



2018 RESEARCH HIGHLIGHT IN MANUFACTURING ANALYSIS

Analysis of Supply Chains and Advanced Manufacturing of Small Hydropower Systems

National Renewable Energy Laboratory:

Parthiv Kurup, Tim Remo, Jason Cotrell,
and Scott Dale Jene

Oak Ridge National Laboratory:

Patrick O'Connor

SUMMARY OF FINDINGS

This project has analyzed the small hydropower (SHP) market (including the trade flows, detailed costs, and potential markets) to help determine the status and opportunities along the supply chain.

SNAPSHOT:

Small Hydropower Has Significant Potential

- Only 3% of U.S. dams presently generate electricity. The remaining non-powered dams (NPDs) represent a substantial market opportunity, and there is the potential by 2050 to add 4.8 gigawatts (GW) of new electricity generation capacity by repowering NPDs, utilizing advanced technologies and low-cost financing (DOE 2016).
- A key strength in the U.S. hydropower manufacturing sector is the significant experience and availability of a skilled workforce, which can be leveraged by the SHP manufacturers to meet the domestic and foreign potential. The primary factors affecting manufacturing decisions for SHP systems include clustered areas of the country with regional strength in SHP, skilled labor availability, product quality, proximity of suppliers to excellent resources, existing supply chains, and existing or growing markets—all are in abundance in the United States.
- Oak Ridge National Laboratory (ORNL) and the National Renewable Energy Laboratory (NREL) have worked together to select and define a representative system for NPDs made up of two 5-MW Kaplan-style turbines (referred to in this highlight as 2x5 MW turbines). For this representative system, a detailed manufacturing cost analysis was created. The manufacturing cost of one representative system (i.e., 2x5 MW turbines) is approximately \$510,000, with a total assembled cost of approximately \$550,000.
- The levelized cost of electricity (LCOE) is sensitive to the overall electro-mechanical equipment cost, but civil works are the biggest driver for SHP LCOE. Electro-mechanical equipment contributes 8%–30% of the total LCOE for NPDs, while civil works constitute between 18% and 58% of the project LCOE. The remainder is from the balance of plant (~25%) and the operations and maintenance (~20%).
- Additive manufacturing (AM) has significant potential for printing complex parts and molds to then produce components, rapid prototyping of scale models for testing, and decreasing the innovation and cycle time to get products to market.

Hydropower in the United States has been a reliable and critical renewable energy generation resource over the last 100 years, and as of 2016, approximately 101 GW of hydropower and pumped hydropower capacity were installed (DOE 2016). As such, strong manufacturing supply chains have been essential. The U.S. hydropower supply chain is distributed across the country with denser concentrations near manufacturing centers, such as the West Coast, Midwest, Great Lakes, and Northeast (Uría-Martinez, O'Connor, and Johnson 2015). The hydropower manufacturing hubs (such as the Northeast and the Great Lakes vicinity), which produce components for all sizes of hydropower generating equipment, can be seen in Figure 1. The major components for hydropower are the gates, valves, generators, penstocks, transformers, and turbines.

To gain a true understanding of the manufacturing opportunities and value along the hydropower supply chain, focus has been given to the 1–10 MWe turbine range, referred to as SHP in this highlight. The U.S. International Trade Commission (USITC) has classified this turbine range (1–10 MWe) under trade code 8410.12. Figure 2 highlights the U.S. export and import values (in dollars) for hydraulic turbines and waterwheels of SHP turbines, where the data are aggregated by country from 2005 to 2015.

The U.S.-centric map in Figure 2 illustrates how the United States interacted with other countries for SHP turbines with a capacity of 1–10 MW from 2005 to 2015. It is worth noting, however, that the current data set does not show each country's total export or import data for the SHP turbines; it shows only the export and import values for the United States

(USITC 2017). The consolidated data from 2005 to 2015 were aggregated into a trade flow map, where the blue lines represent export flow from the United States and the green lines represent imports. The thickness of the line indicates the value of the trade in dollars, either as an export or import. Only countries with significant

trade flows or specific competitive interest to the United States are shown. The data from 2005 to 2015 indicate the SHP turbine market (i.e., 1–10 MW) had an export value of approximately \$35 million for the United States and approximately \$16 million of SHP turbines by value were imported.

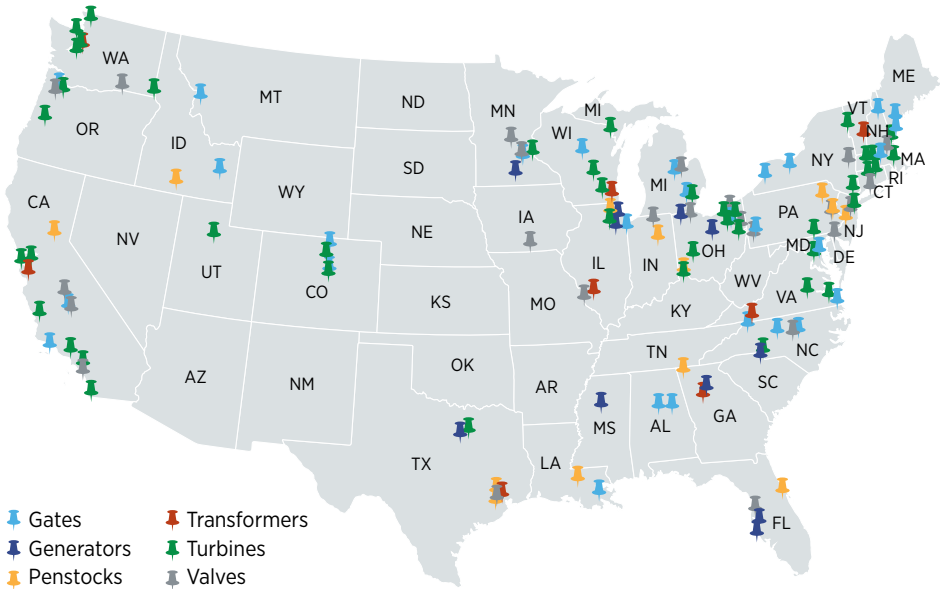


Figure 1. Map of U.S. hydropower manufacturing locations by state and components manufactured (Uría-Martinez, O'Connor, and Johnson 2015)

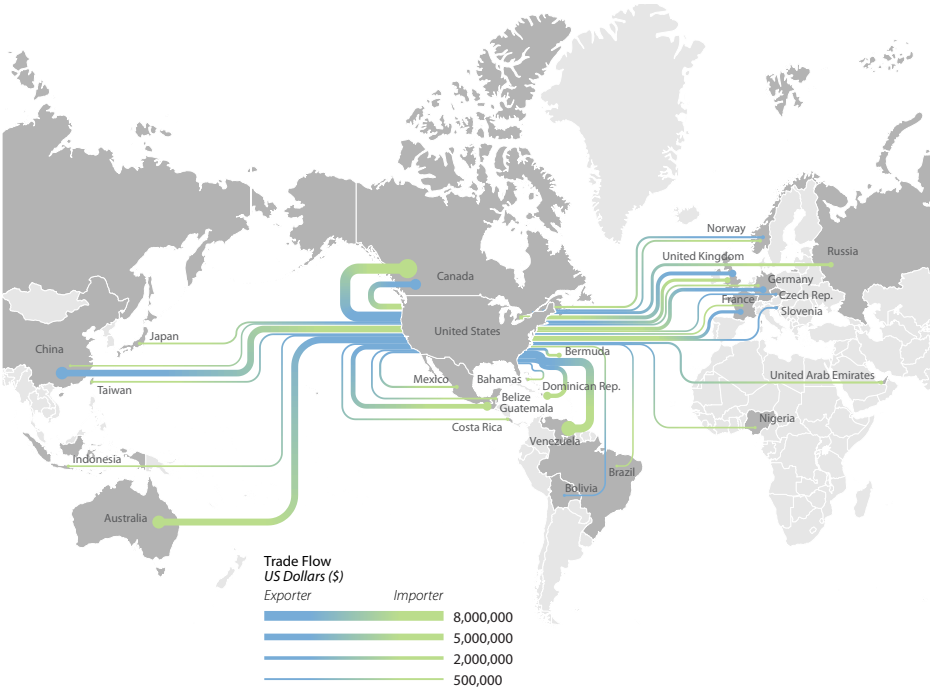


Figure 2. U.S. trade flows for SHP turbines (1–10 MW, HTS 8410.12), 2005–2015 (USITC 2017)

In this time period (2005–2015), the United States exported SHP turbines to 45 countries and imported from 13 countries (USITC 2017). When the same period is looked at for the U.S. export value of the “parts of hydraulic turbines” (i.e., HTS 8410.90), it was found the export value for the United States was approximately \$393 million (USITC 2017). This highlights that while the United States has a small export market for SHP turbines, the parts and regulators for the overall hydropower turbine market is over 10 times in value. A key insight from an ORNL study is that the significance of the parts market is likely due to the rehabilitation and modernizing happening within the U.S. hydropower fleet, where since 2005, “approximately \$3.6 billion has been spent to repair, replace, and refurbish U.S. hydropower facilities” (Uriá-Martinez, O’Connor, and Johnson 2015).

Key countries that the United States has exported SHP turbines to include Australia, Canada, Germany, Norway, and the United Kingdom. Countries that the United States imports SHP turbines from include Canada, China, France, and Germany.

Manufacturing Analysis of a Representative 2x5 MW System

This project has created and refined a detailed bottom-up manufacturing cost analysis of the main turbine equipment of a representative modular SHP system. This representative system is comprised of two 5-MW Kaplan-style turbines. Five representative systems (i.e., 10 turbines) are modelled for manufacture annually.

Figure 3 shows the breakdown of the representative system cost by component type (i.e., the pitch systems, blades, shaft couplings, hubs, and nose cones), and it includes

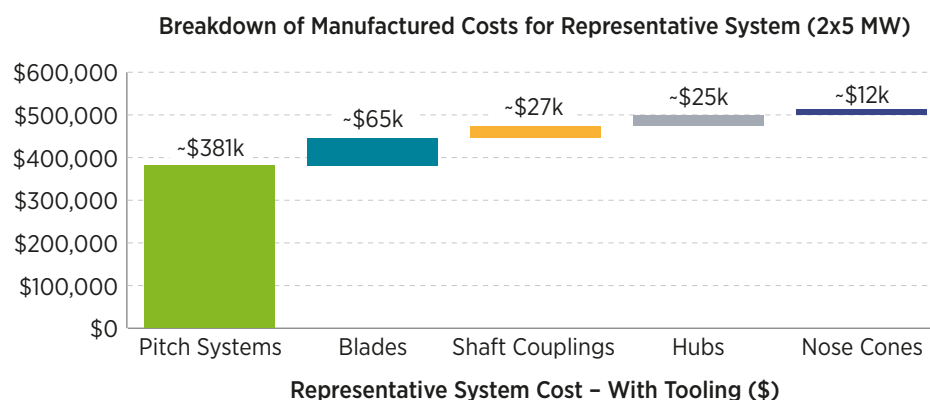


Figure 3. Breakdown of the representative system manufactured cost by main component type

the tooling investment per 2x5 MW system. The two pitch systems for a representative 2x5 MW system made up nearly 75% of the manufactured cost, and the eight blades were the next-largest proportion of the overall system cost at 13%. The total representative manufactured cost of approximately \$510,000 is broken down by the material, setup, process, rejects, and tooling costs allocated to the representative system. Further details are found in the full report (Kurup, Cotrell, Jene, O’Connor, and Remo 2018). When assembly is included, a representative system could cost ~\$550,000 but does not include transport or the civil works to install the representative system.

A key assumption in the analysis was that five representative 2x5 MW systems could be made, allowing for the tooling cost to be split over five sites. The overall tooling cost for the 10 SHP turbines was approximately \$1.75 million. This included the design of sand cast molds for the hubs, blades, and nose cones and the forging presses and hammers for the pitch shaft. If each site used different turbine designs (e.g., due to different heads and flow rates available at that NPD site), it could be expected that the castings needed for the hub, blades, and nose cones would be different at

each site, which could increase the overall tooling investment per site or representative system.

The material cost was approximately \$139,000, which was ~27% of representative system cost. The representative system is sensitive to the material used for each component (e.g., \$/lb for steel for the hub). A $\pm 10\%$ change in material cost (e.g., from \$139,000 to \$154,000) has $\pm 3\%$ change for the overall system cost. It is worth noting that certain high-strength materials (e.g., for the shaft and pitch system of the representative turbine) could be subject to price changes more than the cast steel. When the labor cost is extracted from the manufacturing analysis as a percentage of the overall manufactured cost, it represents a small percentage of the overall cost to manufacture the system. The setup cost is 100% labor, and the process cost is estimated at 60% labor (where the remainder is the respective machine’s rate); this was only \$13,000–\$15,000 of the system cost or only 2.5% of the manufactured cost.

Techno-Economic Impact of Equipment on the Competitiveness of New SHP

This work has helped determine the LCOE impact of the use of such representative turbines as part of the

overall project. This has been done using the ORNL Integrated Design and Economic Analysis (IDEA) model. Figure 4 shows the LCOE impact for the overall potential NPD project. Assuming a 60% capacity factor, the electro-mechanical equipment contributed approximately \$23/MWh of the total \$81/MWh of the project LCOE (i.e., 28% of the LCOE).

The estimated capital cost of this potential NPD project could be approximately \$3,400/kW, of which the biggest contributors were civil works and the electro-mechanical equipment. The electro-mechanical equipment (which includes the turbines as well as other equipment excluded from the manufacturing analysis) is the second-largest contributor to the capital cost at 35% (\$1,176/kW) compared to the civil works at 37% of the capital cost. For this representative project, the cost of equipment is a major—but not the most determinative—cost category.

Opportunity Space

Both in the domestic and foreign markets, there is significant potential for U.S. manufacturers and suppliers to play an important and leading role in the SHP supply chain. As highlighted, there are nearly 4.8 GW of potential to power NPDs (DOE 2016). A key issue that must be addressed by U.S. SHP equipment suppliers and developers for the domestic market is the need to be cost competitive (on the electro-mechanical equipment such as the turbine or generator as well as the civil works and installation) compared to wind and photovoltaics (PV) to allow for the potential of SHP to be met. Foreign export markets such as Chile, China, Columbia, India, and Japan have an estimated 71,795 MW of technical potential that could be serviced with SHP installations (UNIDO 2016). Utilization of existing manufacturing capacity and expertise, along with economies of scale benefits, could result in increased global competitiveness through lower investment requirements

and component costs, which could lead to increased U.S. strength in the export of SHP systems and components.

There are significant opportunities for the use of composites and AM for hydropower components when design changes are made to hydropower systems. By taking advantage of the corrosion resistance, light-weighting, and structural benefits, composites and AM could help significantly alter hydropower structures and installations.

Learn More

See the released technical report on this work titled “*Analysis of Supply Chains and Advanced Manufacturing of Small Hydropower.*” (Kurup et al. 2018)

References

- DOE. 2016. “Hydropower Vision: A New Chapter for America’s 1st Renewable Electricity Source.” DOE/GO-102016-4869. Oak Ridge, TN: DOE. https://energy.gov/sites/prod/files/2016/10/f33/Hydropower-Vision-10262016_0.pdf.
- Kurup, Parthiv, Timothy Remo, Jason Cotrell, Dale Scott Jenne, and Patrick O’Connor. 2018. “Analysis of Supply Chains and Advanced Manufacturing of Small Hydropower Systems.” Golden, CO: NREL. <https://www.nrel.gov/docs/fy18osti/71511.pdf>.
- UNIDO. 2016. “The World Small Hydropower Development Report 2016.” United Nations Industrial Development Organization; International Center on Small Hydro Power. https://www.unido.org/sites/default/files/2016-11/WSHPDR_Executive_Summary_2016_0.pdf.
- Uría-Martínez, Rocio, Patrick O’Connor, and Megan Johnson. 2015. “2014 Hydropower Market Report.” DOE/EE-1195. DOE Wind and Water Power Technologies Office. http://nhaap.ornl.gov/sites/default/files/ORNL_2014_Hydropower_Market_Report.pdf.
- USITC. 2017. “United States International Trade Commission (USITC) - Interactive Tariff and Trade Database.” 2017. <https://dataweb.usitc.gov/>.

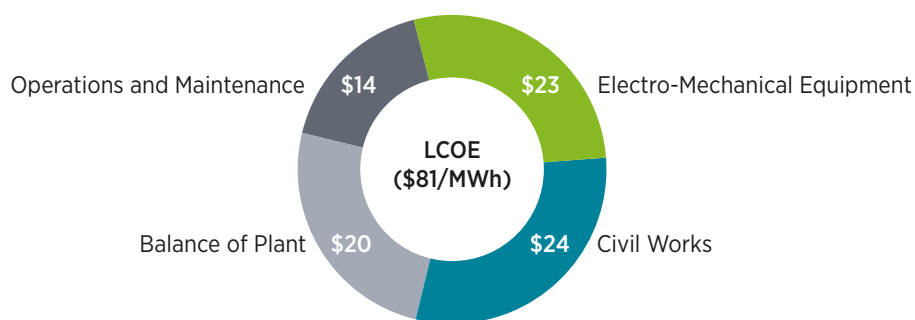


Figure 4. LCOE breakdown for prototypical NPD plant with the 2x5 MW representative turbines