Hidden hydropower at non-powered dams: United States development trends, research priorities, and technology innovations

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Annex XVI: Task 3: Adding Power to Non-Powered Dams and Water Management Facilities

- Review opportunities to add power to non-power dams and water management facilities. Many existing dams, built for water supply, irrigation, flood control etc., have potential to add hydropower to their discharge or diversion facilities. There is also potential to replace pressure reducing valves, add power to existing water conduits, irrigation canals and drop structures.

Red Rock Hydropower Project
36 MW

Lower Saint Anthony Falls Project
9.6 MW
Overview

US non-powered dam (NPD) overview and development trends

US landscape of hydropower development in canals, conduits, and water management facilities

Technology innovations

Research priorities
Non-powered dams
Sources: NHAAP (SHPs), NID (Dams), Foley et al., 2017 (Removals)

> 80% of all non-powered dam hydropower retrofits have occurred in the past 10 years

> 50% of all dam removals have occurred in the past 10 years

< 1% of all dams present today were built in the last 10 years
Most dams have very little energy potential and serve some purpose other than hydropower generation

2,051 dams out of 90,000 have 5,608 MW out of 5,900 MW of hydropower potential…

…that is, 2.2% of the dams have 95% of the hydropower potential

The majority of NPDs were built for recreation, flood control, or water supply

SOURCE: HydroSource, Witt et al., 2018
US experience with NPD identification and assessment

National Lab/DOE
55,000 dams with 12 GW of potential

US Army Corps of Engineers
223 dams with 6 GW of potential

US Bureau of Reclamation
191 sites with 268 MW of potential


US trends in NPD development

Since 2006:
- 58 NPDs licensed by FERC
  - 33 small (<10 MW)
  - 24 medium (10 - 100 MW)
  - 1 large (> 100 MW)
- 888 MW
- 3.7 TWh of annual energy

- Equivalent to removing greenhouse emissions from:

Developed NPDs = 58

Potential NPDs > 100kW = 2,051

SOURCE: Witt et al., 2018
### US Experience with NPD development

<table>
<thead>
<tr>
<th>Powerhouse location</th>
<th># of NPDs</th>
<th>Mean rated power (MW)</th>
<th>Mean turbine head (m)</th>
<th>Mean plant flow (cms)</th>
<th>Mean estimated capacity factor (%)</th>
<th>Primary Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Downstream penstock</td>
<td>19</td>
<td>8.1</td>
<td>38.1</td>
<td>36.1</td>
<td>42.8</td>
<td>1 3 6 6 2 1</td>
</tr>
<tr>
<td>(b) Adjacent to dam</td>
<td>14</td>
<td>34.8</td>
<td>5.9</td>
<td>709.5</td>
<td>50.8</td>
<td>9 4 0 0 1 0</td>
</tr>
<tr>
<td>(c) Downstream of dam</td>
<td>11</td>
<td>12.8</td>
<td>5.5</td>
<td>285.3</td>
<td>52.5</td>
<td>10 1 0 0 0 0</td>
</tr>
<tr>
<td>(d) Through dam</td>
<td>6</td>
<td>11.7</td>
<td>5.3</td>
<td>230.8</td>
<td>60.0</td>
<td>1 4 1 0 0 0</td>
</tr>
<tr>
<td>(e) In gate</td>
<td>5</td>
<td>3.8</td>
<td>22.2</td>
<td>39.7</td>
<td>43.1</td>
<td>1 0 4 0 0 0</td>
</tr>
<tr>
<td>(f) In lock</td>
<td>3</td>
<td>3.4</td>
<td>5.0</td>
<td>77.4</td>
<td>44.6</td>
<td>0 0 0 3 0 0</td>
</tr>
</tbody>
</table>

N = Navigation, R = Recreation, FC = Flood Control, WS = Water Supply, I = Irrigation, FW = Fish and Wildlife.

- = powerhouse location
Some NPD projects have installed costs favorable to intermittent renewables when considering capacity factors.

Installed cost of NPD ($/kW)

Estimated LCOE ($/MWh)

Source: Witt et al., 2018 (hydro); Lazard, 2018 (wind, solar)
Investment in environmental protection and enhancement

• As part of the licensing process, every NPD goes through an environmental review that results in between 4 to 50 protection, enhancement, and mitigation measures

• Annualized costs between $0 and $500,000 per measure
  • Only ~1 in 6 measures exceeds $5,000 annually
  • $0-$90/kW per project (annualized)

• Protection, mitigation, and enhancements makes up 0.25-27% of mean LCOE
  • Average: 6.2%
Basin-scale development approaches – project clustering

Developing multiple NPDs in series on a river simultaneously

- **Standard plant designs** drive cost reductions by duplication and economics of scale
- **Multi-project cumulative impact assessments** help lead to improved system outcomes


NPD development overview

- **Large NPDs** have been disproportionately targeted for development
- Some **movement towards smaller NPDs**
- **Navigation dams** targeted primarily due to predictable pools and consistent generation
- Many projects are **cost competitive** and include protection/enhancement investments
- **Clustering development** approaches gaining traction
- Hydropower retrofit at NPD can help **improve condition** in long-term
- Growing interest in **NPDs to meet carbon free energy goals** because hydro is flexible enough to provide a different set of grid services over time and space
Conduit, canal, water management facilities
US experience with canal, conduit, water management facility hydropower opportunity identification and assessment

- Most active field in terms of # of projects
- No national assessments

https://www.energy.gov/eere/articles/innovative-hydropower-technology-now-powering-apple-data-center
US Experience with conduit identification and assessment

Same basic method as NPDs but data is more scarce. For example:

US Experience with conduit/canal development

- Make up the **majority of plants** currently **planned for development**
  - As of August 2017, **87 conduit projects approved** with a total capacity of **almost 32 MW**
  - Most active in western states, roughly evenly split between **agricultural** and **municipal** projects

- Frequent requests for national inventory of opportunities, none currently exist

- Several **state-level** studies:
  - Colorado: replacing pressure reduction valves could result in **25 MW** of potential at **1,000 to 5,000 sites**
    [https://www.colorado.gov/pacific/energyoffice/atom/60016](https://www.colorado.gov/pacific/energyoffice/atom/60016)
  - California: **255 MW** of potential from man-made conduits at **128 sites**
  - Bureau of Reclamation: **225 MW** at **191 sites**
Technology innovations
Industry-led R&D projects with DOE funding

- Floating powerhouse
- Low head, modular powertrains

https://www.natelenenergy.com/turbines/
Industry-led R&D projects with DOE funding

- Floating intake with siphon
- Permanent magnet generator turbine

Industry-led R&D projects with DOE funding

- Archimedes screw with detachable blades made from composite materials

The cost of a traditional hull ranges from $600,000 to $800,000 and typically takes 3-5 months to manufacture.

Using BAAM reduced hull production costs by 90% and shortened manufacturing time to a matter of days.
Integrated hydraulic channels

3D Printed Components

STICK
The 7-foot-long, 400 lb stick was printed entirely of low-cost steel on the Wolf Robotics Wolf Pack printer in only 5 days. This is the first application of large-scale metals additive manufacturing at ORNL.

CAB
Using the Cincinnati Incorporated Big Area Additive Manufacturing system, the cab was printed in only 5 hours with carbon fiber reinforced ABS plastic.

HEAT EXCHANGER
The 13 lb aluminum heat exchanger was 3D printed entirely on the Concept Laser X line 1000 powder bed machine.
Multi-scale, multi-material capabilities

Small metal and composite components

Large scale demonstration projects

Wind

Windmill component

Marine

Marine vessel components

Auto

Car component

Hydropower...

Aerospace

Aircraft component

Construction

Building component
Axial flow runner and conveyance: **Amjet Turbine Systems**

- Modular AM components
- ~10 kW at 25 ft of head
- Post-processing includes machining and coatings

**Ongoing:** couple CFD to structural solvers to model long-term reliability

http://www.amjethydro.com/
Hydrokinetic turbine runner blades and gearbox housing: **Emrgy**

- Sand casting for metal gearbox (left) and AM parts (right)
- BAAM tooling for hydrofoil and spokes (78% cost savings)

https://emrgy.com/
Research priorities
**US areas of interest**

**Increase awareness and export** of emerging tech for hidden hydropower

Support the development of **low-head, modular designs** that can reduce infrastructure and construction costs and operate flexibly over a range of flow conditions at existing dams.

Promote **environmental stewardship** as essential element of hydropower development at NPDs and water management facilities

**Classification/organization of hidden hydro opportunities journal paper**
- Grouping of similar opportunities into categories
- Highlight examples from member countries
- Include targeted R&D efforts to date like ultra low head power trains

Contribute to broader hidden hydropower **assessment framework** (how can countries identify hidden hydropower opportunities) and business, social, and environmental models used to make hidden hydro pencil out
US general resource assessment approach – can this be extended to other countries and hidden hydro opportunities?

Reliance on detailed dam inventories as starting point

Layer on models and development assumptions

Hydrologic model (flow)

Power and cost estimate

Economics (costs/revenue)

Environmental Attributes (impacts/costs/legal)

Ranking, publication, and data dissemination

http://nid.usace.army.mil

Location
Purpose(s)
Dam type
Year built
Etc.

Technical data (head)

NID by Height (ft.)
- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 808
Discussion questions

• Data availability? If none available, how to generate base level databases?
  • Country/regional access to national inventories
  • New technology – machine learning?

• New low-cost generation technologies
  • 3D printing and alternative materials
  • Low head

• Creative business models
  • Universities with renewables commitments
  • Demand charge reduction (conduit plants)
  • Data centers and ‘green conscious’ corporate buyers
References

HydroSource: https://hydrosource.ornl.gov/

National Inventory of Dams : http://nid.usace.army.mil/

