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Summary Report of Advanced Hydropower Innovations and Cost Reduction Workshop Arlington, VA November 5 & 6, 2015

Patrick O'Connor
Kelsey Rugani
Anna West

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March 2016

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM- 2016/113

Environmental Sciences Division

SUMMARY REPORT OF ADVANCED HYDROPOWER INNOVATIONS AND COST REDUCTION WORKSHOP ARLINGTON, VA November 5 & 6, 2015

Patrick O'Connor (ORNL)
Kelsey Rugani (Kearns & West)
Anna West (Kearns & West)

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OAK RIDGE NATIONAL LABORATORY
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1. INTRODUCTION/WORKSHOP OVERVIEW

On behalf of the U.S. Department of Energy (DOE) Wind and Water Power Technology Office (WWPTO), Oak Ridge National Laboratory (ORNL), hosted a day and half long workshop on November 5 and 6, 2015 in the Washington, D.C. metro area to discuss cost reduction opportunities in the development of hydropower projects. The workshop had a further targeted focus on the costs of small, low-head[1] facilities at both non-powered dams (NPDs) and along undeveloped stream reaches (also known as New Stream-Reach Development or "NSD").

Workshop participants included a cross-section of seasoned experts, including project owners and developers, engineering and construction experts, conventional and next-generation equipment manufacturers, and others to identify the most promising ways to reduce costs and achieve improvements for hydropower projects (see Appendix A for a list of participants).

The meeting objectives were to:

- Identify Opportunities to Advance Hydropower through Innovations that can Achieve Cost Reductions in Producing Hydropower
- Identify Potential Challenges or Barriers to Achieving Innovations and Cost Reductions, Explore Potential Solutions
- Identify the "State of the State" on Advancing Hydropower Through Innovations and Cost Reductions, With a Forecast on Opportunities and Recommendations for Future Advancement

Appendix B reproduces the full workshop agenda.

Tim Welch, DOE Wind & Water Power Technologies Office (WWPTO) Hydropower Technology Lead, welcomed the group and shared his optimism for the meeting. He thanked everyone for their participation, and encouraged participants to think innovatively and creatively about how to develop new small hydropower projects.

After introductions, Anna West, Kearns & West, shared two primary ground rules to stimulate and focus the discussion: (1) **Respect others opinions** and (2) the focus is on technology advancement and cost reduction, **this is not a licensing workshop**; participants should focus their technical expertise and innovative thinking on the technology and process solutions to reduce the cost of hydropower.

2. PARTICIPANT PRESENTATIONS

Following the introduction to the workshop, multiple participants gave short presentations to add context and communicate current advances in technology and project development. These presentations are summarized in the following descriptions, and synthesize both the material from the presenters as well as relevant discussion from participations.

[1] The "head" of a hydropower project refers to the elevation difference between the upstream and downstream reservoirs.

2.1 CONTEXT FOR INNOVATION OPPORTUNITIES: HYDROPOWER RESOURCE POTENTIAL AND COST

Patrick O'Connor, ORNL, provided a context for the workshop by sharing an overview of the current small hydropower market. He clarified that the purpose of the workshop was to explore the potential for reducing the cost of developing and operating small, low-head hydropower. He encouraged the group to focus on strategies for reducing costs, the potential magnitude and impacts of the opportunities/innovations, and what the risk, likelihood, feasibility and barriers are for each opportunity and innovation.

His presentation noted that small hydropower opportunities exist in the following areas.

1. **The addition of power to existing water resource infrastructure on canals and conduits.** These opportunities are not well quantified, but have been estimated as being between a low of hundreds of MWs to a high end estimate of up to 2 GW.

2. **The powering of Non-Powered Dams (NPD)**, with a resource potential of up to 12.1 GW[2] from over 50,000 dams without power. The vast majority of this potential comes from the largest projects—10.8 GW at ~600 dams with potential greater than 1 MW.

3. **Development on New Stream-Reaches (NSD)**. Legally developable power potential along undeveloped stream-reaches in the U.S. is approximately 65 GW from over 100,000 individual stream-reaches[3]. As with NPD, much of this potential is concentrated in projects with potential greater than 1 MW (approximately 40 GW from 10,000 projects).

Discussion with Workshop participants narrowed the definition of "small hydropower" to those projects with less than 30 MW of installed capacity, and "low-head" as those projects designed for an elevation drop of less than 10 meters (approximately 33 feet). Much of the potential from canals/conduits, NPD, and NSD is both small and low-head. These design considerations have strong implications for cost and cost drivers of hydropower development opportunities. To illustrate the magnitude and distribution of these costs, Figure 1 shows the average cost of recent NPD and NSD development as distributed in major components.

The largest cost driver for recent small, low-head hydropower development has been the costs of civil works, such as the construction of the powerhouse, water conveyance system, and in the case of NSD, impoundment structures; the costs of civil work accounts for 44 percent - 51 percent of total costs for projects at NPDs and NSDs. The second highest cost for both types of projects is electro-mechanical equipment.

Patrick summarized that opportunities to reduce capital costs can be categorized into standardization, modularity, manufacturing and materials. Much of the later discussion in the workshop addressed the application of these categories of innovation to electro-mechanical equipment. However, the focus of that discussion was not typically on the cost of the equipment itself, but instead on how taking a new approach to equipment design and project development philosophy could help address hydropower's largest cost driver—civil works.

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[2] DOE and ORNL identified 12 GW of potential across all continental U.S. NPDs in Hadjerioua et al. (2012) *An Assessment of Energy Potential at Non-Powered Dams*. DOE/EE-0711. April, 2012.

[3] See Kao et al. (2014) New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States. DOE/EE-1063. April, 2014.

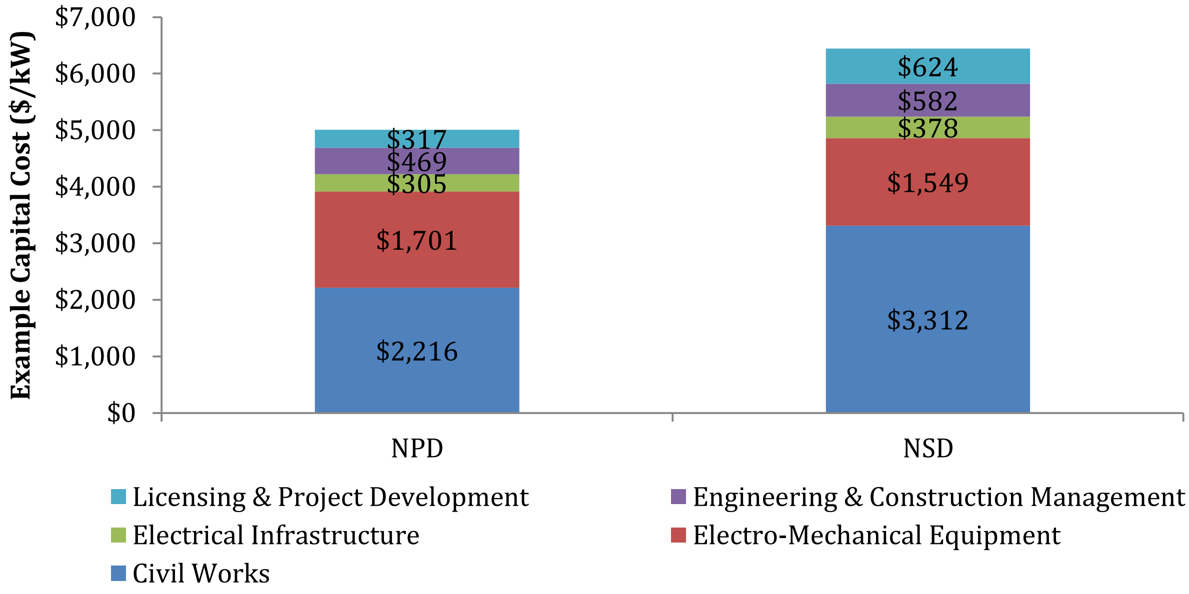

Figure 1. Example distribution of components costs for recent small hydropower projects.[4]

It was also noted that operations and maintenance (O&M) could be a major driver of project feasibility with the costs between facilities being highly variable depending on if the facility is staffed, operated remotely, and if there is preventative maintenance among other factors. Owing to strong economies of scale in hydropower plant O&M, the smallest projects exhibited the highest O&M costs, and participants noted that many of the worst performing small projects were likely to either go out of business entirely, or change hands to an owner capable of cost-effectively running them. Opportunities to reduce O&M costs include standardization and automation.

2.2 A PROJECT DEVELOPER EXPERIENCE WITH MODULARITY

Doug Spaulding, Nelson Energy, shared examples of how Nelson Energy has been able to reduce the cost of hydropower development at NPDs through the use of modular equipment designs. Nelson has previously utilized a modular turbine design—the Andritz HydroMatrix technology—in the addition of power capabilities to the Lower Saint Anthony Falls Lock & Dam in Minneapolis. As opposed to traditional development paradigms, the use of modular equipment at NPDs can allow for the installation of the turbines directly into existing structures—such as spillway gates—in lieu of the construction of large powerhouse and required cofferdam structures typically employed in the construction of low-head hydropower projects. Modularity in that sense directly reduces civils costs (while possibly raising equipment costs to a lesser degree).

The cost-reduction potential of a modular approach to the powering of NPDs is demonstrated by Nelson Energy's Coon Rapids Dam Hydroelectric Project under development on the Mississippi River upstream of Minneapolis. Nelson Energy originally planned to install two S-type horizontal Kaplan units located in a powerhouse in the abutment area of the dam at a cost of approximately $5,800/kW. In addition to being high cost, the construction of the conventional powerhouse would have entailed disturbing significant areas of existing parkland.

[4] These cost values are adapted from O'Connor et al. (2015). *Hydropower Baseline Cost Modeling, Version 2*. September, 2015.

However, an alternative design concept utilizing modular equipment (in this case also HydroMatrix) helped mitigate both the cost and impact concerns. Instead of two units in a conventional powerhouse, the current proposed design uses 16 modular units on the apron downstream of the existing spillway, eliminating the need to construct a powerhouse on-shore. The existing spillway gates will serve as an upstream cofferdam while downstream, the cofferdams will be relatively small and low making it easier to install the much smaller powerhouse, reducing cost to $3,300—a 40% reduction form the original design.

Figure 2 illustrates the proposed project layout—the original concept would have constructed the powerhouse in the south abutment area to the left of the image.

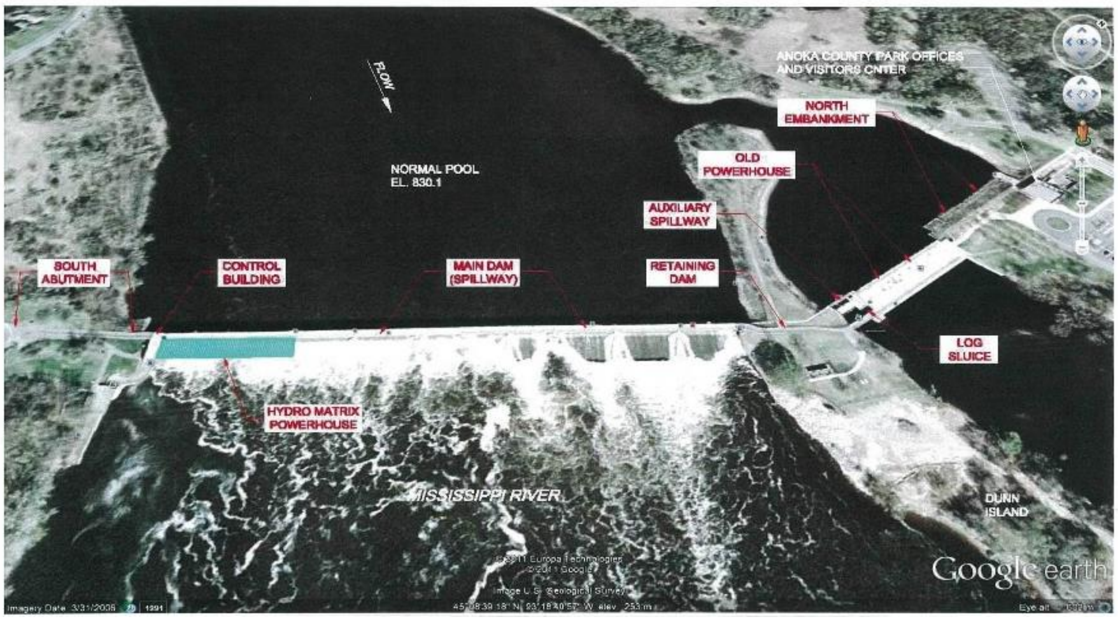

Figure 2. Aerial view of the Coon Rapids Spillway (downstream) and proposed HydroMatrix powerhouse (left side of dam). (Nelson Energy, GoogleEarth, and U.S. Geological Survey)

In addition to reducing costs, a modular approach to powering NPDs can also reduce the visual impact of hydropower development by discharging a small amount of water over the modular powerhouse to simulate the look of a waterfall.

However, a modular approach to development is not without disadvantages. Conventional hydropower design can customize both the equipment and structural design to maximize generation and value at a site—but at much higher cost than a modular approach that lacks full site-customization. In the case of the Coon Rapids, the spillway dimensions constrained generating capability in the HydroMatrix alternative (8 MW vs. 12 MW) and the modular units had lower efficiencies over various ranges in head than the original conventional design.

Generally, Doug explained that engineering expertise was vital for the Coon Rapids project. He advised the group that there is a lot of expertise in the hydropower market that can look at projects and provide innovative and cost effective suggestions on the equipment and project structure.

2.3 LOOKING AT HYDROPOWER FROM A DIFFERENT ANGLE TO REDUCE CIVIL WORKS COSTS

Abe Schneider, Natel Energy, provided an overview of the new manufacturing technologies and materials being developed at Natel, including the installation of their Schneider Linear HydroEngine (SLH) technology at the Monroe Drop project in Oregon and a new proposed design of the SLH technology.

The physics of the existing SLH design require that the power train be fully submerged ("flooded", that is with flow through the turbine under pressure), similar to conventional reaction-type technologies such as Francis or Kaplan turbines. The new approach would utilize the SLH's basic powertrain design, but where the SLH operates similarly to reaction turbines, the "Free-Jet" concept draws on the principals governing the operation of impulse turbines, specifically Pelton or crossflow (also known as Banki-Michell) technologies where water at atmospheric pressure drives the turbine blades. The difference between the two SLH technologies is shown below in Figure 3.

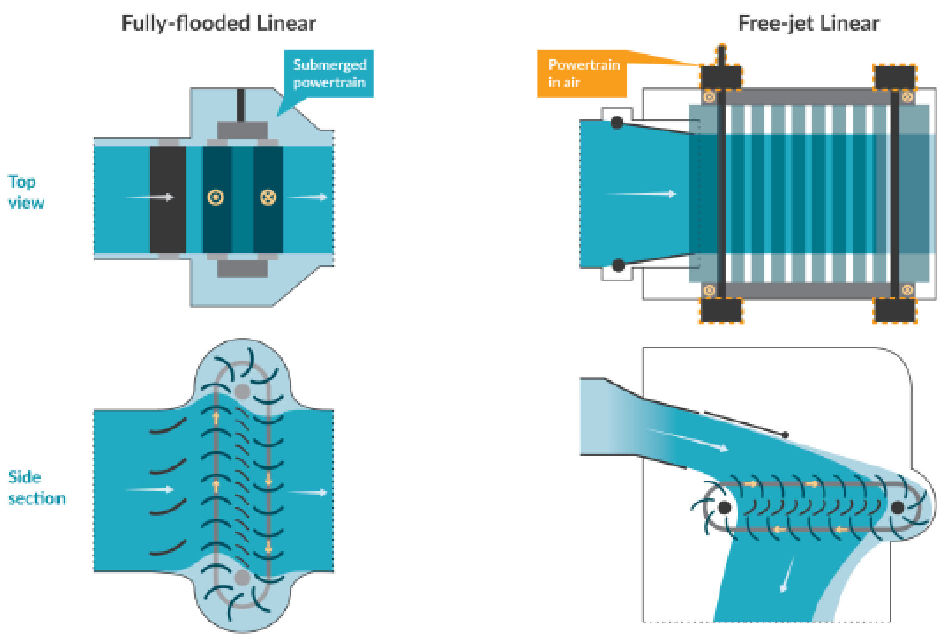

Figure 3. Differences in design concept between the Natel fully-flooded and free-jet SLH technologies.

This difference in design architecture has multiple cost implications. The first is that as the Free-Jet unit extracts most of the kinetic energy from the flow directly within the blades, the use of a draft tube isn't essential, immediately eliminating a possibly larger cost component. The free-jet SLH can utilize the drop between its outlet and tailwater by encasing the unit in an airtight enclosure, and pulling a suction head of water into a short outlet section. Unlike other low head turbines, the new free jet SLH design can safely shut down in a grid-rejection event without water hammer, because it uses a jet deflector to bypass the unit without changing the flow rate. This can reduce overall civil design loads, not just on the turbine but also on the intake and civil works. Also, relative to conventional designs the Free-Jet (as with cross-flow designs in general) must sit above tailwater where a Kaplan-type unit would require being submerged to prevent cavitation—this reduces the cost of the powerhouse and associated excavation and construction flooding protection (i.e., cofferdams). The result of these design choices specifically on require excavation are shown below in Figure 4.

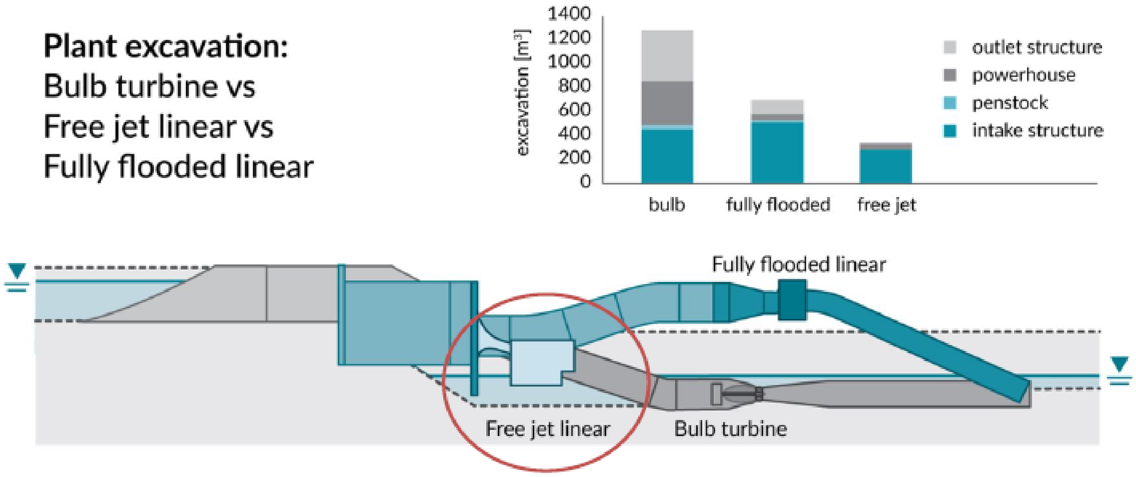

Figure 4. Comparison of excavation requirements between a conventional bulb design and Natel SLH and Free-Jet technologies

While approaching new powertrain technology with civil-works cost reduction in mind can tackle some of the largest economics to hydropower development, doing so can come with trade-offs—in the specific case of the Free-Jet design, efficiencies may be somewhat lower than with highly optimized conventional designs, such as a double-regulated[5] Kaplan units.

More broadly for the development new hydropower technologies, Abe noted the importance of having access to adequate test infrastructure on which to test and validate design concepts. While large manufacturers may have existing test capabilities many smaller technology developers, particularly those exploring new concepts, may not have the resources necessary.

2.4 THE CONTRACTOR PERSPECTIVE

Derek Dykstra, Gracon, LLC, shared his perspective as a contractor in the hydropower market, identifying four general areas where either costs present a barrier to development and/or could result in meaningful reductions.

(1) With today's wholesale power prices, many smaller projects are facing strong economic pressures to even justify development in the first place. One solution to this problem has been to utilize lower cost equipment from suppliers with limited track records in U.S. markets[6], which will at least bring costs low enough to finance and construct the plant. However, these lower upfront costs come with higher uncertainties, and the risk of future reliability problems later in project operation.

(2) Standardize the hydropower market. Standardization can reduce both direct costs (e.g., from equipment) but also streamline other project characteristics.

[5] Double regulation is the ability to control the position of the turbine blades and the angle of the water entering the turbine (via wicket gates), resulting in high efficiencies across a range of flows and heads.

[6] One common—but not the only—source of cheaper equipment is from Chinese OEMs. The reason for concerns over reliability are not that the equipment itself is Chinese-made—in fact, many of the largest global OEMs such as Voith, Alstom, and Andritz, produce equipment under strict quality control guidelines in Chinese factories for use in markets around the world. However, equipment from manufacturers with prices that are lower than North American or European competitors often have no or limited track records in the U.S. or other OECD countries.

(3) "Beginning with the end in mind" is important, specifically that understanding the considerations surrounding grid interconnection are crucial early in project development to avoid pursuing projects that may ultimately prove uneconomic to interconnect. Workshop participants made specific reference to the cost figures (Figure 1) shown in the context presentation, noting that the estimates for Electrical Infrastructure ($300 to $400 per kW) would often be far too low, and that small hydropower projects can often be effectively killed by utility requirements to upgrade local transmission or distribution infrastructure.

(4) Contractor—Developer relationships are important and can improve the probability of executing a successful project. Include contractors earlier in the design and project development process. Contractors can help identify more cost effective solutions if they are involved in the initial design process and can participate in the process, as appropriate. He noted that while sometimes the interests of developers and contractors may seem to be at odds, contractors ultimately have a vested interest in the company and align with the developer's goals to make small hydropower work. Gracon as both a contractor and hydropower project equity holder has first-hand experience in the possible benefits that strategic partnerships can bring.

2.5 LOOKING TO THE FUTURE FOR "OUTSIDE-OF-THE-BOX," "HOME RUN" POSSIBILITIES

Brennan Smith, ORNL, presented on potential cost reduction opportunities, reviewing highlights from the *"New Pathways for Hydropower: Getting Hydropower Built—What Does It Take?"* report[7] sharing that it includes design standards and models for hydroelectric plants to support rapid development. The report also discussed a variety of other ideas which could promote hydropower development, including design standards, best practices for the application of new penstock materials, and improved access to design information such as online toolboxes and databases.

However, the bulk of discussion centered on a potential new modular approach to NSD which would leverage technology and design concept innovation to avoid many of the major barriers associated with the development of new impoundments. Recent hydropower development trends demonstrate that conventional development of hydropower projects on new impoundments is extremely challenging—over the last decade only three projects greater than 1 MW have been constructed.[8] As such, a new approach to developing NSD resources may be necessary to grow that segment of the hydropower industry. Brennan presented on a conceptual development model centered on modularized design and limited impacts. An early-stage concept graphic depicting the major design principles is shown below in Figure 5. As ORNL research in this are continues, new visualizations will better illustrate the research concept.

[7] http://www.hydrofoundation.org/new-pathways-report.html

[8] For more information, see the Department of Energy's *2014 Hydropower Market Report*. http://energy.gov/eere/water/downloads/2014-hydropower-market-report

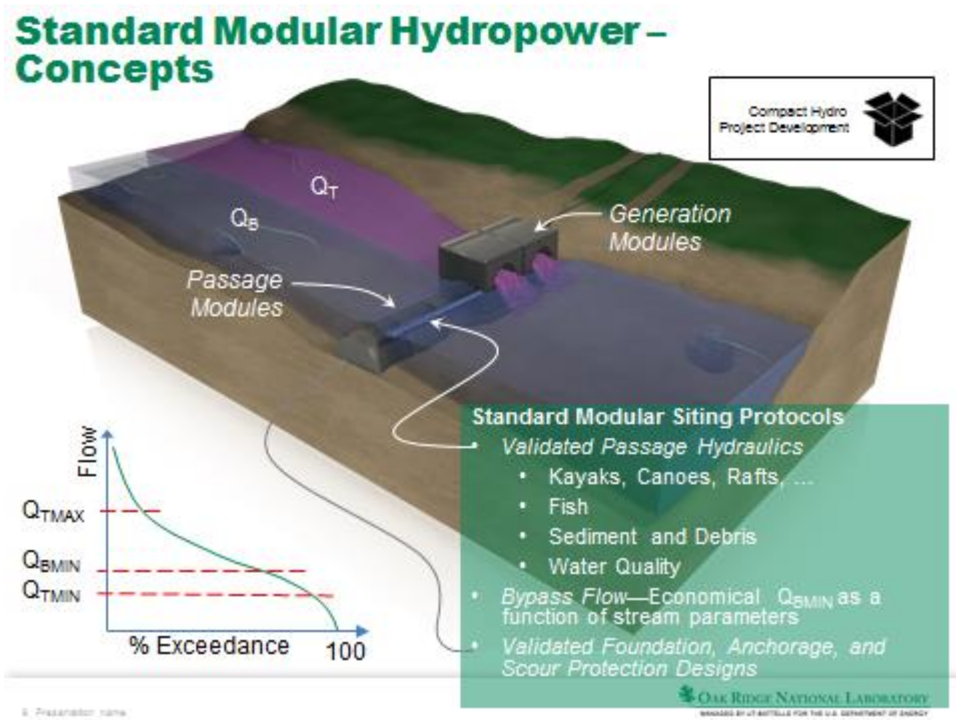

Figure 5. Standard Modular Hydropower Design Concept (Oak Ridge National Laboratory).

While the hydropower industry lacks a universal definition of standardized hydropower, standardizing modular designs could streamline the design process, and possibly also regulatory review. NSD projects would be constructed by installing pre-fabricated "modules" with dedicated functions, such as a generation module, or a flexible passage module which could be raised to impound water for generation, or lower to allow the free transport of aquatic species and recreational traffic (e.g., kayaks, fishing boats). Modules could be factory-assembled and mounted on skips to speed construction.

Module costs could be driven down through various advanced technology opportunities such as alternative and composite materials for use in hydropower plant components, new turbine technology that reduces or eliminates civil construction, and advanced manufacturing processes (e.g., additive manufacturing, also known as "3D printing").

Modular design could also reduce O&M costs, through simple replacement and the ability to improve engineering in monitoring capabilities and environmental sensors.

2.6 DOE LEVELIZED COST OF ENERGY (LCOE) REVIEW

Tim Welch introduced the current version of the hydropower levelized cost of energy (LCOE) "waterfall" charts. The charts outline the LCOE for the following types of costs:

- Civil works
- Electro-mechanical equipment
- Electrical infrastructure
- Engineering and construction
- Licensing and project development

Tim described that the LCOE estimates are a way to measure progress towards lowering costs and they drive DOE's research and development portfolio. Tim noted that these estimates will continue to be revisited and are currently consistent with utility numbers.

Tim shared that these costs provide a baseline and an average distribution of costs, and can be used to make realistic goals regarding cost reduction.

He explained that the waterfall capital cost reductions (approximately 30% by 2030 for both NSD and NPD) are similar in magnitude to cost reduction potential examples presented by the industry participants; no objections to these levels of cost reductions were raised by participants. O&M cost reductions were met with mixed reviews, both actively positive and skeptical. Follow-up discussion on O&M costs are planned to explore these estimates further.

3. DISCUSSION THEMES AND RECOMMENDATIONS

Comments and recommendations were gathered through both days of the work. Explicit feedback was sought at the end of the first day of the workshop, and participants were asked to rank the top three actions or innovations they believed could reduce the cost of hydropower. Below is a comprehensive list of the participants' recommendations and suggestions. The ✓ symbol indicates the number of meeting participants who included a recommendation in their top 3. Ideas generated during the second day often received broad support, but participant interest was not formally tallied. Both sets of comments and actions are captured below, and grouped into broad themes.

3.1 MODULARIZE SMALL HYDROPOWER

Attendees expressed broad—but not necessarily unanimous—support for pursuing technology development to simplify small hydropower projects away from site-specific, custom designs towards a modular approach. Participants identified benefits from modularization that included the potential to reduce development timeframes, streamline regulatory processes, and reduce costs through scale production.

Develop pre-certified modules for NSD development

- Standardize the civil and electromechanical equipment as "packages" which in the future could streamline regulatory approvals ✓✓✓✓✓

- Obtain agencies' approval and buy-in on the modules to assure the intended quality and efficiency outcomes.

Create modular powerhouses units for deployment at existing dams using simplified civil design such as straight walls to reduce civil works costs. ✓✓✓✓

- USACE dams have existing conveyance structures—such as spillway gates—that could be used to house modular units.

- The use of modular/off the shelf designs in conduit projects could also lower the cost of adding generation capabilities to the water supply system.

Develop lessons learned from new approaches in the nuclear industry

- Participants wondered if modularized design aspects of new Small Modular Reactor (SMR) innovations and Generation III+ reactor technologies such as the AP-1000 (nuclear modules, agency approvals) could be applied to modular hydro development.

3.2 PROMOTE THE DEVELOPMENT OF NEXT GENERATION SMALL HYDROPOWER TECHNOLOGIES

Beyond modularity, a variety of suggestions across the spectrum of developing new technologies were provided by workshop participants, ranging from the exploration of alternative materials and manufacturing approaches, to the technicalities of designing new powertrain technology to minimize civil works costs, to the need for the establishment testing infrastructure to accelerate innovation.

Advance low-head hydropower technology development

- Encourage development of modular concrete/civil structures to achieve optimal shapes/projects. ✓✓✓✓

- Develop unconventional low-head hydropower; encourage new design freedoms on electrical Capex and civil works Capex (e.g., avoid excavation)

Develop alternative manufactured materials for civil structures ✓✓

- Explore the application of additive manufacturing methods to the creation of concrete structures
- Investigate alternative materials for penstocks

Develop composite materials for equipment

Develop smart turbines/modules that reduce O&M costs ✓✓

- Turbine units could be "printed" with a full suite of telemetry through the use of advanced manufacturing techniques for online monitoring and predictive maintenance practices

Develop hydropower technology applicable to 21st century infrastructure challenges

- An attendee gave an example of a potential application with respect to California where future water supply needs could be enabled and supplemented by next generation hydropower technologies to capture water run-off for low-head hydropower generation en route to recharging groundwater basins.

- Potential advances include "smart" projects (and systems of projects) with impoundments that can respond in automated ways to be removed during critical species migration times.

Establish full-scale, grid connected test centers

- Provide an ability to test technologies to increase reliability**;** testing must be a long-term process that understands failures are needed to achieve design improvements and new design concepts take several steps to achieve commercial viability (version 1.0, 2.0, 3.0 series). Attendees suggested to DOE that to the extent that DOE funds testing for hydropower technologies, this "learning from failure" approach must be compatible with funding timeline.

- Identify existing “berths” for more immediate testing opportunities available at existing hydraulic test centers, DOD sites and open bays at existing projects.

Invest in academia - attract and invest in developing new engineers.

Investigate connecting small hydropower with battery storage.

Participants discussed that growing the market poses a “chicken and egg” question – there needs to be a product to make the market and there needs to be a market to make investment in the product attractive. The group brainstormed the ideas listed above and also asked how DOE could support building the market’s momentum and development.

3.3 IMPROVE AND STREAMLINE PROJECT DEVELOPMENT PROCESSES

In addition to technology innovation to reduce costs, discussion between representatives from different industry sectors produced a series of recommendations with respect to the structure and efficacy of project development teams as well as suggested best practices for ensuring cost-effective collaboration. Participants recommended benchmarking hydropower projects and tracking the project timelines. Incorporating this information into the lessons learned and having it available for other developers could be very beneficial.

Collaborate early with an integrated delivery team before licensing (developer with OEM/design/engineering teams; could increase knowledge of construction)

Have a simplified, standardized bidding process for OEMs - the cost for manufacturers to prepare bids can be very expensive, encouraging OEMs to use existing configurations, reducing the incentive to innovate for individual projects—particularly small projects

Apply value engineering to small hydropower project design

- Develop design criteria adapted to small hydropower (large and small hydropower are often different in purpose and economics).

- Conduct a concept review at each gateway stage of a project’s development with the OEM/Design/Engineering team; consider the “must have” versus the “nice to have” components

Create a standard, cost-efficient interconnection approach

- There was agreement that electrical interconnection from the project to the electric grid/distribution system presents a major “hidden” cost for small hydropower projects. One example given was the role that transmission system upgrades play in killing otherwise feasible projects—if a utility demands a new substation, costs could run from $1M (interconnection to the distribution system) to $7M (if full high-voltage transmission interconnection was required). Some participants also mentioned the costliness of potentially unnecessary interconnection study requirements.

- Establish guidelines and standards nationwide for how a 1-5 MW facility can be added to the grid, and have these standards adopted regionally.

- Supplement the DOE resources assessment with exploration of potential interconnection points to identify regions with capacity so projects can be developed in areas with excess capacity. Ability to connect into distribution system for small projects can save considerable cost.

Group projects and designs – find like projects in a region/across the country so they can be "bundled" as one initiative (note: this also improves the ability to finance the projects, a key barrier in develop small hydropower).

Valuation opportunities—rather than cost reduction, consider how to increase the valuation of delivery of hydropower (e.g., incorporate ancillary benefits into the valuation).

Consider delivering generation from small hydropower in direct current (DC) rather than alternating current (AC) as this may eliminate the need for additional electrical infrastructure and keep small hydropower locally sourced and used.

Related to improving and streamlining the project development process, participants brainstormed many ideas and discussed external factors to the development process. Participants discussed that a staged approach to project development could reduce costs. For example, a project could be constructed with the basic equipment and structures and then as the facility begins to generate revenue or market conditions become more favorable (i.e., prices), more features or more capacity can be added incrementally. Modular designs would reduce the cost and risk of such an approach, however participants recognized that the current licensing process may not work for this type of incremental approach.

3.4 EXPAND DOE ENGAGEMENT WITH THE HYDROPOWER INDUSTRY

In addition to direct activities to reduce cost, industry participants also provided feedback and recommendations to DOE on subjects ranging from the workshop itself to ways to more effectively engage with the hydropower industry to ensure long-term cost reductions are achieved.

Conduct regional workshops (similar to this one) - participate in NHA regional meetings and utilize NHA's networking capabilities to connect with and maintain industry relationships.

- Gather similar feedback regionally to build on this initial workshop and explore unique regional cost drivers and technology opportunities.
- Alaska with higher electricity costs offers a test bed for small hydropower.
- The small, but technically focused format was considered successful, consider expanding participation to include utility representatives and select environmental NGO representatives.
- Exclusion of licensing as a topic was well-received and considered beneficial to achieving workshop goals, but it was noted that licensing and related topics still slipped into discussion. Some participants provided feedback that the discussion was at times still too focused towards the permitting process.

Engage the construction community to help find innovative solutions to civil works costs.

- Consider participation in major conferences, both those attended by conventional hydropower contractors and those outside of the hydropower industry (e.g., Oil and Gas)—communicate where DOE is investing and searching for new approaches.
- Reach out beyond traditional hydropower contractors, an example was given of a developer of a recent Bay Area Rapid Transit (BART) expansion project; the developer typically constructs ski lifts and brought innovative design perspectives to the design of the transit expansion.

Reach out to developers to understand issues with projects that were *not* built—participants noted that data from recently constructed projects is a self-selecting, necessarily successful, sample of developments. It would also be helpful to understand more about projects that were not developed and why to understand the barriers to development. An oft cited example was the role of electrical interconnection costs in stopping otherwise feasible projects

Collaborate with the industry and national labs – work more closely together to maximize the relevance and impact to the hydropower industry and engage industry as paid project participants (so they have "skin in the game") and encourage early interactions as DOE lab project partners to collaboratively advance ideas/solutions.

"Build the case" for the significant small hydropower opportunity (e.g., the forthcoming *Hydropower Vision* report and recent resource assessments) and highlight how investments are accelerating market development and how there are focused R&D investments in small hydropower.

Demonstrate the market –if OEMs see a profit opportunity, they will innovate and participate

- With adequate demand, supply chains can be optimized and costs reduced. Build momentum and show the significant opportunity

- Example given: France announces a $15 billion public investment in offshore wind and suppliers establish offices, manufacturing facilities, and capability to deliver.

Build broader awareness of small hydropower to those outside of the industry.

- Ideas were suggested such as using social media, public radio and outreach to large technology companies who may be interested in partnering or investing in hydropower in the future.

- Market hydropower as renewable – participants consistently shared that hydropower should be viewed as a renewable energy source. This would help build the hydropower market and could be used to promote and market the industry.

4. WORKSHOP REFLECTIONS/CONCLUSION

Participants thanked DOE, ORNL and Kearns & West for convening the workshop and encouraged DOE to continue having these types of discussion with key members of the hydropower industry, including environmental non-government organizations and utilities in addition to developers, contractors and manufacturers. Participants noted that having a smaller subset of the industry can result in effective and more focused discussions on hydropower issues and opportunities. DOE, ORNL and Kearns & West thanked everyone for their participation.

APPENDIX A. WORKSHOP PARTICIPANTS

- Carl Atkinson, Voith Hydro
- Francois Berthiaume, Alstom
- Norm Bishop, Knight Piesold
- Marisol Bonnet, New West Technologies/DOE
- Derek Dykstra, Gracon, LLC
- Mike Manwaring, MWH Global
- Debbie Mursch, Alstom
- Patrick O'Connor, ORNL
- Daniel Rabon, DOE
- Kelsey Rugani, Kearns & West (facilitation team)
- Abe Schneider, Natel Energy
- Brennan Smith, ORNL
- Doug Spaulding, Nelson Energy
- Timothy Welch, DOE
- Anna West, Kearns & West (facilitation team)

APPENDIX B. WORKSHOP AGENDA

Advanced Hydropower Innovations and Cost Reduction

Workshop Agenda
November 5 & 6, 2015

Day 1: 8:30 am – 5:00 pm
Day 2: 8:30 am – 12:00 pm

Hilton Garden Inn Arlington/Courthouse Plaza
1333 North Courthouse Road
Arlington, VA 22201

Agenda

Meeting Objectives

- Identify Opportunities to Advance Hydropower through Innovations that can Achieve Cost Reductions in Producing Hydropower
- Identify Potential Challenges or Barriers to Achieving Innovations and Cost Reductions, Explore Potential Solutions
- Identify the "State of the State" on Advancing Hydropower Through Innovations and Cost Reductions, With a Forecast on Opportunities and Recommendations for Future Advancement

Thursday, November 5, 8:30 AM – 5:00 PM

I Introduction/Workshop Overview **8:30 – 9:00 am**

- Welcome - Tim Welch, DOE; Patrick O'Connor, ORNL
- Roundtable Introductions - Anna West, Kearns & West
- Workshop Objectives - Patrick O'Connor
- Agenda Review – Anna West

II Hydropower Innovations and Cost Reduction Opportunities **9:00 – 10:30 am**

- Costs Overview and Opportunities - Patrick O'Connor
- Capital (some attendees give 5-min/2-slide examples/perspectives)
  - Modularity in Equipment and Civil Structures
  - Standardized Design
  - Manufacturing Technologies and Materials

- Discussion
  - Examples (within the industry, elsewhere)
  - Merits and Magnitude of the Opportunities
  - Barriers, Ways to Overcome the Barriers?
  - What's Missing? – Other Capital Innovations/Cost Reduction Opportunities?

BREAK **10:30 – 10:45 am**

III Hydropower Cost Reduction Opportunities, Continued **10:45 am – 12 pm**

- O&M (some attendees give 5-min/2-slide examples/perspectives)
  - Designing for O&M
  - Staffing, Automation, and O&M Philosophy

- Discussion
  - Examples (within the industry, elsewhere)
  - Merits of the Opportunities
  - Barriers, Ways to Overcome the Barriers?
  - What's Missing? – Other O&M Innovations/Cost Reduction Opportunities?

LUNCH **12:00 – 1:00 pm**

IV "Outside-of-the-Box," "Home Run" Possibilities **1:00 – 2:45 pm**

- Can small hydropower be reinvented from the ground up? – Brennan Smith, ORNL
- Additional attendee perspectives
  - Different Ways to Develop Projects
  - Achieving Environmental Sustainability AND Cost-Effective Hydropower
  - Other
  - Innovative Examples

- Discussion
  - Merits of the Ideas
  - Barriers to Success
  - Overcoming Barriers
  - Recommendations

V Levelized Cost of Energy (LCOE) Review **2:45 – 3:00 pm**

- Review document – Patrick O'Connor

BREAK **3:00 – 3:15 pm**

VI Breakout Groups on Capital, O&M, and "Home Run" Ideas **3:15 – 4:15 pm**

VII Breakout Group Reports and Day 2 Agenda Review **4:15 – 5:00 pm**

ADJOURN **5:00 pm**

Friday, November 6, 8:30 AM – 12 PM

I Agenda Review and Reflections **8:30 – 9:00 am**

- Agenda Review
- Reflections

II Scenarios, "What If…" **9:00 – 10:00 am**

- External Factors That Might Impact Hydropower's Value – Patrick O'Connor
- Capital, O&M, and Additional "Home Run" Ideas That Could Be Game Changers

BREAK **10:00 – 10:15 am**

III Recommendations to Achieve Greatest Gains for **10:15 – 11:45 am**

IV Hydropower Innovations and Cost Reduction

- R&D Agenda
- Information Sharing – How Might Broadening Understanding Help Achieve Innovations/Cost Reductions?
- What Can Each "Sector" Do?
  - Developers
  - Manufacturers
  - Engineering
  - Environmental Analysis
  - Low Hanging Fruit Innovations
  - Potential High Impact Innovations
  - General Recommendations
  - Other

V Wrap-Up **11:45 am – 12:00 pm**

- Closing Thoughts
- Workshop Feedback