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IEA Hydropower Technology Collaboration Program ExCo 2019

Hidden hydropower at non-powered dams:

United States development trends, research priorities, and technology innovations

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Tokyo, Japan | February 4, 2019

U.S. DEPARTMENT OF ENERGY

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.

Overview

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

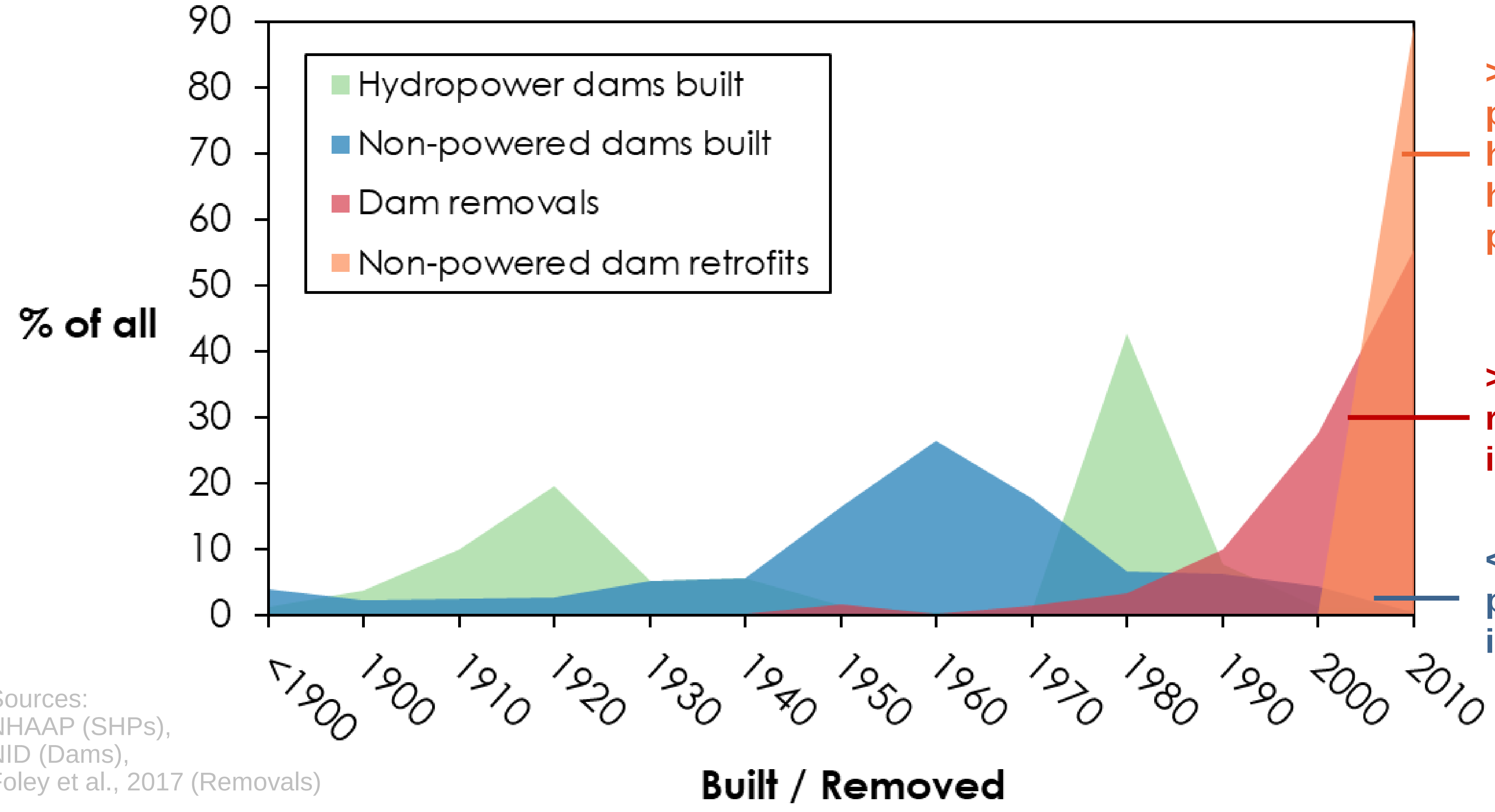
US landscape of hydropower development in canals, conduits, and water management facilities

Technology innovations

Research priorities

Non-powered dams

Dams, past and present



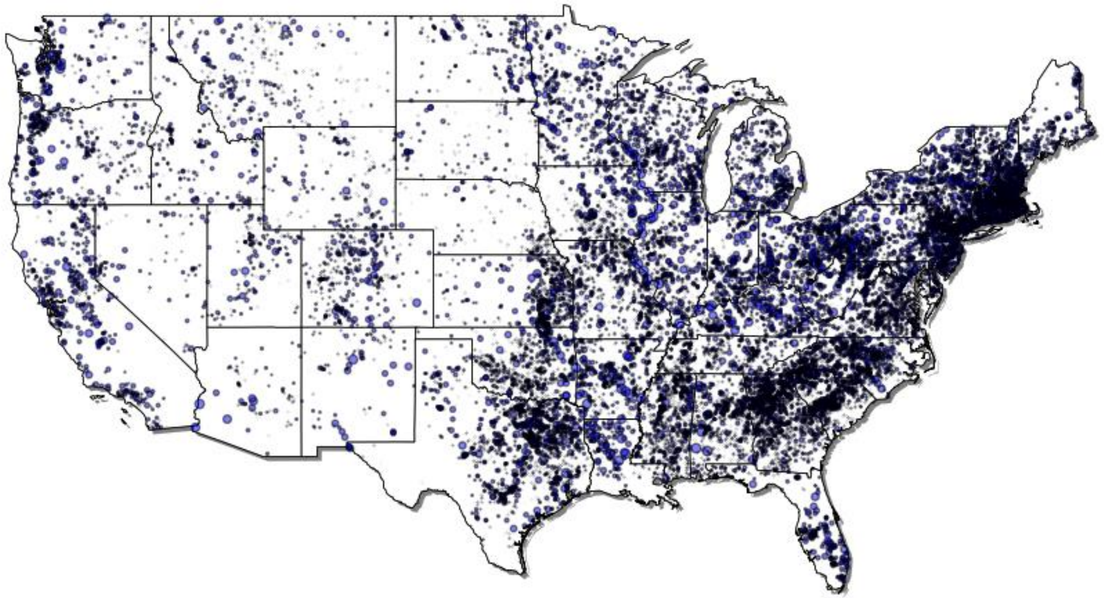
> 80% of all non-powered dam hydropower retrofits have occurred in the past 10 years

> 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

Sources:
NHAAP (SHPs),
NID (Dams),
Foley et al., 2017 (Removals)

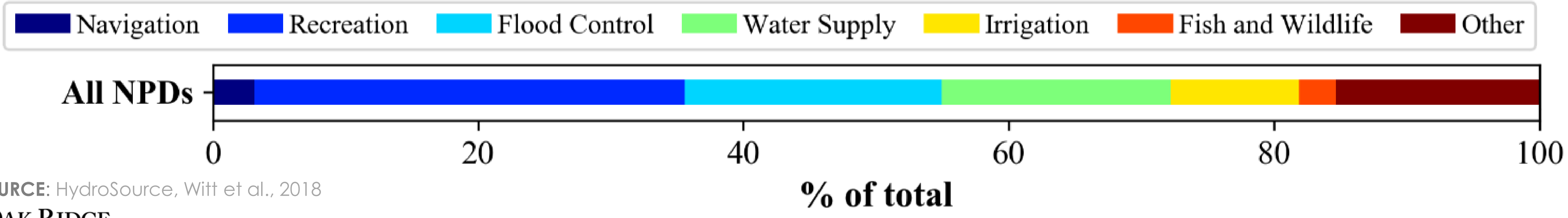
Most dams have very little energy potential and serve some purpose other than hydropower generation



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

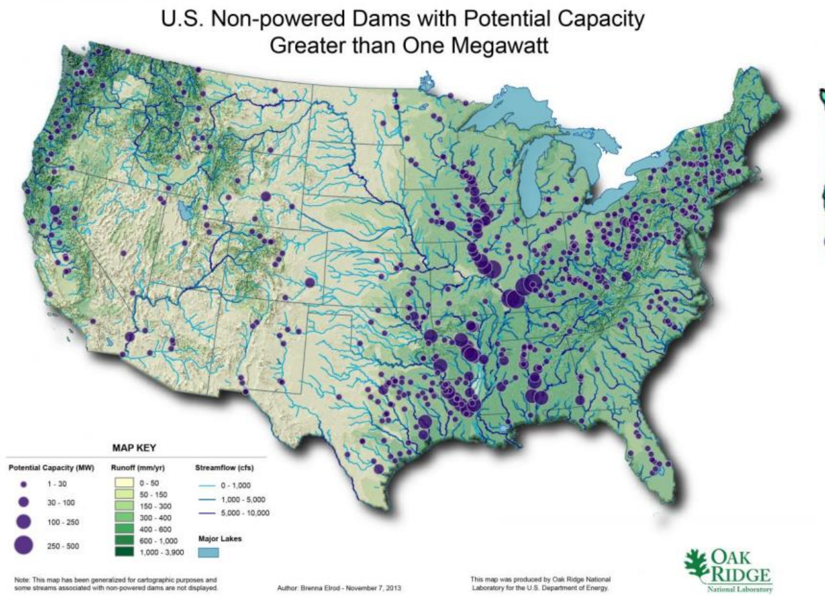


SOURCE: HydroSource, Witt et al., 2018

US experience with NPD identification and assessment

National Lab/DOE

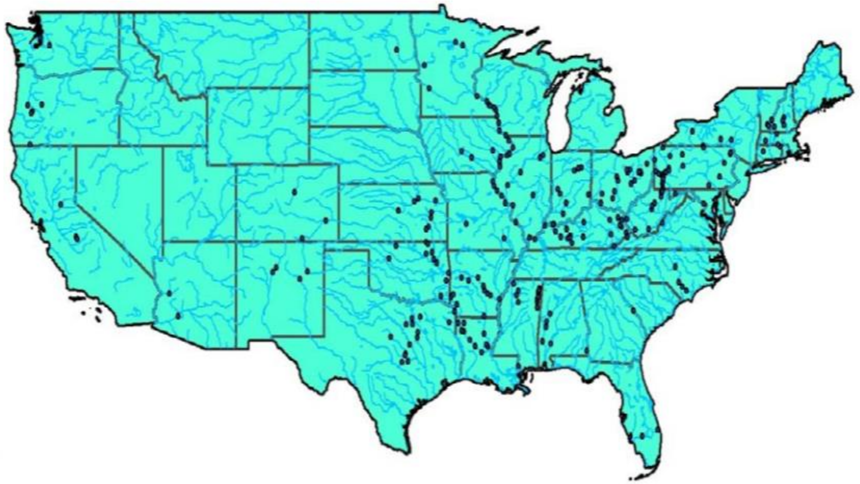
55,000 dams with 12 GW of potential



https://hydrosource.ornl.gov/hydropower-potential/non-powered-dam-resource-assessment

US Army Corps of Engineers

223 dams with 6 GW of potential



http://www.hydro.org/wp-content/uploads/2014/01/Army-Corps-NPD-Assessment.pdf

US Bureau of Reclamation

191 sites with 268 MW of potential

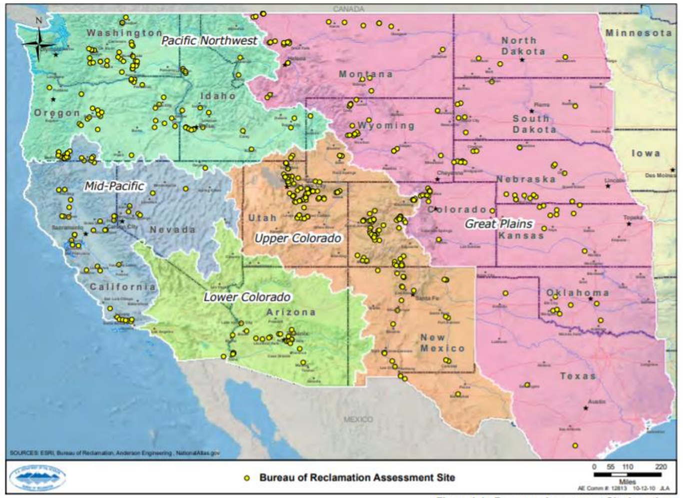


Figure 1-1 : Resource Assessment Site Locations

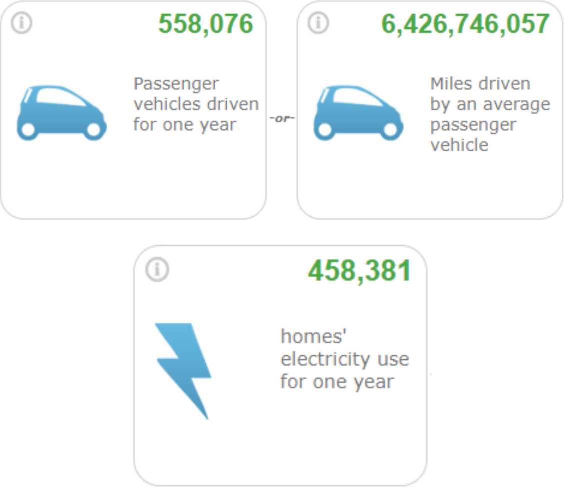
https://www.usbr.gov/power/AssessmentReport/USBRHydroAssessmentFinalReportMarch2011.pdf

US trends in NPD development

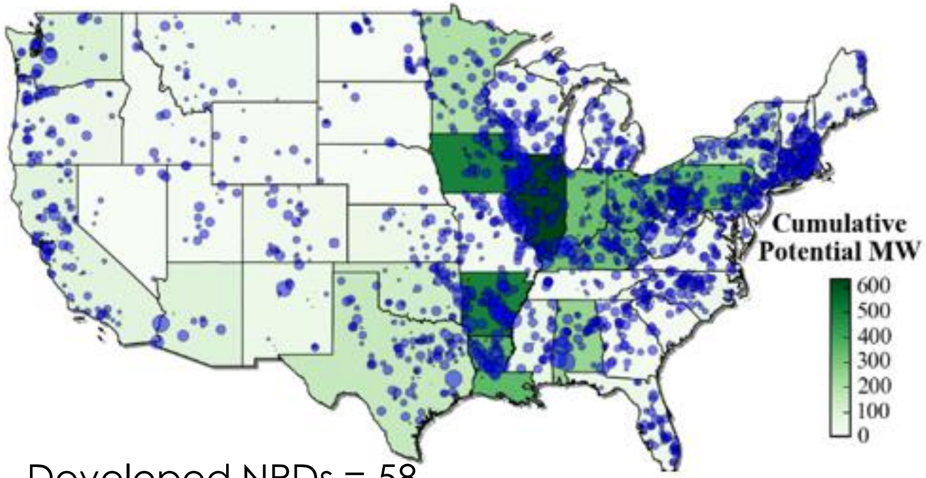
Since 2006:

- 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

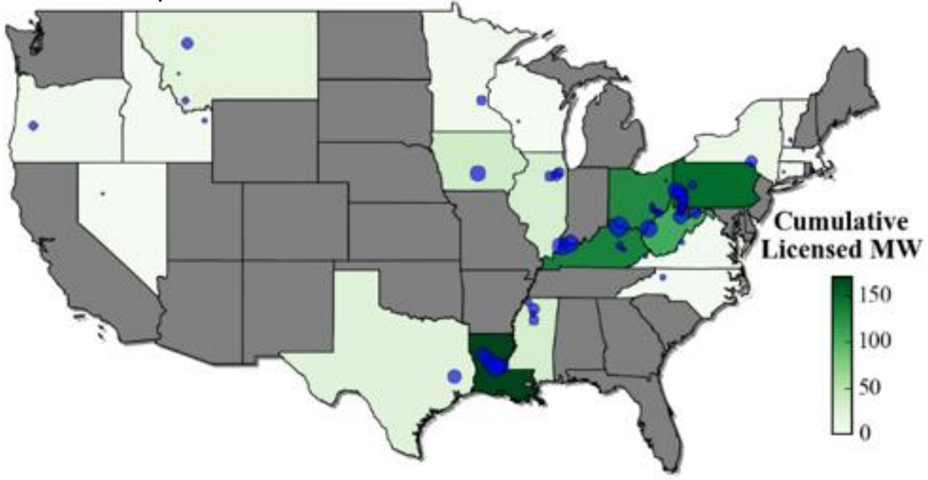
- Equivalent to removing greenhouse emissions from:



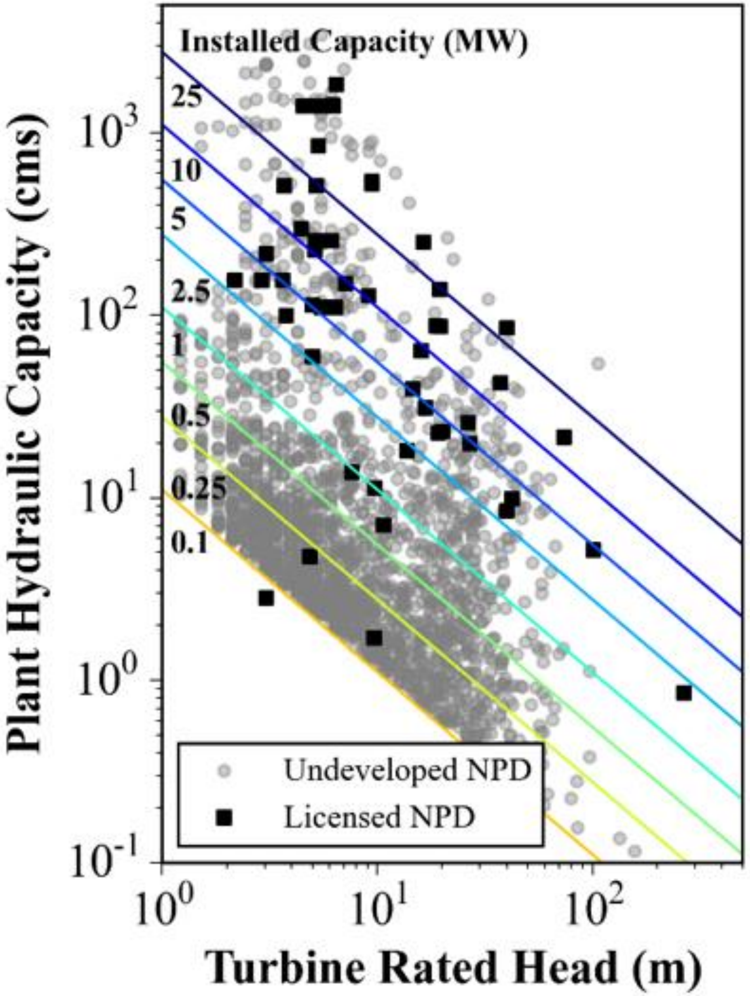
Potential NPDs > 100kW = 2,051



Developed NPDs = 58



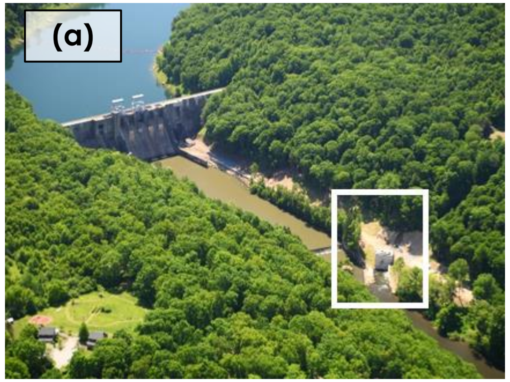
Large MW dams targeted

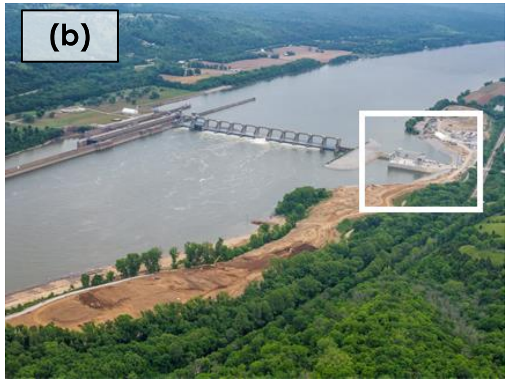


SOURCE: Witt et al., 2018

US Experience with NPD development

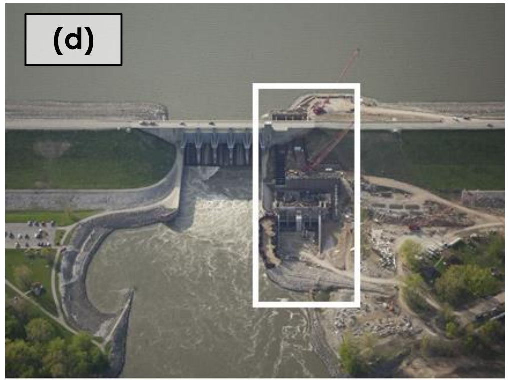
	Powerhouse location	# of NPDs	Mean rated power (MW)	Mean turbine head (m)	Mean plant flow (cms)	Mean estimated capacity factor (%)	Primary Purpose					
							N	R	FC	WS	I	FW
(a)	Downstream penstock	19	8.1	38.1	36.1	42.8	1	3	6	6	2	1
(b)	Adjacent to dam	14	34.8	5.9	709.5	50.8	9	4	0	0	1	0
(c)	Downstream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





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

▭ = powerhouse location



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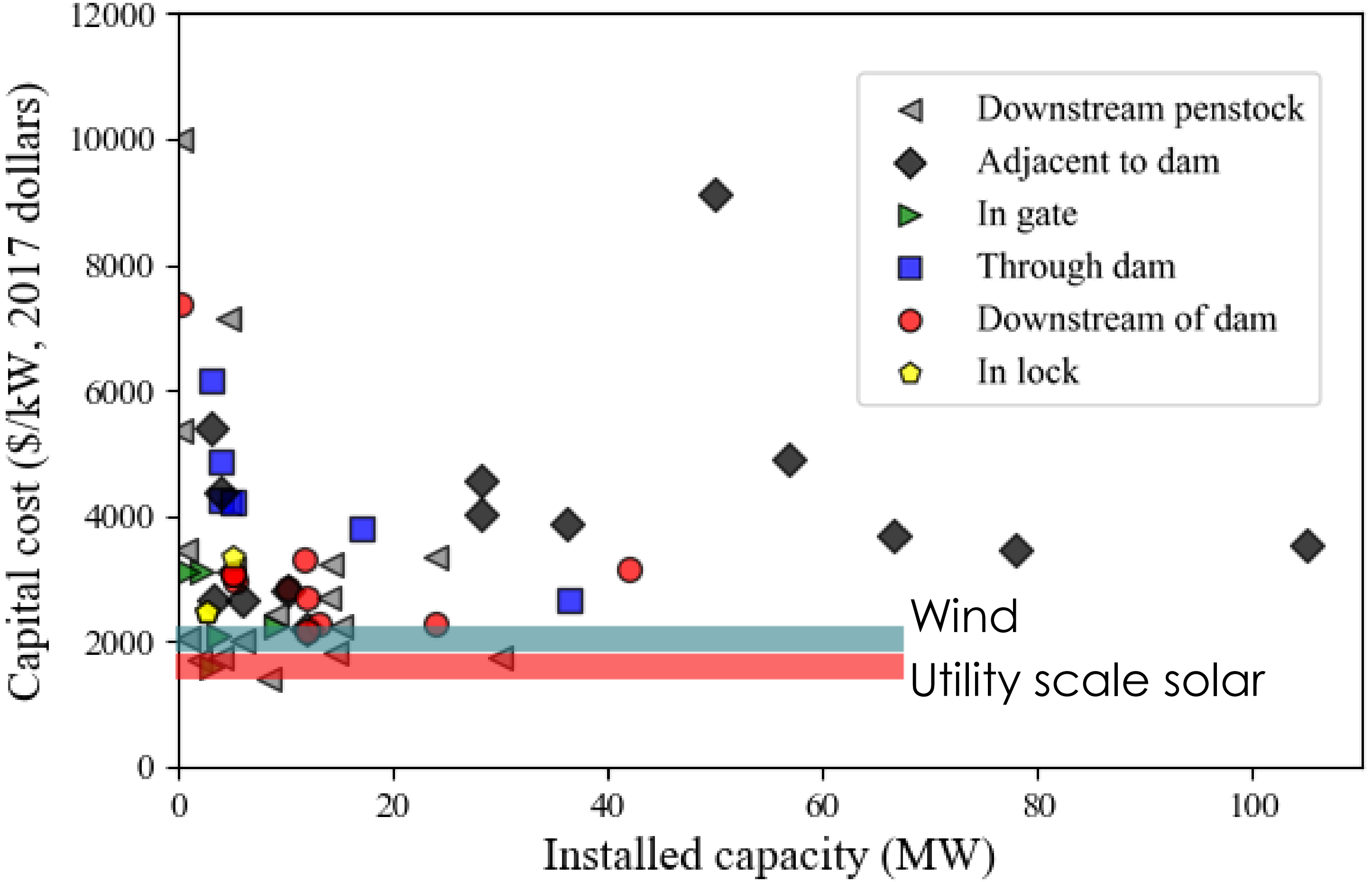
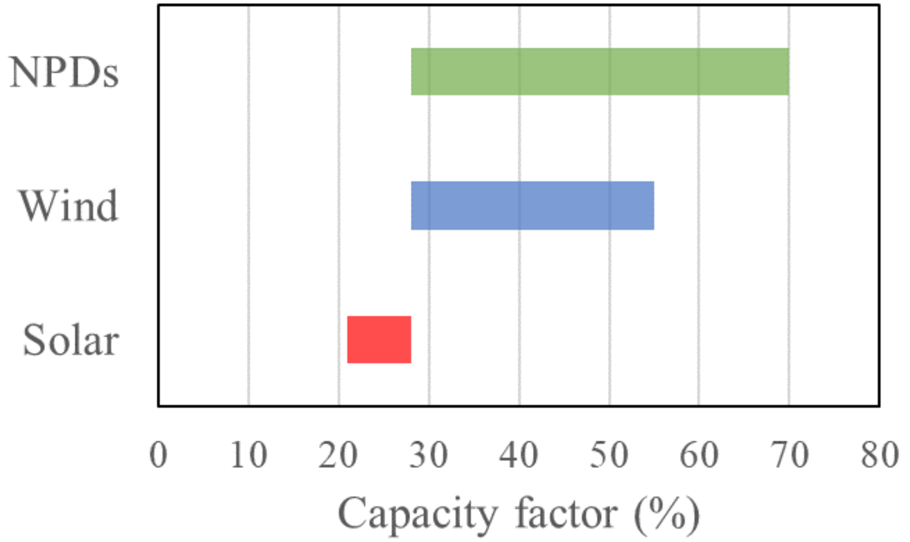
Some NPD projects have installed costs favorable to intermittent renewables when considering capacity factors

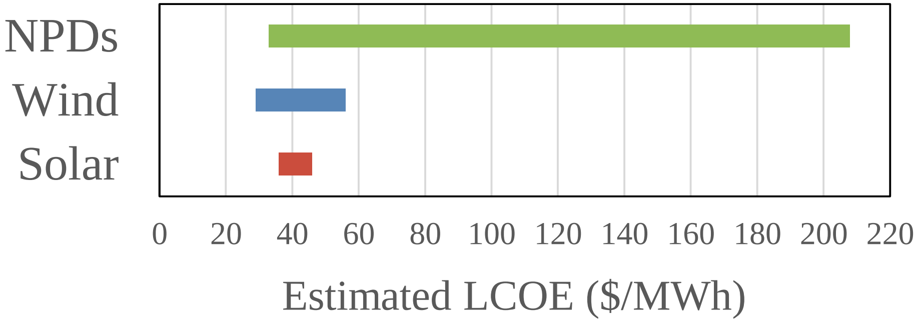
Installed cost of NPD ($/kW)



Estimated capacity factors



Estimated LCOE



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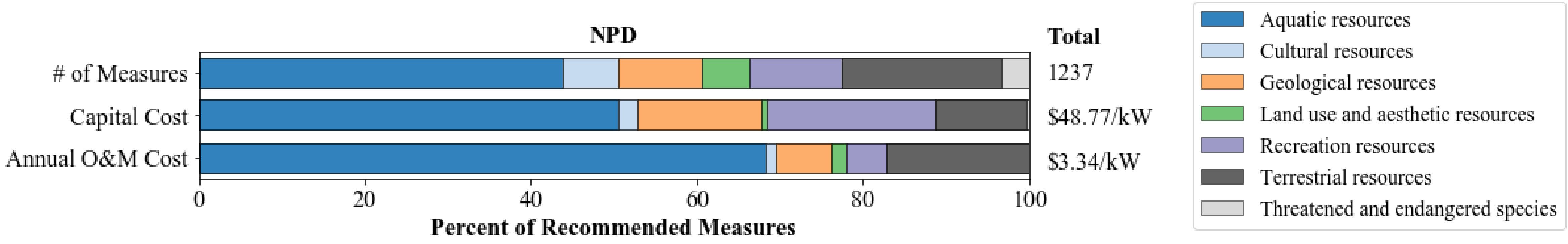
SOURCE: Witt et al., 2018 (hydro); Lazard, 2018 (wind, solar)

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%

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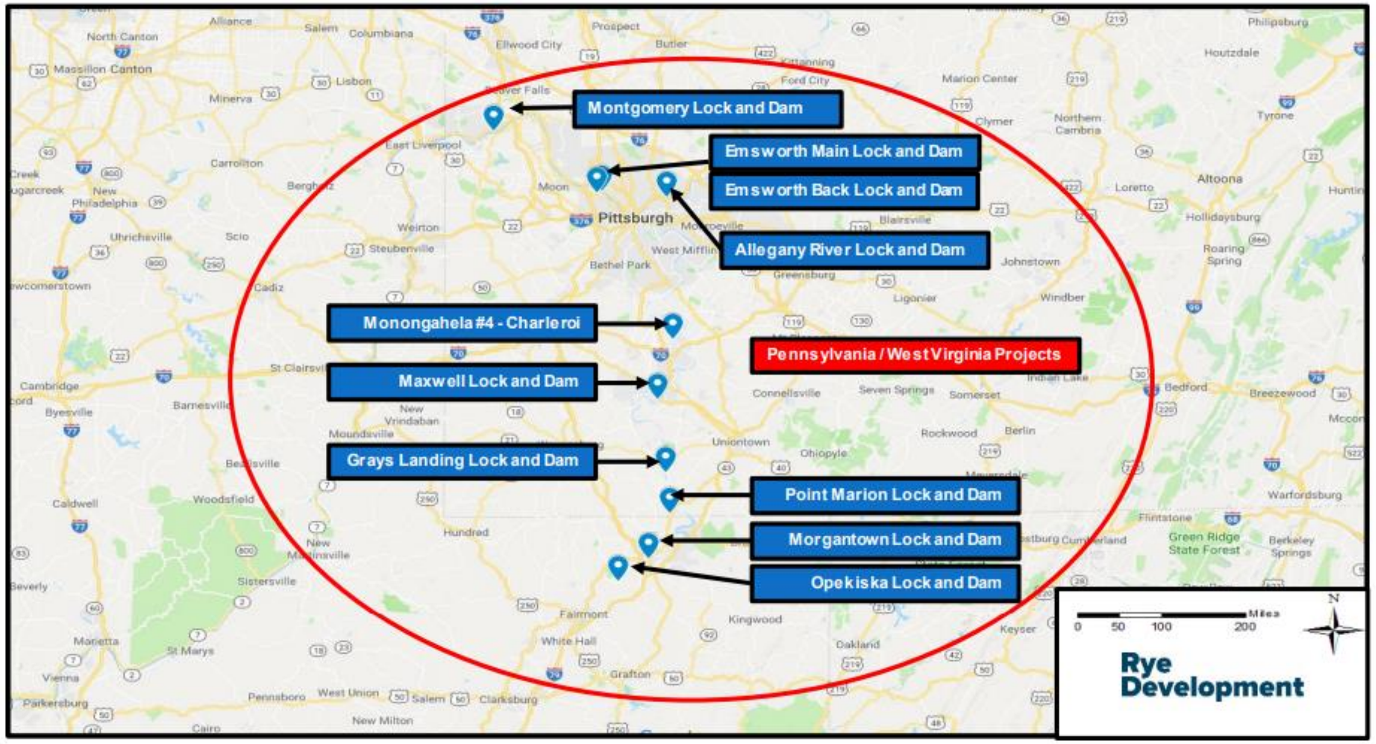
Basin-scale development approaches – project clustering

Developing multiple NPDs in series on a river simultaneously



SOURCE: http://www.ryedevelopment.com/wp-content/uploads/2018/11/EPC-RFQ-28-Nov-2018.pdf

University of Pittsburgh Pittwire

Hydropower Plan Marks Pitt's Largest-ever Commitment to Renewable Energy

SOURCE: https://www.pittwire.pitt.edu/news/hydropower-plan-marks-pitt-s-largest-ever-commitment-renewable-energy

- **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

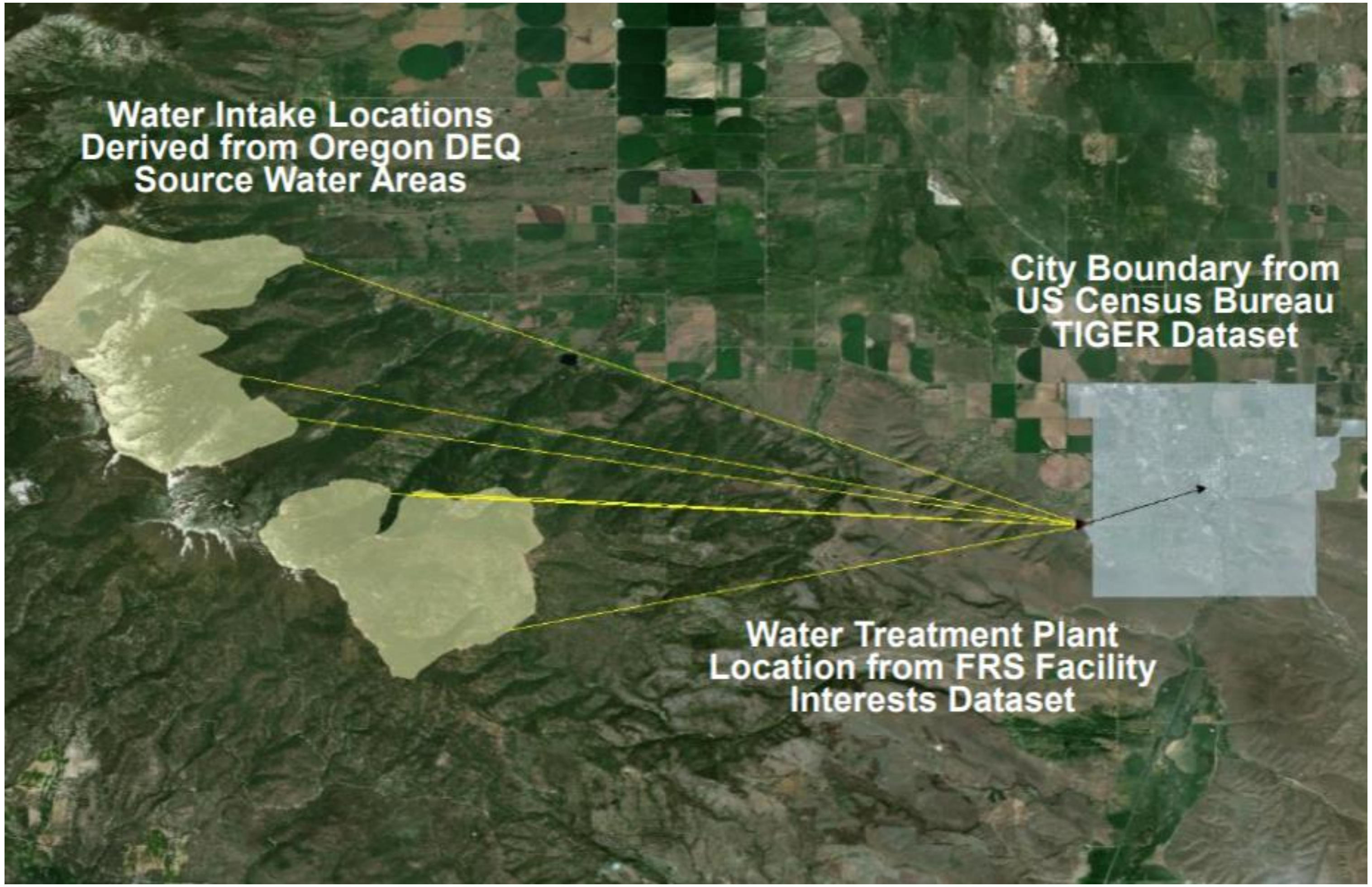
US experience with canal, conduit, water management facility hydropower opportunity identification and assessment

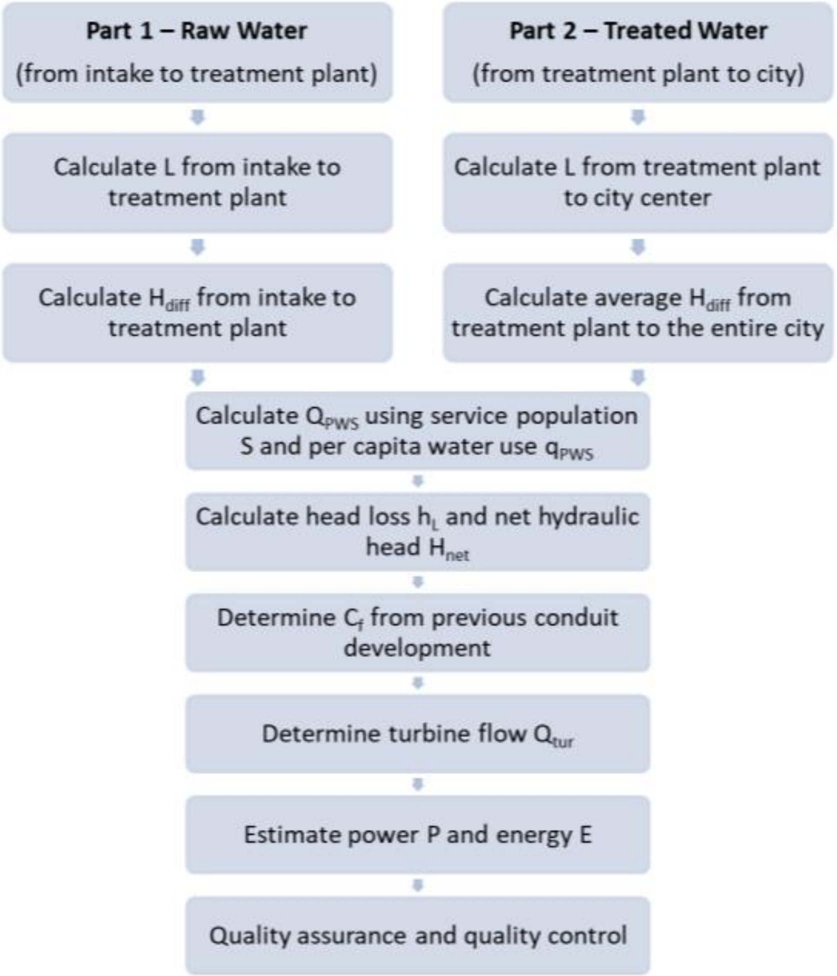
- Most active field in terms of # of projects
- No national assessments

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:





https://hydropower-qa.ornl.gov/docs/projects/CRADA_Telluride_Final_Report_v7_Public.pdf

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

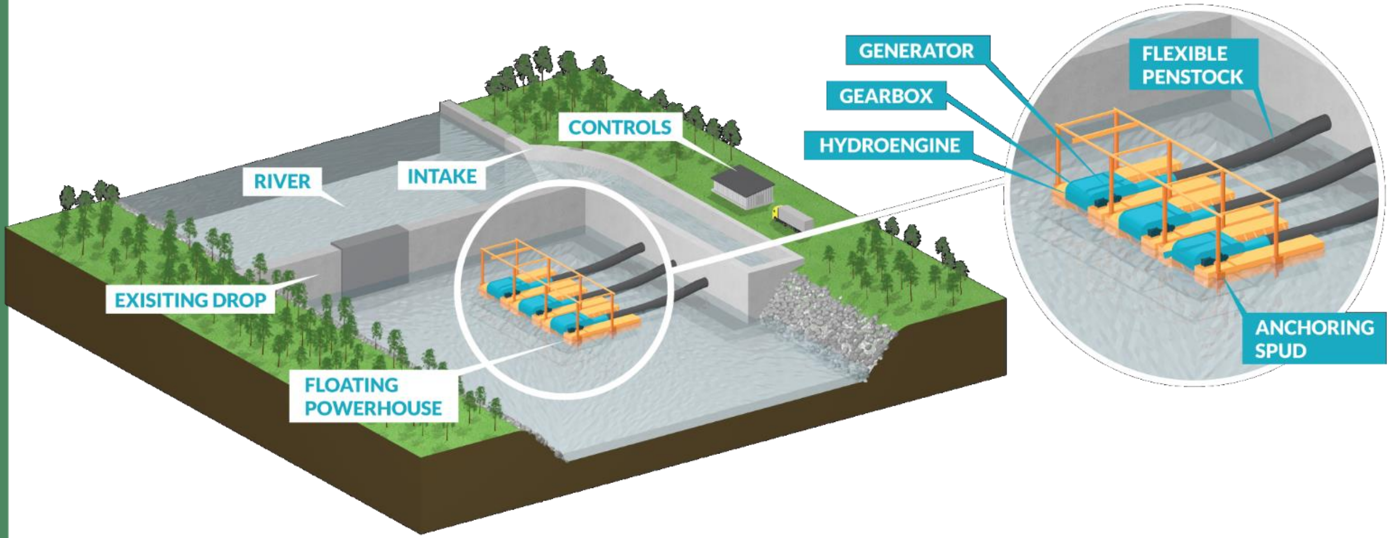
- Frequent requests for national inventory of opportunities, none currently exist

- 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
  - California: **255 MW** of potential from man-made conduitsat **128 sites** http://www.energy.ca.gov/2006publications/CEC-500-2006-065/CEC-500-2006-065.PDF
  - Bureau of Reclamation: **225 MW** at **191 sites** https://www.usbr.gov/power/CanalReport/FinalReportMarch2012.pdf

Technology innovations

Industry-led R&D projects with DOE funding

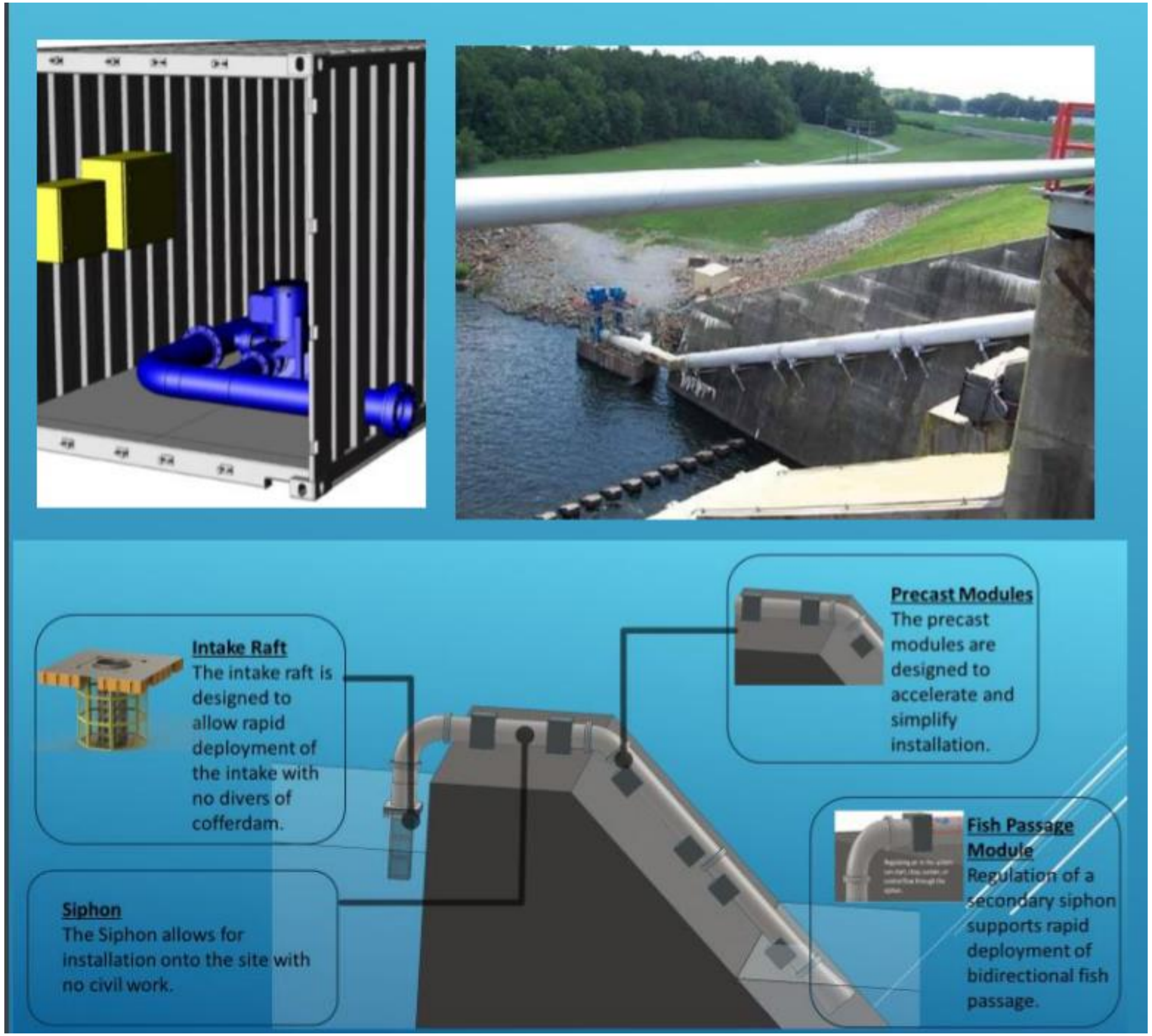
- Floating powerhouse
- Low head, modular powertrains



https://www.natelenergy.com/turbines/

Industry-led R&D projects with DOE funding

- Floating intake with siphon
- Permanent magnet generator turbine

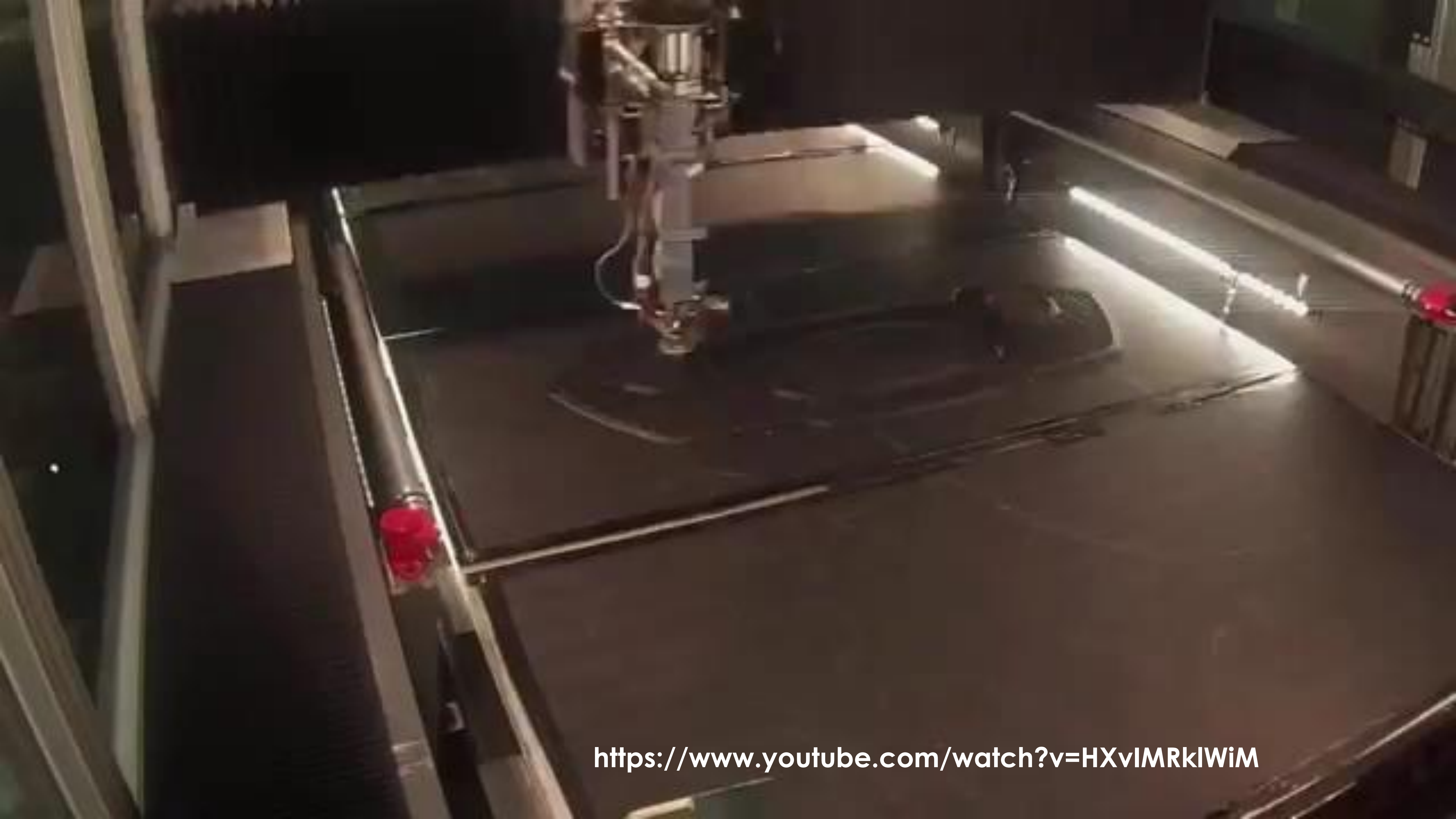


http://www.nwhydro.org/wp-content/uploads/2018/04/Mike-Rickly-Rickly-Hydro-.pdf

Industry-led R&D projects with DOE funding

- Archimedes screw with detachable blades made from composite materials

https://engineering.usu.edu/news/main-feed/2018/percheron-power


https://www.youtube.com/watch?v=HXvIMRklWiM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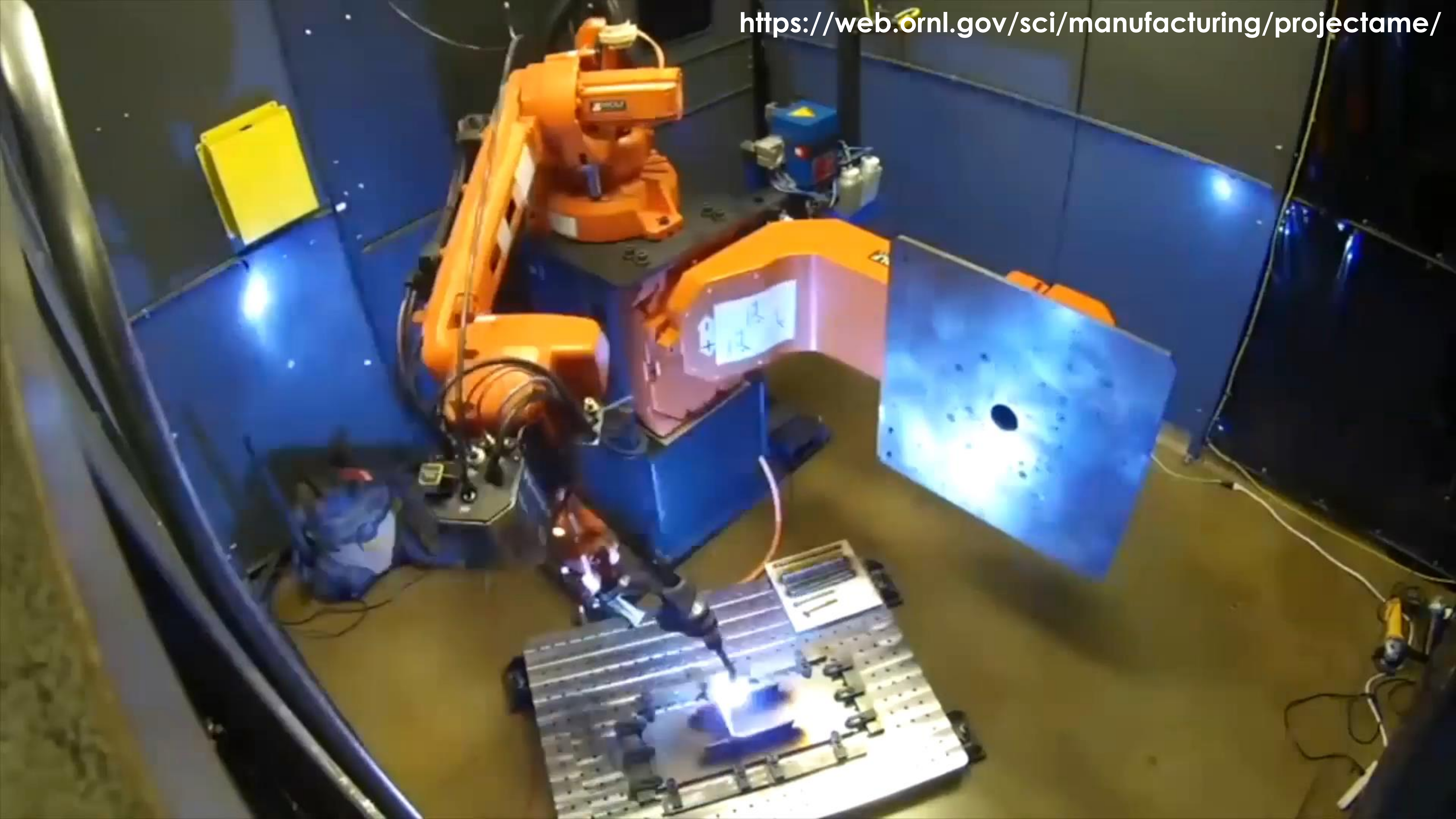
https://www.youtube.com/watch?v=cyX-v83_5Zg https://www.youtube.com/watch?v=TmXv2T03HOE

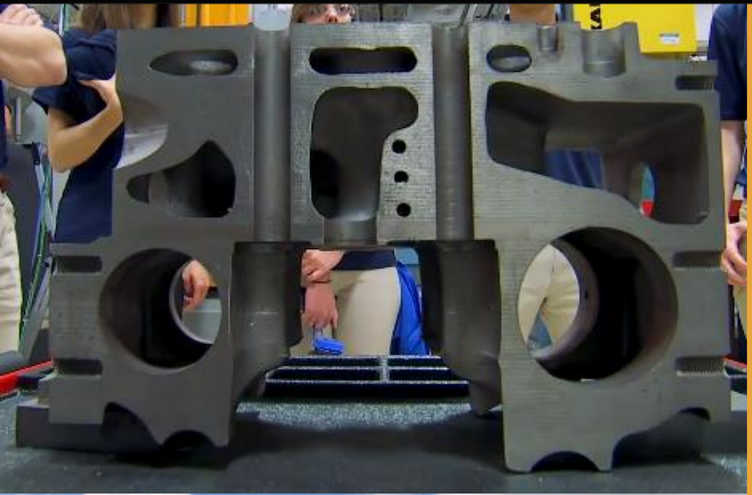
The cost of a traditional hull ranges from $600,000 to $800,000 and typically takes 3-5 months to manufacture.

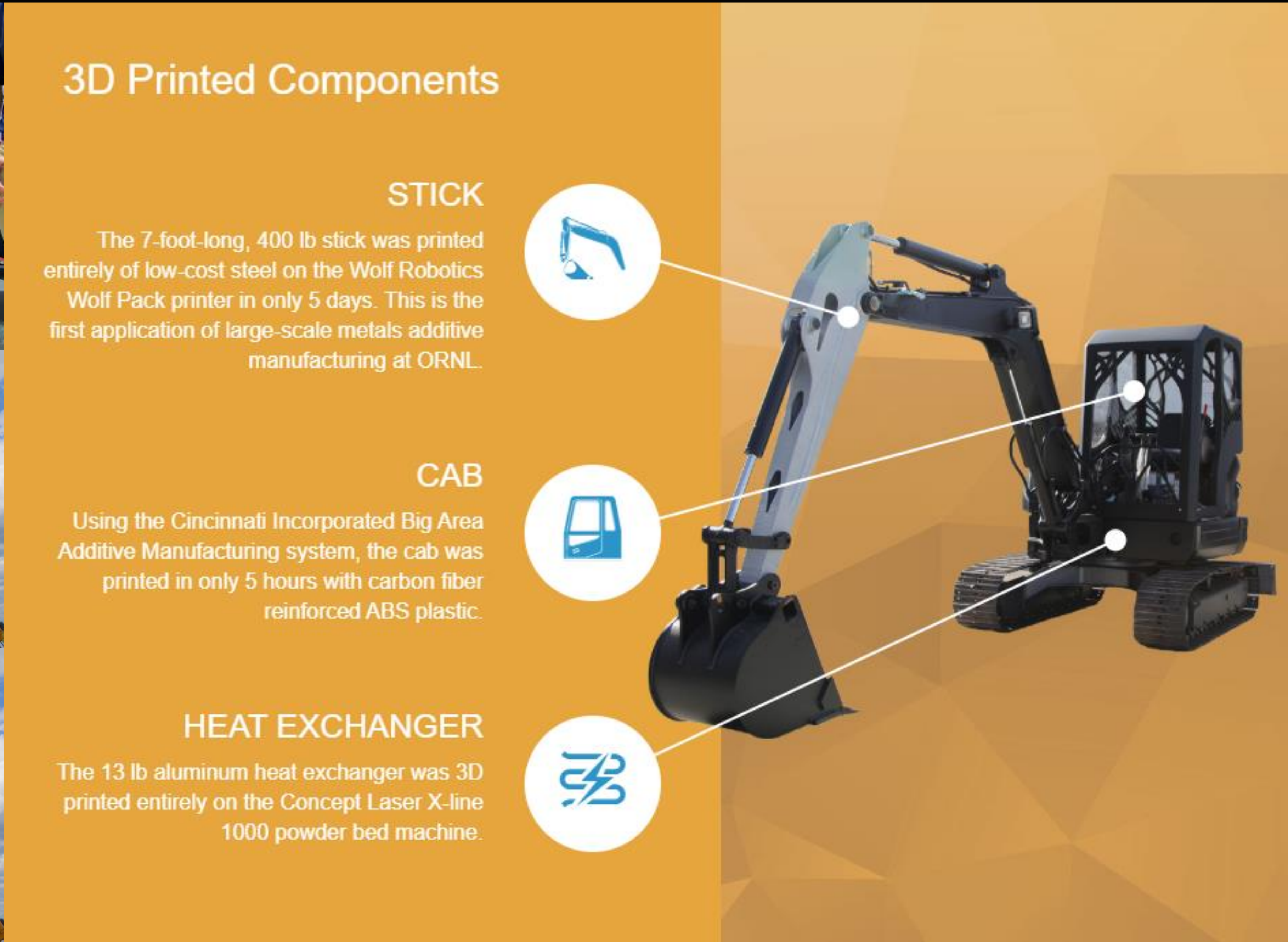
Using BAAM reduced hull production costs by 90% and shortened manufacturing time to a matter of days.

https://web.ornl.gov/sci/manufacturing/projectame/



Integrated hydraulic channels

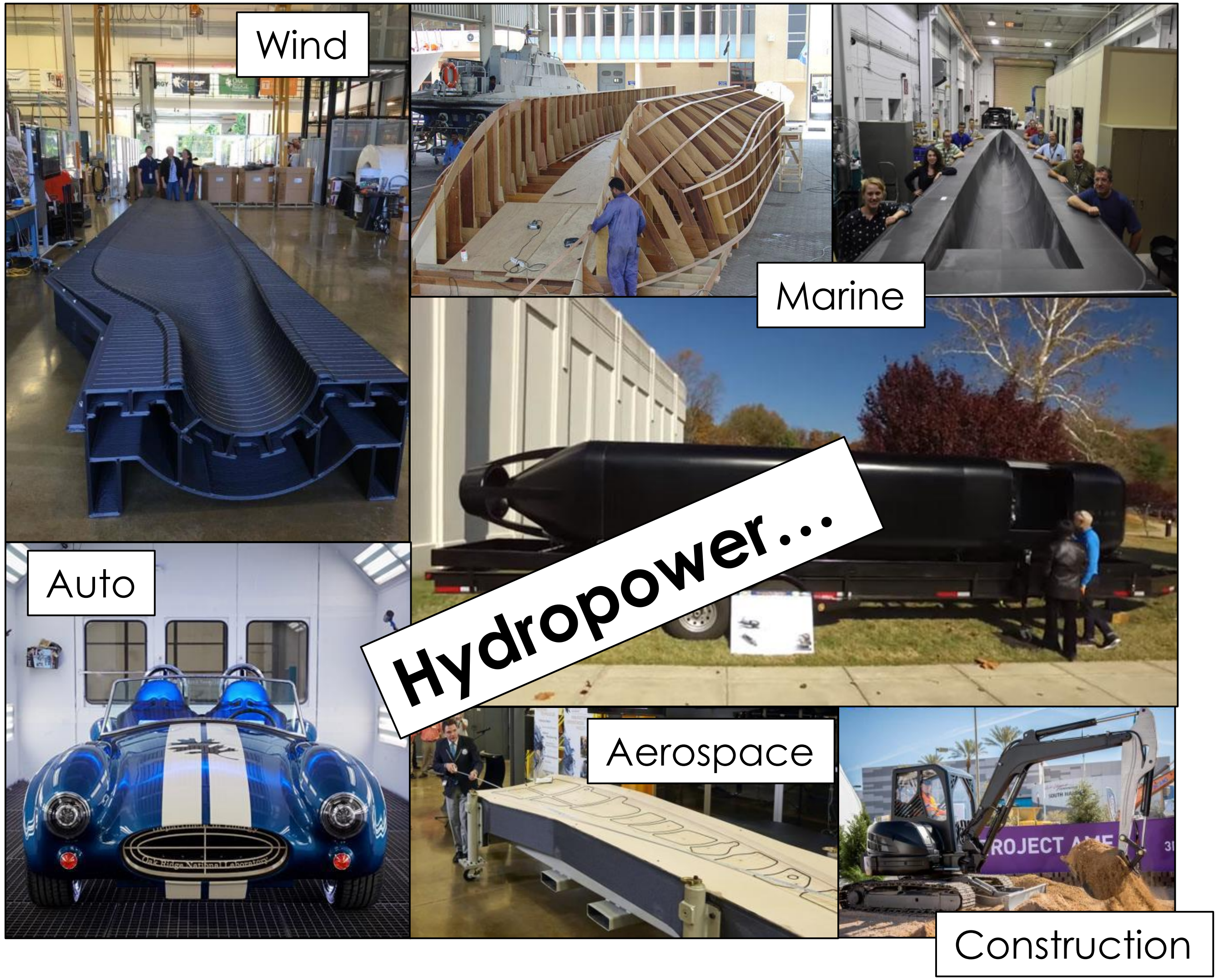




Multi-scale, multi-material capabilities

Small metal and composite components

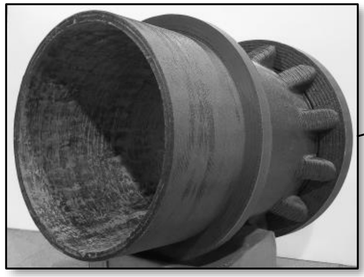
Large scale demonstration projects

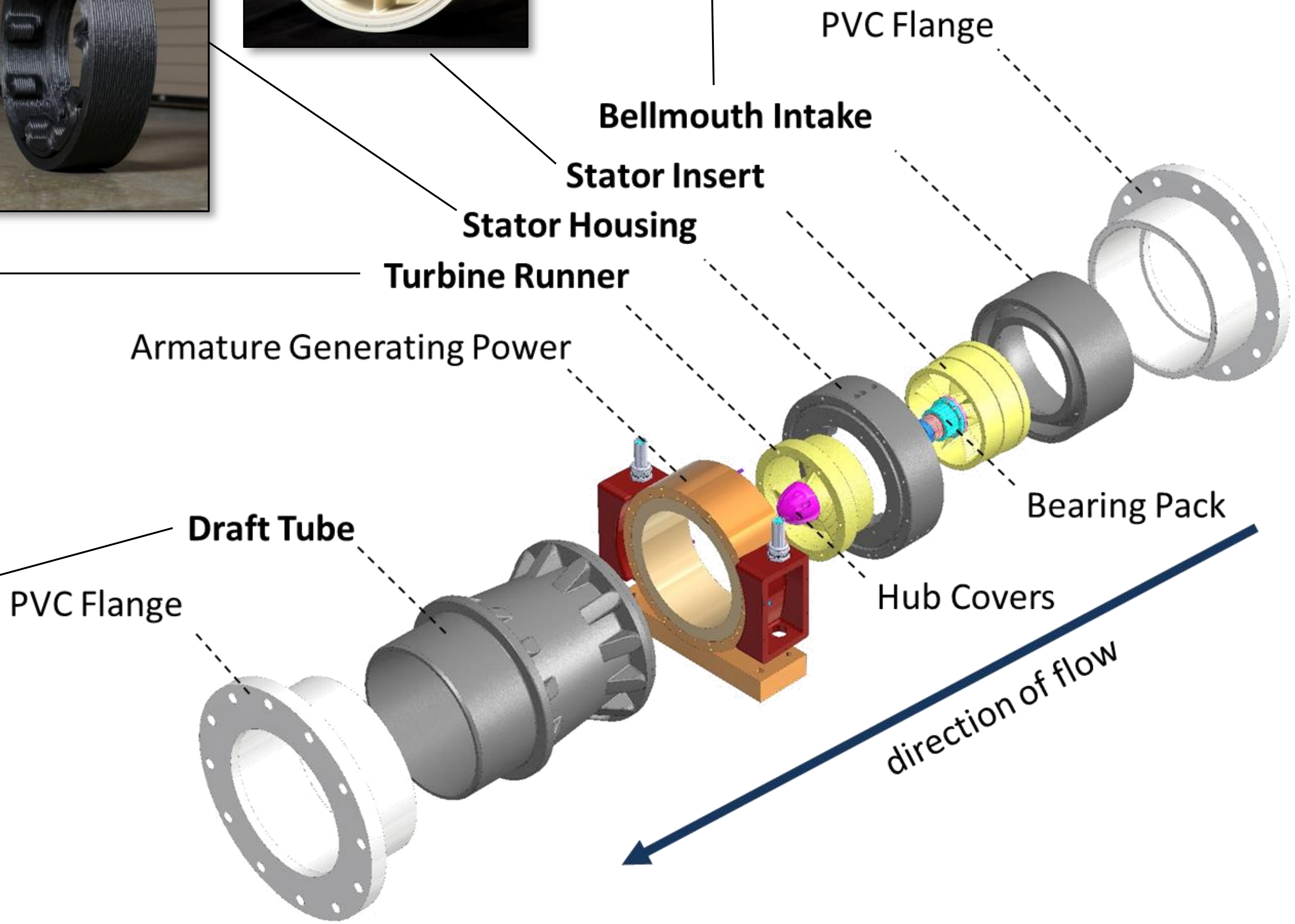


Axial flow runner and conveyance: **Amjet Turbine Systems**

AMJET
Turbine Systems, LLC
AFFORDABLE, RENEWABLE POWER

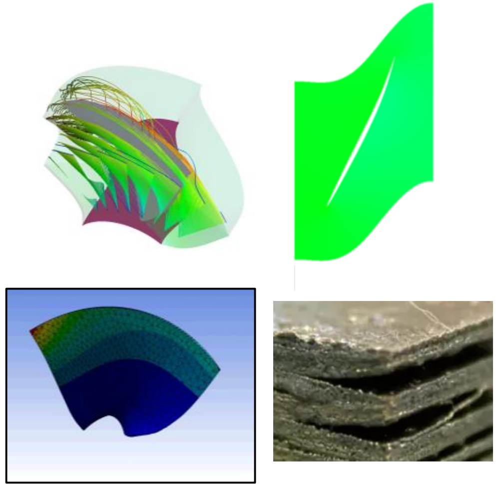
http://www.amjethydro.com/





- 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



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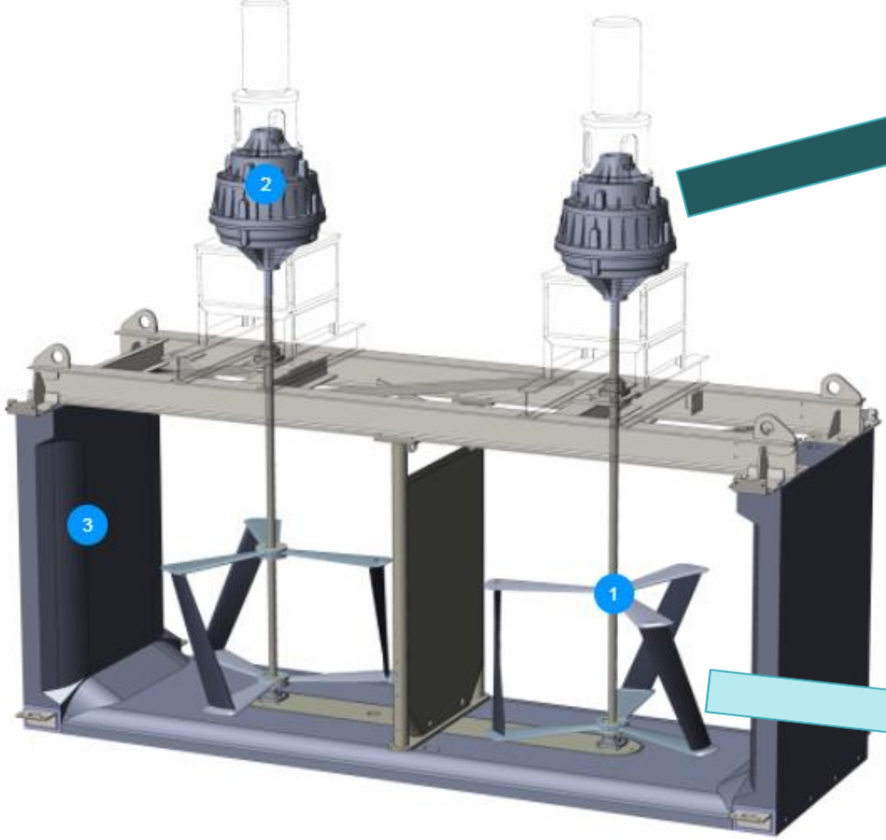
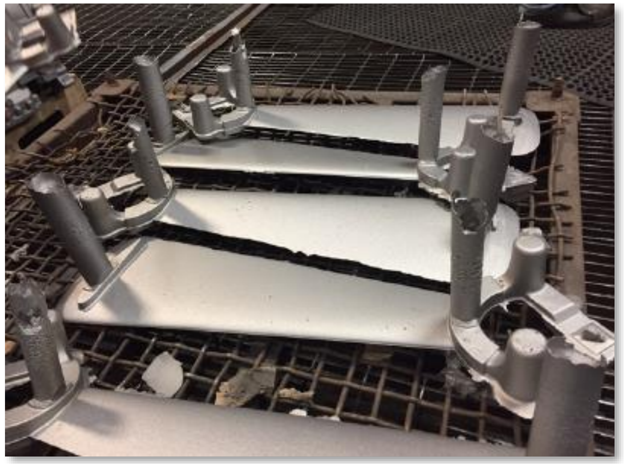
Hydrokinetic turbine runner blades and gearbox housing: **Emrgy**

https://emrgy.com/



- Sand casting for metal gearbox (left) and AM parts (right)

- BAAM tooling for hydrofoil and spokes (78% cost savings)



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

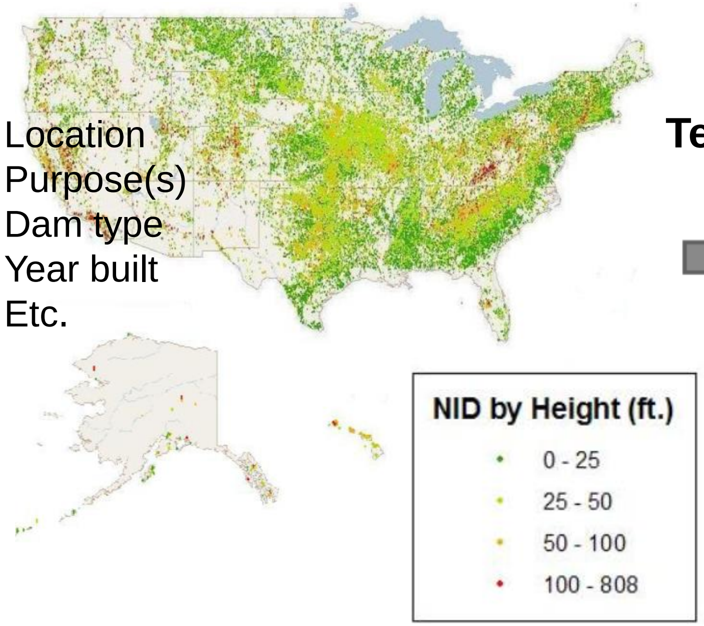
Contribute to broader hidden hydropower **assessment framework** (how can countries identify hidden hydropower opportunities) and business, social, and environmental models used to make hidden hydro pencil out

US general resource assessment approach – can this be extended to other countries and hidden hydro opportunities?

Reliance on detailed dam inventories as starting point

http://nid.usace.army.mil

Location
Purpose(s)
Dam type
Year built
Etc.



Layer on models and development assumptions

Hydrologic model (flow)

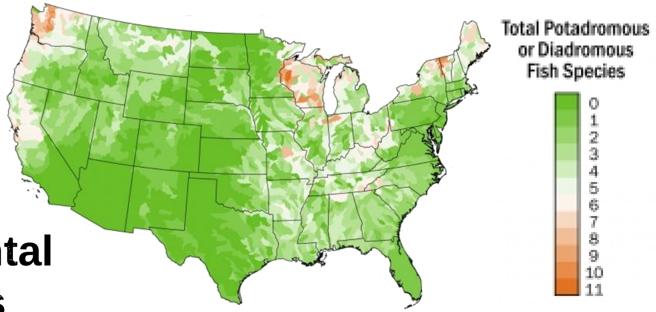
Technical data (head)

Power and cost estimate

Economics (costs/revenue)

Ranking, publication, and data dissemination

Environmental Attributes (impacts/costs/legal)



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/

Foley, M., Bellmore, J., O'Connor, J., Duda, J., East, A., Grant, G., Anderson, C., et al. "Dam removal: Listening in." *Water Resources Research* 53, no. 7 (2017): 5229-5246.

Witt, A., Uria-Martinez, R., Johnson, M., Werble, J., Mobley, M., O'Connor, P. 2018. United States trends in non-powered dam electrification. International Journal on Hydropower and Dams, 33-38. https://www.researchgate.net/publication/327445734_United_States_trends_in_non-powered_dam_electrification

Lazard's Levelized Cost of Energy - Version 12. 2018. https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf