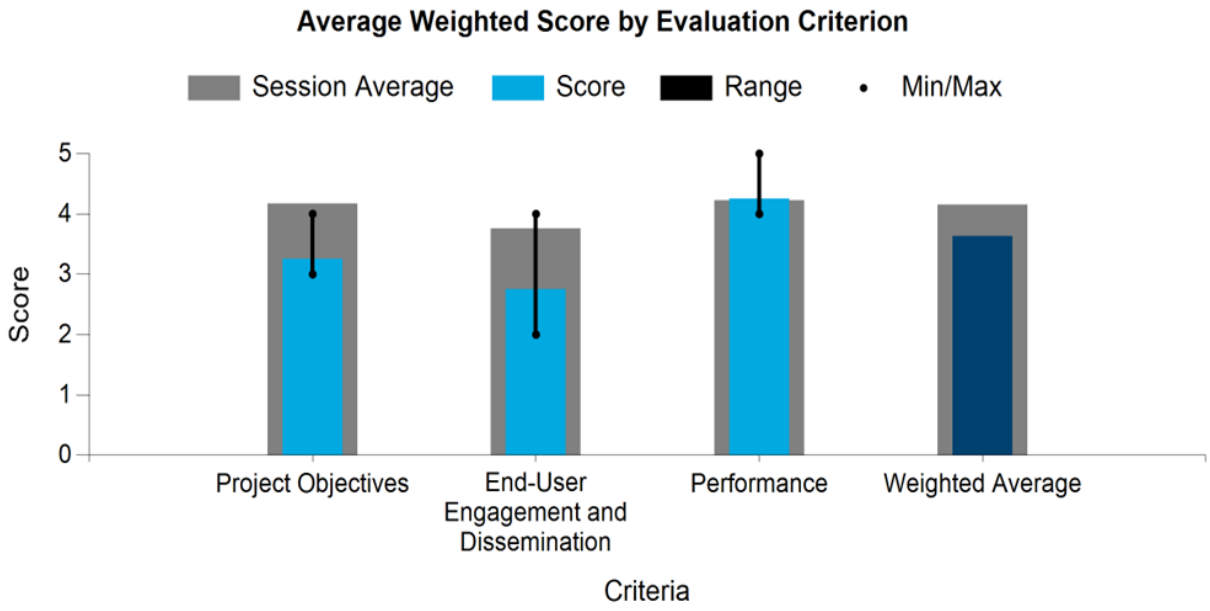
Seawater-Compatible Rotary Pump for Wave Energy Conversion

Resolute Marine Energy, Inc.

WBS:	EE0008385
Presenter(s):	Marcus Gay
Project Start Date:	09/01/2018
Planned Project End Date:	02/28/2022

Project Description

This project aims to design, manufacture, and test a novel, seawater-compatible rotary vane pump to allow for real-time flap modulation in MHK energy systems. This device is necessary to address the end stop issue identified with most PTO architectures for oscillating surge WECs. A scaled pump was manufactured, and a hardwater-in-the-loop system was used to validate the system models for the designed rotary vane pump.



Aggregated Reviewer Comments

- This project has designed and built a prototype for a novel oscillatory salt water pump that delivers the pressures needed to drive a reverse osmosis desalination plant. This is an important achievement and has strong potential to support the provision of potable water for remote communities. This is tightly defined and well executed work on a very interesting idea, and it takes a lot of courage to use seawater as a working fluid. To achieve the full potential of this project, which has a broad range of applications, much stronger dissemination of the results is needed. If dissemination is being held up by a wish to file a patent, then it is disappointing that the patent process was not started early enough to allow proper dissemination. If a patent application is not being made, then I hope a lot of public reports, papers, and public awareness materials are just about to be published.
- This project is complete and awaiting production of its final report. Manufacturing of a prototype double vane pump was successfully achieved, and pump operation within a WEC was tested using a hardware-in-the-loop system. No patents or publications were listed. More details of the plans for dissemination and publication would be useful.
- The brief started with a narrow view of goals/objectives, but should start more broadly and then narrow down to specifics. Reviewers come from a wide variety of backgrounds and this context would help. The pump is designed for one category of users, and the reviewer was unclear on whether there are others who might

become stakeholders. It was stated that the pump is for emergency response, but the reviewer predicts some areas will need this over the long term, which would potentially expand both the stakeholders and design requirements. The discussion of biofouling needs more detail; the response was that this is handled via intake filters/treatment, but those do not keep the microorganisms out, and this pump is dependent on close tolerances of moving parts. The reviewer was unclear on the expected maintenance requirements.

- This appears to be a promising approach to seawater desalination. The reviewer applauds the team's courage in using seawater as the working fluid for their hydraulic system, and other teams would do well to emulate some of these ideas. However, absent a schematic diagram of the overall system, the reviewer can only vaguely visualize the system. Similarly, the reviewer would have appreciated more details on the techno-economic analysis and the mathematical model for the system.

Design of High-Deflection Foils for MHK Applications

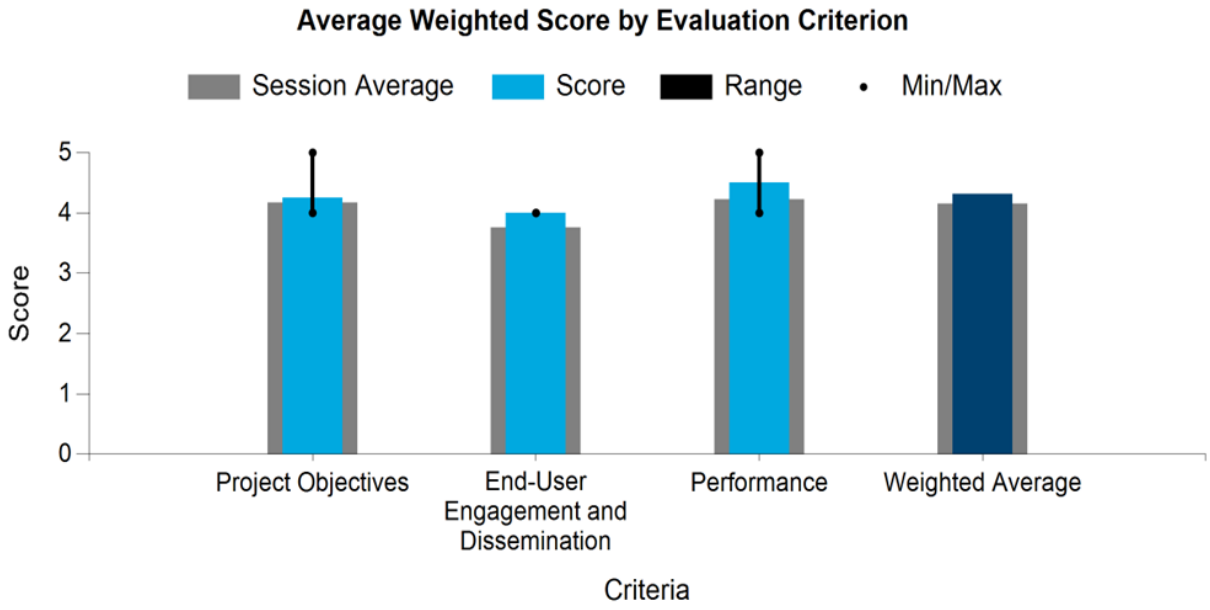
Ocean Renewable Power Company, LLC (ORPC)

WBS:	EE0008386
Presenter(s):	Jarlath McEntee
Project Start Date:	09/01/2018
Planned Project End Date:	12/31/2021

Project Description

This project used model-scale tank testing and fluid-structure-interaction simulations to investigate the behavior of foils with large deflections and the effect of these deflections on crossflow turbine performance with the goal of determining the maximum allowable deflections consonant with efficiency and a robust, durable structure.

A validated modeling and simulation approach was used in the design of an ORPC full-scale turbine. The methodology is applicable to the design of other MHK devices and hydrokinetic turbines that experience significant deflections during operation. Numerous foils exhibiting different deflection behaviors were investigated. The external profile of the test foils was maintained constant, and stiffness of the foils varied using different construction materials. Simulation and validation work focused on developing engineering tools for predicting the effect of high deflection on performance and structural longevity. The tank tests were modeled using computational fluid dynamics and finite element analysis simulations. Methodologies were investigated and refined to allow for load transfer between the computational fluid dynamic and finite element analysis models. A fluid-structure-interaction methodology was validated using the tank test data. Using the analytical methodologies developed in this work, a new high-deflection rotor for ORPC's turbines was designed, making use of the lessons learned in model testing and analytical methods explored in the project.



Aggregated Reviewer Comments

- This is an excellent foundational academic R&D project that has investigated both helical (Gorlov) and straight crossflow turbine designs using a combination of modeling and experimentation (with cross validation). The integration of optical strain measurement systems in the blades delivering continuous strain measurements at a large number of points along the blade is game changing. It was especially good to hear that the resulting datasets will be published on an archival system and provided with a data descriptor in line with best practice

for the publication of large datasets. One issue is that the turbines have been tested in a turbulence-free environment. This is very unrealistic; measurements from real tidal sites and rivers show high levels of turbulence (10% to 20% turbulence intensity) and detailed analysis often shows very large turbulent structures (with length scales exceeding the rotor diameter/blade length) and complex anisotropic flow. Results from the recently concluded European RealTide project have shown that such turbulence is a major driver of loading on blades and is critical when considering fatigue life and control. The reviewer strongly recommends that tests are conducted in flowing water (ideally in a large-scale facility such as FloWave, though an open channel could be used) where the impact of turbulence and perhaps wave loading can be assessed. A further concern is the blockage ratio in the towing tank that has been used. It would be interesting to know how the loadings change and lower blockage ratios (in terms of channel width). This could be achieved using computational fluid dynamic models or by looking at different facilities.

- This project met objectives in generating new knowledge and developing new analysis tools and the study exceeded LCOE projections. This project led to a valuable open-source dataset and student engagement, plus publications at an international conference. The reviewer recommends testing the turbine in a more realistic flow environment to further inform the performance and loading benefits.
- The reviewer reinforced the comment made in discussion about the need for testing to include induced turbulence. The reviewer inquired about whether the tank can handle wave generation. A good first test before going to the field would be no-flow plus waves or controlled-flow plus waves, which could provide some very interesting additions to the dataset. Turbulence/waves will be the norm in any real-use situation.
- The project features an interesting topic and methods, both well summarized in the talk. It was unclear to the reviewer whether scaling up or down involves also scaling structural/material properties. Turbulence effects in real environments need to be accounted for somehow. It was also unclear to the reviewer how people are to interpret and use data for applications at different sites and sizes. The reviewer asked whether this is something to consider for future work.

Performance Testing of an Integrated Magnetic Power Take-Off

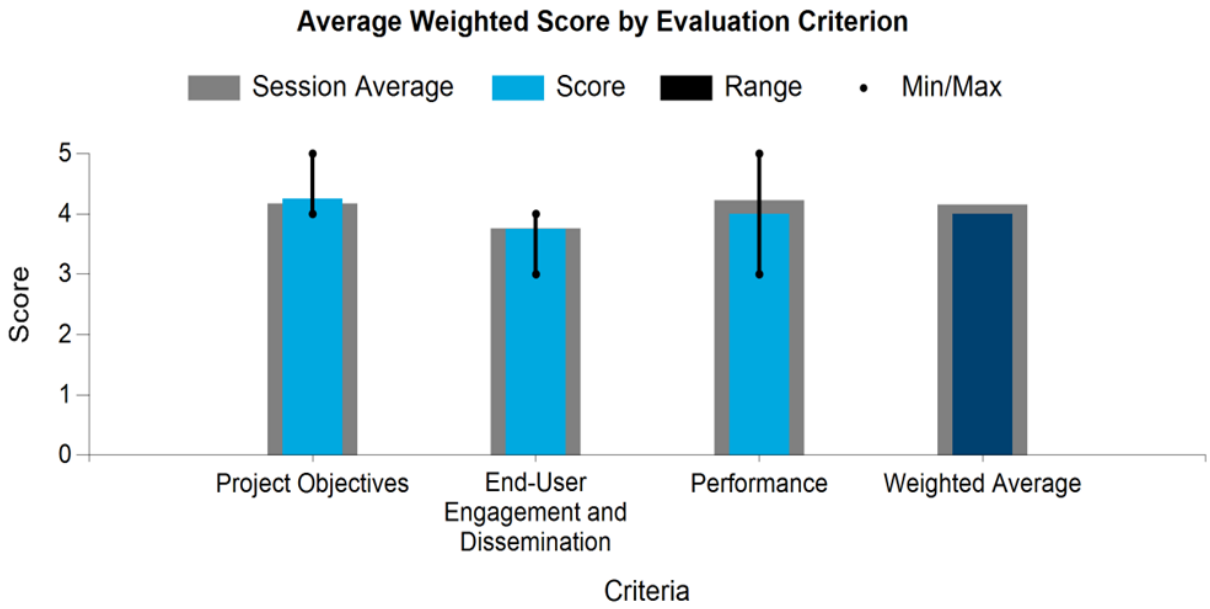
Portland State University

WBS:	EE0008631
Presenter(s):	Jonathan Bird
Project Start Date:	06/01/2019
Planned Project End Date:	06/30/2022

Project Description

The objective of this project is to co-design, fabricate, test, and actively control a new type of rotary magnetic PTO. The magnetic PTO consists of an adjustable stiffness magnetic spring with a magnetic-geared generator. The adjustable stiffness magnetic spring has a linear stroke length with a negative stiffness capability. The project first focused on validating both the rotary and linear stroke length versions of the adjustable stiffness magnetic spring.

By tuning the negative stiffness of the magnetic spring, a WEC can be operated near a resonant state over a wide bandwidth. The magnetic PTO decouples the stiffness and damping needs of the generator system, thereby eliminating the resonant reactive power loading requirement on the generator. This enables smaller WECs to be capable of generating significantly more power. The non-contact magnetic operation should greatly increase reliability and lower maintenance costs. The magnetic torque transfer also provides overload torque protection. At the end of this project, the team seeks to have verified the energy density capability of the adjustable stiffness magnetic spring, demonstrated the potential of a 1/20th-scale magnetic PTO to operate at a resonance condition over a wide bandwidth, and experimentally demonstrated that a magnetic PTO control system can increase the peak-to-average absorbed power ratio by more than 50% over baseline values.



Aggregated Reviewer Comments

- The presentation for this project would have benefited from a much more general introduction and an explanation of the operating principles of the magnetic spring. That said, the reviewer thinks this technology has much broader applications than just in the power train of wave energy devices as there are other applications for adjusting the spring force in this way. Adjustment of the spring force in the control of wave energy devices (and wave makers) has been worked on for a long time and several electro-mechanical systems have been developed (e.g., Salter, S. Wave energy: Nostalgic Ramblings, future hopes and heretical suggestions. J. Ocean Eng. Mar. Energy 2, 399428 (2016). https://doi.org/10.1007/s40722-016-0057-3).

It is important that the adjustable spring force is included into the equations of motion for the WEC and that this is part of the control strategy for the device. Maguire and Ingram ("On Geometric Design Considerations and Control Methodologies for Absorbing Wavemakers," Coastal Engineering, Vol. 58, no. 2, 135-142, 2011. DOI:10.1016/j.coastaleng.2010.09.002.) showed that the absorption efficiency spectrum could be significantly broadened by combining geometric design at one frequency with spring/damper control at a different frequency. This is an area that needs to be investigated by the team and could be done using hardware-in-the-loop bench tests with realistic wave input conditions. The reviewer's final technical concern is that the team plans to perform tests in a wave tank. The reviewer does not understand the need to do this or the benefits of doing so. Subjecting the drive train to realistic, wave-induced motions in a hardware-in-the-loop bench test would be much faster and cheaper and will enable a much broader range of conditions to be examined. The additional complications of building a PTO that can be placed in a WEC and tested in the lab will only muddy the waters. One last point is that it was stressed several times that underrepresented groups of students would be targeted for recruitment. While this is laudable from a diversity and inclusion perspective, no statistics were presented to show that this strategy had had any effect.

- This project achieved its objectives with a prototype built and tested. Results were compared with a finite element analysis numerical model and shown to compare well. A no-cost extension has been granted to the project, and further testing is planned at a national lab with scaled wave conditions in a wave tank. Some delays were due to COVID-19. There was a good level of dissemination and research output with two patents granted and seven research papers published. However, a wider range of applications could be explored.
- It sounds like this effort could assist a broad array of customers. The reviewer inquired whether others been contacted or reached out based on the briefs/publications. It might be beneficial to provide a comparison of the bandwidth resonance shape using this spring. It would have been good to see more of the decision process for the chosen rotary spring and modeling/testing of the choice.
- This is interesting work. The use of magnets to produce a negative spring effect when needed is potentially promising. The reviewer inquired whether the team performed a stability analysis (over a frequency range wide enough to include environmental noise sources) on the whole system with the magnets active. The reviewer also asked whether the team derived the scaling laws for the system and/or performed an energy balance analysis with the magnets active.

Holistic Control Embedded Power Take-Off (PTO) Development

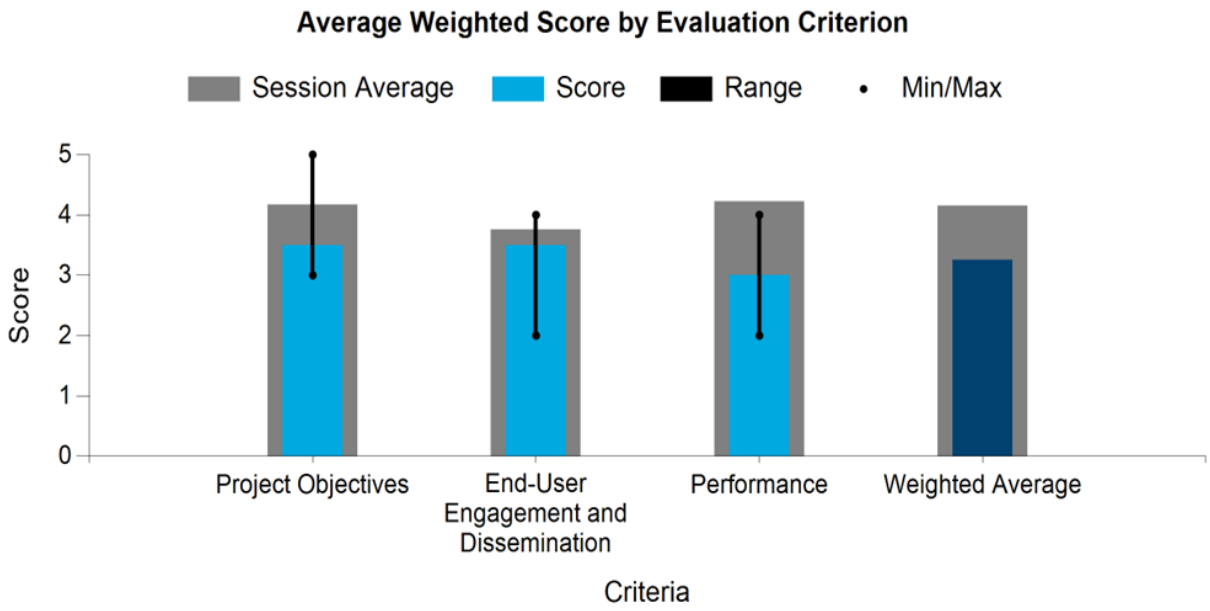
CalWave Power Technologies Inc.

WBS:	EE0008632
Presenter(s):	Marcus Lehmann; Dan Petcovic; Thomas Boerner
Project Start Date:	04/01/2019
Planned Project End Date:	01/31/2022

Project Description

Based on state-of-the-art control strategies for WECs and CalWave's prior development of effective WEC absorber load management strategies, the primary goals of this holistic controls and PTO design project are to inherently couple the design of CalWave's PTO architecture with PTO control design for cost- and performance-efficient PTOs; to further develop a full wave-to-wire simulation, including a precise PTO model coupled with the inherently required PTO control strategy; to integrate primary (absorber geometry) and secondary (PTO) conversion step control strategies into a holistic control framework; and to achieve synergies for lean and efficient design of the PTO in terms of specified PTO metrics (e.g., peak-to-mean force or power).

For demonstration, assessment, and validation of achieving these goals, an advanced PTO system and control architecture will be physically set up and bench tested in a controlled laboratory environment utilizing a real-time, hardware-in-the-loop approach.



Aggregated Reviewer Comments

- This project was one of a number funded by the water power program, and it was not clear to reviewers how the projects were related or what work was conducted under the Holistic Embedded Control PTO project. As the other projects were reviewed by other panels, it would be useful to have a more general overview of the linkages. The reviewer was disappointed that more technical detail on the PTO project was not presented as this makes it very hard to pass a fair judgement. CalWave needs to be congratulated on completing a 10-month deployment off the Scripps Institute pier in California. The review did not understand why field testing is being used to optimize the PTO controller. Such optimizations are normally done based on tank testing and modeling using multidirectional, representative sea conditions. This enables the PTO forces, required damping and spring forces, and aspects of the controller to be designed, hopefully as part of the co-design process discussed by

several of the other Foundational R&D water power program projects under review. This approach is mandatory for developers in both the Wave Energy Scotland and Europe Wave programs and is certainly considered best practice. The approach was taken following the failure of several technology developers that was driven by a rush to "put steel in the water," which is a very expensive way of learning lessons. Working in this back-to-front way seems to have delayed true PTO optimization work while data from the sea trials are analyzed. Surely, the design and operating conditions are known from wave buoy data and met-ocean predictions at the test site. Given that this is a Foundational R&D project, it is unclear how replicable and transferable the results of this project are.

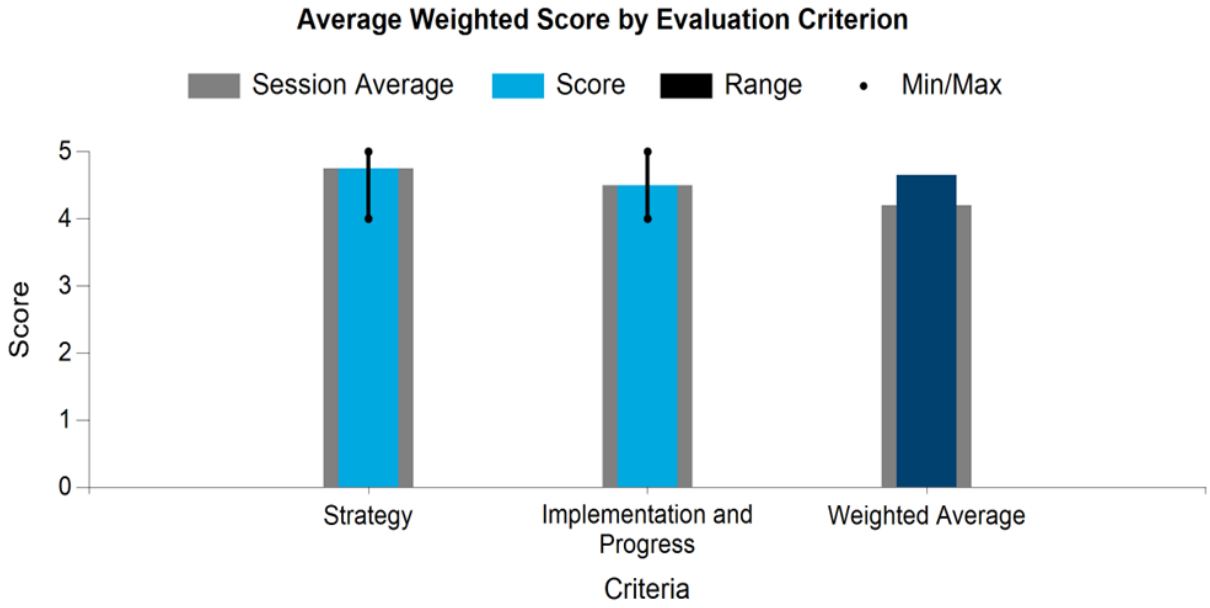
- The relationship of this project to other ongoing projects by the project team should be clarified. There is good dissemination at symposia and workshops. The project is currently underspent due to delays in engaging external partners for the manufacturing step. Modeling and simulation are complete, but design, build, and commissioning and test bench activities are planned for budget period two. Significant budget is allocated to installation and commissioning of the test bench in budget period two.
- This project appears connected to multiple other projects, and it seemed the presentation was primarily about the larger project (or other aspects of the larger project). There seemed to be less about this project. It was unclear to the reviewer how widely compatible this control system would be with other equipment designs. The reviewer also inquired about sea condition limits. This will also impact cable tolerances/choice.
- The reviewer appreciated the presenter's time. It is good to see that the device has been in the water for a long time. In the future, it would help to have an overall schematic of the device and an indication of the geometric shapes and sizes of its components and even of all the mechanical and electrical components involved, particularly because the project title includes terms such as "holistic control."

Technology-Specific System Design and Validation

Activity Area Evaluation

WPTO

WBS:	2.2
Presenter(s):	Elaine Buck



Aggregated Reviewer Comments

- There is an excellent breadth and depth of projects across a range of scales and an excellent range of funding mechanisms available. There are some excellent examples of collaborations between companies, but some projects seem to be running in isolation even when prior knowledge or learning may be of huge value. Enabling and encouraging collaboration and knowledge capture has been of benefit in some projects and would certainly benefit others. It is good to hear WPTO is working with projects to address concerns and challenges rather than sticking rigidly to original plans; this is imperative for achieving the best outcomes, and DOE should be commended for this. It is, of course, vitally important to ensure this remains the case as further challenges are experienced. The reviewer believes it is important to get prototype systems wet ASAP; it is only in real world, at-sea testing where a number of the residual challenges will be discovered. There needs to be a plan in place for funding "updates" to machines following initial deployments to cover the unknown unknowns that will inevitably occur (and could not necessarily be predicted at the beginning of the project). The reviewer recommends some kind of contingency fund (a percent of overall budget perhaps) that is budgeted by DOE and ringfenced at the beginning of the project that can then be accessed during at-sea testing when appropriate rationale is provided. Following on from this, there is a clearly stated goal of kilowatt and megawatt devices, but it is unclear from the information provided how this funding will address the so-called "valley of death" between initial prototype deployment and commercial devices as it is almost guaranteed that support of some kind will still be required. The reviewer thinks it will be important from both a developer's and investor's perspective that there is at least visibility of what funding may or may not be available on the runway through to commercialization. There is a residual concern that in the current environment with budgets getting very tight that the obvious candidate for reduced budget will be O&M activities and equipment that need expenditure toward the end of the project and are often under budgeted anyway. If this occurs, there is equally a concern

that failure to spend properly here can lead to serious health, safety, and environment problems in what is the riskiest part of the project in this regard. This needs close monitoring. Acknowledging this may be due to the assigned projects, the reviewer noted projects predominantly seem to focus on full systems rather than sub-systems or enabling technology. Refining the problem to specific key systems or interfaces may be something worth consideration. It is good to hear a best practices suite of documents is under development; this could be hugely valuable. If it is not already there, the inclusion of a robust work-up program needs to be included in any significant at-sea deployment. (If it can go wrong, it will go wrong. Companies need plans in place for how to deal with that prior to deployment and for gradual exposure of critical system to more energetic conditions.) Also, a work-up program significantly reduces risks during initial deployments and allows on-the-fly validation of critical subsystems before they are really critical.

- The challenges are identified. The reviewer feels that it is missing more emphasis on the design phase. Before the prototype is deployed, there is a need to have a robust design—software, consolidation of analytical methods, good understanding of the safety margins and the limits of the design, etc. There is a need to connect a prototype to improvements in design methodology and identification of degradation and reliability. Standards have to be connected to the lessons learned from the prototype deployments. As there is a multitude of technologies in marine renewables, the learning process will be more complex and more difficult to consolidate on standards. There is a good degree of diversity in the projects. However, some careful considerations should be given to technologies that appear to be based on technologies that have been tried before.
- This is a well-balanced program with good breadth and depth in all areas. There is excellent management of the overall program by committed WPTO staff and leadership. Consideration should be given if the program can sustain its current breadth as its technology's initiatives require more funding and WPTO staff management time as they mature in scale and TRL level.
- This program is very well designed and well planned. The work that has been supported to date is moving the marine energy industry forward, and locations, such as PacWave and the Maine Maritime Academy, offer real-world testing locations that are precisely what industry needs. The support of the companies and the way the WPTO team works with these companies are leading to successes. From the thorough review process to the ongoing support while they are working on projects, the companies have a valuable partner in the work. It is clear from the projects presented that the companies appreciate the opportunities and support they have. This program has been growing for a few years, and the private sector has not been doing its part to "take the ball and run with it." As a result, there is a danger that the companies will have an unpleasant valley of death. It is clear this is a concern for WPTO, and the solution is not clear for anyone. Internationally, there has been some success at getting companies to near commercial, but many companies have collapsed. Given that the private sector has not seen the value yet, it seems that in order to make this technology a viable part of our energy mix going forward, the public sector needs to support it. Internal combustion engines, turbines, nuclear power, and more were fully developed by the military and public sectors before being commercialized. WPTO needs to decide if marine energy is the solution that we all think it can be and, if the office believes it is, then there may need to be full commitment to get the technology to commercial. Overall, WPTO develops comprehensive, clear programs that have achievable goals and push the industry forward while ensuring access and education broadly.

Project Evaluations

Wave-SPARC Structured Innovation

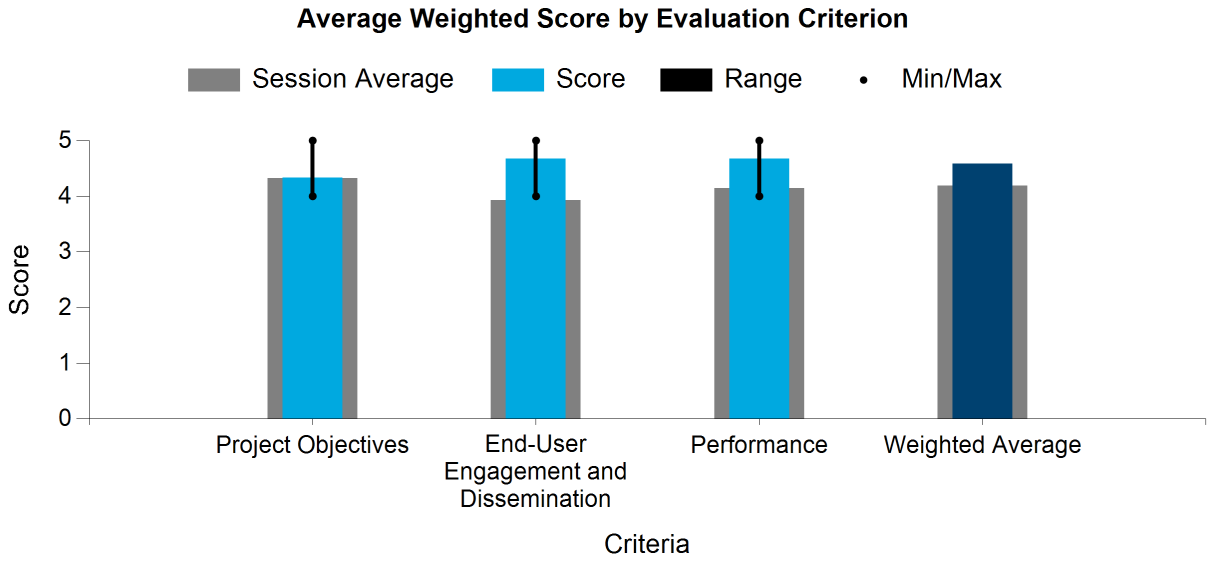
NREL, Sandia

WBS:	2.2.1.402
Presenter(s):	Jochem Weber
Project Start Date:	10/01/2014
Planned Project End Date:	09/30/2024

Project Description

Wave-SPARC is empowering the marine energy community with the tools necessary to achieve a significant improvement in techno-economic performance of wave-generated grid power. A detailed systems engineering approach simultaneously balances around 100 cost and performance drivers (functional requirements and capabilities) of WECs. Publicly accessible technology innovation and assessment methods and tools (new to the wave energy sector) have been delivered. These resources guide technology development trajectories to successful outcomes in less time, at less overall cost, and with less encountered risk. With the use of these methods and tools along with proven and structured inventive techniques, the project continues to deliver high potential novel wave energy technology concepts for validation and subsequent development by industry.

Intended project outcomes include the invention, assessment, identification, verification, and validation of novel and high techno-economic-potential WEC technology concepts to deliver high-confidence "seeds" for subsequent industrial development to full commercial application and economic viability; development and delivery of WEC technology innovation and assessment methodologies and tools and provision of these resources as services available for free to industry and the entire sector; and international collaboration for global best practice alignment of assessment and innovation methods.



Aggregated Reviewer Comments

- The project has an excellent rationale behind it. The PIs understand well where it is useful and where limitations arise. The reviewer liked the comment that the benefit is in the process rather than the output. The reviewer thinks understanding this across the board will be important to more widespread use for development purposes. The long-term project is delivering frequent updates and dissemination. There are multiple use cases that could be valuable (and have been explained), and engagement with potential end users is apparent.
- The objectives are well relevant to the wave sector development. Regarding dissemination and engagement, there is a successful level of involvement of developers, and the project is of interest to all stakeholders. Regarding performance, the outcome of the project is directly related to the use of the process to different stakeholders.
- This is an interesting structured innovation project that is an excellent fit with the WPTO program. The uptake and impact the tool is having on the sector was unclear to the reviewer. There is a good engagement strategy for building the tool, but it is unclear who is actually using the tool. The end-user/industry engagement for the tool's use appears to lacking in this project. This is a very well run and managed project. There seems to be plan to widen its scope; however, it seems a natural next step would be to focus on the uptake and impact of the existing tool.
- This is greatly needed in the industry. It is important that these are living documents that get regular feedback.

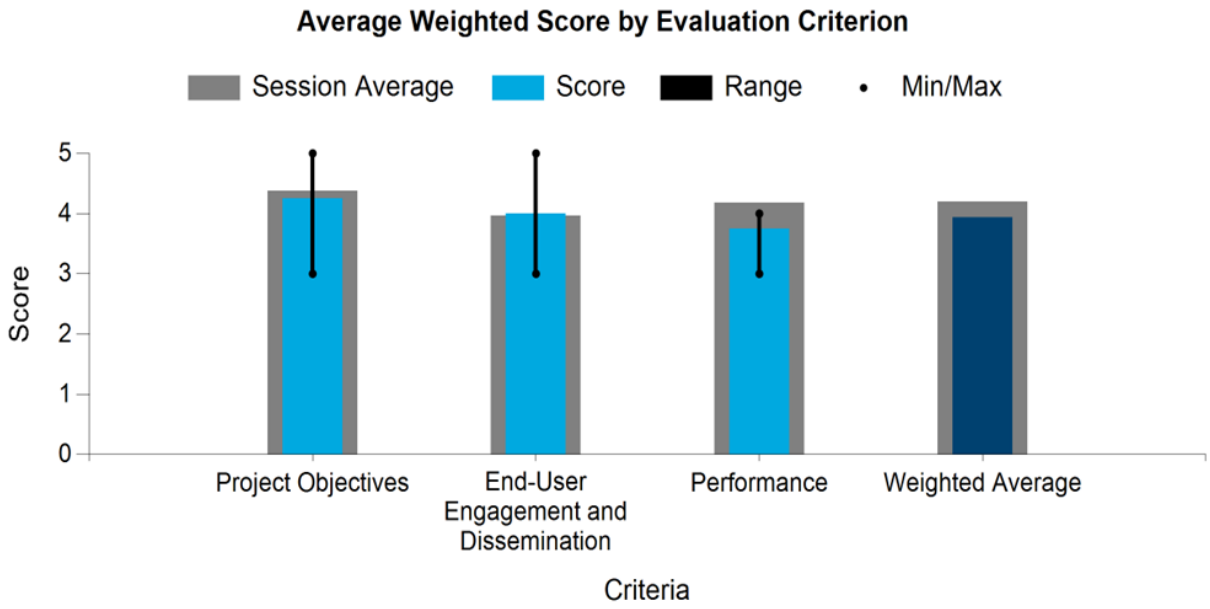
Distributed Embedded Energy Converter Technologies (DEEC-TEC)

NREL

WBS:	2.2.1.407
Presenter(s):	Blake Boren
Project Start Date:	08/01/2018
Planned Project End Date:	03/31/2020

Project Description

Distributed embedded energy converter technologies (DEEC-Tec) could revolutionize how stakeholders conceptualize ocean WECs and view and evaluate the overall viability of ocean waves as a source of renewable energy. However, DEEC-Tec is a nascent and underdeveloped technology domain with a need for in-depth R&D. The overall goals of this project are to advance the scientific and engineering understanding of DEEC-Tec and to study how the DEEC-Tec domain could be best utilized to create effective and viable forms of DEEC-Tec-based WECs (also known as flexWECs). This project will create and disseminate foundational knowledge to empower future research, tool development, and decision making for DEEC-Tec in the marine energy sector.



Aggregated Reviewer Comments

- This disruptive technology is an exciting and worthwhile research avenue that is pertinent for WPTO's longer-term goals for marine energy. However, the reviewer believes this project would sit better within the foundational R&D workstream and, at this early R&D stage of the technology, does not necessarily meet the objective for real-life testing of technology concepts. The reviewer's concern for this project is based on the fact that the focus seems to be primarily on the benefits of flexible WEC technology rather than the limitations that may exist for implementation. (Although the reviewer notes that one of the stated project objectives is to identify bottlenecks for development.) The reviewer notes this because of the comment made stating that the structural base material is a large unknown and without assessment of the full WEC implications and/or identifying the technical challenges that may exist beyond the micro-PTO, full understanding of the potential benefits that could be realized is a challenge. The project plan and methodology seem sound, and the reviewer has no concerns over delivery of useful outputs. Project dissemination is occurring.

- Regarding objectives, distributed embedded energy converters are a very new approach and demand a careful assessment on their potential and possible showstoppers. It is a highly disruptive technology. Constraints on the material scaling up, manufacturing, and sustainability should be identified, and collaboration with possible suppliers and manufacturers is important. There are some developers working with flexible structures but not necessarily with a distributed conversion. Regarding performance, it is an early stage to assess performance, but the elements and plan are in the right direction.
- This is an interesting, disruptive project that is an excellent fit with the WPTO program, but it is not clear how industry can get involved. The end-user/industry engagement for this technology use appears to lacking in this project. This is a very well run and managed project. A plan for considering for this type of disruptive technology could involve Wave-SPARC developing ideas/concepts with industry (could be new entrants), labs supporting industry to prove the concept, and industry taking the technology forward in a specific FOA or prize.
- The project was executed well, and the research was all done. The commercial value of this work to the wider industry is unclear. It is not clear if the team was asked to investigate this by industry. While supporting blue sky research is important, this is very applied research and, therefore, it would be expected that it has an application. The presenter stated that there is a lot of interest from the commercial sector, but it is not clear if that will turn into adoption. It is unclear if the patents will be purchasable by industry or if industry would need to pay for them. If they will not have to pay, then it is not clear why a patent was pursued as publication of the work would have had the same impact.

Significant Cost Reduction Potential for Wave Energy Conversion Devices with Variable Geometry Modules

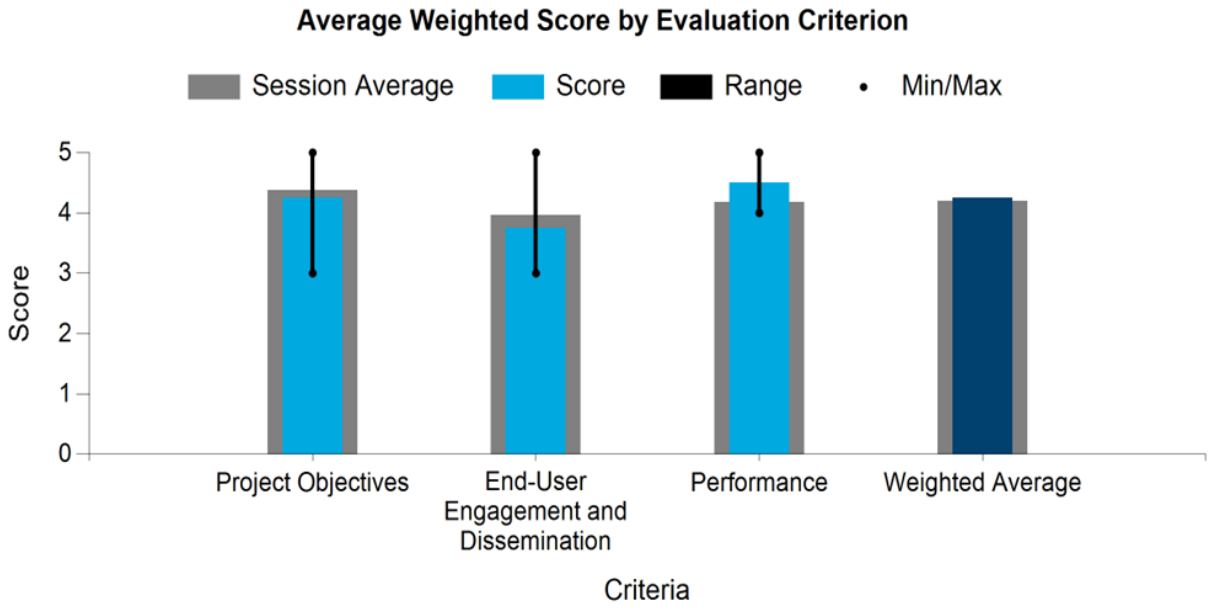
NREL

WBS:	2.2.1.410
Presenter(s):	Nathan Tom
Project Start Date:	06/18/2019
Planned Project End Date:	09/30/2021

Project Description

The Technology Commercialization Fund award is built upon NREL's previous research exploring a bottom-fixed, variable-geometry, oscillating surge wave energy converter (VGOSWEC). However, unlike previous investigations, the VGOSWEC will be raised off the sea floor. Researchers believe that advances in offshore pilings and foundations, such as 3D printing, will provide low-cost and easily deployable structures. There are several benefits to designing a raised VGOSWEC, such as reducing issues with sediment transport and environmental impacts near shore, less expensive deployment and installation as work boats will not risk grounding in shallow water, and deeper water deployments that will improve the wave resource.

The VGOSWEC concept was developed under the assumption that cost reductions and improved system survivability will not be obtained until greater load-shedding capability is designed in the WEC hull. The load shedding capability is enabled through the hydrodynamic control provided by variable-geometry modules. When variable-geometry modules are combined with PTO control, the system can emphasize power production of load shedding. The Technology Commercialization Fund award continued development of the VGOSWEC, adding a raised foundation, to demonstrate the concept is a viable technology that can open a wider range of deployment sites and provide promising cost-of-energy estimates.



Aggregated Reviewer Comments

- Research into variable geometry forms is an interesting potential way to change performance or survivability characteristics of marine energy converters and is an avenue worth exploration for comparative LCOE benefits. Given previous high-profile, flap-type WECs having been developed through to full-scale deployment (with multiple iterations thereof), the reviewer is somewhat uncertain as to the value of this type of project without

specific knowledge that some of it is addressing some/all of the challenges (which, of course, variable geometry might) that have been faced by similar geometry WECs in the past and, therefore, is enhancing the state of the art. If this is the case, then the project would benefit from stating this in some way and make reference back to knowledge capture from previous developers, if possible. This may, of course, have been the case, but this did not come across during the review. The project is disseminating findings and made use of an advisory group. As noted in the presentation, further engagement with the wider marine energy community would also be of benefit. The reviewer's impression is that the project looks at two distinct WEC innovations (variable geometry and raising the WEC). Perhaps distilling these two innovations out and reporting separately on them may be of benefit as they evidently both have different effects and potential effects on the WEC LCOE. The reviewer would have liked to see even comparative value outputs such that the impact of the different innovations can be seen on at least some level (even if not in absolute terms). Without this, it is hard to assess the merit of the projects fully.

- The objectives are clear and focused, but the project seems restricted to this specific technology except if the variable geometry studies can be transferred to other technologies. It seems to the reviewer that raising the flap will increase the energy exposure rather than reducing the loading. The project had limited budget and time for engagement, but it would be interesting to interface with other surge technologies to exchange knowledge and challenges to feed into the project. The reviewer inquired about whether there was any consideration of the PTO restriction or if the results were just for free unrestricted flap. The performance is in line with the objectives of the project. From the information obtained, the next stages would be to look into the implementation. Careful consideration should be given to the mechanisms to change the flap angles as it seems similar to the pitch systems in wind turbines and that is a great source of failures.
- This is a small but interesting wave cost reduction project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, and the project appears to be a good value. The project has a good engagement strategy, but industry engagement was lacking. The project has very good technical planning and progress.
- This is valuable work for the sector and a good use of funding. Publication of the work has real value to the industry at large.

Verdant/NREL Research Measurement Campaign

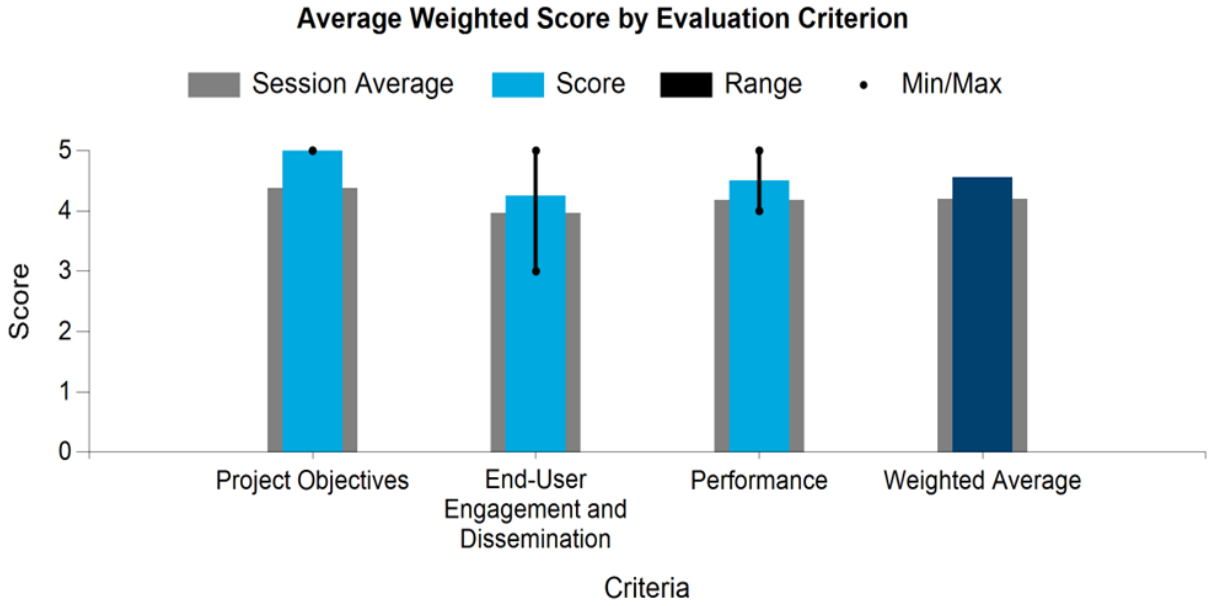
NREL

WBS:	2.2.2.405
Presenter(s):	Robynne Murray
Project Start Date:	08/01/2019
Planned Project End Date:	12/31/2021

Project Description

The marine renewable energy industry primarily uses thermoset composite materials for blades and other hydrodynamic components, which can have up to 50% reduction in strength when exposed to seawater and are not recyclable. Thermoplastic composite materials have been shown at a coupon-scale to have improved seawater saturated properties but have not been validated at full scale.

The primary goal of the project is to demonstrate the structural properties of thermoplastic-fiberglass composite blades compared to epoxy-fiberglass composite blades in seawater at a tidal energy site on an operational turbine. Through this work, NREL manufactured, tested, and deployed thermoplastic blades and a data acquisition system on Verdant Power's turbine TriFrame in the East River in New York City. The thermoplastic blades and data acquisition system were retrieved after a six-month deployment with no signs of degradation, and all cable connections, structural supports, and strain gauges had a 100% survival rate. The blades are currently undergoing post-deployment structural validation to compare their performance to traditional epoxy blades that were deployed for the same amount of time. This will increase confidence in thermoplastic materials and move it closer to commercial adoption as well as increase confidence in the design of a data acquisition system and instrumentation method for a tidal turbine. However, due to an error in the data acquisition system software that was introduced after the data acquisition system and software were validated, no loads data were collected during the deployment.



Aggregated Reviewer Comments

- This is an excellent, well thought out project with clear objectives, a sound scientific approach, and a potentially very usable output in the near term. It is a great example of collaboration between industry and academia to further knowledge in a specific field. The specificity of the project makes results very tangible and immediately useful. The reviewer's only reason for not giving a five for performance is due to the issue with the data capture

system; all other aspects of the project appear to have been run and managed very well. The project was a better value for the money due to the use of data previously available from Verdant Power.

- Regarding objectives, new material requires data and testing in as real conditions as possible. This seems to be achieved here. Regarding performance, a material qualification and design guide on the design and manufacturing for the new material is essential. Testing of the saturated water in the lab to define the ultimate capacity of the blade after the life-cycle dynamic loading had been applied is important. Failure of software has hindered the objectives of the project, but the final tests of the blades will be valuable. Dissemination is still to be performed, but it is important to see how information can be disseminated to the industry without compromising any of Verdant's proprietary information. The project plan was designed to cover all aspects reducing the limitation with data/test results to reduce uncertainties. The score is just impacted by the software failure and the dissemination that basically has not really happened yet.
- This is an interesting blade project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment to avoid the software issue they had. It was believed their end-user engagement strategy could be expanded to the blade manufacturers supply chain. Although there were some software issues, this was a well-managed project with good results.
- This was a great project. The focused direction and involvement of the industry partner was very positive. The work was tangible and clear, and the results can be applied widely. The industry partner appeared to be very happy with the working relationship. The results benefit widely, so it would be worthwhile spending time doing a deep dive on the reasons the industry partner was happy so that can be translated to future work.

Ocean Observing Prize

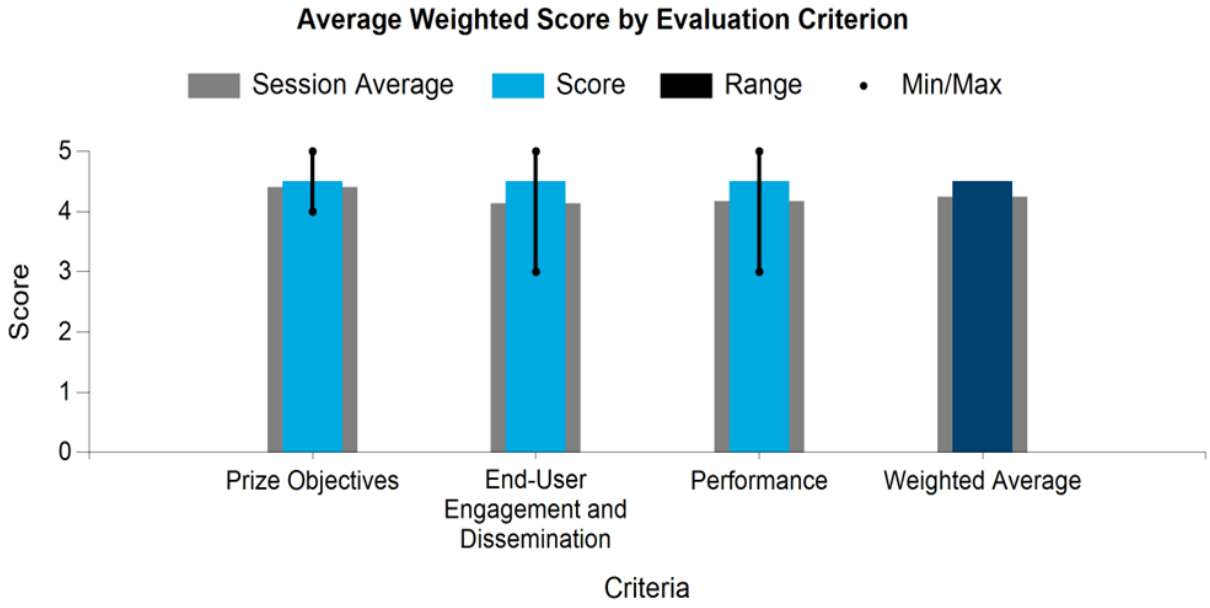
NREL, WPTO

WBS:	2.2.5.401
Presenter(s):	Jenny Wiegele; Carrie Schmaus
Project Start Date:	08/01/2019
Planned Project End Date:	09/30/2022

Project Description

The Powering the Blue Economy™: Ocean Observing Prize is a $2.4 million contest that challenges innovators to develop solutions that integrate marine renewable energy with ocean observation platforms to revolutionize the ability to monitor, manage, and understand the ocean. Competitors are challenged to design, build, and test novel, wave-powered, self-charging autonomous underwater vehicle systems that could be suitable for a six-month deployment in the Atlantic Ocean to monitor hurricane formation.

Through engagement with the end-user ocean observing community, the team identified challenges in a lack of data on storm intensity, endangering coastal communities. This challenge could be addressed by collecting data before, during, and after a hurricane develops and strengthens at sea. Amassing this data, however, requires an ocean observing system that can be deployed at sea for long periods, waiting for approaching storms. To help solve this problem, competitors are working to integrate wave energy capture with autonomous underwater vehicle systems to collect this data, helping to better protect coastal communities from oncoming storms. Solutions developed through this prize aim to enable long-term collection of data before, during, and after a hurricane that will help better forecast storm intensity. The prize mechanism provides an environment to accelerate technology development for innovators and helps to improve awareness of marine energy and its ability to provide power to blue economy applications.



Aggregated Reviewer Comments

- It was interesting to note the comment regarding the prize challenge potentially being too complicated for the purposes of the prize (and this is the reason for the lower score for performance because the outputs are not at as high a level as would have been desirable). The reviewer wondered if, given that wave energy technology is being developed elsewhere within this project, a prize like this would work better if it focused on the more specific problem of WEC-autonomous underwater vehicle interface/energy storage rather than the full problem. Perhaps a WEC (or set of WECs) and the autonomous underwater vehicle could be pre-selected,

and then it is the interface and energy storage/connection challenge that is being sought. These kinds of enabling technologies will be critical to onward development and are a great entry point into the industry for multiple companies without having to dive into full WEC development. There are lots of opportunities for similar enabling technologies—connection systems, umbilicals, elements of mooring systems, etc.—external to the WEC, within the WEC such as specific sensor systems, and other ancillary systems such as maintenance platforms and seals. It would be really interesting to see what WEC developers and people in the industry would like to see developed and perhaps put that out as a prize for some really concentrated development.

- Regarding objectives, it seems there are clear objectives focusing on the critical issues. It was unclear to the reviewer how the WECs will perform in conditions that they normally are not operating in. The reviewer was not sure if a cost target is also part of the prize considerations. Engagement and dissemination seem very successful. It was good to see long-term benefits and a continuation with prize 2.0. Regarding performance, the project seems to be on the right path to achieve the objectives.
- This project has strong relevance to WPTO's program goals. This team worked to incentivize technology development around end-user needs, encouraged engagement from a range of participants, and set up and accessed formal stakeholder advisory groups. The project provided details that showed good use of the funding that was provided to include their distinct focus on creating low barriers to entry and putting in place the structure to strengthen ties between marine energy and ocean observation communities across agencies and in the private sector. The team showcased evidence of advancing marine energy in the blue economy. Their list of outputs was impressive, including communications, community engagement, commercialization support, and one-on-one mentorship. The team showcased a forward-thinking approach and was able to articulate lessons learned that would impact how they could deliver a future project. The reviewer asked the team what it would do radically differently if they were to receive the same amount of funding for another similar activity. They were prepared with an answer and provided details that this was a question they have already considered. The reviewer values the approach they took. It suggests that they were looking to maximize taxpayer funding and adjust the structure of the activity to provide more mentoring and hands-on support to work through the challenges.
- This is an interesting ocean observing wave prize project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention as to how lessons from the prize are transferred to the general wave energy sector. There was good transfer of lessons learned from the desal prize team. There was an excellent engagement strategy and engagement with prize participants and end users.
- This is quite a challenging project for the team. It would have helped the review if there was a sense of the performance metrics that are being pursued. Perhaps later in the project, this information could be presented so that reviewers can gauge the success of the final deployed technology. It would also be helpful to have additional information on the aspects of the project that pertain to the earth observation tools and technologies. This information was not very well presented in the materials. Finally, the team should continue to build partnerships and relationships that will move the project along, especially those organizations and communities that would benefit from the technology should it be successful. These partnerships should go beyond the outreach aspects of the project.
- This prize was an excellent way to introduce marine energy to a wider audience. The program was executed very well with respect to the goals. The blending of ocean sciences and the engineering progress in marine energy are very positive. It would be exciting to see this prize run in a way that it could use the expertise developed by successful WPTO marine energy projects through pairing companies or other ideas the team can come up with. It would be valuable to understand more on how the competition was advertised. This is a challenge and metrics on what media were more successful would be interesting. The reviewer recommends finding a way to get a Netflix or Apple type of organization on board to document or film the work in future prizes, and maybe that could fund the next one.

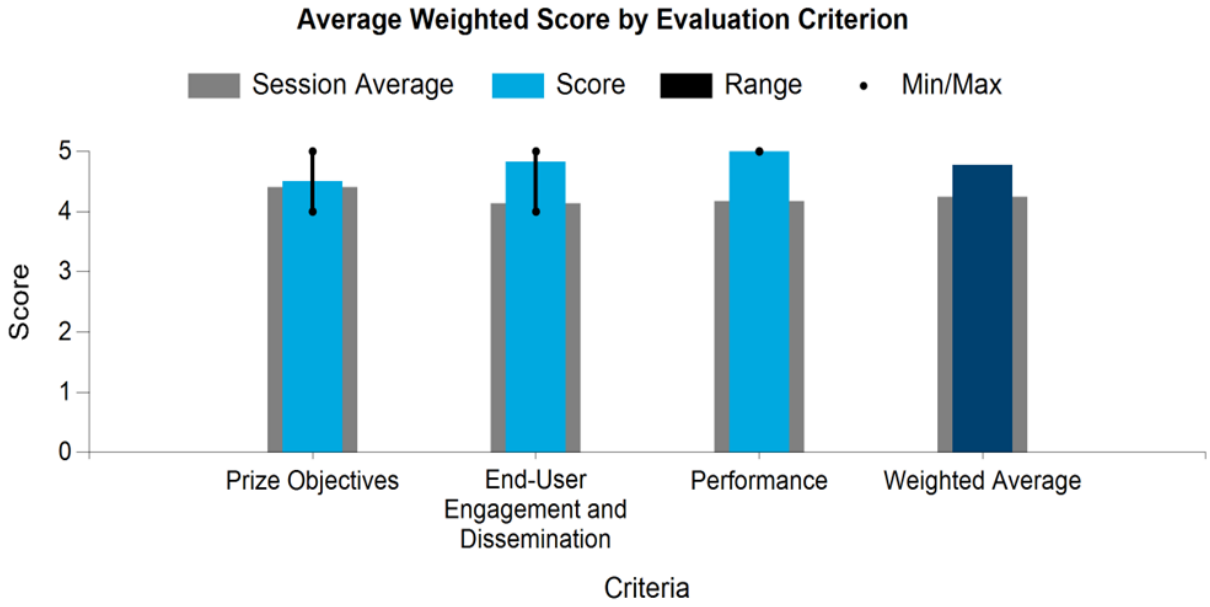
Waves to Water: Desalination Prize

NREL, WPTO

WBS:	2.2.6.401
Presenter(s):	Scott Jenne; Simon Gore
Project Start Date:	01/01/2019
Planned Project End Date:	09/30/2022

Project Description

The Waves to Water Prize was launched in 2019 with the purpose of creating solutions to pair wave energy power with desalination with a specific focus on remote and islanded communities. The Waves to Water Prize administered $3.3 million in prizes over five stages to accelerate the development of small, modular, wave-powered desalination systems capable of providing potable drinking water in disaster-relief scenarios and remote coastal locations. The prize supported the integration of existing and novel wave energy generation technologies with water technologies that can deliver effective, consistent, durable, and low-maintenance water delivery systems.



Aggregated Reviewer Comments

- The positivity and optimism of the presenter was really engaging and got the reviewer excited about this prize. The reviewer liked the fact that learnings surrounding metrics from previous prizes were incorporated. This is an important observation that has relevance in other areas, too. The prize is evidently an excellent way to bring new people and companies into the industry and get them involved as well as to engage the public and gain a wider audience. It is great that the prize is being used to identify future funding and research priorities. It will be important to ensure onward engagement by prize competitors, and the reviewer expects that all finalists had certain advantages and challenges. The reviewer inquired whether there would be any scope for some collaboration of outputs into the state-of-the-art solution. The project adapted well to COVID challenges (with the addition of the ADAPT phase).
- Prizes can promote very positive focus and attention but need careful definition of metrics to avoid distorting complex issues and minimizing important aspects. It is also important not to de-motivate some of the participants and technologies that did not reach the prize but could have some promising technologies. The reviewer inquired how cooperation is handled and incentivized in this case. The project was successful in

engaging participants and the general public. The project was successful considering the objectives, especially regarding the dissemination and engagement with a wider audience. The reviewer inquired about what comes next and how to leverage the project results.

- This team put in place the pieces for a successful project. They reported details of a strong effort to de-risk the project and reduce the barriers to entry to stimulate participation. The project supports WPTO's overall strategy and represents a prize scenario that supports the PBE theme. There is clear evidence that the team has leveraged lessons learned from the Wave Energy Prize, as well as desalination R&D at NREL. The reviewer appreciated the scalability of the program. The presentation showcased the fact that the Wave Energy Prize was the first time many in the audience had seen wave energy as a form of renewable energy. Public engagement efforts were noteworthy and effective in building public awareness on this issue (and included a comic book, numerous public-facing events, etc.). The team highlighted many public-facing events and joint efforts with partner organizations to communicate the effort, purposefully created an event that was fully accessible to the public, and worked to create an environment where people can draw positive conclusions. It is a good move for scientists to bring in a lot of communications folks and program activities that engage audiences. The reviewer appreciated the fact that lessons learned were being documented, leveraged, and shared. The four technologies that they demonstrated produced drinkable water. This fact contributed to the success of the activity and validated their selection of winners. The project relied on numerous partnerships and positioned the model they used as being supportive of a future R&D platform.
- This is an interesting desal wave prize project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention to how lessons from the prize are transferred to the general wave energy sector. There was an excellent engagement strategy and engagement with prize participants. End-user engagement was less clear. There had been some supply chain issues with national instruments, which are out with their control. It was difficult to assess the actual progress and performance of the project. A plan on how to take the winning technologies forward, if appropriate, will be required.
- This project was well designed and took appropriate risks given the early stage of research. The partnerships formed throughout the project were quite notable and important to project success. The presentation did not include much information on commercialization, but it might be too early stage.
- The prize is a great outreach tool. The creativity in all aspects of this project is wonderful. The focus on the application of the technology is a very good way to help the general public understand the opportunity of marine energy. It seems that, as a tool for engaging people in marine energy, this is very effective. It would benefit greatly from industry participation. Military industrial companies would have a vested interest in small-scale desalination solutions as do many municipal governments. It would be interesting to get the end users directly involved in this prize from the beginning.

Reduction of System Cost Characteristics through Innovative Solutions to Installation, Operations, and Maintenance

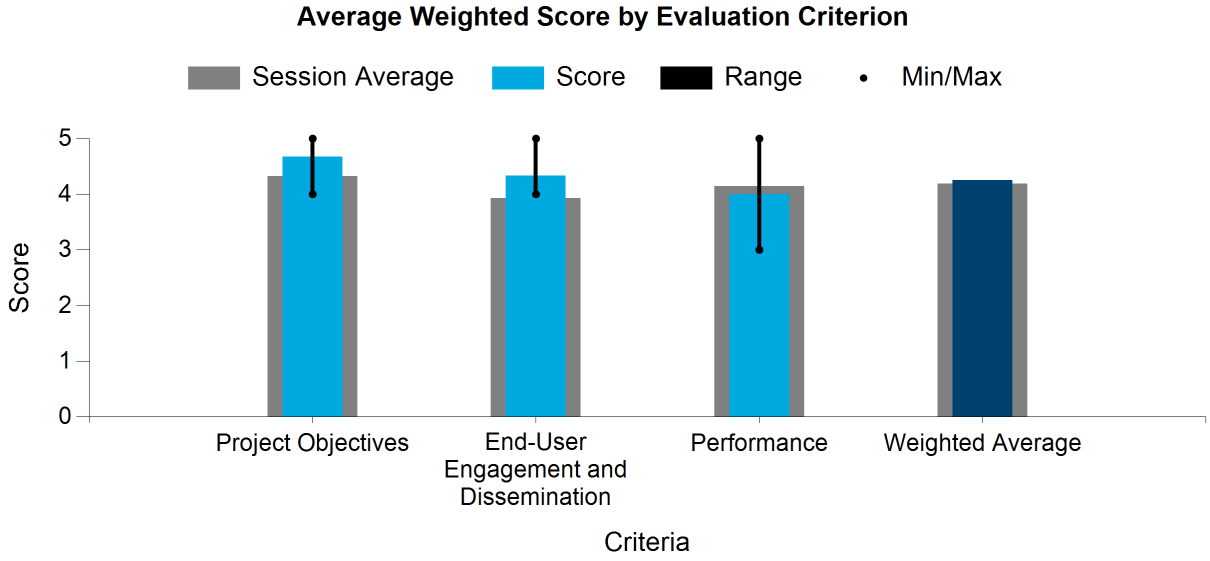
Columbia Power Technologies, Inc. (C-Power)

WBS:	EE0007347
Presenter(s):	Michael Ondusko
Project Start Date:	05/06/2016
Planned Project End Date:	09/30/2022

Project Description

The project designs, builds, and tests the largest practical version of C-Power's SeaRAY low-power WEC architecture that provides an easily transportable and deployable marine power source. The project was revised from the original utility-scale objective to ensure the project-targeted WEC was appropriately matched to available infrastructure and to best leverage mutual investment by DOE and C-Power. Importantly, this WEC completes C-Power's portfolio of low-power, high power-to-weight ratio systems demanded by remote marine power and data customers.

The project is driven by commercial customer requirements in actual applications. The k20 is the subject of multiple commercially funded feasibility studies to evaluate suitability to customer applications globally. The novel mooring design accommodates both shallow and non-shallow locations with a reduced watch circle. This project will demonstrate the integration of commercially available components, such as generators developed for the electric vehicle industry and fuel cells developed for the material handling industry. To demonstrate readiness for blue economy applications, the k20's onboard fuel cell, a novel WEC component, ensures power is available when demanded and has onboard hydrogen storage sufficient to provide well over a megawatt-hour of power.



Aggregated Reviewer Comments

- This project focused on PBE. It has a sensible plan and defined approach. The reviewer liked that this builds on the experience of previous projects and adapts designs and learnings from them. Learnings from this project will also be equally valuable for larger-scale WECs under development. There is clear and obvious engagement with potential end users with commercial partnerships developing. The reviewer liked the mention of iterative risk assessments in the presentation. Among other comments, this gives a level of confidence that a robust design process is being followed. One of the project's stated aims is minimization of IO&M costs, which aligns

well with WPTO objectives. There has clearly been a focus on transportation practicality and efficiency (an excellent outcome) as well as effort focused on offshore operations. There was an interesting comment that one of the major lessons learned from the project so far is familiarity with what is out there. This demonstrates that effort is going into searching for technology transfer opportunities. The reviewer expects this is happening, but there is a need to ensure that any technology being transferred from other industries is a fit for the purpose through lab testing, if possible, prior to deployment. The WEC developer is always the best party to understand the challenges of their particular load regimes and environment, and this may not be obvious to engineers in other industries. Close collaboration with the supply chain is imperative.

- The extent of technology transfer seems to be limited by intellectual property and commercial issues. The performance aspects seem to be on track with the objectives of the project.
- This is an interesting project that is an excellent fit with the WPTO program, although there is a lack of clarity on how meaningful the results will be. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. It was believed their end-user engagement strategy and engagement with the user and their specific requirements could be improved. Although there had been some supply chain issues with national instruments, which are out with their control, it was difficult to assess the actual progress and performance of the project.
- The project is well executed. It was interesting to hear the presenter discuss the changes to the design and learning that came from this work. Given the supply chain and COVID impacts on technical work in general, this project has been very successful. The scaling from 2 kW to 20 kW is encouraging. Using the 20 kW in very challenging or deep environments will be very costly. It will be interesting to see if there is a customer for this version of the system. The addition of the fuel cell is interesting but raises questions about over-complicating the system with additional technology that is also in development. It would be valuable to understand the power quality and how it conforms to the IEC's 62600. It is dissipated into the seabed currently, and it is not clear if the generated power would need to be held in a battery or could be sent directly to the grid. Power connection would be a good next step. It is important to start using the systems that have been developed. Hours on the system are needed to convince the investment community of the value of the system. The involvement in the project of customers and many project partners is very positive.

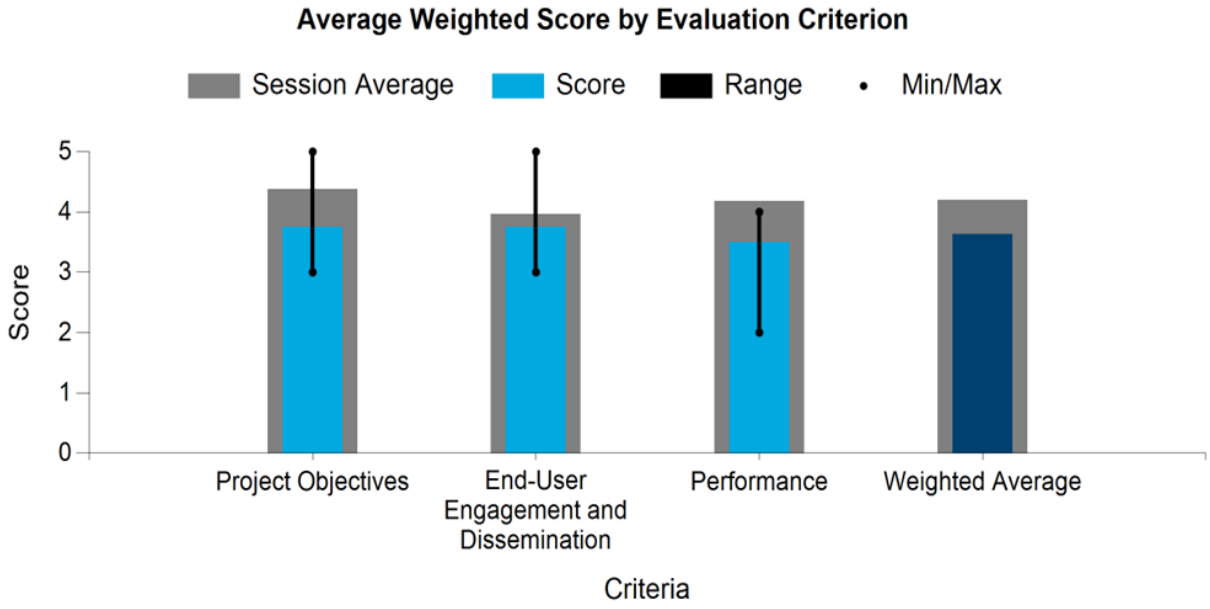
Open Water Testing of a Scaled Next-Generation Point Absorber Wave Energy Device with Phase Control

AquaHarmonics, Inc.

WBS:	EE0008098
Presenter(s):	Alex Hagmuller
Project Start Date:	09/01/2017
Planned Project End Date:	11/30/2022

Project Description

AquaHarmonics began as a concept WEC device to compete in DOE's Wave Energy Prize. The device was designed and manufactured out of a residential office and garage located in southeast Portland, Oregon. The device outperformed 92 other contestants in the prize when it achieved an ACE metric score (which is the ratio of the average climate capture width to the characteristic capital expenditure) of 7.6, a five-time economic improvement over previous state-of-the-art devices, and won $1.5 million. The AquaHarmonics WEC is a floating buoy that is anchored to the sea floor by a single cable. The WEC PTO is unique in the field in that it can provide reactive power in a precise way that allows the WEC to be resonant in a broad range of sea states, which allows for two to three times the power capture of similar-size devices.



Aggregated Reviewer Comments

- The project has evidently faced numerous challenges, and the company has been working through these as they arise. Closer collaboration with suppliers on requirements may be of benefit during procurement to avoid misunderstandings. The project does address WPTO objectives; in some cases there are stronger associations than others. For example, development of human-machine interfaces and controllers is imperative and does address part of the stated objective, but it was not clear to the reviewer that any real thought had been given to safe and efficient offshore operations, which will be a key consideration for deployment and may necessitate design alterations to achieve. More generally, full understanding of through-life requirements of the wider project (e.g., offshore operations, grid connection, and decommissioning) at the outset is necessary for efficient design. Understandably, the project appears to have initially focused on the WEC, but meeting wider requirements appears to have already caused challenges (e.g., grid connectivity) and ensuring these are understood would be valuable. The project's end-user engagement could have been greater. Market

opportunities have been identified, but it is unclear if detailed understanding of these markets or any significant engagement with potential customers has been gained.

- The de-risking at the Sandia Wave Energy PTO Lab is a good strategy, although the incident with a lightning storm was a setback. (Anyway, a new risk to consider and mitigate.) There were several actions and adaptations that the project needed to go through, but that has been a good learning process. The transfer of technology from Space X is interesting considering the impact on LCOE of this different supply sector. The performance aspect seems to be going in the right direction.
- This is an interesting PBE project that is an excellent fit with the WPTO program, although there is a lack of clarity on how meaningful the results will be. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. It was believed their end-user engagement strategy and engagement with the user and their specific requirements could be significantly improved. Although there had been some supply chain issues, which are out with their control, it was difficult to assess the actual progress and performance of the project.
- It is not clear why the system needed a custom-designed motor generator. This kind of decision leads to concerns that the team is unable to control the boundaries of what needs to be accomplished in the project. The mandate was to build a WEC, yet the team appears to have spent significant funds and time on this motor, which really should have been purchased off the shelf or dealt with in another project. The design and build is an accomplishment, and the test results are a substantial contribution to the state of the art.

Water Horse Hydroelectric Harvester Development

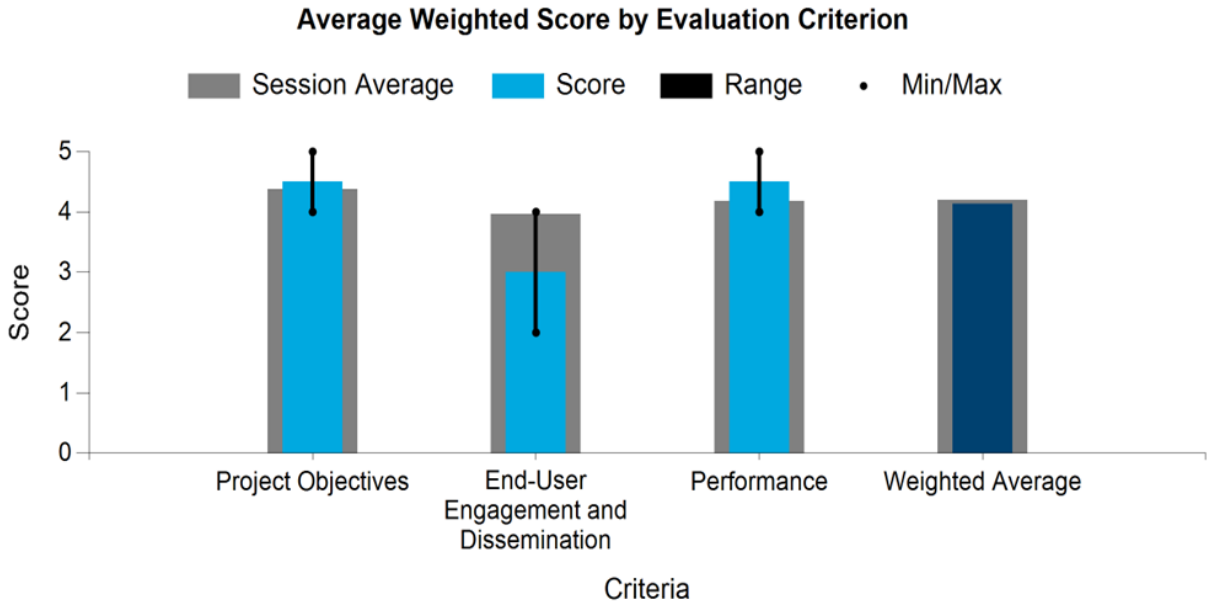
University of Alaska Fairbanks

WBS:	EE0008389
Presenter(s):	Jeremy Kasper
Project Start Date:	06/01/2019
Planned Project End Date:	01/31/2022

Project Description

The Water Horse is a vertical oscillator, hydrokinetic harvester designed by Renerge, Inc. to harvest energy from turbulent water conditions previously deemed unrecoverable. The technology focus is on small, remote, riverine applications where deployment with larger tidal turbines is challenging due to water depth laminations.

This CEC harnesses the gallop motion that results when a bluff body immersed in moving water induces alternating lift through vortex shedding and fluid-body interactions. Through a mechanical transmission linked to a permanent magnet generator, the Water Horse translates the resulting oscillations into electrical power. The system's unique design allows for placement of the generator and structural elements above the water line with the goal of keeping the overall system cost low. The bluff body is connected to the suspension system via a single arm, which allows for incorporation of a break-away mechanism to minimize damage from debris. During the project, a power electronics system consisting of a buck charge controller and battery energy storage system was developed to translate the pulsed electrical voltage from the generator into stable, usable electric voltage. Other design modifications include changes to bluff body size, oscillating frequency, and the PTO based on lessons learned from field testing in 2020. The updated prototype tested in 2021 incorporated uncoordinated upstream and downstream systems to investigate coupling effects between adjacent oscillators. Preliminary analysis indicates the water-to-wire efficiency of the overall system improved from 2.8% to 7.8% due to the design changes. The LCOE will be estimated before the conclusion of the project in late 2022.



Aggregated Reviewer Comments

- This project focuses on the WPTO objective to design and test modular, low-flow, river instream devices. The market for this device is currently limited to off-grid communities with very high energy prices currently. By admission, only very limited end-user engagement has occurred, although the team does have a level of understanding of end-user needs. The project has predominantly delivered on its objectives and multiple lessons have been learned that can feed into future development.
- The project objectives are compatible with the TRL and are covering relevant issues. Dissemination from the project is limited due to low TRL. Nevertheless, the team could make some contact with potential beneficiaries of the technology. This would also give valuable input for the development of the technology such as the development of user requirements. The performance seems to be in line with the objectives. There are many lessons coming from the project such that it will redirecting efforts and focusing on further systems such as debris protection.
- This is an interesting RoR project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. The reviewer believed end-user engagement and their specific requirements could be very significantly improved. It appears there will be very significant challenges in bringing down the cost of the technology. Although there had been some minor supply chain issues, the project was completely on track.
- This is a great project. It is clear in objectives and had a manageable path to the goal. The results are impactful. Using the standards is important, and this stands as a test case of a kind. The approach, the data acquired, and the dissemination pathways are important for the wider industry. Validation of their numerical model is valuable for any research being done in this field. The results and the efficiency and design improvements were very successful. The lack of information provided on the end user is a weak point. It is not clear if there is a viable commercial pathway. The industry partner appears to be very quiet on this project and watching the university prepare results. It is important that they are contributing market study research and have a clear understanding of who is likely to purchase a system like this.

Performance Optimization and System Demonstration of a Multi-Mode Point Absorber

Oscilla Power, Inc.

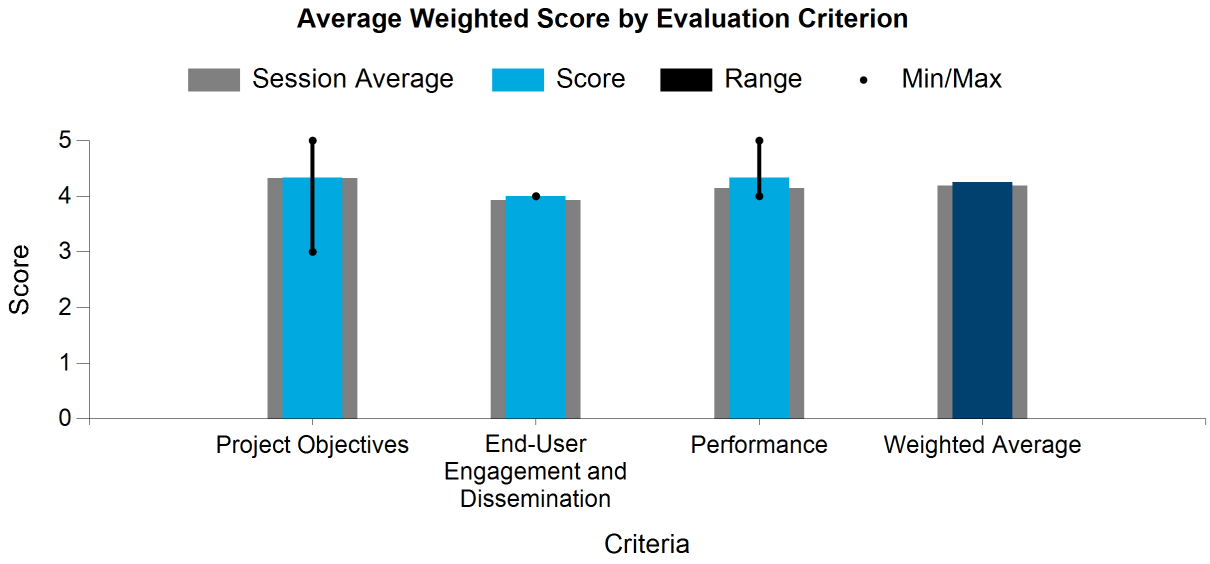
WBS:	EE0008625
Presenter(s):	Tim Mundon
Project Start Date:	06/01/2019
Planned Project End Date:	11/30/2021

Project Description

Oscilla Power is continuing to advance the design of the utility-scale Triton WEC through further optimization, followed by a demonstration at a reduced scale. Oscilla has identified multiple optimization pathways that are being explored in this work, such as geometric optimization, advanced controls and materials, improved installation approach, and others. So far, the project team has met or exceeded all performance goals outlined in this project for Triton, including power performance, capital and operating expenditures, and LCOE.

In budget period two of this project, the team will validate the identified optimizations through a 1:6-scale ocean deployment in a representative climate. This will be achieved during a three-month deployment at a location off Castine Island in Maine. This location has a suitably scaled environment that matches a U.S. West Coast wave climate. This deployment will allow the team to demonstrate the operation of the Triton and validate system operations and power performance, increasing the TRL from five to six.

A separate project (DE-EE0009954) will develop this concept into a complete, detailed design for a full-scale, 1 MW Triton unit for installation at PacWave. Demonstration of the Triton technology at a sufficiently large scale is required for serious engagement by established industry players, and this work forms an important milestone in this process.



Aggregated Reviewer Comments

- This project focuses on iteration of an existing design with key identified areas for improvement. There is a clear link to WPTO objectives by improving on the state of the art with the developer seeking to ultimately deliver a megawatt-scale system. There is a sensible and coherent project plan. End-user engagement has occurred and identified what needs to be delivered (a validated system) prior to significant further development. There has been successful project delivery to date, and a sensible onward plan has been communicated.

- There are clear objectives and they are compatible with the overall level of TRL. Dissemination work is directed toward stakeholders. Technology transfer to industry is limited. Performance seems to be performing clear steps to achieve the objectives. The deployment of 1:6-scale prototype will provide valid learnings.
- This is an interesting Oscilla Power project that is an excellent fit with the WPTO program and has tangible and useful outputs. Although the project appeared on track, the development plan was not fully clear. Additionally, there could be more attention to risks and their assessment. Although there was an end-user engagement strategy and targeting at the utility scale, the reviewer believed engagement with the user on their specific requirements could be improved. There had been no supply chain issues at this stage, and the project was on track.
- The project is well designed and well planned. The data captured to date is encouraging. The LCOE numbers seem optimistic. The reviewer expressed concerns about the robustness of the design. The submerge feature is interesting; however, it is not clear if this is enough for the sea states being proposed.

Cycloidal Wave Energy Converter

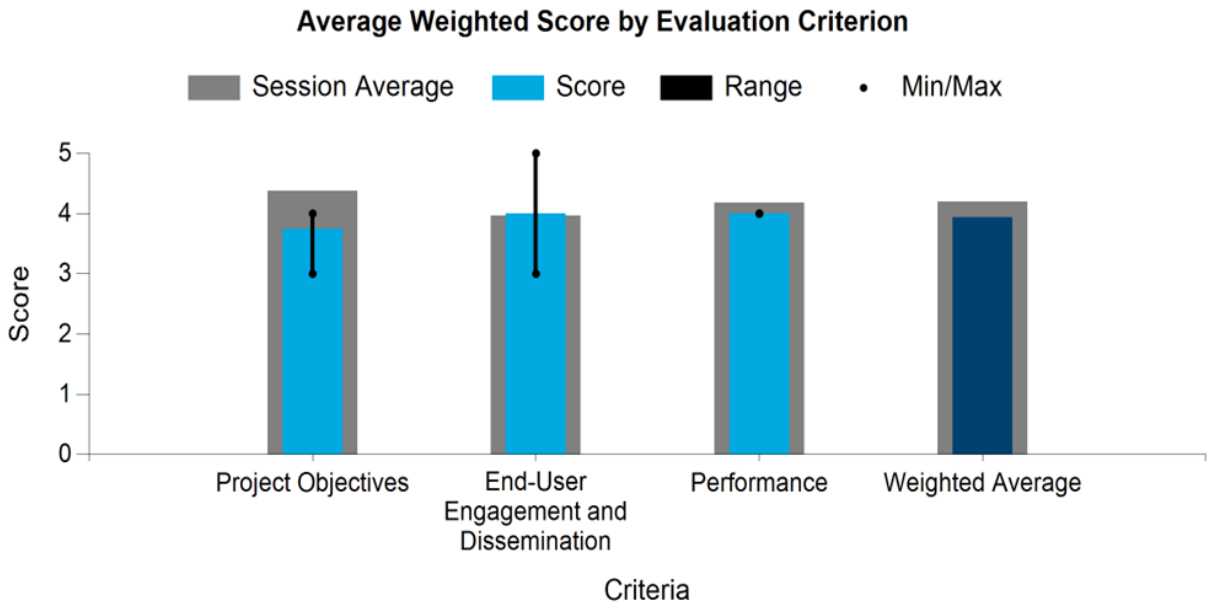
Atargis Energy Corporation

WBS:	EE0008626
Presenter(s):	Stefan Siegel
Project Start Date:	09/01/2019
Planned Project End Date:	09/30/2021

Project Description

The overall goal of the proposed project is to advance the design maturity of the Atargis proprietary Cycloidal WEC from TRL 4/technology performance level (TPL) 7 at the beginning of the project to TRL 6/TPL 7 at the end of the project. This will be achieved by means of numerical simulations at the model scale as well as 1:15-scale wave tank tests. The comprehensive test plan for both will cover all conditions encountered by the device throughout its service life from commissioning to decommissioning. With the expected outcome of the experimental results matching the simulations performed at full scale prior to the start of the proposed work, the Cycloidal WEC will have advanced to TRL 6 and maintained a TPL 7 or higher and will thus be ready for future open ocean tests.

During budget period one, three main technical activities took place: design of a 1:15-scale wave tank model, numerical simulations at the model scale, and bench testing of key model components. The efforts during budget period two will be primarily focused on model construction, commissioning, and testing. Testing will cover harmonic wave generation and cancellation, irregular wave cancellation, short crested waves, storm survival, maintenance, WEC commissioning, and decommissioning. The three-month testing campaign will be the highlight and central activity of the entire program.



Aggregated Reviewer Comments

- The end goal for this WEC is megawatt-scale wave energy and, therefore, in keeping with WPTO objectives. There is a sensible plan concentrating on initial small-scale prototypes and testing, development, and validation. A sensible project plan was proposed and is being delivered. The team has clearly looked at and thought about installation and survival operations and developed systems accordingly. The risk analysis is noted as having been done as part of the project, but it was also noted that the main approach to managing risk is use of tried-and-tested technology. Technology transfer from other industries is being used, which

is good, but the reviewer has a residual concern that there is a level of overconfidence in the reliability of such technology straight away in a wave energy application despite wave energy being a novel environment for the technology (with associated high-risk levels until qualification is complete). Dissemination of results has occurred, but there has been limited end-user engagement at this stage. An intended basic plan to commercialization was not presented.

- The project objectives are in line with the TRL and WPTO objectives. Dissemination seems far from commercialization, and this is probably due to the present stage of development.
- This is an interesting wave project that is an excellent fit with the WPTO program with tangible and useful outputs. The ability to scale is a major attraction of the technology. Although the project is using the lab's LCOE model, the reviewer believes there needs to some validation of the inputs to the LCOE model. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. Although there was an end-user engagement strategy, the reviewer believed this engagement with the user and their specific requirements could be improved. It was difficult to assess the overall progress and performance of the project as it is now on hold for cost-share fundraising.
- This is a very interesting design. Comprehensive work was done to get the results presented. The reviewer would encourage the team to engage an industry partner to see if this design is something that would have commercial potential.

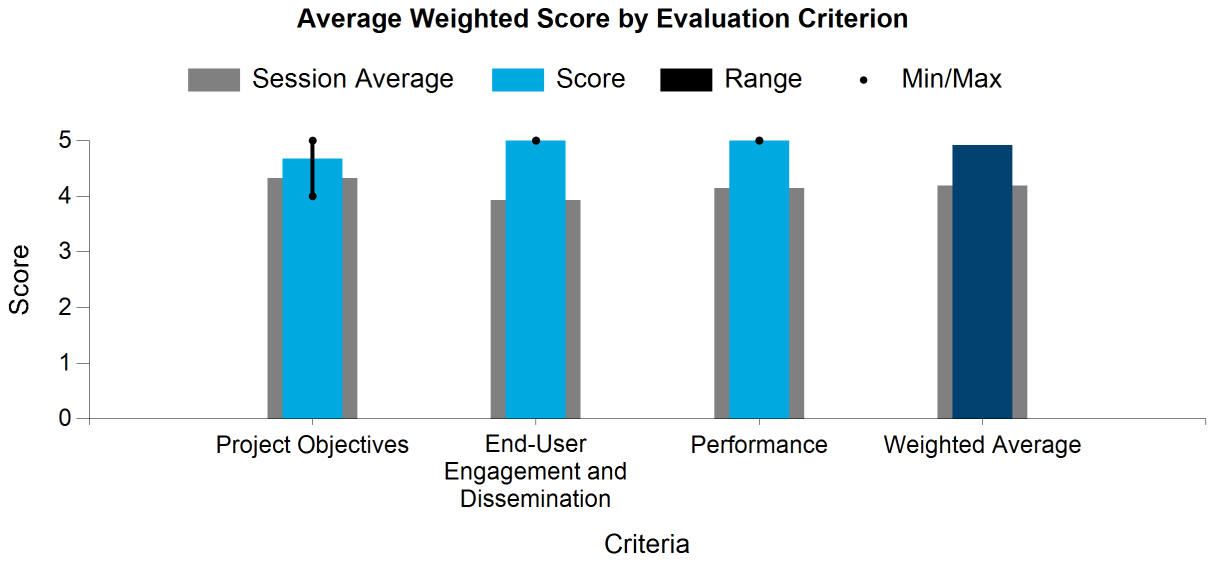
Design, Build, and Test of Novel, Remote, Low-Power Wave Energy Converter for Non-Grid Applications

C-Power

WBS:	EE0008627
Presenter(s):	Erik Hammagren
Project Start Date:	05/01/2019
Planned Project End Date:	09/30/2022

Project Description

The proposed project goal is to design, deliver, and test a novel, low-power autonomous offshore power system that lowers operational costs, complexity, and carbon intensity and provides robust, new capabilities for customers in the maritime environment. The autonomous offshore power system is a WEC-based system that builds on C-Power's prior R&D efforts and is intended to be an easy-to-transport, reliable, and survivable power and data communications system for resident mobile and static marine assets, such as data-gathering systems and uncrewed vehicles, for applications in shallow- and deep-water locations that lack desirable, resident, and/or sufficient power sources. The prototype WEC, the SeaRAY, is designed with the ability to be rapidly deployed, has power electronics with integrated energy storage, and can deliver continuous power to supported assets as required. The project will demonstrate the SeaRAY autonomous offshore power system's high techno-economic appeal for the marketplace, appropriately balancing survivability, cost, and ease of handling/servicing with a clear path for future open-water testing at a larger scale and in deeper water. Once designed and built, the full system will be deployed for six months at WETS where it will demonstrate the ability to generate and store electricity for powering the various seafloor assets connected to it as well as to provide the assets with a connection to the data cloud.



Aggregated Reviewer Comments

- This project focuses on powering the blue economy, which aligns well with WPTO stated objectives. Learnings from this project will also feed into other projects by the same developer with a focus on larger-scale WECs. Technology developed as part of this project (such as the electro-optical-mechanical mooring line) has applicability to other projects and industries. A sensible project plan is being delivered, and the reviewer especially liked the apparent robust design approach that includes significant lab validation of components and subsystems prior to integration with the wider system and at-sea deployment. Clear end-user engagement has occurred.

- Objectives are in line with the requirements of the program. Considering all the fast development and deployment of autonomous vehicles, it is an interesting application. It seems that the early work done has supported efforts to define the functionality (engagement with potential customers and deployment of a small-scale prototype, for example). Dissemination and engagement with potential customers seem very positive, and the reviewer believes that needs to continue as the requirements will be changing quickly as the autonomous vehicles are evolving fast. Regrading performance, it seems to be progressing in line with the objectives.
- This is an interesting project that is an excellent fit with the WPTO program with tangible and useful outputs. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. Although there was an end-user engagement strategy, the actual engagement with the user and their specific requirements was also good. Although there had been some supply chain issues out with their control, the project progress and performance were on track.
- The focus on low cost and ability to deploy is positive. Engaging early with customers is encouraging. The design experience on previous iterations has clearly allowed the company to build a system that can reach higher TRLs quickly.

XCT System for Harvesting In-Current Hydrokinetic Energy from Low-Velocity Sites

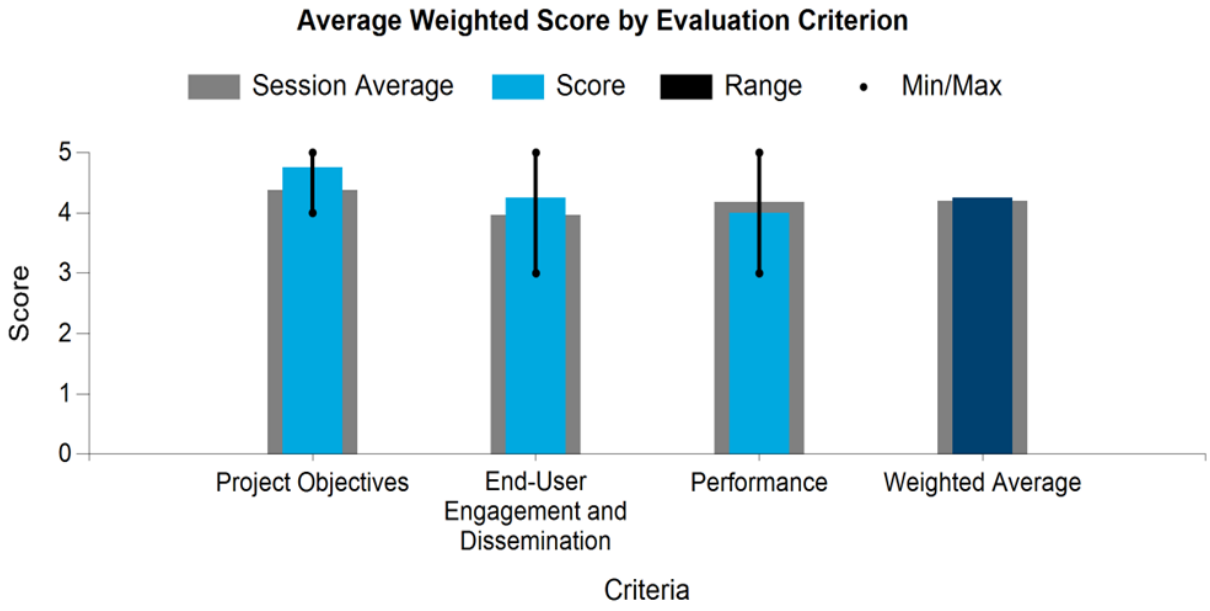
Littoral Power Systems Inc.

WBS:	EE0008628
Presenter(s):	David Duquette
Project Start Date:	08/01/2019
Planned Project End Date:	12/31/2022

Project Description

The kinetic energy in river and ocean currents is an abundant resource that could support a potential $20 billion global market. However, an estimated 80% or more of this potential is in relatively slow-moving waters where currents flow at 2 meters per second or less. Unlocking this resource with an economically viable technology is a challenge since these slow speeds characterize nearly all in-current hydrokinetic energy resources in the United States. While pioneering teams have installed CEC projects, there are still no viable technologies to harness this resource that even come close to generating electricity at utility-scale pricing.

In early 2017, Littoral Power Systems began to conjecture that moving small, inexpensive turbines through the water rapidly could give rise to much lower LCOE than conventional devices. With a lift device in an open fluid, power harvest grows as a cubic function of velocity but only as a linear function of swept area, and it stands to reason that swept area could be traded for velocity. Littoral Power Systems subsequently developed a concept for a crosscutting turbine known as the XCT. The XCT machine is simple and reliable and eliminates gearboxes. It is anticipated to reduce maintenance requirements and can be used with a variety of inexpensive mooring and deployment strategies. The purpose of the work is to understand performance characteristics, identify and mitigate reliability risks, and provide data to advance the CEC industry toward achieving cost competitiveness in sites that were not previously practical economically.



Aggregated Reviewer Comments

- This is an interesting concept the reviewer had seen before. A sound rationale for development was put forward, and a sensible project plan was developed and is being delivered. This project is well aligned to WPTO objectives. The reviewer especially liked the approach statement that "the ocean always wins" and the design

philosophy that was developed accordingly. The reviewer sees potential for technology transfer for flooded components. Failure mode effect analysis was mentioned, and the project changed in response to this, giving confidence to a robust overall approach to technology development. End-user engagement was conducted. Dissemination was conducted and a base of a commercialization plan was mentioned. The team is addressing project challenges with respect to IEC standard compliance positively, but the reviewer suggests that, if possible, discussions with the standards developers may be beneficial to see what the intent of the specific clause is and if or how that applies to the CEC being developed where multiple rotational axes exist. Learnings are being gained and incorporated into the future project plans. Collaboration with other funded projects is apparent.

- The objectives are in line with WPTO objectives. Engagement with potential users has been carried out. The presenter referenced Minesto, which is positive as they are looking for experiences from systems with a similar approach. Regarding performance, the project has progressed, although late due to supply chain issues. It was stated that failure mode effect analysis has been extensively used. The reviewer recommended adapting the requirements from the IEC TS 62600-200/300 to the technology.
- This is an interesting project that is an excellent fit with the WPTO program, although there is a lack of clarity on how meaningful the results will be. They have a well-developed and thought-through plan and a good risk register. The reviewer believed their end-user engagement strategy and engagement with the user and their specific requirements could be improved, and there was no clear appreciation of market size and requirements. They do expect some supply chain issues in the future, which are out with their control, and the actual progress and performance of the project is on track.
- Plots or charts of the results would be valuable to see. A cut in speed of 0.35 m is interesting. Seeing the power curve would be very helpful for understanding the potential for this system. The design approach is sound. The customer interviews approach is very encouraging. The economic approach is critical to have success in this sector.

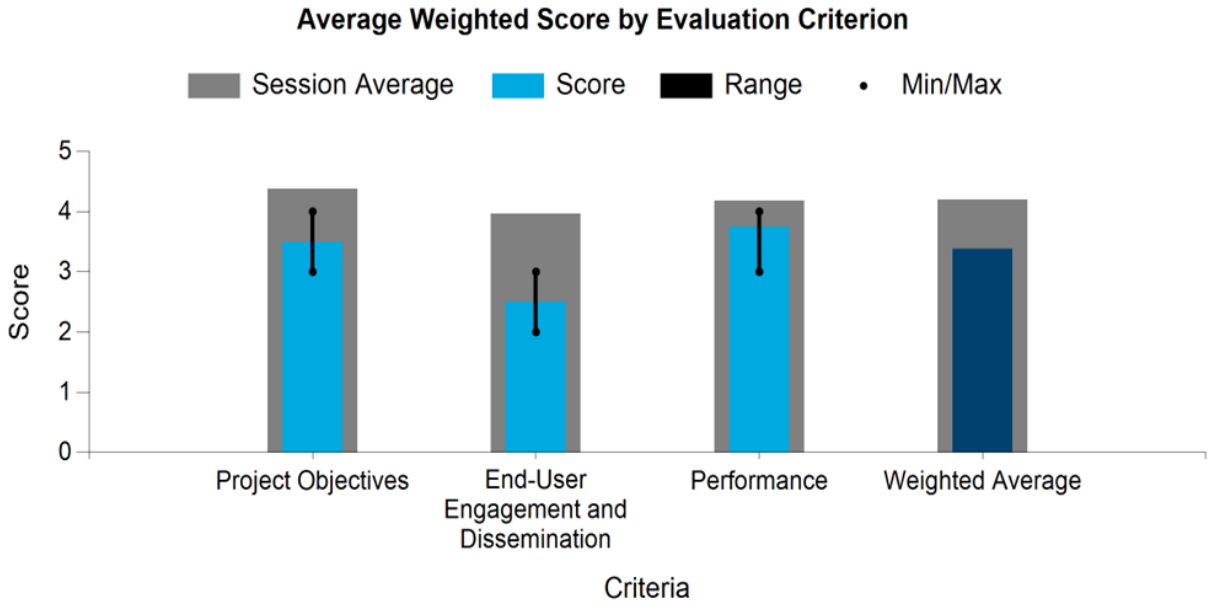
Hawaii Wave Surge Energy Converter (HAWSEC)

University of Hawaii Systems

WBS:	EE0008629
Presenter(s):	Patrick Cross
Project Start Date:	09/01/2019
Planned Project End Date:	09/30/2022

Project Description

This project aimed to develop an oscillating wave surge energy converter concept through numerical modeling and wave tank testing at two scales: 1/9th and 1/3rd. The project utilized off-the-shelf or readily fabricated, proven hydro turbine concepts for power takeoff, which represented an opportunity for LCOE reduction. The project team investigated both high head and high flow versions in budget period one (small scale) before down-selecting in budget period two (medium scale).



Aggregated Reviewer Comments

- The project's initial focus is on PBE applications, which links well to WPTO objectives. The team also has a stated ambition to scale up, but the plan for doing this is not clear at this stage. The team does not appear to have sought to engage with previous flap-type WEC developers or expertise to leverage their experience and expertise. This may help shape more efficient project programs with greater value being delivered overall from leveraging that previous experience. Challenges experienced have been dealt with by the project team to keep the project moving forward. The focus for LCOE improvement is on utilization of commercial, off-the-shelf equipment. The concern, as for other projects, is that there is an overconfidence on this equipment's reliability in a WEC context with WEC-specific loading requirements, etc. Technology qualification is a must, and risks must be managed accordingly throughout the process. Limited user engagement has occurred to date, but the project team recognizes that this needs to increase.
- Objectives are in line with the TRL. It is interesting that some initial indications are obtained regarding degradation of the different systems. Regarding engagement, maybe engagement with stakeholders is a bit early, but nevertheless, some identification of user requirements would be useful. Regarding performance, it was unclear to the reviewer how lessons from previous surge devices were taken on board. The selection of the size of the device may help to overcome the issues faced by Aquamarine. (That was a large-scale, megawatt device.)

- This is an interesting surge wave project that is an excellent fit with the WPTO program and has tangible and useful outputs. The overall development plan is not clear, and there could be more attention to risks and their assessment. It is not clear who the end user of this technology will be, and there appears to have been little or no end-user customer engagement. The overall project has made good progress so far. International engagement with similar technologies would help transfer lessons learned and avoid duplication of effort in this project.
- The work was well executed. The design is robust and has a simplicity that is attractive. The team has not engaged with any potential end users. Even if this is at an early stage, a customer needs to be identified if the project is not simply an academic exercise. It appears as though this will be directed to island and remote communities. There should be a stakeholder engagement plan early in the design stage to ensure that there will be some future for this design.

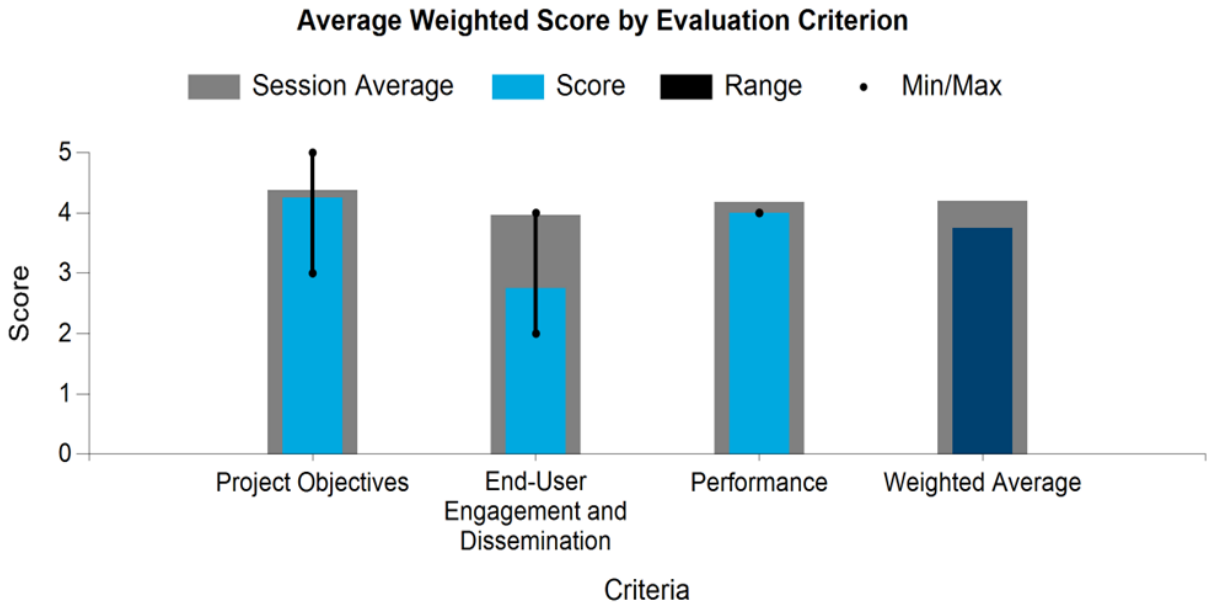
An Innovative SR-WEC for a Market-Disruptive LCOE

Texas A&M Engineering Experiment Station

WBS:	EE0008630
Presenter(s):	HeonYong Kang
Project Start Date:	09/01/2019
Planned Project End Date:	01/31/2023

Project Description

This project aims to develop and test a scaled prototype of the Surface Riding Wave Energy Converter (SR-WEC), which can produce average power in the scale of 5 kW for a market-disruptive LCOE below 40 cents per kilowatt-hour by combining an extended operating window; amplified average power output by simple but optimum control, adaptable to varying sea states in peak periods; and costs consequently lowered by the high performance over the wide range of sea states. While developing the design methodology and proper simulation tools with correlation to experimental data, the project intends to complete optimum design of SR-WEC for the maritime market applications; confirm full performance of the 5 kW SR-WEC using scalable wave tests of the scaled prototype in the ocean basin and advanced, fully nonlinear global performance simulation; confirm the market disruptive LCOE for single operation in the target application using the global performance simulation correlated with the scalable tests; and identify remaining uncertainties and risks to be resolved in the larger-scale prototype tests.



Aggregated Reviewer Comments

- This project appears to be more focused on foundational R&D rather than technology validation (e.g., outputs include tools for the wider WEC community), but it is attempting to address stated WPTO objectives. The project description includes ensuring extended operating windows and lower costs, but this is not mentioned again in the presentation. It is unclear if these objectives have been delivered or are being considered. The project appears to be focused on the WEC rather than wider wave energy infrastructure and costs required. Sound research is being conducted and information and understanding are being developed, but it is not clear that all stated project aspects were considered as yet. End-user engagement was not conducted, but some dissemination of information is occurring. There is no clear path to commercializing at this stage.

- Considering the low TRL, the objectives are in line with the requirements of the program. Regarding dissemination, the reviewer was not sure on the end-users list, but it is a good initiative to look at the market for a 5 kW device. Regarding performance, it is in line with the objectives and low TRL, early-stage technology. It would be useful to declare the level of uncertainties in the LCOE evaluation and follow up on the next steps as more information is obtained. If a large device is to be considered, careful consideration should be given to the challenges of scaling up, achieving competitive LCOE, and the reliability and feasibility of the components.
- This is an interesting project that is an excellent fit with the WPTO program with a robust project plan. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. To date, there had been no end-user engagement, but this was planned for the future. There has been good progress with a good research methodology.
- There are many potential uses for this system, and it is being well designed and tested. It is not clear what performance results are real and which are estimates and anticipated. The presentation of the work would benefit from some more traditional power curves. It is likely most of the work is getting the system working, but there should be some measurement of power at all stages of development. Additional detail on the expected LCOE would also be valuable. The reviewer inquired about the opportunities for LCOE reduction, the costs, and how economy of scale influences this. There is a plan to engage end users, but it is not clear if any have been approached. This needs to happen sooner than later. There will be a lot of time and effort in this system, and if there are fundamental challenges with the design for user applications, this should be identified now.

Device Design and Robust Periodic Motion Control of an Ocean Kite System for Hydrokinetic Energy Harvesting

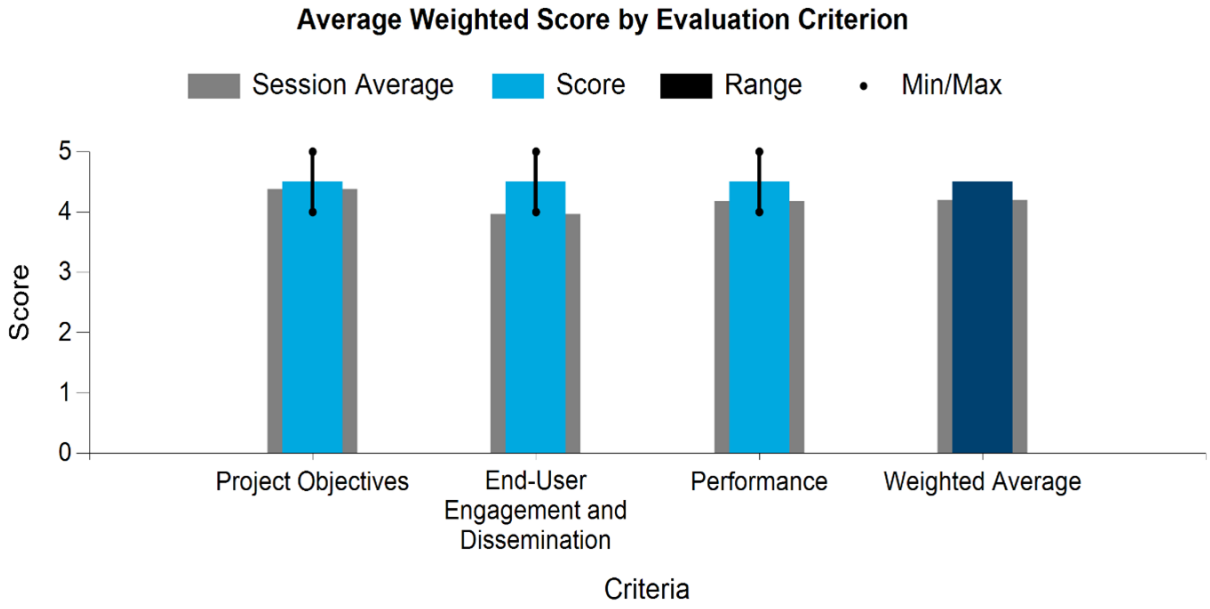
North Carolina State University

WBS:	EE0008635
Presenter(s):	Chris Vermillion
Project Start Date:	05/01/2019
Planned Project End Date:	04/30/2022

Project Description

This project aims to develop a unique design, open-source modeling tools, and periodic optimal control systems for a unique variant of an energy-harvesting underwater kite. The technology will rely on a winch system for power generation, spooling tether-out under high tension in high-speed, cross-current motions and spooling-in under low tension. This removes all rotating machinery on the kite but demands an efficient design, spooling algorithm, and an algorithm for setting/adapting the kite's flight path. These algorithms are instrumental to the system realizing its full techno-economic potential. Technology-to-market development efforts primarily focus on identifying early adopters of the technology at relatively small scales, focusing attention on blue economy applications such as autonomous underwater vehicles and observational station charging.

The team has developed a suite of open-source dynamic modeling tools that characterize the kite, tether, environment, and floating platform (if the kite is deployed off a floating platform). The team has adapted economic iterative learning strategies to the challenges of cyclically optimizing spooling and flight profiles, developed a three-level progressive experimental prototyping framework for validating its models and controllers, and validated its models and control approaches in all three environments. Additionally, it has secured ongoing funding from a top defense contractor to further develop the kite technology to provide power to long-endurance, high-payload autonomous underwater vehicles.



Aggregated Reviewer Comments

- This early-stage project is looking at the fundamentals of the technology, so the technology is a bit further into the future, but the team has identified follow-on projects that would be required to take further steps toward commercialization. The open-source nature of outputs has potential for value in more projects than just this one. There is a sound project plan that steps up through progressively more challenging tests. The reviewer

really liked the iterative learning that was incorporated and can see this experience being of benefit to more projects. It is good that collaboration with Minesto is being sought and discussions are underway. The reviewer applauds the team for reaching out to industry to leverage learning and increase the value of the project to industry accordingly. End-user engagement has occurred as evidenced by work with Martin Defense Group, but wider engagement with other potential end users would also be beneficial to ensure widest possible applicability.

- This project has a good dissemination and engagement program. Open-source controls provide a good input to industry. It is a good approach to contact Minesto, but it would probably be useful to contact kite developers for wind. An adaptation of IEC TS 62600-200 requirements is required. Regarding performance, the plan and results so far are in line with the project objectives.
- This is an interesting tidal kite project that is an excellent fit with the WPTO program, although there is a lack of clarity on how meaningful the results will be. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment as this is potentially a high-risk, high-reward project. Although there is good contact with Martin Defense, the reviewer believed the project's end-user engagement strategy and engagement with the user and their specific requirements could be improved. There has been good actual progress and a future plan. There is good engagement with their European counterpart, which is essential to avoid duplication of effort.
- The project has made excellent progress. Great presentation of powering data, and the end-user engagement is very positive.

Low-Flow Marine Hydrokinetic Turbine for Small, Autonomous, Unmanned Mobile Recharge Stations

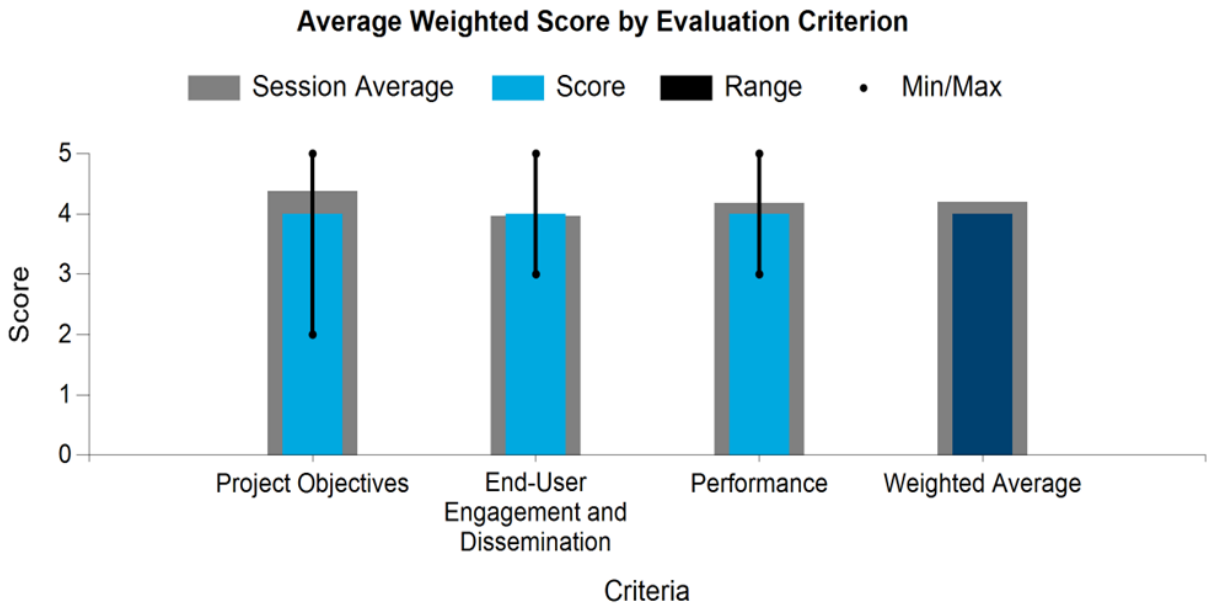
Florida Atlantic University

WBS:	EE0008636
Presenter(s):	Manhar Dhanak
Project Start Date:	07/01/2019
Planned Project End Date:	06/30/2022

Project Description

The project goal is to develop a prototype low-flow (0.5 to 1.0 meter per second) marine current turbine to provide partial power to recharge battery banks onboard an unmanned mobile floating recharge station for small aerial drones. A small autonomous surface vehicle available at Florida Atlantic University serves as the mobile floating platform from which the turbine is to be deployed. Sub-components of the system being developed include an undershot waterwheel, a PTO device, an automated platform anchoring system, and a flight-deck onboard the platform to support landing, takeoff, and charging of small aerial drones.

Specific objectives are to design and develop a prototype undershot waterwheel and other subsystems utilizing commercial, off-the-shelf components wherever possible; conduct laboratory tests and, once environmental permits are granted, field tests that will be conducted in the tidal flow-driven intracoastal waterways and coastal waters offshore of Ft. Lauderdale, Florida; analyze acquired data for assessment of system performance; and develop plans for market transformation and engage industry.



Aggregated Reviewer Comments

- The reviewer's perception is that this is a niche market being targeted with limited wider applications. The reviewer would have liked to see more about the application use cases and potential end users plus any limitations or specific requirements of the industry (such as sea states for use or seabed conditions required) to confirm commercial onward viability of the system. (The reviewer notes that some potential users have expressed an interest in the project.) End-user engagement is occurring but would benefit from being better integrated into the project to ensure end-user requirements are being met. The approach to use an already available unmanned vehicle is reasonable but learning with respect to the CEC will be limited based on design

choices made. The benefit of the project will therefore be focused on integration of systems and addressing those challenges.

- Regarding objectives, it is important to check that the efficiency and strength of the PTO is satisfactory in actual sea conditions as it seems to be able to attract a considerable loading. It is understood that the sea conditions will be compatible with drone operation conditions. However, swell waves can be disconnected from wind conditions. The reviewer inquired whether it would be in the plans to provide multiple drones charging at the same time. There is a good engagement plan. Regarding performance, the project is focused on the initial objectives.
- This is an interesting tidal stream project that is an excellent fit with the WPTO program, although there is a lack of clarity on how meaningful the results will be. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. Although they say they have end-user interest, the reviewer believed their end-user engagement strategy and engagement with the user and their specific requirements could be improved. There have been good bench tests and good overall progress.
- This is a great project. The direct planned application is ambitious, but the unmanned autonomous vehicle is not the challenge for this project. The partners engaged and planned for engagement are a great choice for this project. The performance data is well presented and shows a viable system. Additional information on the storage system, if there is one, or the ways of dissipating energy when not in use would be interesting.

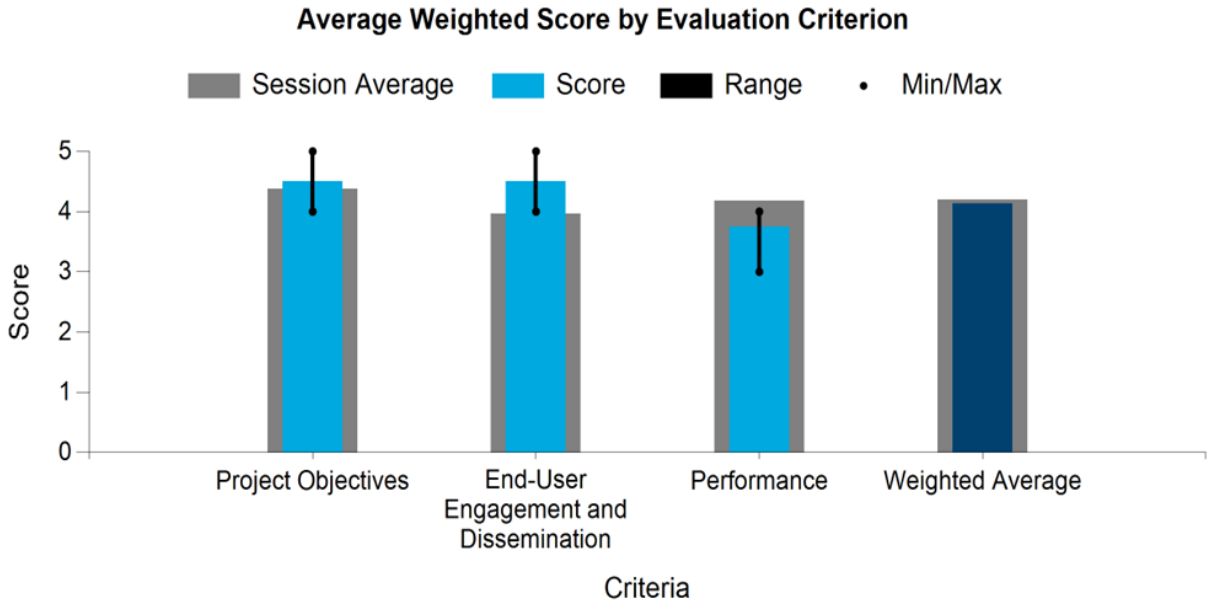
Modular RivGen

ORPC

WBS:	EE0008948
Presenter(s):	Ryan Tyler
Project Start Date:	03/16/2020
Planned Project End Date:	05/15/2023

Project Description

The Modular RivGen development project aims to create a hydrokinetic power system that can be rapidly installed, produce meaningful power in low flows, and be easily scaled for array operations. When installed as an array, this system will provide a low-cost option for a wider market by identifying and targeting specific early adoption use cases. System designs were developed through market-based requirements, lessons learned over numerous past installations, manufacturing-based cost reduction strategies, and industry standards. Numerical and analytical models developed throughout this project have led to novel device structures and performance predictions, which exceed project goals. Partnerships with national laboratories will provide independent validation of performance predictions and further insight into market resources. Full-scale deployment of a two-unit connected array will validate system costs, operations, and performance, providing a critical step toward commercialization of the technology. Through its development and validation, the Modular RivGen will address a fundamental challenge of the hydrokinetic industry of how to reduce cost of electricity while operating in less energetic environments.



Aggregated Reviewer Comments

- This project adapts current technology to make it more adaptable to different use cases and deployment environments to enable near-term deployment of river generation systems, which is well aligned to WPTO goals. It also builds on previous experience and projects and extends and iterates from them. There is a robust system development plan that includes both laboratory and field testing to mitigate risks during the development process. The project also included third-party review, which is good to hear. End-user engagement has occurred and continues.

- Regarding objectives, although modularity is expected to help on installation of arrays, it would be interesting to include consideration of maintenance (such as repair on one module or replacement of any module). It would also be useful to consider debris management. Regarding dissemination and engagement, there seems to be a good plan. There is also a study on how to adapt IEC 62600-300 to the technology. Regarding performance, the actions to achieve the project outcome seems adequate considering the proposed objectives.
- This is an interesting project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. It was believed their end-user engagement strategy and engagement with the user and their specific requirements could be improved, including the target size of the product required. There is a good methodology and progress, although they expect some supply chain issues in the future.
- A modular system is a great design for lower flows, and the potential for commercial success is high. The performance data is not present in a way that allows full understanding of the capabilities of the system. Claims are made with no data or metrics presented to back them up. The interviews are encouraging. It is not clear what dissemination of this work has been done to date.

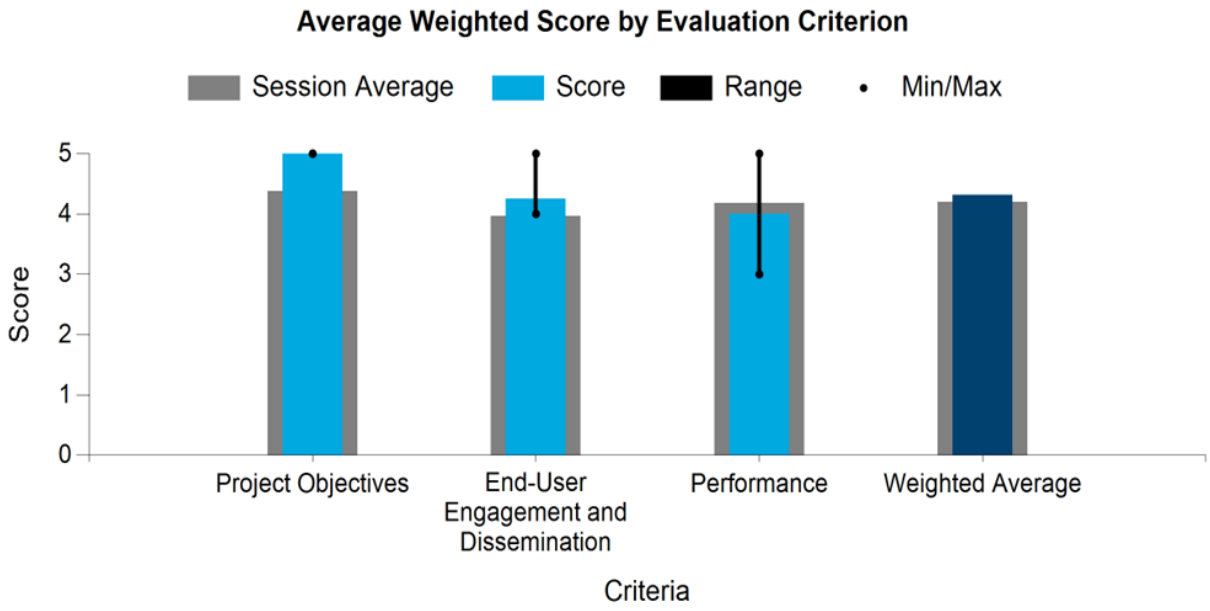
Advancing CalWave's WEC Design for PacWave

CalWave Power Technologies Inc.

WBS:	EE0008951
Presenter(s):	Thomas Boerner
Project Start Date:	03/01/2020
Planned Project End Date:	09/30/2022

Project Description

The objective of this project is to evolve the xWave detailed design to a scale for island/remote markets and ensure the device design is suitable for deploying at the PacWave South test site. A smaller-scale xWave system was developed with DOE support under FOA-1663 and has completed 10 months of open ocean testing in San Diego. This project scales up the xWave architecture to a size relevant for remote and island communities.



Aggregated Reviewer Comments

- This project builds on previous projects and is focused on PacWave deployment in the near future, which is clearly aligned with WPTO objectives. Comments such as "path toward certification," "risk evaluation and mitigation," and "criticality of pre-deployment testing" give confidence to the approach being taken. These statements were supported through questioning after the presentation. The company is engaging with end users and seeking avenues toward commercialization, including looking at co-location with wind.
- Objectives are in line with the requirements from the program. Engagement and dissemination are satisfactory to the objectives, and it seems to be a good platform for the long-term definition of the market and users' requirements. Performance activities are well defined and in line with the objectives of the project. It was unclear to the reviewer how the power cable is designed considering an additional aspect of changeable submergence of the floater.
- This is an interesting wave project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan, but there could be more attention to risks and their assessment. It was believed their end-user engagement strategy and engagement with the user and their specific requirements could be improved. There is good overall progress and performance of the project.

- This is an exciting project. In the presentation, some names of potential customers or some blanked out statements of support would be helpful. Some charts or data showing the metrics of the work done in the project would be helpful in evaluation. It is not clear what is previous work and what level of detail has been accomplished in this project. The awards and event participation are very positive.

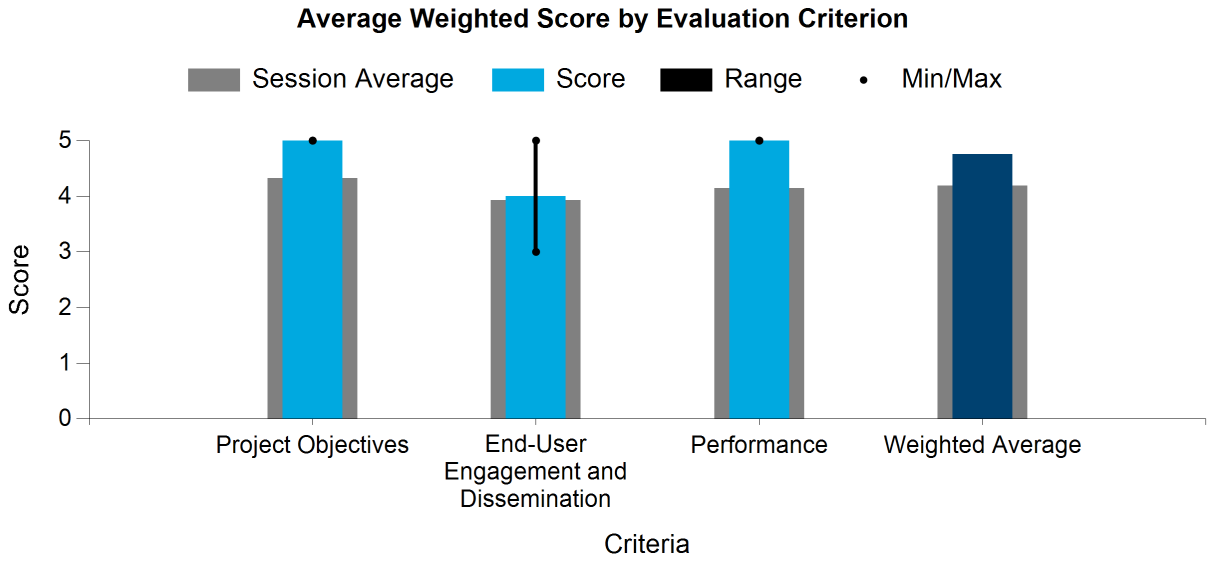
MARMOK-Oscillating Water Column (OWC)

Idom, Inc.

WBS:	EE0008952
Presenter(s):	Borja de Miguel Para
Project Start Date:	05/01/2020
Planned Project End Date:	04/30/2022

Project Description

The aim of this project is to advance the future commercial viability of the floating oscillating water column technology through the development of a commercial-size WEC specifically suited to PacWave South site conditions. This spar-type WEC design is based on a previous low-power prototype deployed and tested offshore for more than two years and incorporates several innovations to contribute to the LCOE reduction potential of the technology. It is a grid-connected prototype in which applicable IEC and IEEE standards have been followed. A technology commercialization plan has also been developed that identifies potential markets for each of the development stages.



Aggregated Reviewer Comments

- This is an impressive presentation and discussion. The project leverages and builds on previous experience with a view toward MW-scale WECs and the potential for near-term deployment and further learning. All major aspects of the full project were considered including WEC, O&M, moorings, umbilical, control, etc., and onward commercialization plan. There is a robust design approach that includes lab testing of critical systems within this pre-project, prior to ocean deployment of the full system. The project successfully delivered. Dissemination is occurring, and a commercialization plan was developed.
- The objectives are in line with the needs of the project (considering the previous work carried out in the technology) and in line with the program. The reviewer inquired about work involving export cable (installation and operation), plans for dry-testing of the PTO (including the turbine), and activities for definition of inspection and maintenance (including structure). Regarding performance, the project seems to be missing end users in the engagement. It is expected that the deployment of the previous prototype has given important input to LCOE evaluation.

- This is an interesting spar buoy project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan. There is an excellent engagement strategy and engagement with the user and their requirements. There has been good progress, and the team completed the overall project very well.
- This is a well-tested system. The use of standards is very positive. The results to date are very encouraging. It is not clear, however, if there has been much engagement with potential customers and end users. Use cases are identified, but it is not clear if these have been made in collaboration with stakeholders.

Floating Oscillating Surge Wave Energy Converter Using Controllable, Efficient Power Take-Off System

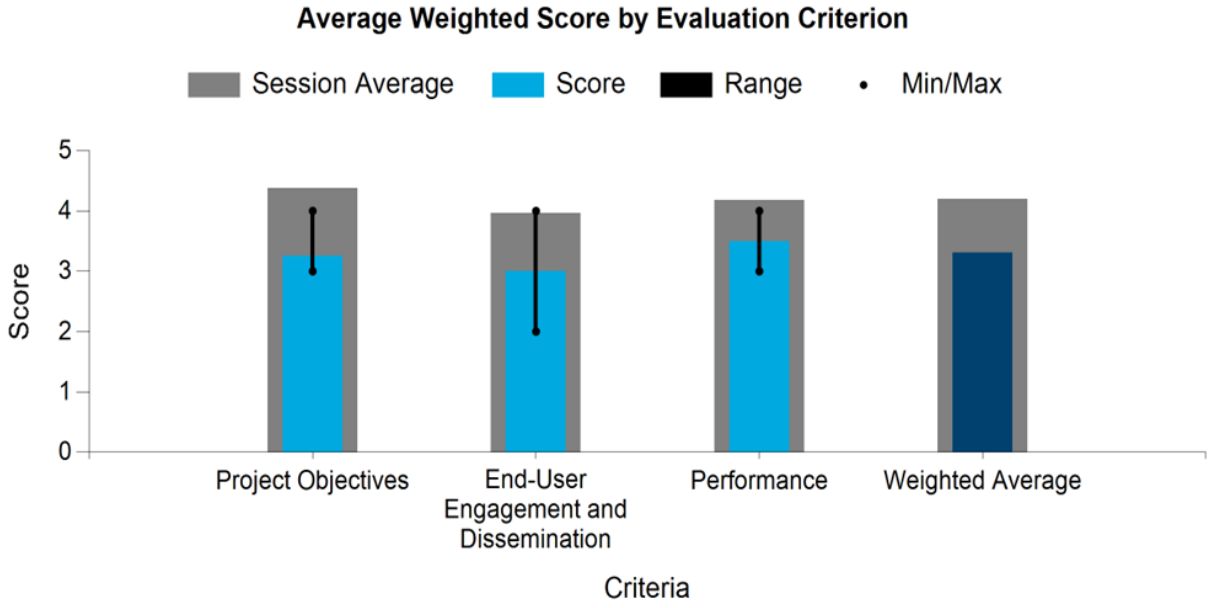
Stevens Institute of Technology (Inc.)

WBS:	EE0008953
Presenter(s):	Muhammad Hajj
Project Start Date:	06/01/2020
Planned Project End Date:	05/31/2022

Project Description

This effort is in direct support of expanding and diversifying the nation's renewable energy portfolio and is a critical step on the way to developing both grid-scale and distributed wave power generation systems by extending bottom-hinged surge wave converters in shallow water to converters placed over a floating platform. The innovative 100 kW, dual-flap floating oscillating surge wave energy converter (FOSWEC), as designed here, can be deployed at any water depth.

One innovation is to enhance the structural stability at minimum cost by placing the two flaps at an optimal separation. A second innovation is to design, build, and test an active mechanical motion rectifier as an integral component of the PTO system of the FOSWEC. The scope also includes development of a manufacturing plan, ocean test plan, risk register, compliance with IEC/IEEE standards, commercialization plan, and National Environmental Policy Act compliance requirements. Benefits of this design include increasing the capture-width ratio from 18% to 40%, reducing the peak-to-average ratio by 50%, and ultimately reducing the LCOE by 40% when compared to Reference Model 5. The ultimate goal is to build and test the designed system at the PacWave South test site.



Aggregated Reviewer Comments

- The floating flap-type WEC device is a different approach to flap-type devices than those previously seen (to the best of the reviewer's knowledge). Investigating this potential is therefore a reasonable thing to do in pursuit of marine energy advancement and is in line with WPTO objectives. The technology is at a relatively early R&D stage and requires significant development before at-sea testing can be realistic (e.g., as identified, further irregular wave or spread wave considerations and how these may affect technology). The team should be commended for seeking out expertise of Matt Foley with previous experience of a similar technology at a large

scale with at-sea deployment experience, but it was unclear to the reviewer how this guided the project's goals or objectives and if this had a very specific remit or was able to guide some of the technology more generally. Other previous technology development programs may also be of relevance as well as wider experience-based advisory to ensure that previous lessons learned are integrated from the outset. There are multiple areas of crossover from other technology development projects that could potentially be leveraged. Dissemination has occurred. It is also good to see engagement with third parties for verification purposes.

- The reviewer inquired as to whether there are any lessons learned from Langlee WEC (floating dual flap) established in 2006. The engagement of a third-party is positive. The scope hopefully addressed the whole technology. Dissemination and engagement do not seem to address end users and other stakeholders directly. Performance seems to be compatible with the stage of technology development.
- This is an interesting surge wave project, but it is not clear how meaningful the results will be compared to past surge wave projects. There could be significantly more attention to risks and their assessment. It was believed their end-user engagement strategy and engagement with the user and their specific requirements could be significantly improved. There appeared to be good progress and methodology.
- This idea has many risks and challenges. It is important that they are well described. Bringing in the ABS partner earlier in the design process would be beneficial as part of the project's next phase. It is not clear if there is an investigation or conversation regarding the commercial application of this system.

Optimization, Design, and Commercialization Planning of Next-Generation StingRAY H3 Wave Energy Converter

C-Power

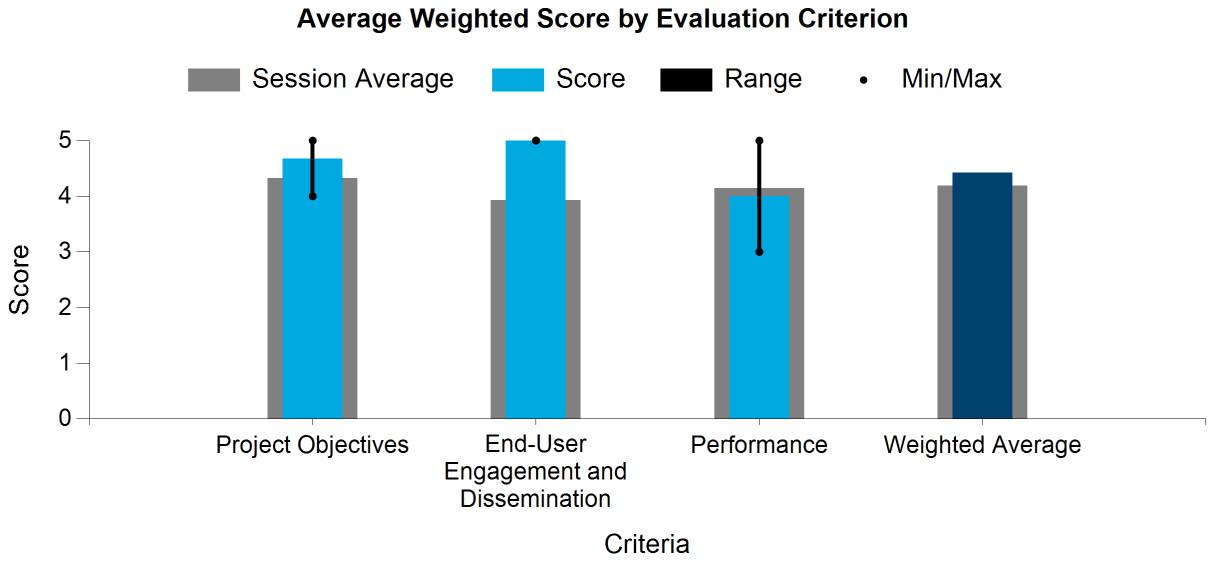
WBS:	EE0008954
Presenter(s):	Pukha Lenee-Bluhm
Project Start Date:	02/01/2020
Planned Project End Date:	04/30/2022

Project Description

This project's primary objective is to develop a standards-compliant, fabrication-ready, next-generation design of C-Power's StingRAY WEC. The H3 StingRAY will be designed for grid connection and at least two years of continuous testing and operation at the PacWave South test site. The design is intended to deliver an innovative, high-performance, survivable, and reliable device that is acceptable to potential customers, regulators, and other stakeholders, while also demonstrating the StingRAY's path toward cost-competitive electricity.

The H3 design builds upon C-Power's experience designing and testing WECs and is an iterative improvement of the previous H2 WEC design. C-Power's risk-driven design approach relies on conformance with relevant design standards, numerical modeling validated with scaled tank testing, and an iterative risk analysis process.

Clean, renewable marine energy is a challenging engineering problem but will be a critical component of climate change mitigation. The H3 is intended to service non-terrestrial loads—diesel genset replacement, at-sea vessel charging, larger-class remotely operated underwater vehicles and autonomous underwater vehicles, and others—and will be well placed for terrestrial applications when those become available. This project represents a key step to delivering the initial prototype for a later validation project and a practical and concrete step toward the future development of a larger utility-scale H3.



Aggregated Reviewer Comments

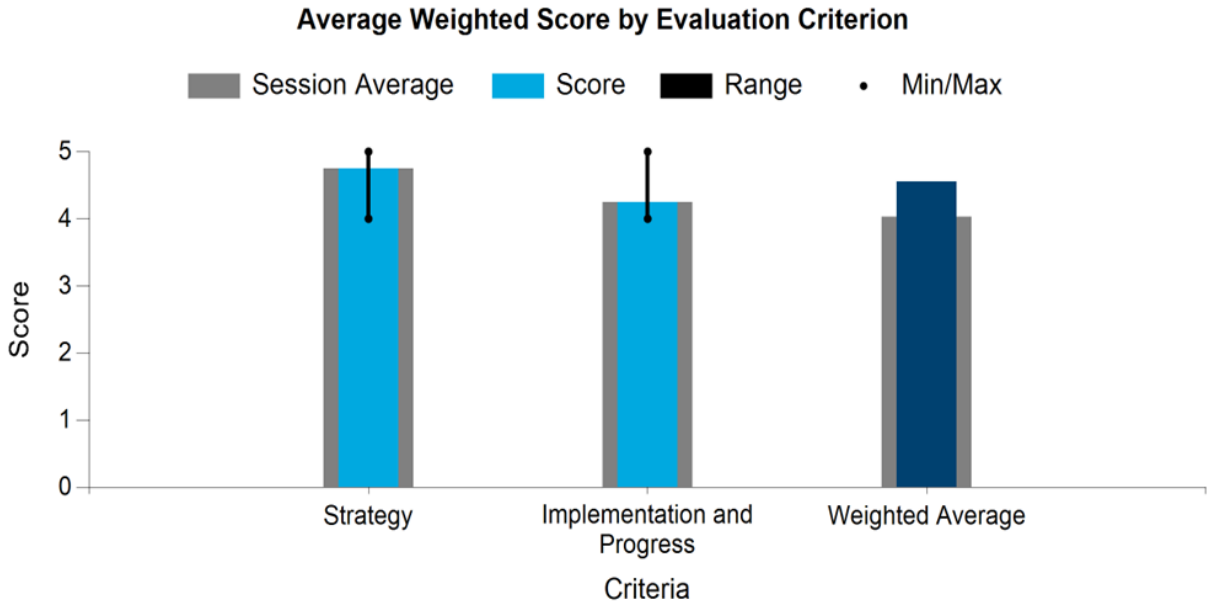
- The development of a design for near-term deployment at PacWave is well aligned with WPTO objectives. The project looks to scale up as experience grows (PBE first then larger scale later, representing a sensible approach to development). The project builds on previous project experience and learnings. There was no mention of lab or sub-system qualification testing of key components in the project plan or presentation generally. This may be worth considering to de-risk ocean operations further. Engagement with potential near-term users is being undertaken (though outputs or learnings are not known). The reviewer believes optimistic maintenance plans are in place based on remote and on-site maintenance for a first-of-a-kind prototype. Consideration for the unexpected is necessary at this stage and may be of benefit to the project.
- Objectives are in line with the program objectives. Dissemination activities seem to target the most important stakeholders. Regarding performance, it seems that all activities were in line with the objectives of the project.
- This is an interesting project that is an excellent fit with the WPTO program. They have a well-developed and thought-through plan. There is a good end-user engagement strategy and engagement with the user and their specific requirements. Performance and progress are all on track.
- This is a great project that is well executed. The end-user and potential customer engagement is very positive. It is difficult to evaluate the performance without some data or charts.

Reducing Barriers to Testing

Activity Area Evaluation

WPTO

WBS:	2.3
Presenter(s):	Lauren Ruedy



Aggregated Reviewer Comments

- Nothing to add.
- The Reducing Barriers to Testing Activity Area has a well-defined strategy to meet the specific challenges facing marine energy industry and stakeholders. The organization and rationale of the sub-activity areas and research priorities are well articulated, justified, and communicated. Most importantly, the work WPTO is doing and supporting is vitally and fundamentally important to the U.S. endeavor to advance marine energy production. The projects included in the Reducing Barriers to Testing Activity Area are well aligned with the stated goals and objectives from the MYPP. The breadth, depth, and contribution to reducing barriers that the projects represent are impressive, accelerating the opportunity for the United States to move toward marine energy generation and commercialization. The projects are generating real, measurable, and important results and deliverables. Just as important is the work of assembling and articulating project accomplishments and how they contribute to the marine energy community. In addition, the network of researchers of all types that is fostered by this large, government-funded program will leverage the advancements of any one individual project. The reviewer strongly recommends the development of a series of workshops to help bring the results of the breadth and depth of this work to researchers, developers, and regulators that are not actively part of the network formed by those within projects funded by WPTO. The advantages of such a series of workshops include the potential to accelerate uptake and commercial viability, reduce time to permitting, and enhance a wider understanding of the transferability of the technologies and methodologies tested and developed through this activity area. The work of this activity area is vitally important.
- The Reducing Barriers to Testing Activity Area is well run and is successfully addressing the objectives of the MYPP. The activity area manager understands these objectives and is executing a clear strategy to meet them. In accordance with the goals and objectives of the activity area, WPTO is funding many different areas

of technology that will reduce barriers to testing marine energy devices. These barriers are both physical locations for performing tests and permit acquisition for tests. To address these barriers, the activity area funds sensor development for measuring the environmental effects of marine energy devices to assist regulators in judging the permit applications for those devices, facilitates access to existing lab and field test sites, and is installing an open ocean test site. The portfolio of projects funded under the activity area demonstrates that the activity manager has a clear understanding of the needs of the industry. As stated above, the activity area funds projects that provide assistance to device developers in the testing of their prototypes in laboratory and field test sites. This testing assistance is accomplished through several projects, specifically Triton, TEAMER, National Lab and University Collaboration for MHK Instrumentation and Data Processing Tools, NMREC Infrastructure Upgrades, and PacWave. These efforts provide significant aid to marine energy device developers by supplementing their in-house expertise and providing test facilities, thereby accelerating the development and eventual deployment of renewable marine energy. Many of the efforts make use of leveraged funds from other sources. Individual projects are monitored by WPTO staff to ensure that taxpayer funds are properly spent, and schedules and milestones are followed as closely as practical. Inevitable delays, principally due to field tests facilities, are handled in an open and professional manner.

- The Reducing Barriers to Testing Activity Area does have a defined strategy that clearly reflects both the need of the program and the sector. There is clearly development for previous investments and work, which supports the ongoing needs of the industry. It is clear that the ability to test and validate not only marine energy technology but the devices by which performance and environmental impact are monitored, measured, and evaluated is a clear priority in meeting the MYPP. Of the nine projects within this activity area, there was a high degree of diversity ranging from the development of effective technology to monitor underwater sound and its impact to the delivery of a full-scale wave technology testing facility offshore. Only a very small number of project deliverables were not considered effective or were lacking in sufficient detail at this review stage to be determined as meeting the relevance and needs of the program. If all projects are able to overcome some of their delays, ensuring there is a broad and international dissemination of results and stakeholder engagement, then it is believed that the activity area is likely to meet its performance and objectives as defined in the MYPP.

Project Evaluations

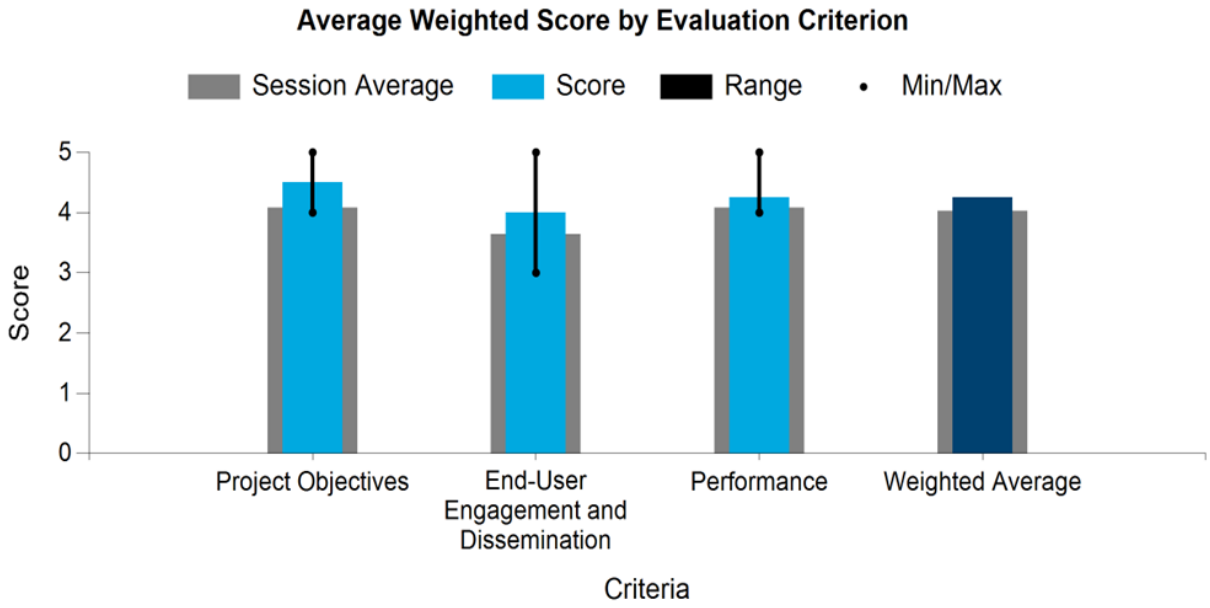
Triton Initiative

PNNL

WBS:	2.3.2.601
Presenter(s):	Joe Haxel; Garrett Staines
Project Start Date:	07/01/2015
Planned Project End Date:	09/30/2021

Project Description

The Triton Initiative is focused on reducing barriers to testing marine energy devices through R&D of technologies and approaches to improve understanding of potential environmental effects. Triton's evaluation of methods and instrumentation for environmental monitoring aims to address regulatory concerns and better inform decision making for permitting and licensing of marine energy projects. Triton's goals are to provide recommendations for economical commercial-off-the-shelf instrumentation for data collection, demonstrate recent improvements in technologies, and research and develop new tools to make environmental monitoring more efficient and effective. Triton works toward these goals by providing support for DOE-funded marine energy environmental monitoring technology development teams and performing in-situ, field-based demonstration and validation of commercial-off-the-shelf sensors. Triton has produced peer-reviewed and open-access publications, monthly subscriber newsletters, blog stories, social media, and website content, and presented webinars providing technical guidance, suggestions, and best practices for consistent and transferable environmental monitoring data collection and analyses at marine energy sites. Additionally, the Triton team collaborates with industry and academia to fill data gaps that improve overall understanding and reduce environmental concerns for permitting marine energy converters.



Aggregated Reviewer Comments

- Triton has a lot of "pots on the fire" with several different monitoring arrays over a large geographical area and with several institutions and labs. The combination of monitoring equipment to collect needed marine energy site dynamics and device stressor/receptor data is impressive. However, the cost effectiveness and the tremendous amount of data to store and transfer has yet to be seen for a long-term test in the open marine environment. The algorithms to pare down data to meaningful from clutter will have to be seen. If able to work

in unison, the monitoring suite could be effective and get solid, usable data to the end user without the need for massive data analysis. The tethered balloon system is novel but very dependent on perfect water clarity conditions and weather. The Probability of Encounter Model task has real potential for refining fish collision and interactions with marine energy devices and getting a massive volume of data to a usable end with far less time for analysis. Overall, Triton has great potential to provide a suite of environmental monitoring data, and some other WPTO projects (such as the Spatial Environmental Assessment Toolkit (SEAT)) and TEAMER could provide data analysis and outputs.

- High scores were awarded because the high-quality work produced directly contributes to the WPTO mission of reducing barriers to device testing. In this case, this involves barriers posed by the uncertainty in changes and risks to ecosystems presented by the introduction of these new technologies into the habitat. The work of evaluating, developing, and recommending approaches and technologies to establish ecosystem risk is particularly important in an effort to develop best practices in these specifically energetic environments. In addition, the project has initiated and activated a comprehensive framework for disseminating findings. Given the challenges to those on the frontline of the work of getting devices permitted, the central dissemination afforded by this multifaceted project is particularly valuable. Given the breadth of the projects associated with Triton, the reviewer was unclear which ecosystem components are still in need of testing or development of devices and approaches for measurement or monitoring. The one area for which the reviewer would like a deeper understanding is the translation from dissemination to uptake. The April 2022 article, One Size Does Not Fit All, is a recognition that the translation from dissemination to uptake is not straightforward. The reviewer suggests considering the development of a web-based, living document that contains decision trees that help the reader get to the right technology or approach to test, based on their site characteristics (biotic and abiotic), and act as a summary of the technologies or approaches tested and found to be less than a best practice (i.e., help the reader "rule out" as much as "rule in"). Within the appropriate boxes of the decision tree, references or links where the reader could find out more about the particular technology or approach would be particularly useful. Overall, the breadth, depth, and high quality of the work, publications, and dissemination efforts of this project are encouraging.
- The Triton project objectives contribute to WPTO's mission of reducing the barriers to testing by demonstrating an impressive quality and quantity of accomplishments in the project areas of FOA Support, Triton Field Trials, Environmental Technology Development, and Researching Stressor Receptor Interactions. The expected outputs of these projects will make significant contributions to future testing of marine energy systems by providing relevant data to regulators who will be making judgements on permits for those systems. The project timelines show well-defined and reasonable milestones for future work. The success of the work that has already been accomplished indicates that the project management team will be able to be equally successful for the future work. Regarding end-user engagement and dissemination, the team's Triton Communications Framework formalizes their process of communicating their many results to appropriate stakeholders. This includes 23 Triton stories published, 16 newsletters sent to 144 subscribers, 2,900 new website users, Triton Talks webinar series launched, and 178,000 impressions on social media. The team is also making a significant contribution to the Journal of Marine Science and Engineering special issue: Technology and Methods for Environmental Monitoring of Marine Renewable Energy. The reviewer did not identify any weaknesses.
- The project's objectives show clear alignment to reducing regulatory barriers and perceived risk to marine life from in-water marine energy devices. There are four key tasks within the project, each aiming to utilize off-the-shelf technology for improved data collection to inform collision risk assessment, underwater sound, marine species interaction with devices, and data processing with a focus on how to optimize data volumes and collection. The key output here is environmental monitoring package development for use with WEC deployments at the marine energy test site in Hawaii. The project also considers the collection of underwater sound data and monitoring utilizing a balloon above the water. Automated acoustic cameras will be utilized, which have been optimized to remove issues with field of view and will record image analysis. There have been

some delays to the ability to test the technology in a live environment due to delays in the deployment of WECs at the test site. Overall, this appears to be an incredibly useful review of available monitoring equipment, which seeks to optimize, refit, and rework the ability to collect data in the marine environment. The reviewer hopes that the processing aspect of the data, including seeking regulatory acceptance on the output, will be part of the ongoing program to 2024. It will be critical to ensure that the data and analysis are accepted fully by stakeholders to ensure the application of these novel equipment uses and optimization is fully utilized.

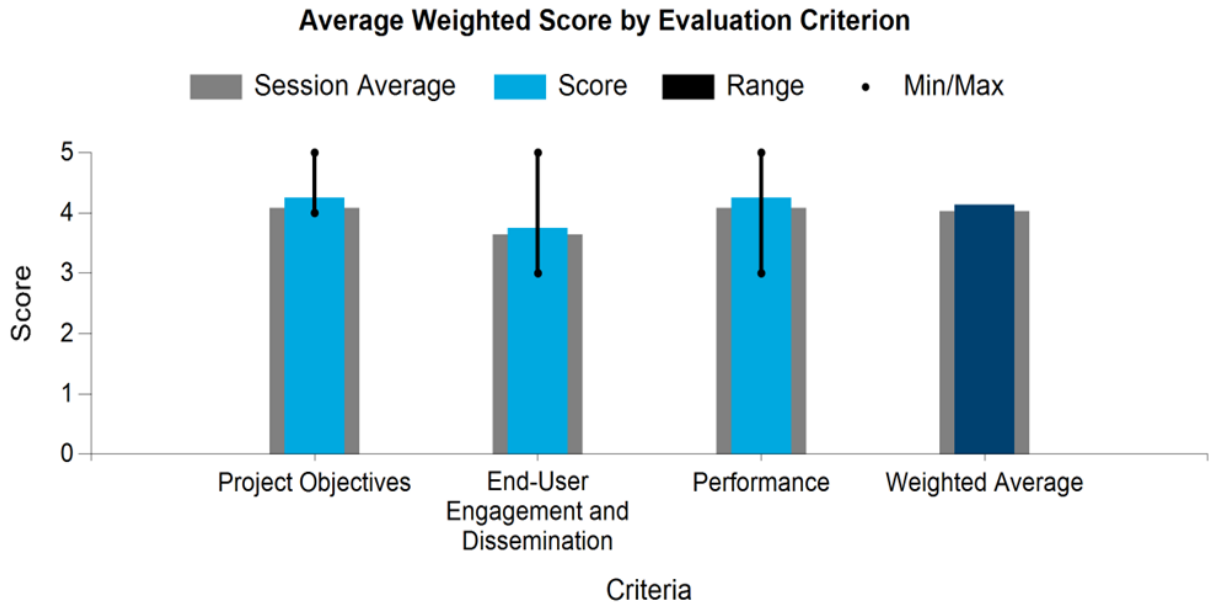
National Lab and University Collaboration for MHK Instrumentation and Data Processing Tools

NREL, PNNL, Sandia

WBS:	2.3.3.404
Presenter(s):	Rebecca Fao
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021

Project Description

Field and laboratory validation, testing, demonstration, and operation are critical steps for increasing the TRL of marine energy converters because they provide high-quality testing and performance data that are critical to inform all aspects of technology development. This project, in partnership with industry, enables the MHK community to reliably and efficiently collect, process, manage, and share quality data by facilitating access to and development of instrumentation, guidelines, and data processing/quality assurance tools. Under this project, open-source data processing code and tools, instrumentation, data acquisition systems, and measurement guidance tools were developed to facilitate the collection and processing of quality laboratory and field data. Overall, this project is intended to improve the quality of the data collected during laboratory and field demonstration projects by standardizing the collection and processing techniques and by improving access to instrumentation, code, and measurement guidance. Quality data will, in turn, lead to improved knowledge capture following marine energy device testing.



Aggregated Reviewer Comments

- The National Lab and University Collaboration for MHK Instrumentation and Data Processing Tools project has good potential to reduce the analysis of data to usable data for developers and regulators on marine energy devices. The analysis of huge amounts of data for marine energy device monitoring can be a big barrier to a developer. The Marine and Hydrokinetic Toolkit (MHKiT) software system could greatly reduce this time and expense. The miniature data acquisition system sensor appears to offer real-time load sensing data to moored devices, but the reviewer is not sure if it is a barrier for marine energy devices' in-water use. Outreach also appears to be light and more along the webinar routes. This project and SEAT are of similar outputs and will help reduce barriers for in-water marine energy devices.

- This project appears to fill an important need for standardization and the development of standards for high-quality analysis of device readiness. The high scores are attributable to the clear articulation of needs identified (2017 workshop) and the solutions developed in response and to the list of engagement and dissemination categories. However, a quantification of the output within each of those categories would have been useful. From the contents of the last slide, the majority of the category of "Scientific Articles: Journal and conference articles and presentations targeting industry and academia have been published" appear to be conference presentations, leaving the reviewer with the impression that this portion is overstated and, therefore, makes it difficult to determine the impact of the other engagement efforts. The reviewer does recognize, however, the noted dissemination of MHKiT (11,000 downloads in three years).
- The project addresses three of the MYPP Marine Energy Program Activities: Program Activity 2: Technology-Specific System Design and Validation, Program Activity 3: Reducing Barriers to Testing, and Program Activity 4: Data Access, Analytics, and Workforce Development. The focus is on open-source software, which maximizes continued use by the marine energy community. Examples include MHKiT, Marine Energy Data Pipeline, and miniature data acquisition system posting on GitHub. User engagement is executed through knowledge hubs; webinars and workshops for industry, academia, and focus groups; journal and conference articles and presentations; industry and university partnerships; and news articles in industry publications. Various products will guide the industry toward standardized methods of data collection and reporting. Examples include the marine renewable energy code catalog, the Telesto knowledge base in PRIMRE, published guidelines for mechanical and PTO load sensors for larger-scale field testing, and a data quality control standards document. The reviewer did not identify any weaknesses or recommendations.
- The project will develop a suite of instrumentation guidelines and data processing/quality assurance tools to ensure that laboratory and field data is analyzed in a standardized way. A full logic model was included in the presentation, which was useful in determining how the project is considered in the MYPP. There were clear links to the program activity (including activities 2, 3, and 4), so the project clearly has relevance across the program. The standardization of data collection and analysis will be hugely important in the future development of marine energy projects by supporting the financial, technical, and impact assessments of viable projects. Providing open-source software tools makes the process highly accessible, and the focus should support broad dissemination. At present, social media and tutorials on YouTube are useful, but a more focused effort ensuring outputs are known and understood by the sector will be useful. The reviewer notes the output of 10 peer-reviewed papers, which is useful.

Improvements to Hydrodynamic and Acoustic Models for Environmental Prediction

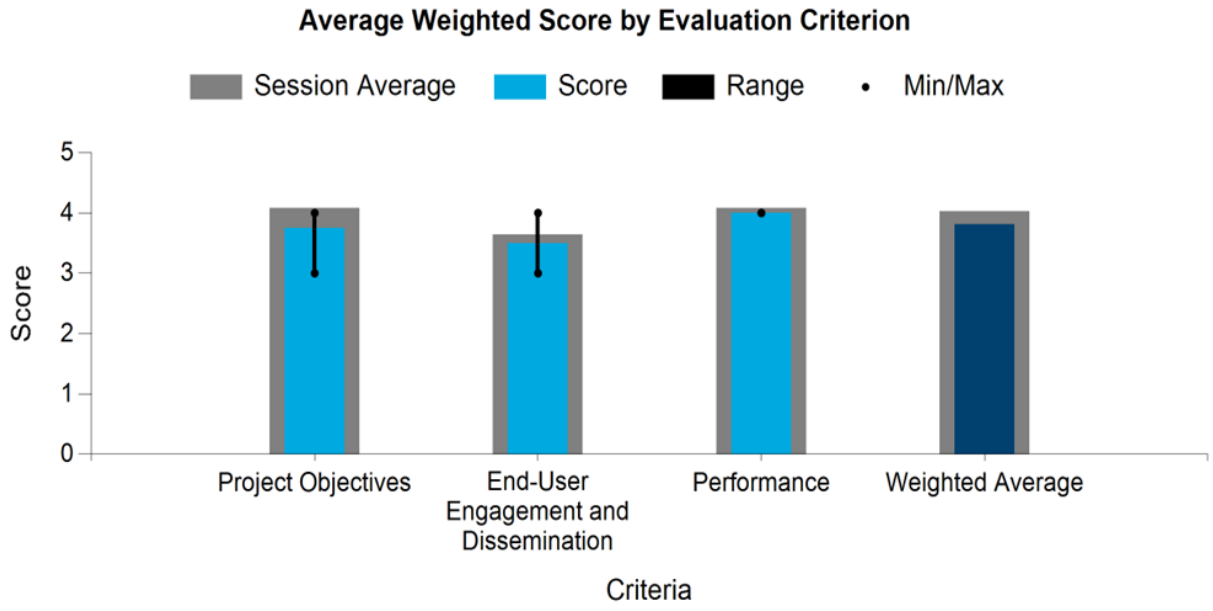
Sandia

WBS:	2.3.3.701
Presenter(s):	Jesse Roberts
Project Start Date:	10/01/2014
Planned Project End Date:	09/30/2025

Project Description

Successful development of marine energy projects will balance renewable energy production with risk to ecosystem health. Reducing environmental risk and permitting costs of marine energy projects can be supported with high-quality site characterization for site planning and better, a priori understanding of the potential environmental impacts associated with deploying marine energy arrays. Of utmost importance is for marine energy developers, regulators, and stakeholders to have the ability to plan marine energy array layouts that maximize energy production, support PBE applications, and minimize potential environmental risk.

Today, industry relies on disparate tools in project planning with limited effort or know-how to coherently coalesce results into actionable form. Tools that optimize marine energy production and ecosystem risk simply do not exist. Sandia is fulfilling this industry challenge by developing SEAT, which is made of linked, open-source, user-friendly models capable of characterizing marine energy sites and mitigating environmental risks associated with marine energy devices. The models characterize wave, hydrodynamic, and acoustic environmental stressors as a function of self-prescribed array specifications. Integrated into QGIS, SEAT creates a virtual laboratory to accurately assess and visualize environmental risk versus power generation. This allows developers, regulators, and stakeholders to effectively communicate with game-changing certainty.



Aggregated Reviewer Comments

- The SEAT project has the potential to provide a usable GIS data program for determining impacts on numerous stressor/receptor, geophysical, and acoustic parameters. This type of modeling would greatly help developers and regulators determine potential and actual impacts and the design of specific monitoring plans. Questions on validation of the data to modeling output could be of concern since there are no in-water outputs. Outreach

also appears to be light, and training and/or assistance in the use of the modeling software are unknown. Overall, SEAT has good potential to provide vital marine energy device environmental modeling for developers and regulators.

- This project is vitally important to the marine energy sector. It addresses the real need for a tool to quantitatively assess the potential impact of marine energy development and to serve as a visual and quantitative foundation to discuss and weigh the costs and benefits of development. The reviewer would have liked to have heard more about the investment of the human and data resources required to implement this tool at specific sites and the engagement and dissemination plans for meaningfully converting for updates and broad adoption. Overall, the concept of the tool is an exciting contribution.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by developing a comprehensive, multipart software suite that addresses several aspects of the planning process for a marine energy converter. The combination of wave, hydrodynamic, and acoustic models into one overall suite of models with GIS capabilities that can analyze WEC device specifics is a significant achievement. User engagement is executed through in-person workshops and demonstrations, conference presentations, peer-reviewed publications, and publicly available models and tutorials. Citation information would be helpful. This is a very useful planning tool; however, it is a combination of three sophisticated numerical models that cannot be verified or validated due to the lack of WEC or CEC arrays in the field. Therefore, some caution in its use is warranted. The reviewer could not understand many aspects of the presentation. For example, the legend and axis names are not explained (potential risk calculation colored bands on slides 11 and 12, the colored bands on slide 14, and the vertical axis of the bottom chart on slide one), and the erosion, deposition, and mobility information on slide 12 is difficult to decipher. The reviewer does not know what percent coverage refers to. It is not clear in the presentation which of the conference presentations, peer-reviewed publications, and publicly available models and tutorials via GitHub have occurred already or are planned in the future (except for the Offshore Technology Conference and model demonstrations for potential end-users noted on slide nine). The reviewer recommended improving the presentation of results for future reviews.
- The requirement to understand and manage the interaction and effect of marine energy devices on areas of marine resources (wave and tidal stream) is critical to the commercialization and acceptance of marine energy projects. The projects will use experimental tools to review resources and assess fluid-structure interactions and environmental risk at an array level through SEAT. The range of outreach and workshops to highlight the extensive nature of the tool was good to see, with engagement with the regulator as the end user and a common use of metadata. It would be useful to understand how the model will be verified when projects are live—in effect, how SEAT will perform against live, measurable data. Yield analysis and array interactions are two key areas of concern. In some cases, increasing arrays by a small percentage can have a significant effect on capacity factors in tidal environments. It would also be useful to understand how the model deals with the high degree of variability in the device types, which may require validation in the field. Clearly, the quality of the data being input will be key. While this was proposed as an area of key consideration, it was not demonstrated what quality assurance processes or decisions are made on data input. Overall, the project will be incredibly useful, especially as in validating demonstration deployments and extrapolating to array scale where there is a high degree of uncertainty.

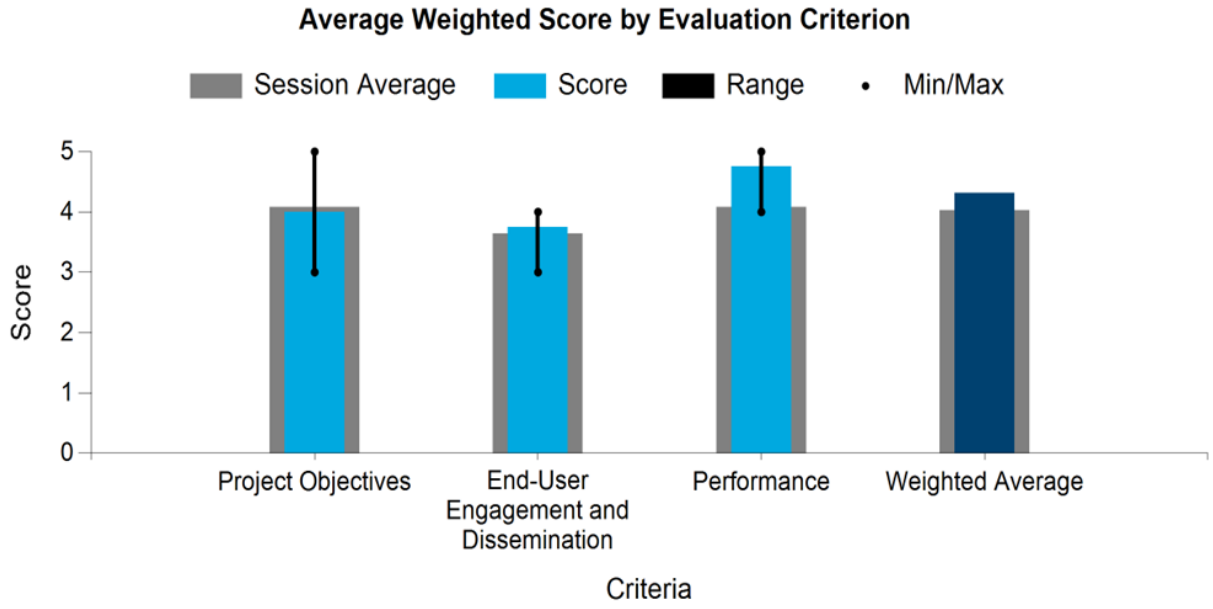
Rapidly Deployable Acoustic Monitoring and Localization System Based on a Low-Cost Wave Buoy Platform

Integral Consulting Inc.

WBS:	EE0007822
Presenter(s):	Kaustubha Raghukumar
Project Start Date:	12/01/2016
Planned Project End Date:	11/30/2021

Project Description

The primary objective of this project is to develop a cost-effective, fit-for-purpose environmental monitoring system that characterizes, classifies, and provides accurate location information for anthropogenic and natural sounds in real time. NoiseSpotter has been developed to support the evaluation of potential acoustic effects of MHK projects. By utilizing a compact array of three acoustic vector sensors, NoiseSpotter triangulates individual bearings to provide sound source localization, allowing for the ability to discern MHK device sounds relative to other confounding sounds in the environment while providing location estimates to nearby marine mammals for environmental mitigation purposes.



Aggregated Reviewer Comments

- The NoiseSpotter device appears to be an excellent, cost-effective means to collect marine energy environmental data and can be installed and removed quickly with a small commercial fish vessel. This device will provide quick, usable information for the industry and regulators to address environmental monitoring concerns pre-construction and when a device is installed. NoiseSpotter offers services with the device to support installation, recovery, and quality assurance/control data, providing an experienced, independent analysis of the data. NoiseSpotter has the best immediate and cost-effective means for providing focused data for developers and regulators on a marine energy device.
- This project provides an important advancement toward the potential to understand acoustic effects of marine energy technology introduced into marine habitats. It will be interesting to see the insights that this new device can bring to differing marine energy sites and devices. The reviewer came away wishing that the content of the Technical Performance Analysis table was presented in a form such that the important takeaways were more easily evident. The reviewer recommends the team consider breaking that table into multiple smaller tables of

focused content such as those categories relevant to gaining habitat insights, implementation considerations, and technical features. In addition, separating the score and comments into separate columns and using a color scheme that matches the legend would allow the reader to more readily skim through the scores of interest. The reviewer needs more explanation as to the meaning of "location estimation accuracy: bearing estimate within 2 m" given that bearing is generally a measure of direction.

- This project covered the successful development of the NoiseSpotter system, which measures the noise properties of marine energy systems, other non-marine energy noise sources, and acoustic particle velocities. All three data collections will be extremely helpful for environmental mitigation purposes and dealing with environmental regulators. The project included three rounds of in-water tests and numerous conference presentations and peer-reviewed publications. NoiseSpotter is patented and trademark registered, and the project came in very near original budget. The reviewer did not identify any weaknesses or recommendations.
- This project aims to optimize the extraction of sound data in the marine environment to enable better assessment of the impact of the deployment of marine energy devices in a live marine setting. The project is highly practical, having deployed the sensors in a range of environments, utilizing triangulation to allow MHK technology sound to be distinguishable from other marine and anthropogenic sounds. The project was presented with clear, logical relevance to the MYPP decision logic and was one of the few projects to clearly show the project program and go/no-go decision matrices. The project had considered not only the technical capability of the technology but also the associated costs, keeping deployment costs to less than $35,000 per deployment. The dissemination of the project has included some good, related peer-reviewed papers but will require additional end-user acceptance, particularly from a regulatory assessment process. While the data and methodology may show positives in terms of a test and validation environment, there should be clear links and engagement with end users to ensure the data outputs can be used to remove regulatory risk. The operational environments, including tidal sites to 2.5 meters per second and wave environments up to 2 meters at 15 seconds with a depth of almost 200 meters, appear to cover a wide range of applicable marine energy sites; however, more testing will be required to fully assess reliability and risk in deployments in energetic and diverse marine environments.

Long-Range Target Detection and Classification System for Environmental Monitoring at MHK Sites

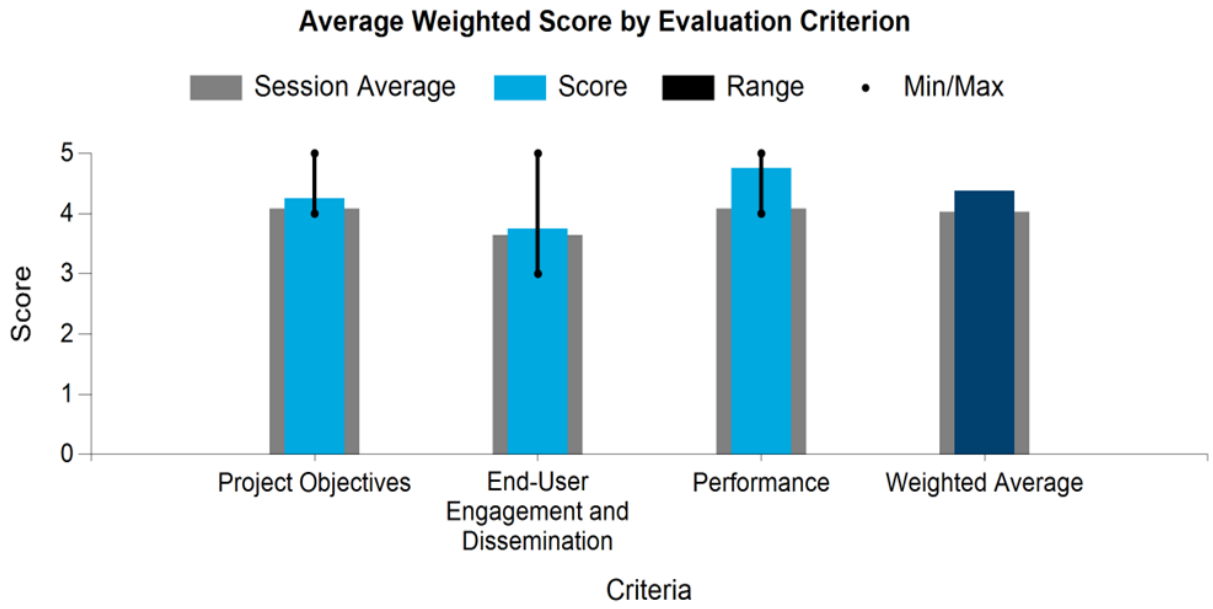
Biosonics, Inc.

WBS:	EE0007824
Presenter(s):	Tim Acker
Project Start Date:	01/01/2017
Planned Project End Date:	06/30/2022

Project Description

Marine energy developers, regulators, and the public need to understand how candidate marine energy devices affect the behavior of fish, marine mammals, and other marine life for responsible project permitting decision making and to provide an early warning of anomalous or dangerous marine life activity. This automated target detection, localization, and classification system will help answer key questions including whether the presence of a marine energy device alters the natural migratory and/or foraging behavior of marine mammals and other migratory species by repelling or attracting these animals, and whether marine mammals become entangled in marine energy device mooring cables. By unobtrusively monitoring marine life behavior before, during, and after marine energy device installation, this technology helps to further understand the potential environmental risks to marine organisms from devices.

The goal of this project is to deliver a practical, robust, and cost-effective long-range (200 to 300 meters) active acoustic monitoring system with innovative, shaped pulse-and-chirp capabilities to suppress off-frequency sound energy within the hearing range of marine mammals to automatically assess marine life behavior at marine energy sites. The one-of-a-kind sonar system successfully integrates a 360-degree perimeter detector to automatically detect and geolocate targets at range and a focused split beam directed classifier to track and classify target types.



Aggregated Reviewer Comments

- The BioSonics device is unique in marine energy environmental monitoring by being able to identify and track targets in a somewhat far field area around a marine energy device. The combination of active and passive sonar with real-time reports could greatly reduce barriers for testing and monitoring and provide usable, quick data to developers and regulators for informed decisions on device placement and monitoring plans. The noise

reduction and ability to lessen background noise clutter and target detection down to the size of a herring out to close to 150 meters is impressive. Go/no-go decisions were met early. Outreach to industry and end users seems to be light and in the works. BioSonics, similar to NoiseSpotter, has good immediate and potentially cost-effective data for its end users.

- This project looks very interesting. There is intriguing acoustic engineering to reduce the signals at frequencies overlapping with marine animal vocalizations and reducing the amount of time the energy is in the water at any particular direction. The reviewer would have appreciated reporting on the site and target characteristics required for this technology to be viable out to the hundreds of meters reported and, in the interest of uptake, the price to implement this system. In addition to potential cost, it is unclear to the reviewer how the output from this system will be actionable or used in the quantification of risk to ecosystem components. The tracking demonstration included one target. The reviewer inquired how the output of the system will be used/useful in a region of high biological presence and activity. The reviewer's main concern in the project objectives category is the transition to uptake. Where applicable, the ability of this technology to synoptically track directional movement will enhance regulator and stakeholder understanding of habitat use.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by developing an active acoustic system that monitors marine-life behavior near marine energy devices. This capability can document the effects the marine energy device has on marine life. The data collected will be crucial to regulators who issue permits for marine energy devices. The project successfully achieved go/no-go 1 and 2 milestones. A project strength includes reduced sonar frequency transmissions in the hearing range of marine mammals. This allows the behavior of marine mammals near the marine energy device to be attributed to the marine energy device and not to the sonar system itself. The project successfully tested the prototype system on the seabed at the PNNL Marine Sciences Laboratory test site, which included tracking man-made targets. The time series echogram shown on slide 13 shows successful natural cluttered background removal. The six-month field deployment with the C-Power SeaRAY and SAAB unmanned underwater vehicle docking station at WETS in Hawaii is an excellent test of the system. User engagement was executed via conference articles and presentations. Regarding weaknesses, the reviewer did not notice any journal papers. The reviewer did not have any recommendations.
- The project aims to improve long-range target (marine species) detection and classification using Biosonics' existing technology. The project would produce outputs including biological species classification out to a 360-degree perimeter with successful suppression of low frequency sound. The device would be powered by coupling to a deployed (and presumably operational) marine energy device, and the project demonstrated a clear and understandable project plan with reference to how the go/no-go decisions were made within the project. It is understood the project has been subject to some delays due to the anticipated deployment of a marine energy device (WEC) at WETS. The data will be used alongside direct classifier and behavior-based classification to determine types of marine species interaction with devices. Clearly, from a regulatory perspective, development of classification algorithms to ensure a high level of confidence in type of marine organism (pelagic fish, cetacean, etc.) will be key as will species-level identification to ensure that key species or receptors that have a particular conservation value can be identified. Further work should focus on risk identification and mitigation given the device will be closely linked to marine energy devices. It would be useful to undertake extensive end-user engagement with a range of technologies and applications to ensure technical compatibility and uptake.

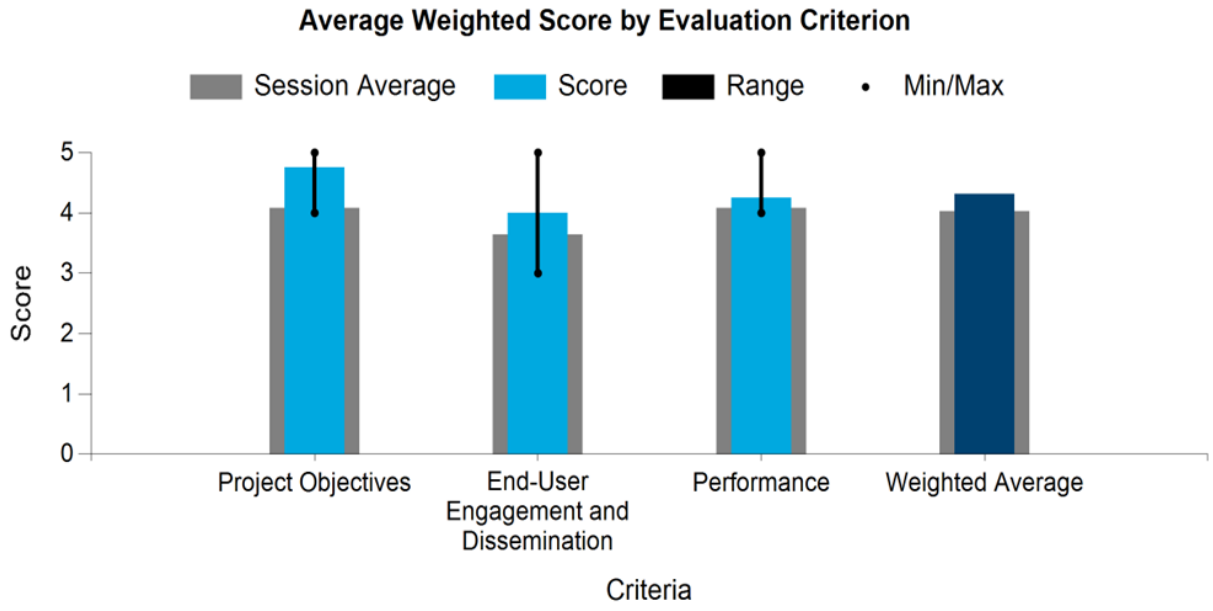
Enabling Cost-Effective Electricity from Ocean Waves: PacWave

Oregon State University

WBS:	EE0007899
Presenter(s):	Burke Hales
Project Start Date:	05/01/2017
Planned Project End Date:	07/31/2023

Project Description

PacWave South is a fully energetic, pre-permitted, utility-scale, grid-connected wave energy conversion test facility that is currently under construction. Located in 75-meter water depth, 7 miles offshore southwest of the port city of Newport, Oregon, PacWave South will offer four independently cabled test berths with subsea power transmission cables, each rated to 5 MW at about 35 kilovolts. PacWave recently completed underground construction of the conduits in which the power and data cables will be installed and the connection vault where the subsea and terrestrial cables will join. Negotiations for subsea cable procurement and installation are underway, and the request for proposals for a shore-side power-conditioning and data-collection facility is near release. When complete, PacWave will offer accredited testing of a range of WEC devices via relationships with partner agencies. PacWave will be a first-of-its kind facility in North American waters and will reduce barriers to testing a wide array of WEC and monitoring devices.



Aggregated Reviewer Comments

- This project has good fundamentals as a WEC regional testing site with potential to provide excellent in-water device data collection for functionality, environmental monitoring, and power delivery. Concerns related to getting the cable infrastructure installed and the availability of cable and support ships for installation were well noted and understood time delays and impacts to getting PacWave up and running. The lack of established universal mooring is concerning as a barrier to any end user with increased cost and permitting requirements. It is unknown if there is a business for costs to use the facility. Overall, this project will meet vital needs for testing in-water WEC devices under a variety of conditions and conducting environmental monitoring for marine energy moving forward.

- The presentation was well done and well received. The content was sufficient to convey the importance, vision, and contribution of the project. The reviewer was really struck by the magnitude of the challenges faced and not yet done with in an effort to bring this important project to completion. The end-user engagement/ dissemination score is reflective of the fact that the transfer to commercialization once the project is complete is not yet in place. From the conversation during the question period, it sounds like this is something that is already being thought through while still attending to the very large and very real immediate infrastructure needs.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by providing a pre-permitted, grid-connected, open-ocean, high wave energy test site for marine energy developers. This will accelerate the development of marine energy devices. The license application is a significant step. It is not clear from the presentation whether the license has been awarded. Accreditation to developers is an interesting concept. It was unclear to the reviewer who awards the accreditation. Significant progress was demonstrated with the release of the cable request for proposals, completion of the underground construction at the park, and the completion of the four beach-landing, horizontal directional drilling bores and conduit installation. User engagement is executed through engagement with local stakeholders and agencies. PacWave is also coordinating with DOE awardees for use of the site. The reviewer did not identify any weaknesses. The reviewer recommended that the cable design-build contractor should have ocean cable experience. Based on sketches of the PacWave site, there will be several miles of ocean cable from the seaward exit of the beach-landing conduits to the subsea pod. Some form of protection (burial, armoring) is essential. The seafloor cable industry has much experience in these methods.
- The PacWave facility will be the first of its kind in U.S. waters to allow for testing and small demonstration arrays of WECs. The four berths, with a total facility capacity of 20 MW, will be cabled to shore and allow WECs to be tested, measured, and accredited at the site. The projects' locations, some 7 kilometers offshore in a high energy environment, has resulted in cables being laid in conduits, which have been constructed. The ability to install and pull the cables will be high risk and require significant risk mitigation. It would also be useful to consider the business model for continuation of the site and potential upgrades. Monitoring of economic activity, gross value added, and associated societal benefits from the test site should also be recorded carefully to ensure value for money. It will be useful, when the site is operational, to run a lessons learned workshop and look at how operational data and experience can be shared more widely with the sector. It was not clear if users of the site were engaged in the process or if end users had been identified; however, it was assumed that this was the case. The completion of PacWave and the installation of wave energy devices on the West Coast of the United States offer enormous potential to accelerate the development of wave energy technology and the associated innovations. It has the potential to yield useful and verifiable data and knowledge on the performance, impacts, and value of wave energy. The results and activity at PacWave should be widely disseminated.

Network Director for the Testing Expertise and Access for Marine Energy Research (TEAMER) Program

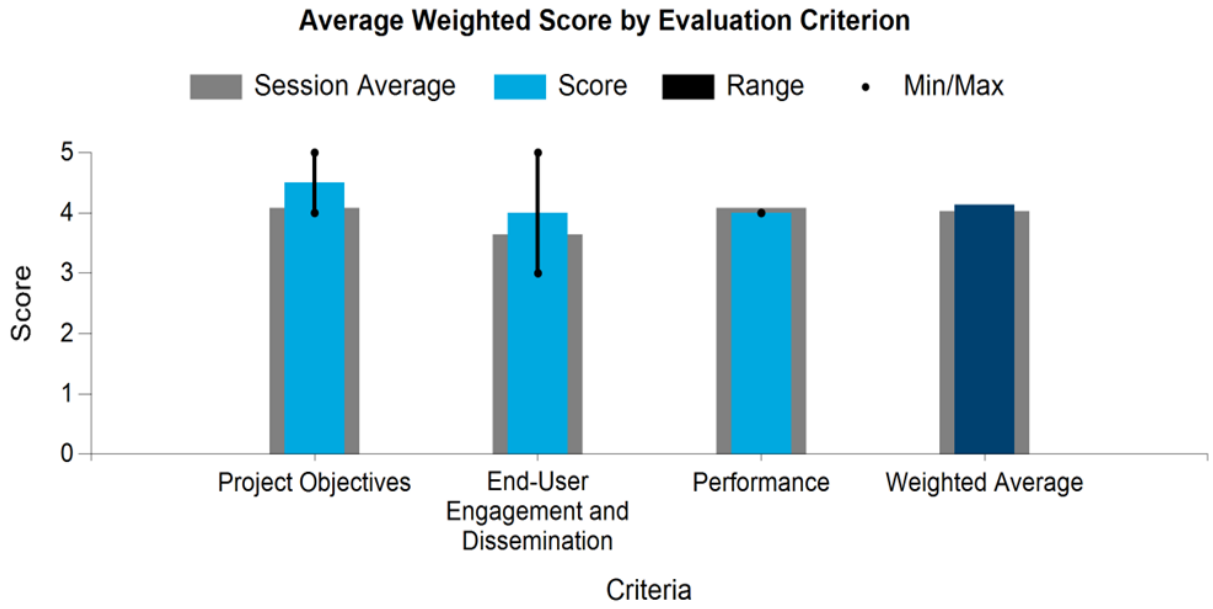
Pacific Ocean Energy Trust

WBS:	EE0008895
Presenter(s):	Matt Sanders
Project Start Date:	12/01/2019
Planned Project End Date:	11/30/2024

Project Description

Marine energy device developers and researchers are constrained by the cost of and limited access to device testing facilities and specialized numerical modeling and engineering expertise, particularly during the early stages of technology development. The TEAMER program was initiated to address that challenge for technology developers and researchers by providing easy access to testing infrastructure at qualified facilities at minimal cost and in a timely manner, leveraging world-class expertise and testing support from the nation's leading marine energy experts, and contributing to the marine energy community's knowledge base by providing lessons learned and post-processed test data to a repository that will serve the industry as a whole.

TEAMER is unique by offering regular and repeated opportunities for assistance, making it a one-stop shop for browsing and comparing U.S. marine energy facilities that have opted into the network and a hub to collect lessons learned, share outcomes and best practices, and converge on key standards and norms. Outcomes for TEAMER will include reduced iteration cycles for developers using TEAMER, quick and efficient access to testing infrastructure and expertise for design and device evaluation, and increased collaboration between technology developers and foundational research institutions.



Aggregated Reviewer Comments

- The TEAMER project appears to be an overarching regional manager of facilities for researchers and developers for testing of devices. It is unknown if there is an issue to access for established labs and test facilities, and it appears to be a networking connection for developers and researchers with facilities. It does not appear TEAMER reduces the costs for environmental monitoring since open-water testing facilities most likely have some form of umbrella federal and state environmental permits. TEAMER has 34 facilities with more than 100

different capabilities but only offered seven requests for support from 2020 to present of which all appear to be lab/flume tank projects. No open-water requests for support occurred. Actual outreach for end users is unknown.

- The project is impressive in its breadth, reach, and value, and its relevance to the marine energy community was well articulated in the presentation. The reviewer congratulated the program on the extended network of developers and organizations supported to date. The reviewer recommended considering the addition of webinars about the projects to the list of dissemination activities.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by providing a formal mechanism (requests for technical support) for marine energy developers to gain access to specialized expertise and testing facilities. This will accelerate the development of marine energy devices. Support provided by TEAMER Facility Network members (numerical modeling and analysis, laboratory and bench testing, tank/flume testing, and open-water testing and support) is crucial to the successful development of a marine energy device and is the type of specialized expertise that developers are unlikely to have in house. The program also helps the TEAMER Facility Network members maintain and sharpen their expertise and support faculty and students. The success of the program is demonstrated by the 78 projects currently supported through six requests for technical support noted on slide 10. Other indicators of success from slide 10 are the 49 technology developers/organizations supported and the 25 organizations supporting current requests for technical support. The 74% TEAMER Facility Network member utilization rate is a healthy number, and it is good to see that the TEAMER network director will work to increase it in the future. User engagement is executed through workshops and training opportunities. The reviewer did not identify any weaknesses or recommendations.
- The TEAMER program is an effective way to ensure that there is a good understanding and collaboration between test facilities in the United States. It provides testing expertise and access to facilities for marine energy research. The program also looks to leverage world-class expertise and provide a repository for lessons learned. The process includes a request for technical support and has had 34 applications so far. There is a clear focus on wave energy technologies, which is indicative of prevailing technology development in this geographic region. There was a lack of clear go/no-go frameworks; however, a strong project plan was presented. It would be useful if more end-user engagement was undertaken to strengthen the experiences and knowledge generated by beneficiaries of the TEAMER program. It is important to note that the premise of providing this sort of coordination and access will reduce cost, time, and risk to developers of devices and components and remove duplication of capital spend on areas that have already been investigated. This is positive, but the team should ensure there is broad dissemination of the capacity of the project to deliver. National-level coordination of data, knowledge, and expertise should support technologies at low TRL levels and also potentially remove barriers to project development. It will be critical to ensure there is a legacy here and that repositories and databases are well used by not only the request for technical support applicants but the broader marine energy sector and stakeholders.

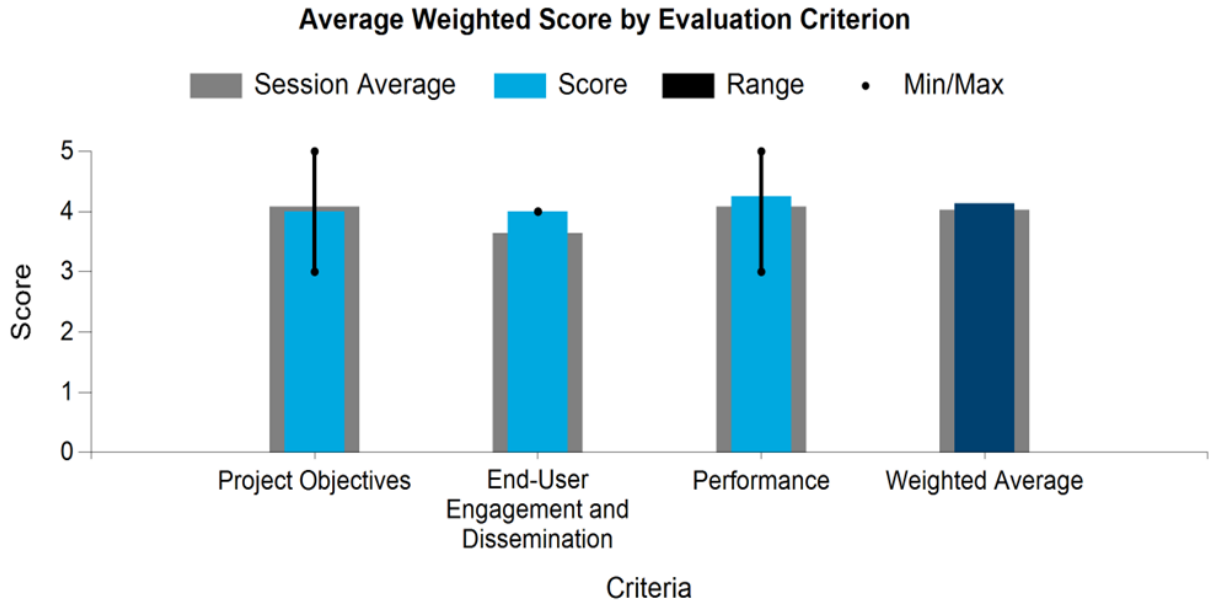
National Marine Renewable Energy Center Infrastructure Upgrades

University of Washington

WBS:	EE0008955
Presenter(s):	Brian Polagye
Project Start Date:	04/01/2020
Planned Project End Date:	03/31/2023

Project Description

Since they were established in 2008, the NMRECs have supported a wide range of research, development, and testing in collaboration with academic, national laboratory, and industry partners, leading to outcomes that have advanced the foundational understanding of marine energy systems. The wide range of upgrades being undertaken across institutions affiliated with a NMREC are intended to maintain and expand that research capacity in response to end-user needs. These upgrades include new capabilities that address gaps and "pain points" in existing infrastructure, replacing infrastructure that has reached the end of its service life, and forward-looking investments that support the next generation of student researchers. When complete, these upgrades will enable research to understand the fluid-structure interactions for multiple types of marine energy converters, expand the range of conditions that can be generated in laboratory experiments, reduce barriers to testing marine energy systems in open-water environments, and facilitate testing of marine energy systems with blue economy applications.



Aggregated Reviewer Comments

- This project has identified gaps in marine energy industry needs for WEC and CEC devices both in laboratory and open-water infrastructure. Each NMREC had vastly different needs and capabilities. These upgrades seem to be more designed on the academic end than for specific end-user/industry needs in reducing barriers to device testing and monitoring. These upgrades have more to do with R&D than providing necessary testing data for device monitoring and reducing barriers for in-water grid devices. The identification and outreach for end users/industry are light and more regionally based, and there appears to be some overlap with other WPTO projects. This project is focused more on infrastructure needs for marine energy R&D and laboratory testing; yes, it will potentially reduce barriers for developers but will have more of an academic research use.

- It would have helped the reviewer to have some sense of the breadth of the need fulfilled by each of these upgrades and a clearer understanding if the upgrades fulfill a need versus a gap. It was unclear to the reviewer whether the outreach to identify gaps and needs was sufficiently broad so as to include representatives of industry. The presentation indicated that it was the universities affiliated with NMREC that collaborated to identify the infrastructure priorities. The efforts identified as internal capacity building are important and well selected as are the end-user engagements as this project moves to completion.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by working with all the NMRECs to improve facilities available to marine energy developers. By establishing a coordination mechanism among the NMRECs, the duplication of capabilities is minimized and each NMREC can improve its area of expertise. This makes the best use of scarce development funds. Gaps were identified first to ensure selection of the most useful upgrades. Upgrades were made to laboratory, computational, and field capabilities and an equipment pool of environmental sensors. New capabilities are already being used at the Tanana River test site of the University of Alaska Fairbanks. Another strength was the coordination with TEAMER to make new capabilities available to developers. User engagement is executed through coordination with TEAMER, conference presentations, and webinars. The reviewer did not identify any weaknesses or recommendations.
- The NMRECs include five universities within this project that are upgrading, enhancing, and future proofing their facilities in response to end-user needs to support marine energy systems research. The receiving institutes reviewed both their own capability gaps and feedback from end users to identify key areas of enhancement. It is understood that there have been some delays in facility upgrades due to the global health pandemic with some underspend attributable to issues with larger fabrication delays. The project is associated with TEAMER, which should ensure significant uptake and use of the facilities. The tasks within the project are not serialized, and the project should consider how risk management can be effective in the program. It would be useful to also future proof the facilities to consider not only wave technology, components, or monitoring equipment but also any new and innovative blue economy solutions that may be able to make use of the facilities and infrastructure. The project should ensure that its outreach is not confined to academic peer review but is extensively disseminated across the industry, stakeholders, and potentially other areas of blue economic development. This should help maximize the use of the facilities and potentially create longevity in the project.

Current Turbines Mobile Testing Vessel

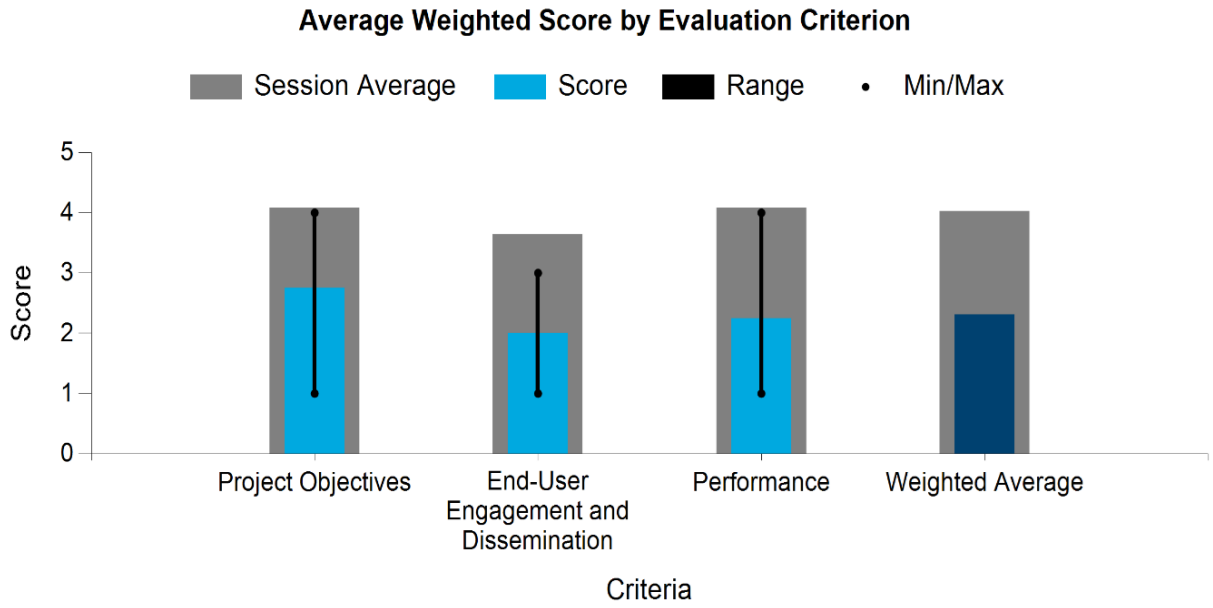
Idom, Inc.

WBS:	EE0009452
Presenter(s):	Alvaro Garcia
Project Start Date:	10/01/2021
Planned Project End Date:	03/31/2023

Project Description

As the marine energy industry continues to advance technologies toward commercialization, there is an ongoing need for testing at all stages of development. The slow pace of design and in-water testing cycles is further exacerbated by the limited availability of testing infrastructure at various scales, complex and time-consuming permitting processes, and expensive environmental monitoring. These challenges have limited the ability of turbine technology developers to assess the performance of devices and components, innovate solutions where necessary, and deploy the next generation of devices. CEC prototypes must be tested in real-world environments to fully characterize and validate the performance, reliability, maintainability, and potential environmental impact. Existing U.S. testing infrastructure can only accommodate small-scale CECs with rotors between 2 and 3 meters in diameter. There is a need for a mobile testing capability that can accommodate CECs with up to 8-meter diameter rotors for testing turbines in a wide range of conditions.

With the aim to help propel the development of marine energy technologies toward the commercialization phase, this project is aligned with DOE's objective of filling the gap on testing infrastructures for CECs in real conditions at large scales. It enables developers to be focused on technology development and power performance-related issues, offering a mobile test vessel that can be shared since it can be easily transported to different sites depending on the end-user needs. This will help reduce the cost of technology development associated with testing, infrastructure, and foundations. This project aims to design, test, fabricate, and operate a mobile test vessel to be used as mobile test infrastructure for CECs.



Aggregated Reviewer Comments

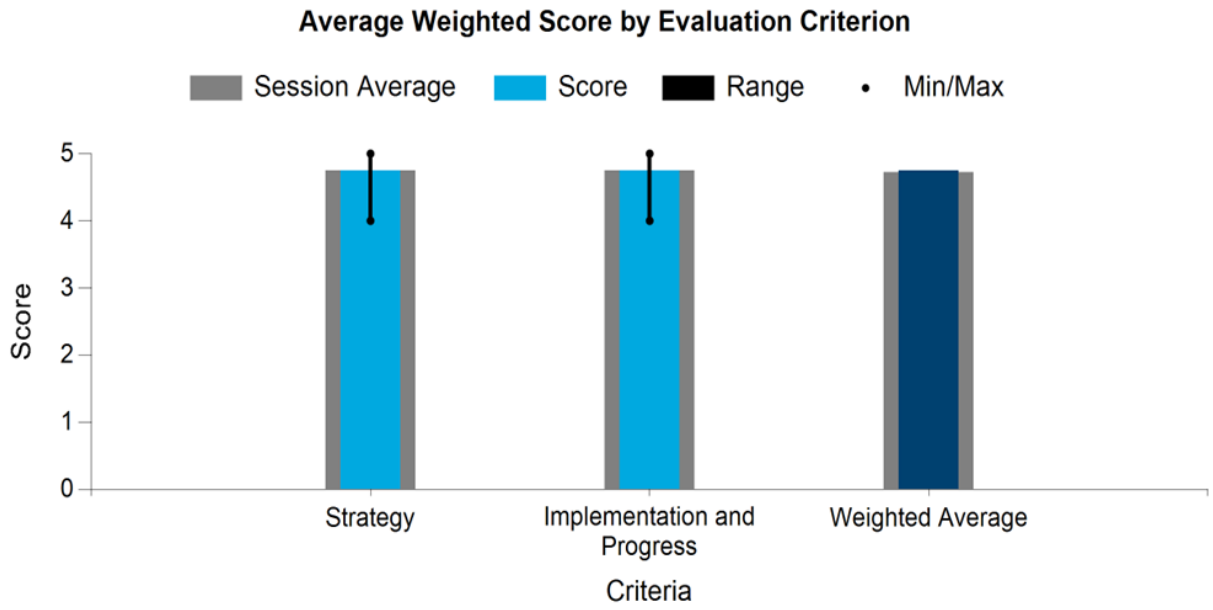
- This project has identified the points of go/no-go well on its timeline and a well-thought-out objective approach for the design of the project. They have identified possible and potential gaps needed for testing marine energy CEC devices; however, the identification of needed end users/industry is lacking along with the adaptability of the vessel to different CEC devices, use/transport to specific study areas, and who would bear the cost of use. Additional barriers would come up for different sites such as mooring systems, National Environmental Policy Act, and USACE and state regulatory environmental permitting. There are critical concerns with this project on end users, adaptability for device testing, mobility to locations for device testing, and costs associated with all aspects (such as O&M, crew, and berthing).
- The low scores for this project are a reflection of the fact that while the project is intriguing and interesting, it was not sufficiently clear that the project fulfills a need articulated by the marine energy community. The presentation of the project objectives, approach, and timeline were helpful in understanding the scope of the project and its undertaking. However, although the concept of a mobile testing platform is intriguing and is a gap in the current availability of testing infrastructure, the end-user interest for such a project has not been identified or sufficiently articulated, and it is unclear if the project fills a need (as opposed to a gap). Given that use of the platform would require additional engineering by the developers, the cost-benefit of this project needs to be clearly articulated along with the costs, additional engineering, and fabrication for connectors for developers to make use of such a platform and indicate that this is the right solution for testing large turbines.
- This project directly addresses Marine Energy Program Activity 3: Reducing Barriers to Testing by developing a craft to facilitate the testing of CEC technologies. It also allows for convenient environmental monitoring. Collected data will be uploaded to the MHK data repository. This will allow the entire marine energy community to benefit from the results of this project. The project approach is logical and well considered as described in the specific items listed under the conceptual, preliminary, and final designs of budget period one. The division of tasking of the key stakeholders is comprehensive. Regarding weaknesses, the reviewer inquired if the test vessel has enough customers. Comprehensive user engagement is required. The reviewer also inquired if the vessel will be able to accommodate a wide variety of CECs. The reviewer recommended the team select a competent naval architecture firm with experience designing vessels for the ocean environment.
- The project has recognized the need for testing infrastructure for tidal energy convertors (or CECs) by proposing the design and construction of vessels that will have the capability to test turbines in the range of 2 meters to 8 meters in diameter. This is a three-year program that started in the 2022 fiscal year. The project has a very clear decision process and project plan, which was well articulated. It is understood that conceptual design is ongoing; this should be very closely linked to end-user requirements. It was not clear how many end users had expressed a requirement for the facility or how the diversity of tidal energy environments (including turbulence and other site-specific issues) could be better understood by utilizing a vessel such as this design. If there is uptake, the vessel could be useful in reducing the timeline of design iterations in multiple tidal flow devices and could provide the ability to validate cost and performance; however, it is not yet clear if this is achievable.

Marine Energy Data Access, Analytics, and Workforce Development

Activity Area Evaluation

WPTO

WBS:	2.4
Presenter(s):	Allison Johnson



Aggregated Reviewer Comments

- Regarding the strategy, the program has a defined strategy that reflects both the needs of the industry and the stakeholders and challenges faced. The key results from each of the four activities—especially around testing of devices both in the lab and on site and improving regulatory efficiencies—are key to move the industry forward. Focusing on the Data Access, Analytics, and Workforce Development projects, while all the projects are very impressive with useful outputs being produced, at the moment there is not enough evidence that these projects have resulted in improved regulatory efficiencies or reduced uncertainty around environmental impacts from a regulatory perspective. Moreover, it is not clear if the tools/methods created in these projects are likely to be widely implemented in the future for decision making. However, this might be due to the early stages of the projects given that all the tools have a huge potential to streamline permitting and licensing if widely used by developers and regulators. Specific to the Workforce Development projects, it is unclear if the program will attract people who do not have a previous interest in the area or knowledge of the field. It would be useful to clarify with whom the resources are being shared.
- The scope of the Marine Energy Data Access, Analytics, and Workforce Development program is well aligned with the objectives of WPTO's MYPP. Tools developed through this project, like PRIMRE, provide relatively easy access to data and information for end users (e.g., researchers, developers, and regulators) that would otherwise be difficult to locate and compile. In doing so, this project facilitates the development of the marine energy sector in the United States and assists in the global expansion of innovations that are needed to ensure a sustainable transition of our energy supply to marine renewable sources. Crucially, this work has been informed by prior engagement and consultations with industry and stakeholders and incorporates feedback from these groups in addressing sector needs. The workforce development aspects of this project (programs, products, outreach, etc.) are also of tremendous value for the future expansion of the marine energy sector. Overall, this program is well aligned with WPTO's overall strategic direction.

- The Workforce/STEM strategy is well thought out and progressing nicely from when it began in 2019. The stakeholder feedback is especially helpful, and it is good to see that the program is attempting to redress the gaps identified in the survey. The reviewer identified some questions and concerns that may or may not be addressed and just not identified in the presentations provided. The education and workforce aspects of the program seem very bifurcated. A lot of educational content is being created, but it is not clear how this connects to opportunities for potential employers and employees other than as a resource. The reviewer urges the program to be mindful of connecting them more and beyond MECC and fellowship opportunities to realize a larger potential workforce interested in powering the blue economy. Perhaps this takes urging NHA to provide dedicated staff and resources to marketing and workforce development as the industry needs to have heavy skin in the game to address retirement and diversity challenges. It is not clear how industry is integrated with DOE and invested in this issue. It is unclear who is presenting and attending the bimonthly dialogue and how outreach is done. MECC and fellowships engage only a limited number of students and potential employees in marine energy. Students can participate in MECC only if their universities and professors are prepared to dive deep into marine energy. There are so many more students who, if exposed to marine energy, would be interested in working in it. There is a big leap between these targeted efforts and the many that the PRIMRE pages purport to engage. It takes another level of effort to engage university career services offices and student clubs (e.g., Society of Women Engineers) to expand who is invited to attend the bimonthly dialogue and exposed to PRIMRE. Many undergraduate majors have the skills to work in marine energy, even if they are not taking the curricula being designed by the program. Students are keenly interested in existing internship and job opportunities, so connecting information to actual paid work is the best way to advertise marine energy's opportunities. Potential employees may visit PRIMRE if a job or internships exists but are unlikely to find or visit PRIMRE by itself. (Note: A Google search for marine energy jobs did not point to PRIMRE. First was the Marine Corps, followed by Indeed.) While it is nice to have a DEI outreach strategy, marine energy is at such an early stage that it is most important to have an inclusive strategy that is not solely focused on women and minorities (unlike hydropower). Be mindful of what educators need at each level. K-12 teachers need to understand the energy system and clean energy's role in that. It is good that marine energy materials are being woven into existing curricula rather than as standalone materials that the program would expect individual teachers to grasp. Community college and university professors have their own needs, which often trump what students/potential employees want/need. Going beyond classroom materials is needed to engage students beyond MECC and the fellowships. It is not clear how much the program is involved in workforce and education efforts at EERE and DOE and with other U.S. government offices. It is good that a DOE federal employee is engaged in the workforce tiger team. This is a worthwhile effort to stay focused on to maximize exposure and opportunities. There are a number of missing ingredients from other EERE (except MECC), DOE, and industry resources. For example, consider connecting with other key U.S. government resources like the U.S. Department of Labor resources such as the Renewable Energy Competency Model. For MECC, consider launching a (private) MECC alumni association on LinkedIn, which is condoned by the U.S. government. (Note: This was done for the Solar Decathlon Alumni Association and blessed by the Office of Management and Budget.)
- Creating the MECC was great, and the development of other competitions is excellent. PRIMRE is an excellent tool to disseminate scientific data over a broad range disciplines. If possible, the reviewer recommends continuing international collaboration and incorporating with DEI and multidisciplinary education.

Project Evaluations

Marine Energy STEM and Workforce Development

NREL

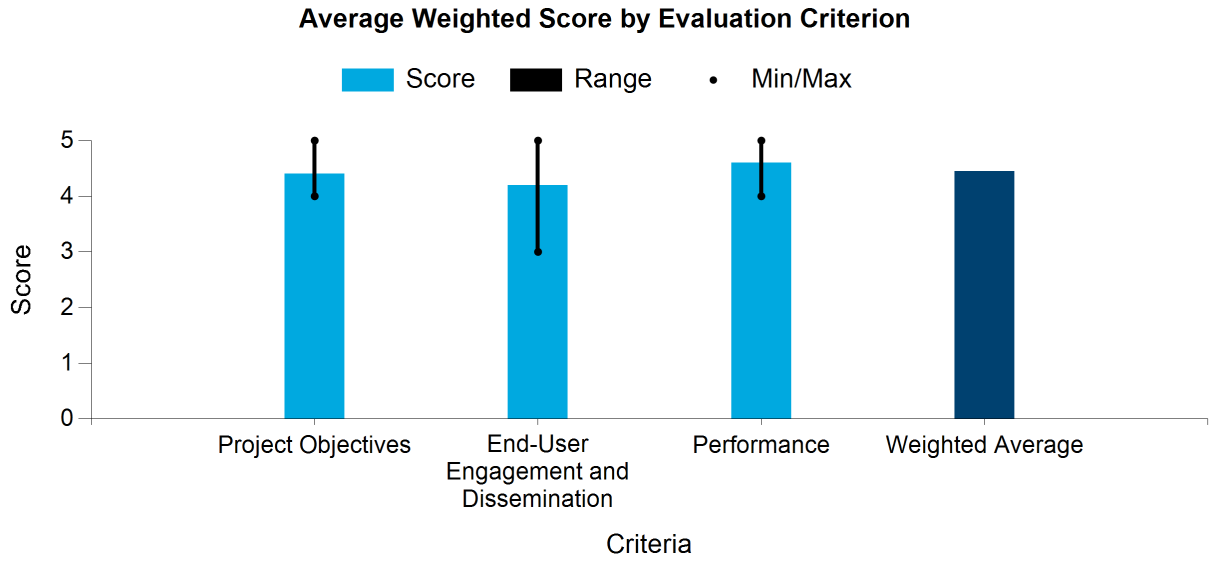
WBS:	2.4.2.405
Presenter(s):	Arielle Cardinal
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2020

Project Description

Due to the nascent stage of the marine energy industry, there is not currently a steady flow of research, funding, or jobs in this sector, but with growing interest in marine energy, there is an opportunity to grow a new domestic marine energy workforce in the United States.

In partnership with WPTO, NREL has been working to help grow the marine energy workforce of the future by strengthening the STEM workforce pipeline. This work has included deep engagement of the marine energy industry and academia to understand their challenges. The project team has sought student perspectives on the marine energy industry and availability of educational courses, and found strong student interest in marine energy but less awareness of what the industry has to offer and how to pursue a career.

To address these challenges, the project team's work has focused on improving accessibility and distribution of educational materials and increasing awareness of marine energy as a renewable energy career field. These efforts have also served to increase the level of public knowledge on career opportunities in these sectors and help identify typically underserved communities that may benefit from marine energy career pathways. The project team is developing resources to include a publicly available web portal with information on the marine energy workforce, educational materials including curricula and digital applications, research, prizes, competitions, networking, and career building information on the STEM web portal: https://openei.org/wiki/PRIMRE/STEM.



Aggregated Reviewer Comments

- The project matches WPTO Data Access, Analytics, and Workforce Development objectives to support development of new educational resources where gaps currently exist, including curricula and training, to support an evolving marine energy workforce and increase awareness of marine energy opportunities. Including more information regarding marine renewables in school curriculum, especially at a high school level, is an excellent idea to increase awareness of the field as potential career path. It was not clear with whom the material (marine energy workforce opportunities and career paths) is being shared at university levels. Depending on with whom these materials are being shared, there is the risk that they attract people who already had a previous interest in the field rather than increase the number of people interested. It would be useful to share this over multiple disciplines, e.g., business, marketing, marine sciences, computer science, etc., which may be the case, but it is unclear from the presentation. The project has made appropriate progress toward addressing the project objectives with the development of useful material. However, critical go/no go decision points were not addressed in the presentation.
- The Water Power STEM Workforce Development project for marine energy has highlighted a critical gap in the development and implementation of marine renewable energy technologies—the absence of training programs to maintain and expand a skilled labor force to support the marine renewable energy sector. Developing a pipeline for skills that are relevant to the design, installation, and maintenance of marine renewable energy devices, as well as the knowledge and capacity to examine environmental and ecological effects of these devices, are crucial for the future growth of the sector in the United States. This program is taking an innovative three-pronged approach to address this issue and is in line with WPTO's goals of advancing the marine energy sector. There is an absence of curricula focused on marine renewable energies at all levels of primary, secondary, post-secondary and graduate level education, and the work being done through this program will help support growth of the marine renewable energy sector and ensure its success. The program goals are relevant, meaningful, and achievable, and the broad scope of engagement activities (e.g., collegiate competitions, after school programs, Renewable Energy Discovery Island) undertaken to date highlight the success of this work. Given the magnitude of the task ahead, the reviewer believes this program should continue to be supported indefinitely.
- The reviewer noted that the evaluation criteria did not make a lot of sense for this project, so it was difficult assigning scores for a non-R&D project. The three-pronged approach makes a lot of sense and is presented in a good way. The Marine Energy STEM portal contains helpful information and is presented nicely. Conducting a school survey is an excellent first step to figure out the baseline of educational offerings. MECC is an excellent way to expand knowledge of and recruit for the still nascent marine energy industry. The outputs and planned future work are all well thought out and strategic. In particular, working with industry is in the planned calendar and needs to be the center point of this effort. It is not clear how much the educational content being developed is aligned with workforce and education efforts at EERE and DOE and with other U.S. government offices. The reviewer recommended connecting with other key U.S. government resources, like Department of Labor resources such as the Renewable Energy Competency Model. The reviewer noted that this identifies skills needed until reaching water. It is nice to see that the MECC is included in the EERE STEM and Education portal, but it is not clear that effort is made to make sure that effort goes beyond populating the Marine Energy STEM portal. While the Marine Energy STEM portal is nicely done and well laid out, there is nothing mentioned about efforts to work with other EERE renewable energy programs to present a common renewable energy approach to workforce. This is especially important in the K-12 space as effort should be on getting kids interested in renewable energy and providing info about marine and hydropower as part of that as a secondary concern. Educators cannot be expected to be experts on individual renewable energy technologies, especially since it would be enough for them to understand the energy industry and system and how renewable energy fits into that. The program is partnering with excellent organizations (KidWind, the National Energy Education Development Project, and Bonneville Environmental Foundation), and it is good that content is being designed

to weave into existing curricula. Overworked educators cannot be expected to wade through information only specific to water power technologies. The reviewer noted that they attended the Clean Energy Workforce conference that KidWind led. While it is a good conference, it is clear that too many participants represented one technology, which was confusing to educators who should not be advocating for one renewable energy technology over another, and education should concentrate on understanding the energy system and how renewable energy in total fits into that. It is great that a number of meetings will be held with industry players, but there was not enough information to understand what happened in the monthly dialogue series. It would be good to have representation beyond the Hydropower Foundation. There is also not enough information to know if coordination is happening between industry players and undergraduate career services and clubs (such as the Society of Women Engineers) that university students look to for career information and active engagement. The advisory committee charter does not seem to be focused on creating internship and related opportunities for community college and university students. Current students will only become interested in pursuing a career in marine energy if there are work opportunities. The reviewer noted focusing on DEI may not be as necessary for marine as hydropower.

- This is a wonderful program and important for the development of the marine energy sector. The K-12 and broader community outreach is well organized and well considered work. The programs are appropriate, and the wide reach is impressive. The reviewer sees value in having a goal to be deep rather than broad for the university-level work. Supporting undergrad and graduate students to complete a big project in marine energy has a potentially big impact on the wider industry. Helping some universities that have shown or invested in marine energy expertise to build mass capacity of marine energy work in their institutions is very important. The reviewer recommends supporting participation in international competitions, travel funding for conferences and international collaborations, and student organizations that have already been started in the sector.
- Overall, the team seems to be doing an excellent job and is making significant progress. In particular, its efforts appear to be steadily building general awareness of marine energy. Enhancing the number of students with interest in marine energy is a good goal. The team should consider ways to appeal to people's emotions as well people's intellect, as oceans and energy demand equal investment in both domains. The reviewer recommends the team consider requesting further support from WPTO to establish a professional society dedicated to marine energy engineering and science, starting with student chapters in universities and local chapters.

MHK Data Products and User Community Development (PRIMRE)

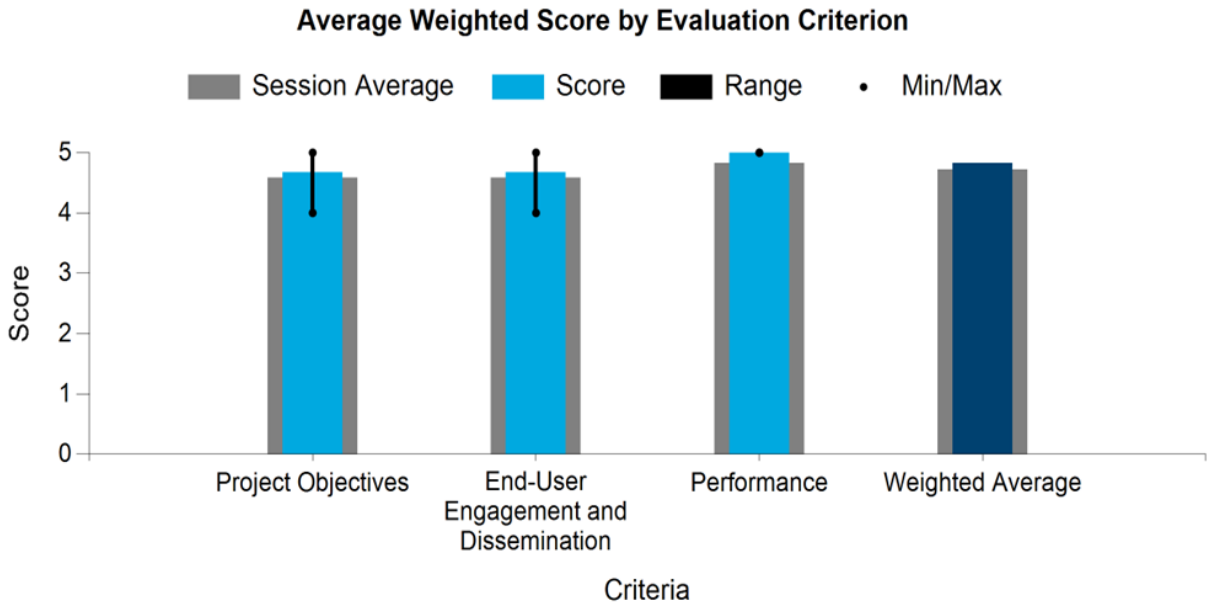
PNNL, NREL, Sandia

WBS:	2.4.1.601
Presenter(s):	Andrea Copping
Project Start Date:	10/01/2016
Planned Project End Date:	09/30/2021

Project Description

PRIMRE is an integrated system that brings together all data and information related to marine renewable energy in the United States with strong international components and links. PRIMRE acts as the portal to seven Knowledge Hubs that each contain a particular type of marine energy data or information.

Information within all seven Knowledge Hubs can be accessed with a one-stop search in PRIMRE and by navigating the individual Knowledge Hubs. PRIMRE allows ready access to some key WPTO-funded projects that are related to one another through an organizational scheme known as Signature Projects and acts as a platform for value-added material that includes lessons learned from the marine energy industry. As an open-access portal, PRIMRE encourages use by all individuals, large and small institutions, and underserved communities. Moreover, PRIMRE is guided by an external Steering Committee and maintains an active outreach and engagement program to bring the marine energy community together on the use of data and information.



Aggregated Reviewer Comments

- The project aggregates and provides access to marine energy data and informational resources. It is a fantastic tool and very impressive. Having all resources centralized in one site makes it easier for anyone interested in the field (e.g., academics, developers, regulators) to access the information. It is well disseminated both nationally and internationally. The reviewer's only comment is that the tool would benefit by having more information regarding international projects (e.g., lessons learned, methodologies used, data publicly available), although the reviewer understands this might be out of the project scope. Future work objectives are clear. Overall, this is an amazing project.

- Compiling and providing access to data and information from myriad WPTO-funded projects for end users (e.g., researchers, developers, and regulators) in a centralized, searchable repository (PRIMRE) is an ambitious project. This team has executed that task masterfully and continues to find ways to integrate additional information into PRIMRE to facilitate the growth of the marine energy sector in the United States. This tool has tremendous inherent value not only for end users in the United States but is directly applicable for the growth of the sector globally. This project plays an important role in WPTO's overall program by providing access to data and information from seven complementary knowledge hubs that are required for the continued growth of the marine energy sector in the United States. Project objectives are reasonable and attainable, and the project timeline is feasible given the excellent progress made to date. The variety of means by which the project team is disseminating information to end users is commendable. The project team should be congratulated on a job well done.
- The future development of outreach and engagement, such as using social media platforms, is excellent! PRIMRE is an exciting tool, and its progress is remarkable. Having an external steering committee is great. If possible, the reviewer recommends including non-WPTO-funded projects in data sources.

International Environmental Data Sharing Initiative (Annex IV Project and Tethys Database)

PNNL

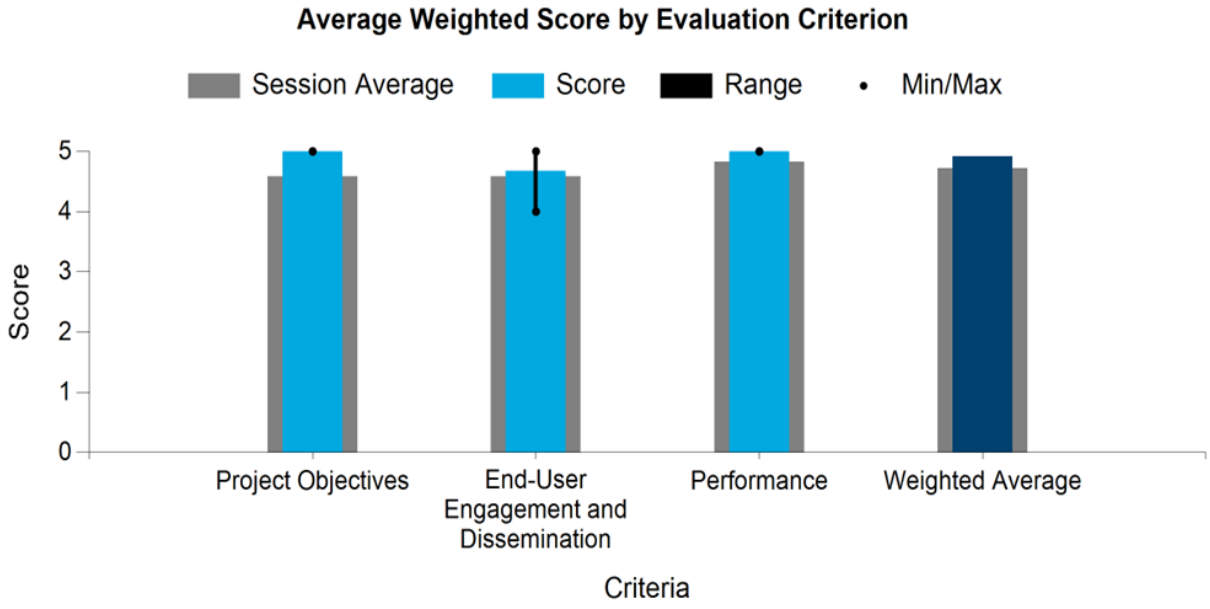
WBS:	2.4.1.602
Presenter(s):	Andrea Copping
Project Start Date:	09/30/2016
Planned Project End Date:	09/30/2021

Project Description

PNNL implements the United States-led OES-Environmental initiative, an IEA OES task supported by 15 other nations, that collects, synthesizes, and disseminates research and monitoring efforts on environmental effects of marine energy. This information, gathered in the Tethys Knowledge Base, helps to reduce the scientific uncertainty that has slowed the development of marine energy projects. OES-Environmental represents the most comprehensive effort to gather data and bring together the marine energy community around potential environmental effects of marine energy development worldwide.

PNNL developed a robust outreach and engagement strategy to bring relevant scientific information to and connect with marine energy audiences in the United States and internationally. Data gaps are examined in cooperation with stakeholders; strategies are developed (e.g., risk retirement pathway and guidance documents); and appropriate studies and monitoring programs are proposed to help fill important data gaps.

The outcomes of this project support the development of reliable and cost-competitive marine energy technologies by providing access to the data and information needed to reduce critical permitting barriers. With greater certainty on the need to collect data that is proportional to the environmental risks from marine energy development, the industry can move forward sustainably.



Aggregated Reviewer Comments

- The project contributes to the Marine Energy Program Activity 4: Data Access, Analytics, and Workforce Development. The Tethys platform provides a global overview of environmental research being conducted, and The State of the Science is a fantastic document (both the full report and the summaries) that can be used by a wide variety of people with different levels of interest. Personally, the reviewer uses Tethys almost daily to keep

up to date with the latest research and finds the knowledge hub intuitive and easy to use. The project has a sound stakeholder and/or end-user engagement strategy with the multiple dissemination paths including email blasts. Overall, this is a fantastic project.

- Uncertainty about the environmental effects of marine energy devices on ecosystems and ecological processes is an important barrier to sector growth in the United States and around the world. The international data-sharing initiative performed under OES-Environmental has done a superb job of identifying multiple stressor-receptor interactions that are of concern, leading the development of State of the Science reports that compile and synthesize the most recent research on those interactions, moving toward "risk retirement" for some stressors, and exploring opportunities for data transferability between jurisdictions to reduce redundancies and facilitate the installation of marine energy devices. The team has done a fantastic job with international engagement since the inception of this project and secured participation from 16 countries. The project objectives are well aligned with WPTO's program goals, and the results to date are tangible and will assist in reducing barriers to testing and facilitating device installations. The development of Tethys provides a searchable repository for information about environmental effects, and the dissemination of relevant information to users via the Tethys blast is an excellent outreach tool. The project has recently expanded its purview to new research topics focused on system-level effects and highlights the progressive thinking that underlies the team's success. This is truly excellent work. To consider in the project going forward, the reviewer notes regulators are not always accepting of the results of environmental effects studies for devices conducted in other regions with respect to their applicability to project permitting in their jurisdiction. While the results of studies may not be transferrable, the methodologies underlying the study likely are, so an effort to compile and make accessible methodological approaches for understanding environmental effects of devices may provide another means to facilitate device testing and project permitting for marine energy devices.
- Engagement with regulators to limit the time to deployment is highly desirable. This team should be commended on the ability to transfer data across different disciplines. Moving forward, the reviewer recommends the team consider identifying the needs and requirements of different types of marine renewable energy.

Grid Value Proposition of MHK

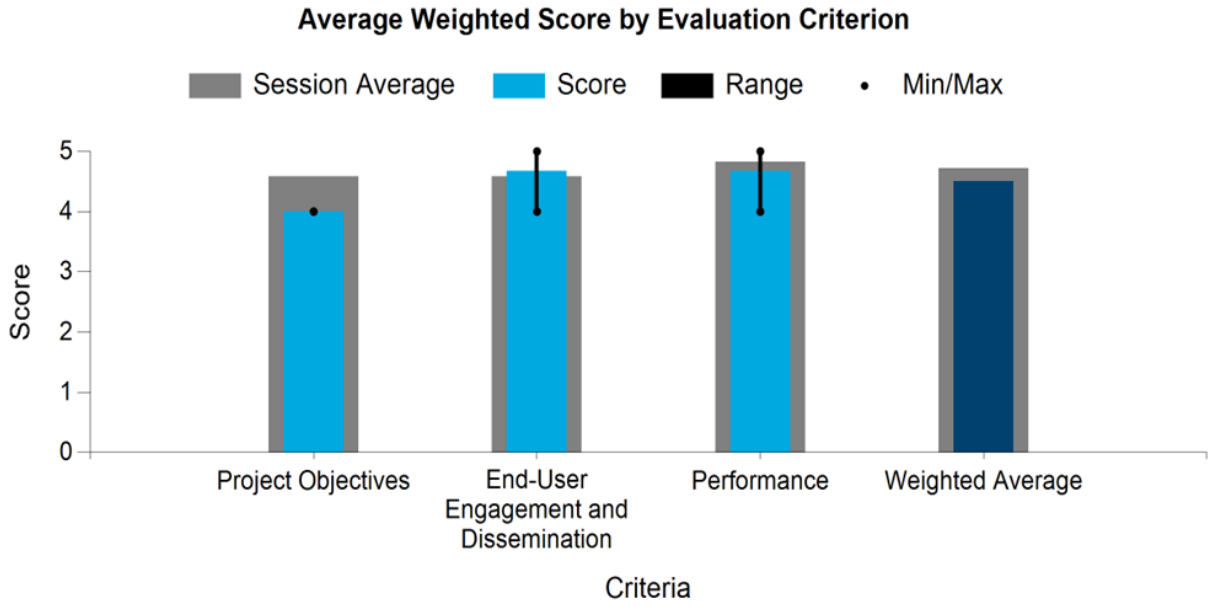
PNNL, NREL

WBS:	2.4.3.603
Presenter(s):	Levi Kilcher; Dhruv Bhatnagar
Project Start Date:	10/01/2018
Planned Project End Date:	09/30/2021

Project Description

A study commissioned by DOE estimated the nation's annual marine energy potential to be approximately 2,300 terawatt-hours per year across the 50 states or more than 57% of U.S. electricity generation in 2019. However, the marine energy industry still faces hurdles to commercialization. While high costs relative to wind energy and solar power remain a key challenge, other hurdles relate to marine energy's value streams not being well characterized and not captured by traditional energy comparison metrics like LCOE. To address this challenge, this project undertakes several types of analyses to identify and illustrate value propositions for marine energy resources. It provides a fresh framework for considering electric system benefits based on unique marine energy attributes and provides analyses illustrating and quantifying those benefits.

Although the technology remains in a development stage, many potential opportunities exist for the deployment of marine energy technologies both in the near term and within typical utility planning timeframes (i.e., up to 20 years). From a resource and technology perspective, marine energy resources can deliver distinct and valuable benefits to different configurations of the grid, whether the bulk system, isolated distribution systems, or remote communities, islands, and microgrids. Marine energy resources can be valuable in increasing technology diversity in a generation portfolio, providing energy where it is otherwise difficult to come by, supporting local resiliency, complementing and being complemented by other resources, and avoiding land constraints.



Aggregated Reviewer Comments

- The project matches WPTO's Data Access, Analytics and Workforce Development objective by providing a method to identify the potential value that marine energy devices present, thus accelerating the understanding of marine energy's value and ensuring marine energy technologies are considered in energy planning. The Grid Value Proposition of Marine Energy: A Preliminary Analysis document is useful and has meaningful applications.

However, it is not clear from the presentation how this method was received by target audiences. It was unclear to the reviewer how likely this is to be adopted in the future. The scope of future work seems appropriate for the completion of the overall objectives of the project; however, go/no-go decision points were not clear.

- This project provides a new way to look at marine energy projects—from a value proposition perspective rather than the more typical (and perhaps myopic) cost perspective. The reviewer finds this project and its approach to be novel and to provide an innovative way to evaluate the contribution of marine energy projects to the power grid at a variety of spatial scales. This is a good project that is in line with overall WPTO objectives. The outputs are meaningful to the continued development and implementation of marine energy devices, and the level of engagement and dissemination of results has similarly been good. This project provides an honest and balanced approach for understanding the value and contribution of marine energy to future energy needs.
- The reviewer enjoyed the use of grid value proposition, and the presentation, as a whole, was enlightening. The assessment of environmental impacts is highly desirable. The reviewer appreciated that the team included an abstract in its submission. Updating wave energy resources for array concepts is needed and highly desired.

Improving the Efficiency and Effectiveness for MHK Permitting: A Toolkit and Engagement for Success

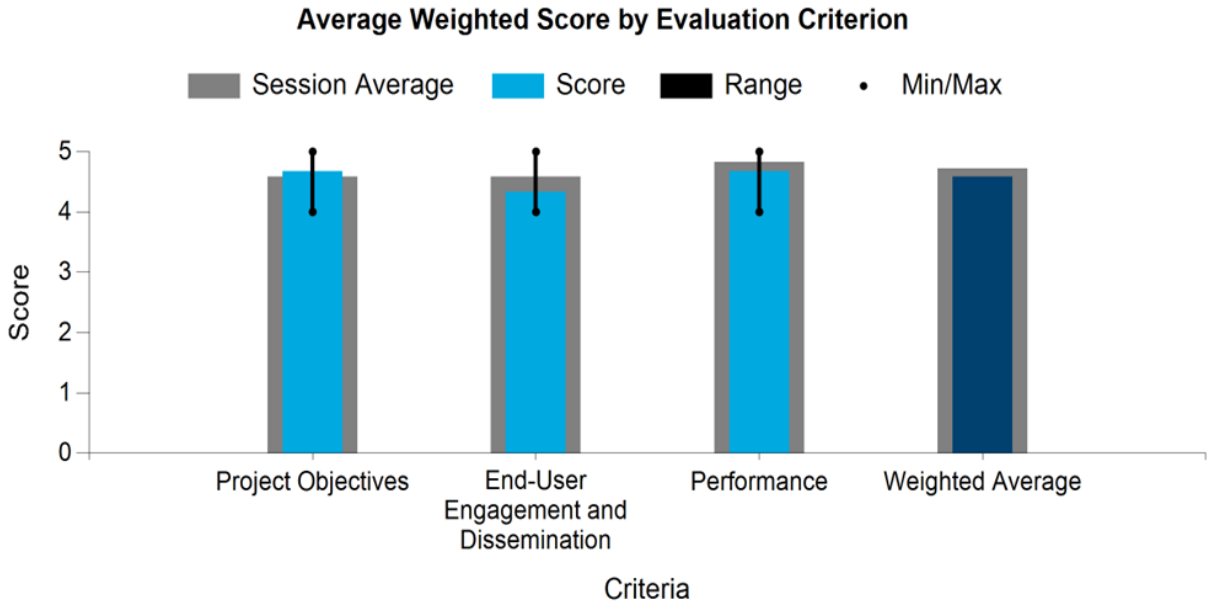
Kearns & West, Inc

WBS:	EE0008634
Presenter(s):	Zach Barr
Project Start Date:	06/01/2019
Planned Project End Date:	12/31/2021

Project Description

The Marine Energy Environmental Toolkit for Permitting and Licensing aims to increase regulators' and developers' understanding of marine energy projects and potential environmental effects to reduce the time and costs required to permit and develop projects. Existing environmental, spatial, regulatory, and scientific data is compiled and distilled into an easy-to-navigate, one-stop-shop webpage organized by technology, stressor, receptors, project phase, consequences, and management measures.

Existing open-source information is used to make the toolkit a transparent and sustainable tool for developers and regulators in the permitting and licensing process. The toolkit is a long-lasting, sustainable solution that can be updated automatically from the existing sources of information. It can also include future applications to address stakeholder needs. The toolkit was developed using a user-centered design with a focus on regulators' needs to gain buy-in for the toolkit's use during the permitting and licensing of a marine energy project.



Aggregated Reviewer Comments

- The project meets the Data Access and Workforce Development activity by aggregating and providing access to marine energy data and informational resources, particularly to reduce cost, time, and uncertainty around the marine energy permitting processes. The toolkit is an amazing tool for developers when applying for permitting by providing a step-wise guide to the regulatory process for different types of marine energy projects as well as timelines from other projects and potential environmental impacts. Early engagement with regulators means the tool meets regulatory needs. Based on the feedback, it seems the tool is a huge success. However, it is not clear at the moment if the tool created is likely to be widely implemented in the future for decision making, but this will likely be clearer after the pilot test. Well done!

- This project advances the marine energy sector by providing a tool for developers and regulators with respect to permitting and accessing environmental effects data. The objectives of the project are well founded and in line with WPTO aspirations, and the approach is reasonable. The project is progressive in that it builds on prior public-sector investment through WPTO, and the expected outputs will be useful as indicated by user testimonials. End-user engagement was employed to assist with the design of the tool, something that was repeatedly highlighted as being important during the program review, so that's particularly encouraging. Outreach and engagement have also been good. Overall project progress and accomplishments are good. This project should assist industry and regulatory agencies with project permitting processes.
- This toolkit is highly useful, and the reviewer is impressed with its development. The reviewer inquired whether the type of people who use the software for workforce development can be measured. This can help broaden the audience and identify and address the needs of new hires. The reviewer was impressed by the vast amount of novel data.

Appendix A : Peer Review Agenda

Hydropower Program Peer Review Agenda

July 25–29, 2022

Hydropower Program Opening Plenary

DAY 1 – MONDAY, JULY 25, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:30 AM	WPTO Overview	WPTO	Jennifer Garson
10:30 AM	10:45 AM	Peer Review Introduction	WPTO	Ali Hewett
10:45 AM	11:30 AM	Hydropower Program Overview	WPTO	Tim Welch
11:30 AM	11:40 AM	BREAK		
11:40 AM	12:05 PM	Data Access, Analytics, and Workforce Development Activity Area Overview	WPTO	Corey Vezina, Allison Johnson
12:05 PM	12:35 PM	Hydropower STEM and Workforce Development	NREL	Elise DeGeorge
12:35 PM		ADJOURN AND MOVE TO ACTIVITY AREA BREAKOUTS (Days 2–4)		

Activity Area Breakout Sessions

WPTO's Hydropower Program Activity Areas Color-Coded Key

Innovations for Low-Impact Hydropower Growth
HydroWIRES
Fleet Modernization, Maintenance, and Cybersecurity
Environmental and Hydrologic Systems Science

Innovations for Low-Impact Hydropower Growth Review Session

DAY 2 – TUESDAY, JULY 26, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:30 AM	Innovations for Low-Impact Hydropower Growth Activity Area Overview	WPTO	Katie Jackson
10:30 AM	11:00 AM	Groundbreaking Hydro and I AM Hydro Prizes	NREL, ORNL, WPTO	Tessa Greco, Scott DeNeale, Katie Jackson
11:00 AM	11:25 AM	The Design and Development of a Composite Hydropower Turbine Runner	Composite Technology Development, Inc.	Paul Fabian
11:25 AM	11:35 AM	BREAK		
11:35 AM	11:50 AM	Cold Spray Process Development for In Situ Repair and Mitigation of Cavitation Erosion	PNNL	Chris Smith
11:50 AM	12:15 PM	Standard Modular Hydropower Technology Acceleration	ORNL	Scott DeNeale
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Restoration Hydro: A Watershed Approach to Standard Modular New Hydropower	Natel Energy, Inc.	Abe Schneider
1:25 PM	1:50 PM	Prefabricated Standard Modular Hydropower Installations for Low-Cost Small Hydropower	Littoral Power Systems Inc	David Duquette
1:50 PM	2:15 PM	Small Hydro Interconnection Study	PNNL, ORNL	Alison Colotelo, Todd Wall, Chris O'Reilly, Hope Corsair
2:15 PM	2:40 PM	**Reviewer Debrief**	**Reviewers**	
DAY 3 – WEDNESDAY, JULY 27, 2022				
10:00 AM	10:25 AM	Development of a Modular Helical Fish Passage for Low Head Applications	Percheron Power, LLC	Jerry Straalsund
10:25 AM	10:50 AM	Advanced Compact Generation Module with Fish Safe Runner Technology	Natel Energy, Inc.	Gregor Cadman, Sterling Watson
10:50 AM	11:15 AM	Prefabricated Zero Ascend Omnispecies (ZAO) Modular Fish Passage Modules Using Advanced Manufacturing Techniques	Littoral Power Systems Inc.	David Duquette
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	A Novel Sediment Passage Module Design for Support of Standard Modular Hydropower	Regents of The University of Minnesota	Jeffrey Marr
11:50 AM	12:15 PM	National Conduit Resource Assessment	ORNL	Shih-Chieh Kao
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Integrated Water Power Resilience	PNNL, INL	Juliet Homer, Shiloh Elliott
1:25 PM	1:50 PM	Irrigation Modernization	PNNL, INL	Thomas Mosier
1:50 PM	2:15 PM	Alternative Opportunities for Hydropower	PNNL, INL	Rajiv Prasad, Thomas Mosier
2:15 PM	2:40 PM	Cost Data Collection & Modeling for Hydropower	ORNL	Gbadebo Oladosu
2:40 PM	3:05 PM	**Reviewer Debrief**	**Reviewers**	

HydroWIRES (Grid Reliability, Resilience, and Integration) Review Session

DAY 2 – TUESDAY, JULY 26, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:40 AM	HydroWIRES Initiative Overview	WPTO	Sam Bockenhauer
10:40 AM	11:05 AM	Hydropower Flexibility Framework	Electric Power Research Institute, Inc.	Francisco Kuljevan
11:05 AM	11:30 AM	Increasing Operational Flexibility of Francis Turbines at Low Head Sites, Through Analytical and Empirical Solutions	GE Renewable Energy Hydro	Guillaume Rudelle
11:30 AM	11:40 AM	BREAK		
11:40 AM	12:05 PM	Exploring Multidimensional Spatial-Temporal Hydropower Operational Flexibilities by Modeling and Optimizing Water-Constrained Cascading Hydroelectric	Stevens Institute of Technology	Lei Wu
12:05 PM	12:30 PM	Identifying Hydropower Operational Flexibilities in Presence of Streamflow and Net-Load Uncertainty	University of California, Irvine	Soroosh Sorooshian and Bita Analui
12:30 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Geomechanical Pumped Storage	Natel Energy, Inc.	Abe Schneider
1:25 PM	1:50 PM	Modeling And Optimizing Pumped Storage in A Multi-Stage Large Scale Electricity Market Under Portfolio Evolution	University of Missouri System	Rui Bo
1:50 PM	2:15 PM	Value And Role of Pumped Storage Hydro Under High Variable Renewables	GE Power	Christina Bisceglia
2:15 PM	2:40 PM	Predicting Unique Market Pumped Storage Significance (PUMPSS)	Electric Power Research Institute, Inc.	Aidan Tuohy
2:40 PM	3:00 PM	**Reviewer Debrief**	**Reviewers**	
DAY 3 – WEDNESDAY, JULY 27, 2022				
10:00 AM	10:30 AM	FAST Commissioning Prize for Pumped Storage Hydropower	NREL, WPTO	Tessa Greco, Corey Vezina
10:30 AM	10:55 AM	PSH-TES Tool	PNNL, ANL	Mark Weimar, Patrick Balducci
10:55 AM	11:20 AM	HydroWIRES Topic D1: CEM Enhancements	NREL	Stuart Cohen
11:20 AM	11:30 AM	BREAK		
11:30 AM	11:55 AM	Value Drivers Quantification	ANL, NREL, PNNL	Todd Levin
11:55 AM	12:20 PM	HydroWIRES Topic A: Environment-Flexibility Win-Wins	ORNL	Brenda Pracheil
12:20 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	PSH Portfolio Evaluation and Innovation Study	ANL	Vladimir Koritarov
1:25 PM	1:50 PM	Life Cycle Assessment of Storage Technologies	NREL	Greg Stark
1:50 PM	2:15 PM	Scope Improvements to Power Flow and Stability Models	PNNL	Slaven Kincic
2:15 PM	2:30 PM	**Reviewer Debrief**	**Reviewers**	

DAY 4 –THURSDAY, JULY 28, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:25 AM	HydroWIRES Topic C: Quantifying Reliability/Resilience	PNNL, ANL, INL, NREL, ORNL	Abhishek Somani
10:25 AM	10:50 AM	HydroWIRES Topic D2: Transmission/Storage Equivalence	PNNL, ANL	Jeremy Twitchell, Zhi Zhou
10:50 AM	11:15 AM	Idaho Power Run-of-River Hydropower and Battery Modeling	PNNL	Feng Pan
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	Hydropower Plant Controller Prototyping using Remote Hardware in the Loop	NREL	Mayank Panwar
11:50 AM	12:15 PM	Integrated Hydropower and Energy Storage: Providing Essential Reliability and Ancillary Services using Individual or Coordinated Hydropower Plants	INL, NREL	Thomas Mosier, Vahan Gevorgian
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Hydropower Storage Capacity Dataset	ORNL	Carly Hansen
1:25 PM	1:50 PM	HydroWIRES Topic B1: Enhancing the Representation of Conventional Hydropower Flexibility in Production Cost Models	NREL, PNNL	Greg Stark, Nathalie Voisin
1:50 PM	2:15 PM	HydroWIRES Topic B2: Improving the Representation of Hydrologic Processes and Reservoir Operations in Production Cost Models	NREL, PNNL	Greg Stark, Nathalie Voisin
2:15 PM	2:40 PM	HydroWIRES Topic D3: Forecasting	PNNL, INL	Nathalie Voisin, Thomas Mosier
2:40 PM	3:00 PM	**Reviewer Debrief**	**Reviewers**	

Fleet Modernization, Maintenance, and Cybersecurity Review Session

DAY 4 –THURSDAY, JULY 28, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:25 AM	Fleet Modernization, Maintenance, and Cybersecurity Activity Area Overview	WPTO	Kyle DeSomber
10:25 AM	10:50 AM	Digital Twin	PNNL, ORNL	Osman Ahmed, Hong Wang
10:50 AM	11:15 AM	Hydropower Fleet Intelligence	ORNL	Pradeep Ramuhalli
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	Cybersecurity Value-at-Risk Framework	NREL, ANL	Mayank Panwar
11:50 AM	12:15 PM	Hydropower Cyber-Physical Reference Framework	PNNL, ANL, NREL	Ken Ham
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Hydropower Cybersecurity Risk/State of Fleet	PNNL	Marie Whyatt
1:25 PM	1:50 PM	Hydropower Fleet Cybersecurity Response and Recovery	PNNL	Darlene Thorsen
1:50 PM	2:15 PM	**Reviewer Debrief**	**Reviewers**	

Environmental and Hydrologic Systems Science

DAY 2 – TUESDAY, JULY 26, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:30 AM	Environmental and Hydrologic Systems Science Activity Area Overview	WPTO	Dana McCoskey
10:30 AM	10:55 AM	A Real-time and Autonomous Water Quality Monitoring System	PNNL	Daniel Deng
10:55 AM	11:20 AM	Shad Tag Development	PNNL	Daniel Deng
11:20 AM	11:30 AM	BREAK		
11:30 AM	12:00 PM	Fish Protection Prize	NREL, WPTO	Tessa Greco, Dana McCoskey
12:00 PM	12:25 PM	**Reviewer Debrief**	**Reviewers**	
DAY 3 – WEDNESDAY, JULY 27, 2022				
10:00 AM	10:25 AM	Demonstrating Value of River Data Aggregation and Visualization Capabilities	PNNL	Kyle Larson
10:25 AM	10:50 AM	GMLC Water Risk for the Bulk Power System: Asset to Grid Impacts	NREL, ORNL	Ariel Miara
10:50 AM	11:15 AM	Methane Emissions	ORNL	Natalie Griffiths
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	FERC eLibrary	PNNL	James Bradford, Bo Saulsbury
11:50 AM	12:15 PM	Hydro Fleet Database Development and Analyses (HydroSource)	ORNL	Debjani Singh
12:15 PM	12:35 PM	**Reviewer Debrief**	**Reviewers**	

Reviewer Debrief with WPTO *closed door*

DAY 5 – FRIDAY, JULY 29, 2022			
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**
10:00 AM	11:00 AM	HydroWIRES Reviewer Debrief with WPTO	Reviewers and WPTO
11:00 AM	11:45 AM	Environmental and Hydrologic Systems Science Reviewer Debrief with WPTO	Reviewers and WPTO
11:45 AM	12:15 PM	STEM and Workforce Development	Reviewers and WPTO
12:15 PM	1:00 PM	BREAK	
1:00 PM	2:00 PM	Innovations for Low-impact Hydropower Growth Reviewer Debrief with WPTO	Reviewers and WPTO
2:00 PM	2:30 PM	Fleet Modernization, Maintenance, and Cybersecurity Reviewer Debrief with WPTO	Reviewers and WPTO
2:30 PM	3:00 PM	Prize Reviewer Debrief with WPTO	Reviewers and WPTO

Marine Energy Program Peer Review Agenda

July 18–22, 2022

Marine Energy Program Opening Plenary

DAY 1 – MONDAY, JULY 18, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:30 AM	WPTO Overview	WPTO	Jennifer Garson
10:30 AM	10:45 AM	Peer Review Introduction	WPTO	Ali Hewett
10:45 AM	11:30 AM	Marine Energy Program Overview	WPTO	Tim Ramsey
11:30 AM	11:40 AM	BREAK		
11:40 AM	12:20 PM	Powering the Blue Economy Overview	WPTO	Tessa Greco
12:20 PM	12:50 PM	Marine Energy STEM and Workforce Development	NREL	Arielle Cardinal
12:50 PM		ADJOURN AND MOVE TO ACTIVITY AREA BREAKOUTS (Days 2–4)		

Activity Area Breakout Sessions

WPTO's Marine Energy Program Activity Areas Color-Coded Key

Foundational R&D
Technology Specific System Design and Validation
Reducing Barriers to Testing
Data Access, Analytics, and Workforce Development

Foundational R&D Review Session

DAY 2 TUESDAY, JULY 19, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:40 AM	Foundational R&D Activity Area Overview	WPTO	William McShane
10:40 AM	11:10 AM	Demonstration of an Advanced Multi-Mode Point Absorber for Wave Energy Conversion	Oscilla Power, Inc.	Tim Mundon
11:10 AM	11:35 AM	Seawater Compatible Rotary Pump for Wave Energy Conversion	Resolute Marine Energy, Inc.	Marcus Gay
11:35 AM	11:45 AM	BREAK		
11:45 AM	12:10 PM	Design of High-Deflection Foils for MHK Applications	Ocean Renewable Power Company, LLC	Jarlath McEntee
12:10 PM	12:35 PM	Performance Testing of An Integrated Magnetic Power Take Off	Portland State University	Jonathan Bird
12:35 PM	1:25 PM	LUNCH		
1:25 PM	1:50 PM	Holistic Control Embedded Power Take Off (PTO) Development	CalWave Power Technologies Inc.	Thomas Boerner, Marcus Lehmann, Dan Petcovic
1:50 PM	2:15 PM	**Reviewer Debrief**	**Reviewers**	
DAY 3 – WEDNESDAY, JULY 20, 2022				
10:00 AM	10:25 AM	Fatigue and Structural Load Analysis and Control for Variable Geometry Wave Energy Converters	NREL	Nathan Tom
10:25 AM	10:50 AM	Next Generation WEC PTO CoDesign	SNL	Ryan Coe
10:50 AM	11:15 AM	Wave Energy Converter Modeling	NREL, SNL	Dave Ogden, Kelley Ruehl
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	WEC Array Power Management and Output Simulation Tool	NREL, PNNL	Toan Thanh Tran
11:50 AM	12:15 PM	WEC Design Optimization	SNL	Ryan Coe
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Wave Energy Converter Interlink Umbilical Cables Design Requirements, Best Practices and Recommended Design Improvements	PNNL	Leo Fifield
1:25 PM	1:50 PM	Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme	NREL, PNNL, SNL	Levi Kilcher, Vincent Neary, Zhaoqing Yang
1:50 PM	2:15 PM	**Reviewer Debrief**	**Reviewers**	

Technology-specific System Design and Validation Review Session

DAY 2 TUESDAY, JULY 19, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:40 AM	Technology-Specific System Design and Validation Activity Area Overview	WPTO	Elaine Buck
10:40 AM	11:10 AM	Reduction of System Cost Characteristics Through Innovative Solutions to Installation, Operations, And Maintenance	Columbia Power Technologies, Inc.	Michael Ondusko
11:10 AM	11:35 AM	Open Water Testing of a Scaled Next Generation Point Absorber Wave Energy Device with Phase Control	Aqua-harmonics, Inc.	Alex Hagmuller
11:35 AM	11:45 AM	BREAK		
11:45 AM	12:10 PM	Water Horse Hydroelectric Harvester Development	University of Alaska Fairbanks	Jeremy Kasper
12:10 PM	12:35 PM	Performance Optimization and System Demonstration of a Multi-Mode Point Absorber	Oscilla Power, Inc.	Tim Mundon
12:35 PM	1:25 PM	LUNCH		
1:25 PM	1:50 PM	Cycloidal Wave Energy Converter	Atargis Energy Corporation	Stefan Siegel
1:50 PM	2:15 PM	Design, Build and Test of Novel, Remote, Low-Power Wave Energy Converter for Non-Grid Applications	Columbia Power Technologies, Inc.	Erik Hammagren
2:15 PM	2:40 PM	Hawaii Wave Surge Energy Converter (HAWSEC)	University of Hawaii	Patrick Cross
2:40 PM	3:05 PM	**Reviewer Debrief**	**Reviewers**	
DAY 3 WEDNESDAY, JULY 20, 2022				
10:00 AM	10:25 AM	Xct System for Harvesting InCurrent Hydrokinetic Energy from Low-Velocity Sites	Littoral Power Systems Inc.	David Duquette
10:25 AM	10:50 AM	An Innovative SR-WEC for a Market-Disruptive LCOE	Texas A&M Engineering Experiment Station	HeonYong Kang
10:50 AM	11:15 AM	Device Design and Robust Periodic Motion Control of an Ocean Kite System for Hydrokinetic Energy Harvesting	North Carolina State University	Chris Vermillion
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	Low-Flow Marine Hydrokinetic Turbine for Small Autonomous Unmanned Mobile Recharge Stations	Florida Atlantic University	Manhar Dhanak
11:50 AM	12:15 PM	Modular Rivgen	Ocean Renewable Power Company, Inc.	Ryan Tyler
12:15 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Advancing CalWave's WEC Design for PacWave	CalWave Power Technologies Inc.	Thomas Boerner

DAY 3 TUESDAY, JULY 20, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
1:25 PM	1:50 PM	Floating Oscillating Surge Wave Energy Converter Using Controllable Efficient Power Takeoff System	Stevens Institute of Technology (Inc)	Muhammad R. Hajj
1:50 PM	2:15 PM	MARMOK- Oscillating Water Column (OWC)	Idom, Inc.	Borja de Miguel Para
2:15 PM	2:40 PM	Optimization, Design, And Commercialization Planning of Next-Generation Stingray H3 Wave Energy Converter	Columbia Power Technologies, Inc.	Pukha Lenee-Bluhm
2:40 PM	3:05 PM	**Reviewer Debrief**	**Reviewers**	
DAY 4 THURSDAY, JULY 21, 2022				
10:00 AM	10:40 AM	Waves to Water: Desalination Prize	NREL, WPTO	Scott Jenne, Simon Gore
10:40 AM	11:20 AM	Ocean Observing Prize	NREL, PNNL, WPTO	Jenny Wiegele, Carrie Schmaus
11:20 AM	11:30 AM	BREAK		
11:30 AM	11:55 AM	Wave-SPARC – Structured Innovation	NREL, SNL	Jochem Weber
11:55 AM	12:20 PM	Distributed Embedded Energy Converter Technologies DEECTEC	NREL	Blake Boren
12:20 PM	1:05 PM	LUNCH		
1:05 PM	1:30 PM	Significant Cost Reduction Potential for Wave Energy Conversion Devices with Variable Geometry Modules	NREL	Nathan Tom
1:30 PM	1:55 PM	Verdant/NREL Research Measurement Campaign	NREL	Robynne Murray
1:55 PM	2:25 PM	**Reviewer Debrief**	**Reviewers**	

Reducing Barriers to Testing Review Session

DAY 3 WEDNESDAY, JULY 20, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:40 AM	Reducing Barriers to Testing Activity Area Overview	WPTO	Lauren Ruedy
10:40 AM	11:20 AM	Triton Initiative	PNNL	Joe Haxel, Garrett Staines
11:20 AM	11:30 AM	BREAK		
11:30 AM	11:55 AM	Rapidly Deployable Acoustic Monitoring and Localization System Based on A Low-Cost Wave Buoy Platform	Integral Consulting Inc.	Kaustubha Raghukumar
11:55 AM	12:20 PM	Long-Range Target Detection and Classification System for Environmental Monitoring at MHK Sites	Biosonics, Inc.	Tim Acker
12:20 PM	1:00 PM	LUNCH		
1:00 PM	1:25 PM	Improvements to Hydrodynamic and Acoustic Models for Environmental Prediction	SNL	Jesse Roberts
1:25 PM	1:50 PM	National Lab and University Collaboration for MHK Instrumentation and Data Processing Tools	NREL, PNNL, SNL	Rebecca Fao
1:50 PM	2:15 PM	Network Director for The Testing Expertise and Access for Marine Energy Research (TEAMER) Program	Pacific Ocean Energy Trust	Patrick Cross
2:15 PM	2:40 PM	**Reviewer Debrief**	**Reviewers**	
DAY 4 THURSDAY, JULY 21, 2022				
10:00 AM	10:25 AM	Enabling Cost Effective Electricity from Ocean Waves: PacWave	Oregon State University	Burke Hales
10:25 AM	10:50 AM	National Marine Renewable Energy Center Infrastructure Upgrades	University of Washington	Brian Polagye
10:50 AM	11:15 AM	Current Turbines Mobile Testing Vessel	Idom, Inc.	Alvaro Garcia
11:15 AM	11:45 AM	**Reviewer Debrief**	**Reviewers**	

Data Access, Analytics, and Workforce Development Review Session

DAY 4 THURSDAY, JULY 21, 2022				
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**	**Speaker**
10:00 AM	10:25 AM	Marine Energy Data Access, Analytics, and Workforce Development Overview	WPTO	Allison Johnson
10:25 AM	10:50 AM	MHK Data Products and User Community Development (PRIMRE)	PNNL, NREL, SNL	Andrea Copping, Cesar Castillo, Jon Weers
10:50 AM	11:15 AM	International Environmental Data Sharing Initiative (Annex IV Project & Tethys Database)	PNNL	Andrea Copping
11:15 AM	11:25 AM	BREAK		
11:25 AM	11:50 AM	Improving The Efficiency and Effectiveness for MHK Permitting: A Toolkit and Engagement for Success	Kearns & West, Inc.	Zach Barr
11:50 AM	12:25 PM	Grid Value Proposition of MHK	PNNL, NREL	Dhruv Bhatnagar, Levi Kilcher
12:25 PM	12:45 PM	**Reviewer Debrief**	**Reviewers**	

Reviewer Debrief with WPTO *closed door*

DAY 5 FRIDAY, JULY 22, 2022			
Start (ET)	**End (ET)**	**Presentation Topic**	**Organization**
10:00 AM	11:00 AM	Foundational R&D Reviewer Debrief with WPTO	Reviewers and WPTO
11:00 AM	12:00 PM	Technology-Specific System Design and Testing Reviewer Debrief with WPTO	Reviewers and WPTO
12:00 PM	12:45 PM	BREAK	
12:45 PM	1:45 PM	Reducing Barriers to Testing Reviewer Debrief with WPTO	Reviewers and WPTO
1:45 PM	2:15 PM	Data Access, Analytics, and Workforce Development Reviewer Debrief with WPTO	Reviewers and WPTO

Appendix B: Evaluation Criteria

Scoring Scale

Superior	Good	Satisfactory	Marginal	Unsatisfactory
5	4	3	2	1
All aspects of the criterion are comprehensively addressed. There are significant strengths and no more than a few—easily correctable—weaknesses.	All aspects of the criterion are adequately addressed. There are significant strengths and some weaknesses. The significance of the strengths outweighs most aspects of the weaknesses.	Most aspects of the criterion are adequately addressed. There are strengths and weaknesses. The significance of the strengths slightly outweighs aspects of the weaknesses.	Some aspects of the criterion are not adequately addressed. There are strengths and significant weaknesses. The significance of the weaknesses outweighs most aspects of the strengths.	Most aspects of the criterion are not adequately addressed. There may be strengths, but there are significant weaknesses. The significance of the weaknesses outweighs the strengths.

Evaluation Criteria – Program

Using the following criteria, please evaluate the Office's programs at a strategy-level, both numerically and with specific, concise comments to support each evaluation.

Score Weighting

Program Evaluation Criteria	
Strategy	50%
Implementation and Progress	50%

1. Strategy

Please evaluate the degree to which:

- The program has as a **defined strategy** that is outlined in the Multi-Year Program Plan (MYPP), including clear **vision, mission, and intended outcomes**.
- The program's strategy reflects an understanding of the **near and long-term challenges** facing industry and other stakeholders.
- The program's strategy has **considered industry and stakeholder needs** and builds on past work.
- The program's strategy effectively communicates the rationale for and organization of the priority R&D activity areas.
- The program **leverages appropriate funding mechanisms** (i.e., financial assistance to industry and academia vs. national lab procurement vs. prizes/competitions) to achieve intended outcomes.

2. Implementation and Progress

Please evaluate the degree to which:

- The program is **funding the most relevant technologies, tools, and studies** to achieve stated outcomes from the MYPP and drive the greatest impact.
- The program effectively **balances R&D priorities** in line with WPTO's role as a public research and development organization and allocates resources appropriately.
- The program demonstrates good stewardship of taxpayer funds by **transparently communicating** program priorities and resulting investments.
- The program maximizes the impact of WPTO-supported R&D by **effectively disseminating progress** on and results of projects.

3. Qualitative Feedback for WPTO (Not Scored—Required)

Please explain your scores by commenting below using complete sentences. Provide both strengths and weaknesses. What, if any, recommendations would you like to convey to the program manager? **Note: your feedback in this section will summarized for inclusion in the final public report.** (Maximum 500 words)

Evaluation Criteria – Activity Areas

Using the following criteria, reviewers are asked to evaluate the program's initiatives and activity areas, including sub-activities, at a strategy-level, both numerically and with specific, concise comments to support each evaluation.

Score Weighting

Activity Area Evaluation Criteria	
Strategy	60%
Implementation and Progress	60%

1. Strategy

Please evaluate the degree to which:

- The activity area has a **defined strategy** that is outlined in the Multi-Year Program Plan (MYPP), including clear **performance goals, objectives, and research priorities**.
- The activity area's strategy reflects an understanding of the **near and long-term challenges** facing industry and other stakeholders.
- The activity area's strategy has **considered industry and stakeholder needs** and builds on past work.
- The activity area's strategy effectively communicates the rationale for and organization of the sub-activity areas and research priorities.
- The activity area **leverages appropriate funding mechanisms** (i.e., financial assistance to industry and academia vs. national lab procurement vs. prizes/competitions) to achieve intended goals and objectives.

Score: 1–5

2. Implementation and Progress

Please evaluate the degree to which:

- The activity area has selected **diverse and complementary R&D projects** that are closely tied to the program's strategic direction.
- The activity area is **funding the most relevant technologies, tools, and studies** to achieve stated goals and objectives from the MYPP.
- The activity area is **likely to meet performance goals and objectives**, as defined in in the MYPP, based on the current portfolio of projects.

Score: 1–5

3. Qualitative Feedback for WPTO (Not Scored—Required)

Please explain your scores by commenting below using complete sentences. Provide both strengths and weaknesses. What, if any, recommendations would you like to convey to the Activity Area Lead? **Note: your feedback in this section will summarized for inclusion in the final public report.** (Maximum 500 words)

Evaluation Criteria – Projects

Using the following criteria, reviewers are asked to evaluate the project work presented in the context of the program objectives, both numerically and with specific, concise comments to support the evaluation.

Score Weighting

Activity Area Evaluation Criteria	
Project Objectives	25%
End-User Engagement and Dissemination	25%
Performance	50%

1. Project Objectives

Please evaluate the degree to which:

- The project objectives contribute to WPTO's mission of enabling research, development, testing and commercialization of new technologies to advance marine energy as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid.
- The project performers have identified a project management plan that includes well-defined milestones—especially critical go/no-go decision points—and adequate methods for addressing potential risks.
- The project's expected outputs (i.e., products or deliverables) are useful and have meaningful and relevant applications.
- Successful completion of the project will yield meaningful short-term outcomes (i.e., the earliest intended effects of outputs on target audiences, resulting from the uptake or usage of products).

Score: 1–5

2. End-User Engagement and Dissemination

Please evaluate the degree to which:

- The project has a sound stakeholder and/or end-user engagement strategy; the project team has a solid understanding of who will benefit from this project and a plan for meeting specific stakeholder needs and disseminating project results to target audiences.
- The project performers have engaged or plan to engage specific water power industry or end-users at appropriate points in the project lifecycle (i.e., establishing an advisory group, assessing end-user needs, communicating progress/preliminary results, and/or disseminating final results/tools/data).
- If relevant, the project has a clear technology transfer and/or commercialization plan for all products.

Score: 1–5

3. Performance

Please evaluate the degree to which:

- The project has made appropriate progress towards addressing the project objectives and, if applicable, has produced meaningful accomplishments since the beginning of their project or since the 2019 Peer Review.
- The project performers implemented sound research and development methodologies and demonstrated/validated the results needed to meet their project objectives.
- The accomplishments have been achieved on schedule within the planned scope. Where applicable, the project performers have addressed or mitigated challenges to project execution/completion and any delays related to COVID-19, supply chain disruptions, or other challenges beyond the project team's control.
- The scope of future work—specifically key milestones and go/no-go decision points—are appropriate for the completion of the overall objectives of the project.

Score: 1–5

4. Qualitative Feedback for the PI (Not Scored—Required)

Please explain your scores by commenting below. Provide both strengths and weaknesses. Provide any additional notable comments on the project content or direction that you would like. What, if any, recommendations would you like to convey to the PI of this project? **Note: your feedback in this section will be anonymously shared with the PI and summarized for inclusion in the final public report.** (Maximum 300 words)

5. Qualitative Feedback for WPTO (Not Scored—Optional)

What, if any, recommendations would you like to convey to the WPTO lead of this project? Note: your feedback in this section will only be viewed by WPTO and will not be shared with the PI or incorporated into the final public report. (Maximum 300 words)

Evaluation Criteria – Prizes

Using the following criteria, reviewers are asked to evaluate the prizes presented in the context of the program objectives, both numerically and with specific, concise comments to support the evaluation.

Score Weighting

Activity Area Evaluation Criteria	
Prize Objectives	35%
End-User Engagement and Dissemination	35%
Performance	30%

1. Project Objectives

Please evaluate the degree to which:

- The prize objectives contribute to WPTO's mission of enabling research, development, testing, and commercialization of new technologies to advance marine energy as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid.
- The prize team has a sound project management plan that includes well-defined milestones—especially critical go/no-go decision points—and adequate methods for addressing potential risks.
- The prize's expected outputs (i.e., products or deliverables) are useful and have meaningful and relevant applications.
- Successful completion of the prize will yield meaningful short-term outcomes (i.e., the earliest intended effects of outputs on target audiences, resulting from the uptake or usage of products

Score: 1–5

2. End-User Engagement and Dissemination

Please evaluate the degree to which:

- The prize has a sound stakeholder and/or end-user engagement strategy; the project team has a solid understanding of who will benefit from this project and a plan for meeting specific stakeholder needs and disseminating project results to target audiences.
- The prize team engaged specific water power industry stakeholders or end-users at appropriate points in the project lifecycle (i.e., establishing an advisory group, assessing end-user needs, communicating progress/preliminary results, and/or disseminating final results/tools/data).
- If relevant, the prize incentivizes or supports competitors to develop clear technology transfer and/or commercialization plan for all products.

Score: 1–5

3. Performance

Please evaluate the degree to which:

- The prize administrator incentivized and supported competitors to make appropriate progress towards addressing the prize objectives.
- The prize administrator implemented and/or incentivized sound research and development methodologies and demonstrated/validated the results needed to meet the prize objectives.
- The accomplishments have been achieved on schedule within the planned scope. Where applicable, the prize administrator has addressed or mitigated challenges to task execution/completion and any delays related to COVID-19, supply chain disruptions, or other challenges beyond the prize team's and prize competitors' control.

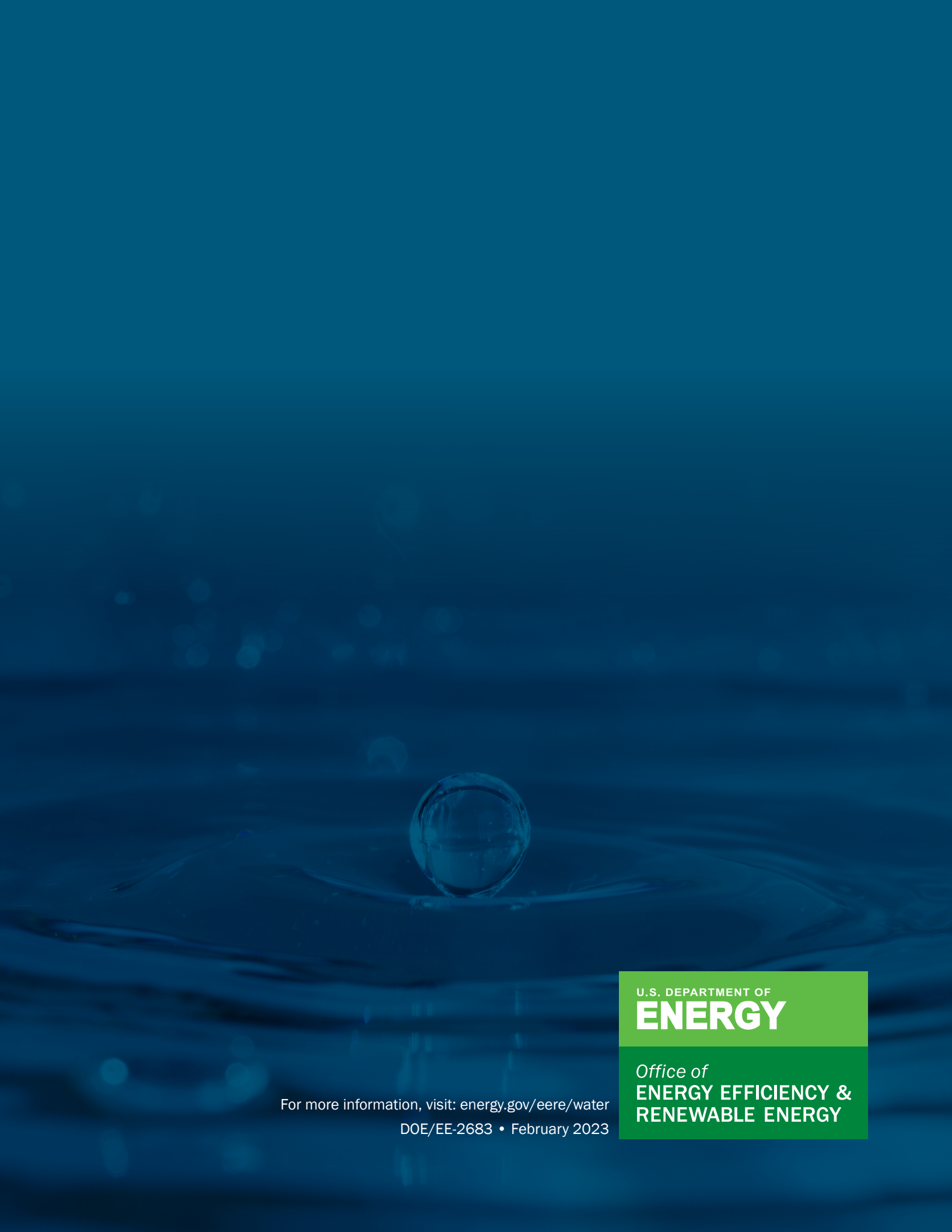
Score: 1–5

4. Qualitative Feedback for the Prize Administrator(s) (Not Scored—Required)

Please explain your scores by commenting below. Provide both strengths and weaknesses. Provide any additional notable comments on the project content or direction that you would like. What, if any, recommendations would you like to convey to the prize administration team? **Note: your feedback in this section will be anonymously shared with the prize administration team and summarized for inclusion in the final public report.** (Maximum 300 words)

5. Qualitative Feedback for WPTO (Not Scored—Optional)

What, if any, recommendations would you like to convey to the WPTO lead of this project? Note: your feedback in this section will only be viewed by WPTO and will not be shared with the prize administration team or incorporated into the final public report. (Maximum 300 words)



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