Modular Roots-based Rotor Turbine-Generator System for Small Hydro

EE0006927

Hydropower Program

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Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

- Opportunity: 50GW of potential residing in 25k low-head, low-flow non-powered dams (NPDs) in the US
- Problem: Cost
- Proposed Solution: Roots-based turbine-generator system
- Roots device is uniquely qualified because it has a broader efficiency window when compared to traditional turbine runners

Project Objective & Impact

- Challenge: low-head + low-flow + seasonal variations = limited power generating revenue
- Traditional Solutions: Low cost low efficiency vs high cost high efficiency
- Develop a Roots-based turbine-generator system:
  - Reduce initial capital cost (ICC) by 20% to $2000 per kW
  - Reduce levelized cost of electricity (LCOE) by 20% to $0.056 per kW-hr
  - Maintain >80% efficiency from 30% to 100% flow

Project Information

Project Principal Investigator(s)

David Yee – Eaton Corporation

WPTO Lead

Rajesh Dham
Erik Mauer

Project Partners/Subs

Alden Research Laboratory
Kettering University
Roush Industries
Oak Ridge National Laboratory

Project Duration

- Project Start Date: May 1, 2015
- Project End Date: December 31, 2019

Alignment with the Program

Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

- Technology R&D for Low-Impact Hydropower Growth
- R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet
- Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

Technology R&D for Low-Impact Hydropower Growth

- Enable the design and development of new Standard Modular Hydropower (SMH) technologies for both existing water infrastructure and new stream-reach development. This new approach to systems design for hydropower projects incorporates ecological and social objectives for river systems earlier in design processes
- Leverage new advancements in manufacturing and materials to dramatically lower costs of SMH components and systems designs
- Support development of necessary testing infrastructure for new technologies

We are modularizing the turbine-generator system package to eliminate the non-recurring engineering cost associated with customizing the turbine runner for each specific site. Meeting the site generating capacity requirement will be achieved by deploying multiple modular units.

We are employing additive manufacturing to low volume components that are capital intensive when using traditional fabrication approaches.

We believe our cost reduction approaches will reduce the initial capital costs (ICC) the proposed system.

Project Budget

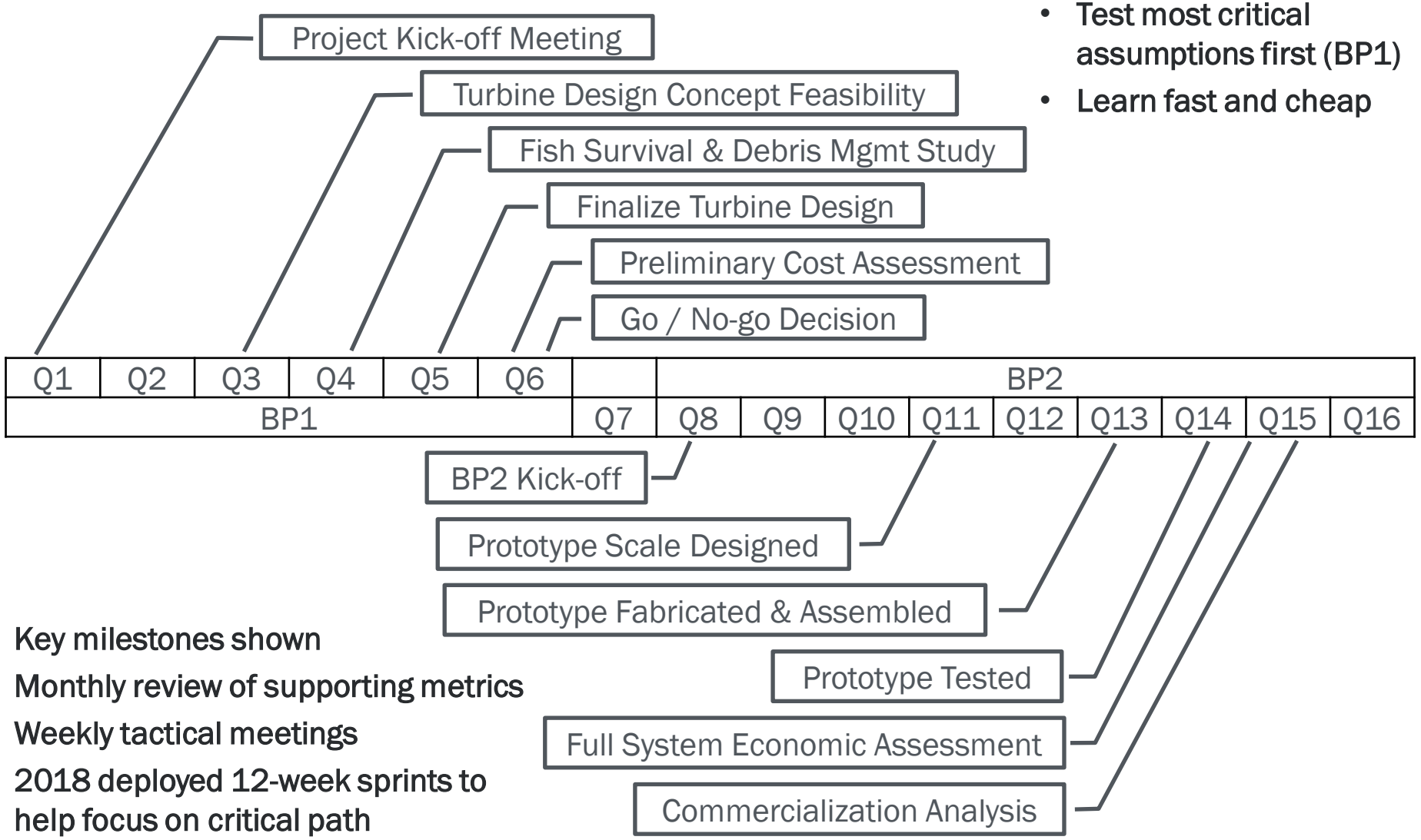
Total Project Budget – Award Information		
DOE	Cost-share	Total
$1,999K	$550K	$2,549K

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Actual Costs FY17-FY19 Q2 & Q2
Costed	Costed	Costed	Total
$490K	$692K	$367K	$1,549

- **The project has experienced significant delays due to a single supplier fabricating the prototype housing.**
  - No penalties associated with missing intermediate delivery dates
  - Lessons learned: Financial incentives for early delivery and penalties for late delivery in the contract
- **Housing wall thickness is too thin to accommodate the dimensional variations in a weldment.**
  - Future weldment prototypes should be fabricated with at least 2x the wall thickness of the original design

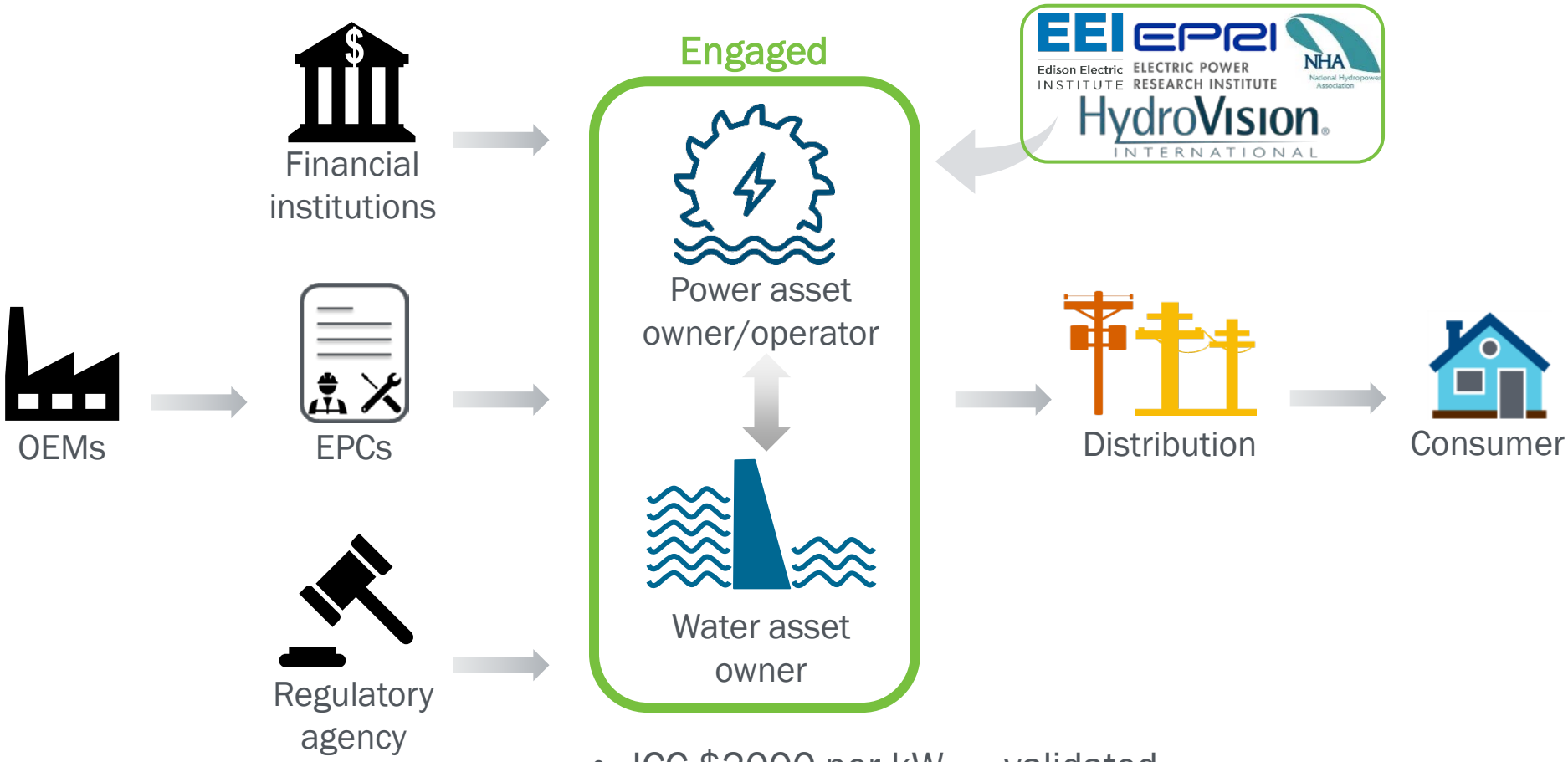
Management and Technical Approach

- Test most critical assumptions first (BP1)
- Learn fast and cheap



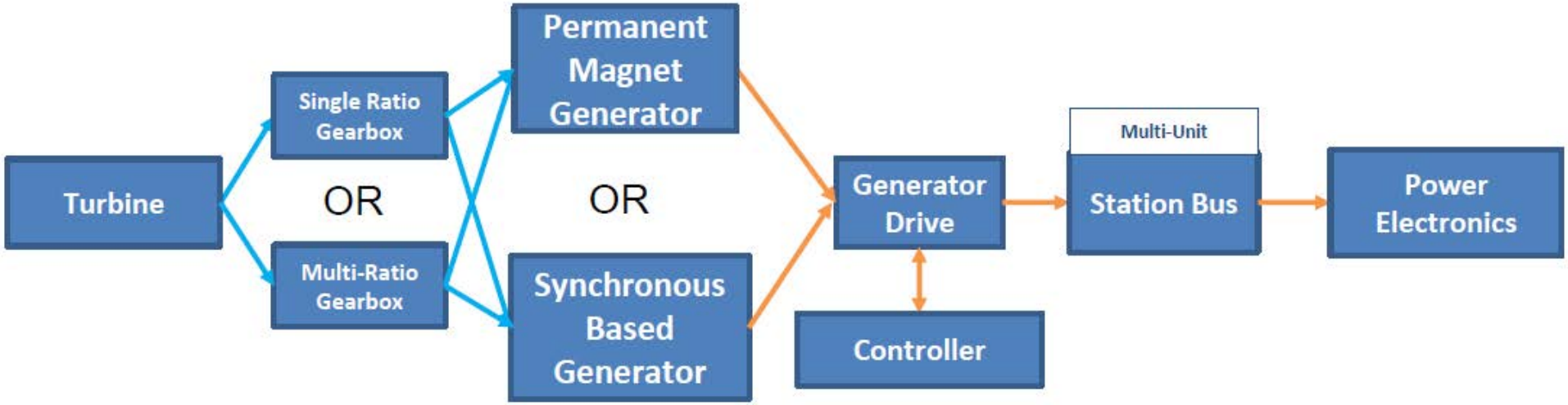
- Key milestones shown
- Monthly review of supporting metrics
- Weekly tactical meetings
- 2018 deployed 12-week sprints to help focus on critical path

End-User Engagement and Dissemination Strategy



- ICC $2000 per kW ⟶ validated
- LCOE $0.056 per kW-hr ⟶ depends on region
- >80% efficiency from 30 to100% flow ⟶ site specific

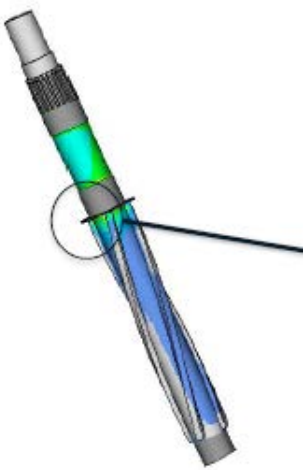
Technical Accomplishments Powertrain Assessment*

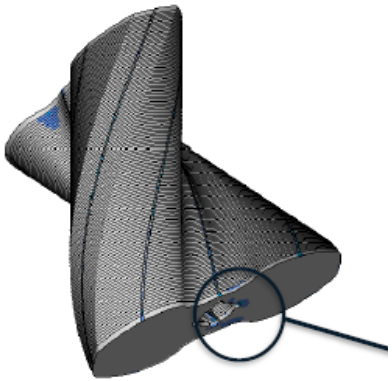


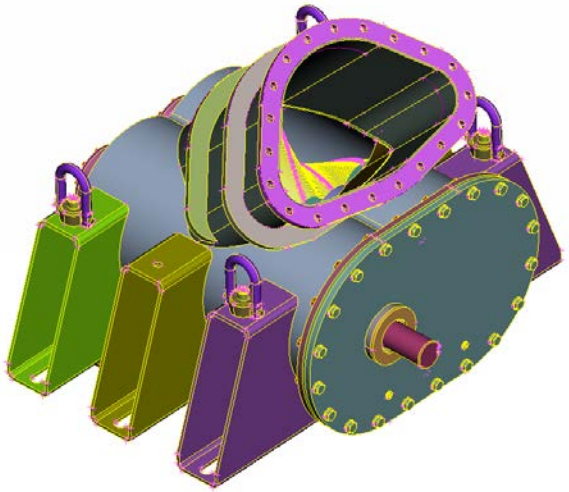
- Varied gearbox (multi-speed vs fixed ratio) and generator (synchronous vs PM)
- Evaluated performance at representative dam sites
- Key Learnings:
  - No 'silver bullet' configuration
  - Eaton's commercial-off-the-shelf transmission could be used as a multi-speed gearbox for some low head applications
  - Synchronous generator costs were predictable and lower
  - PM generator costs were unpredictable and higher
  - The cost of the power electronics did not scale linearly with kW

* "Optimizing the Value of Variable Speed Systems for Low Head Dams," presented at HydroVision 2018

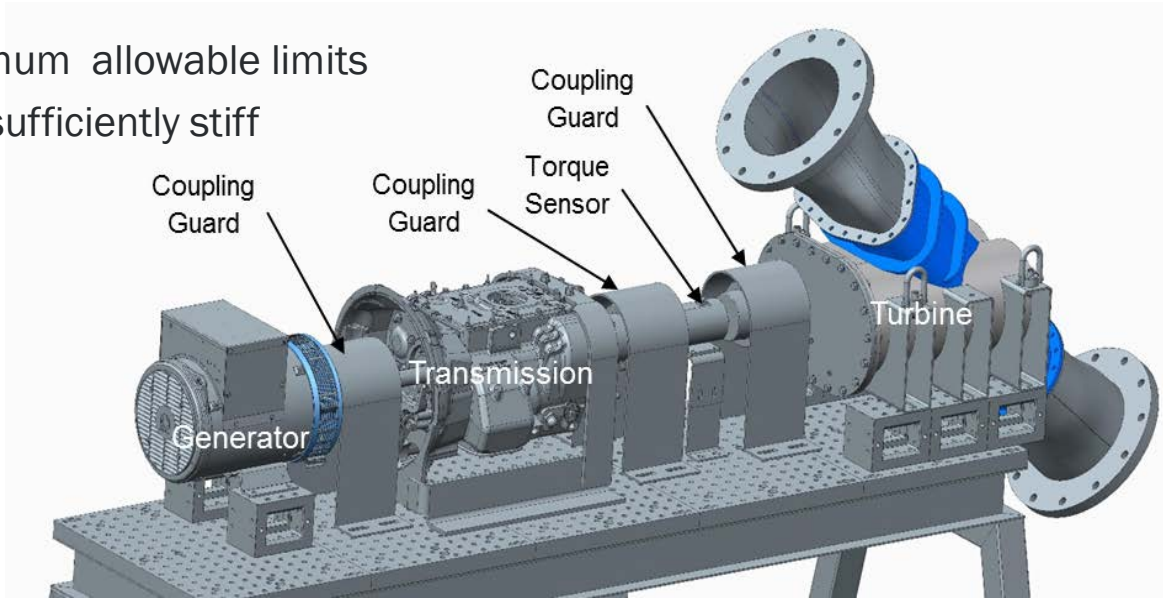
Technical Accomplishments
Prototype Design







- Stresses in the shafts, rotors and housing (including heat affected zones) are less than 171MP, the marine endurance limit for 316ss
- Displacements are within the maximum allowable limits
- Modal analysis predicts housing is sufficiently stiff

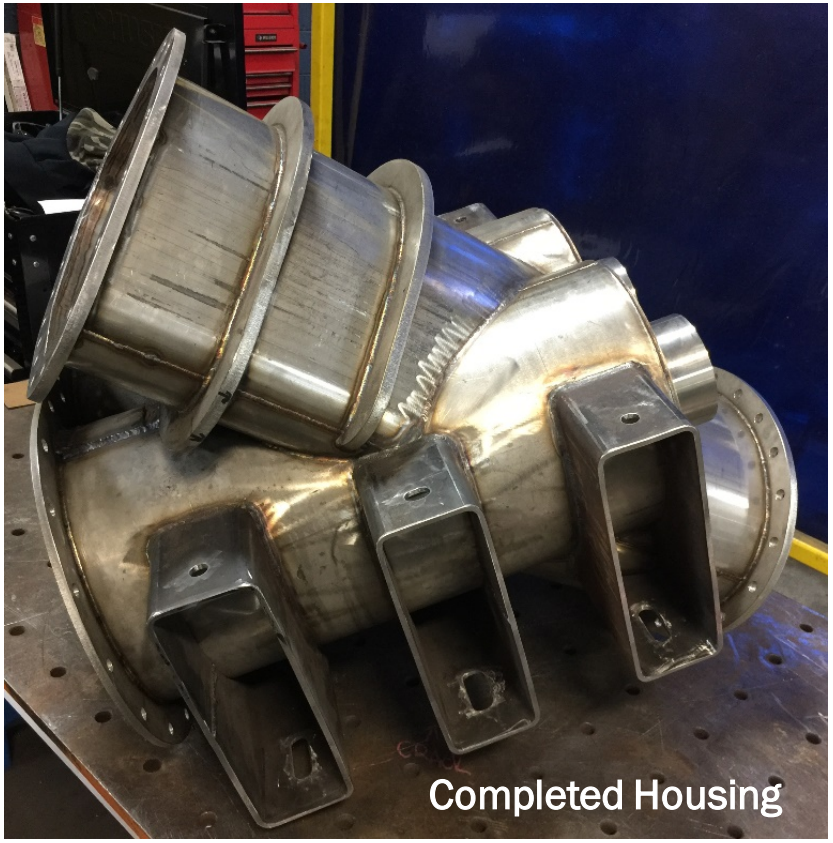


Technical Accomplishments
Prototype Rotor Fabrication

- Rotors fabricated using additive manufacturing
- Plates are stacked on the shaft and welded
- Net shape – no finished machining required

Completed Rotors

Technical Accomplishments
Prototype Housing Fabrication



- Significant delays with housing supplier
- Missed intermediated delivery dates of sub-components

Technical Accomplishments
Prototype Assembly


Rotors on Gear Housing


Timing Gears


Housing over Rotors

- Interference between housing and rotors
- Addressing interference caused more delays
- Supplier claims the housing wall thickness specification is too thin to accommodate variations in weldment process

Technical Accomplishments
Test Stand

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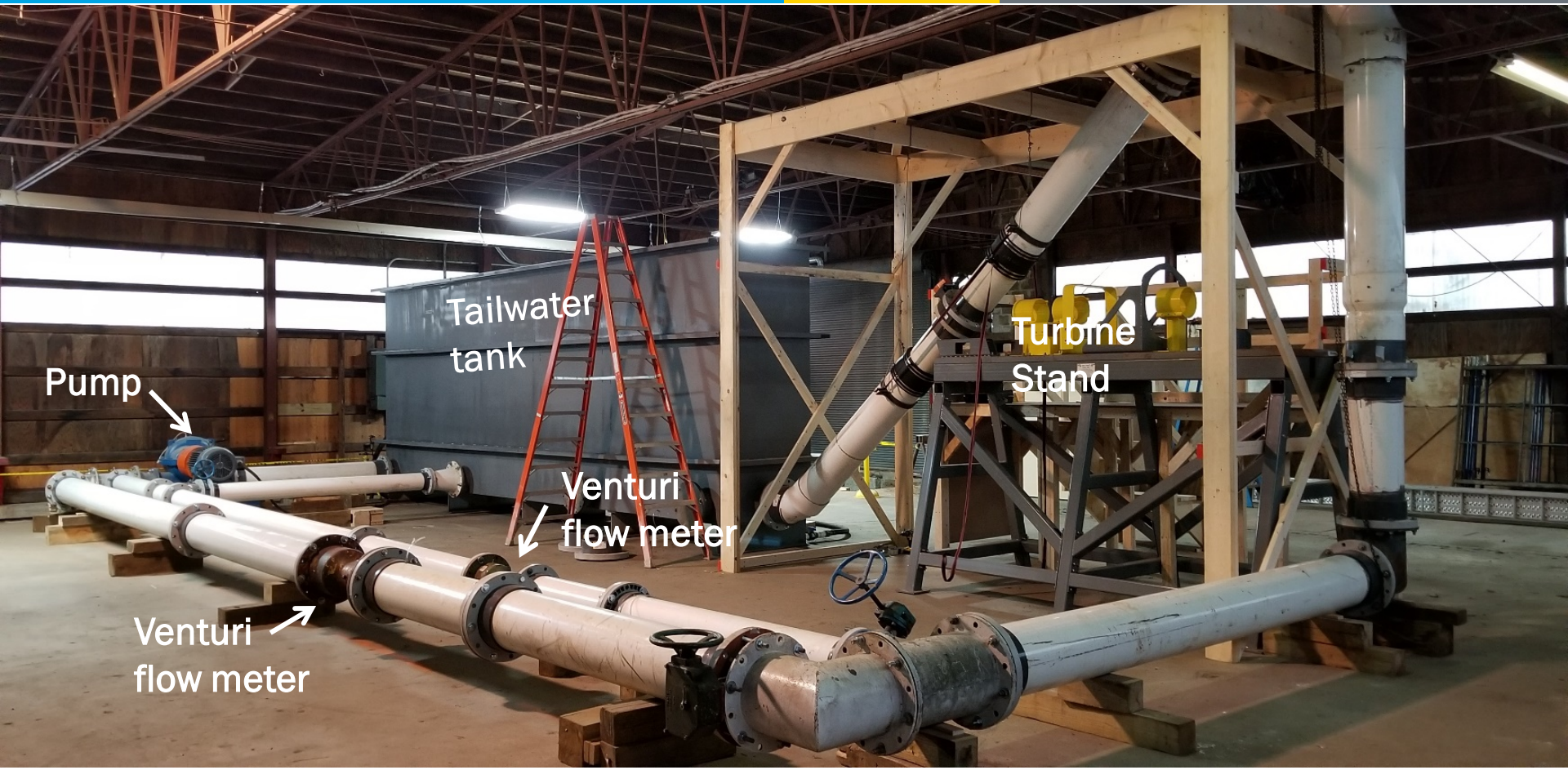

Test loop assembled. Targeted flows achieved.

Progress Since Project Summary Submittal

- Reserve for work completed after submission of narrative