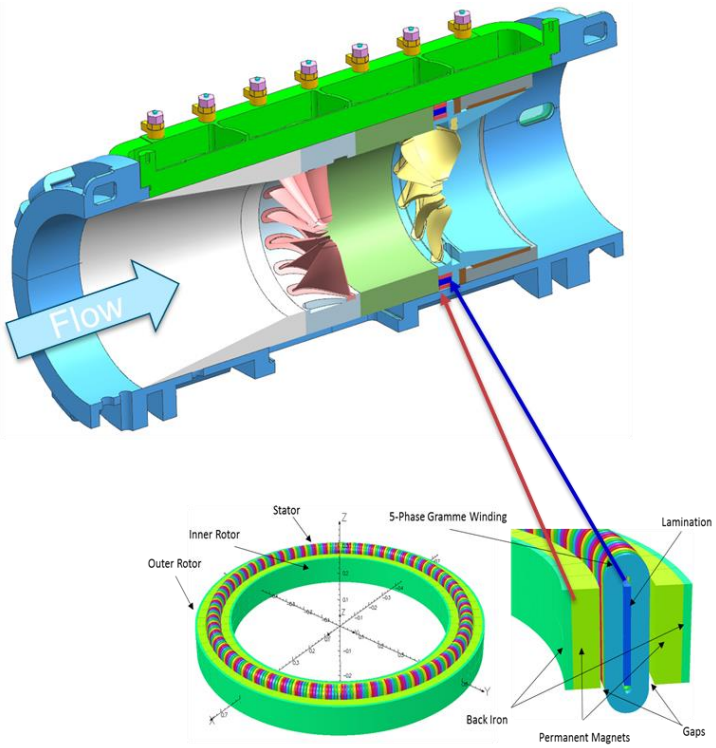


# Rapidly Deployable Advanced Integrated Low Head Hydropower Turbine Prototype

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# Project Overview

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

## Rapidly Deployable Advanced Integrated Low Head Hydropower Turbine Prototype:

- Develop and demonstrate a rapidly deployable advanced integrated hydropower turbine-generator system with a low levelized cost of energy (LCOE)
  - Compact turbine generator design with high efficiency covering a wide operating envelope, self cleaning and fish passage potential
  - Leveraging advanced additive manufacturing technologies
  - System health monitoring - uninterrupted unit operation, mitigate catastrophic failure, reduce mean time between maintenance intervals resulting in reduction in operation and maintenance costs.

## The Challenge:

- Implement low-cost health monitoring with a predictive capability to convert unscheduled maintenance into scheduled maintenance.

## Partners: CIMP3D, General Atomics

# Next Generation Hydropower (HydroNEXT)

## Optimization

- **Optimize technical, environmental, and water-use efficiency of existing fleet**
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

## Growth

- **Lower costs of hydropower components and civil works**
- **Increase power train efficiency for low-head, variable flow applications**
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- Reduce costs and deployment timelines of new PSH plants
- Prepare the incoming hydropower workforce

## Sustainability

- Design new hydropower systems that minimize or avoid environmental impacts
- **Support development of new fish passage technologies and approaches**
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- Increase resilience to climate change

# Next Generation Hydropower (HydroNEXT)

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## The Impact

- Turbine / Generator: optimized scalable design with high efficiency over wide operating range, compact design for modularity and low cost installation
- Additive Manufacturing Technology: low cost
- Structural health monitoring (SHM): uninterrupted unit operation, mitigate catastrophic failure, reduce mean time between maintenance intervals, reduction in operation and maintenance costs

# Next Generation Hydropower (HydroNEXT)

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## Sustainability

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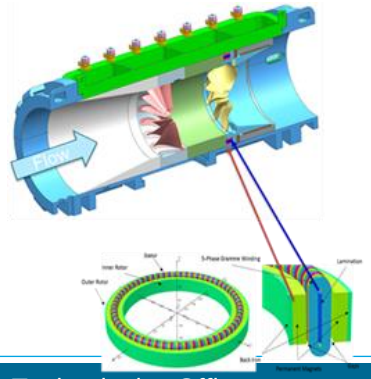
## The Impact

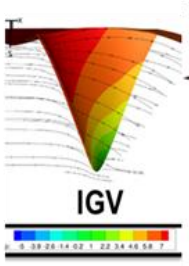
- Hubless design enables self cleaning on turbine blades and potential for unobstructed fish passage

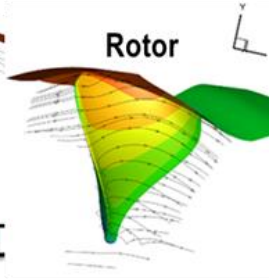
# Technical Approach

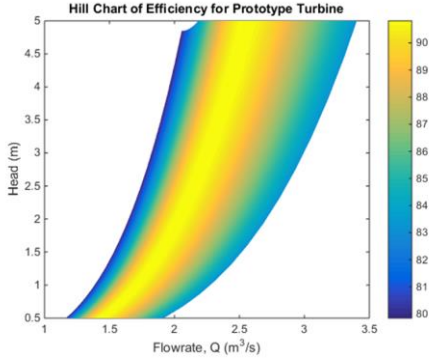


- Turbine design: The hydrodynamic design for the turbine will be undertaken using a validated, in-house design process developed for marine turbomachinery devices. This process incorporates a coupled 3-D analysis with a Computational Fluid Dynamics (CFD) assessment of design performance, and a computational structural analysis for design integrity and vibration. The design will consider additive manufacturing techniques for the final prototype design for manufacture of the turbine.
- Additive manufacturing of the prototype: The prototype model will be manufactured using ARL's additive manufacturing capabilities. The final deliverable will be a functional prototype model to be installed and tested in the ARL 1.22 m Diameter Garfield Thomas Water Tunnel.
- Rim-drive generator design: The rim-drive generator design will be performed by General Atomics (GA). GA will deliver a rim-drive generator design with improved operational efficiency over a wide range of operating revolutions per minute and a cost analysis of building and implementing the generator into the prototype model for future field deployment.
- Implementation of Health Management to enable CBM into the prototype model: The CBM deliverable will be a working system and a plan to optimize O&M costs. The final deliverable will be the working prototype model, a technology transfer plan and a detailed LCOE analysis per DOE guidelines showing predicted cost savings.
- Hybrid multi-material concept application: A design study will be carried out to evaluate how hybrid multi-material concepts can be employed to the turbine design for further cost reduction.
- Validation Testing: Validation testing will be performed in the final quarter of the project and will include prototype model performance, CBM test results with implementation guidelines for Operation & Maintenance (O&M) procedures with the goal of positively impacting O&M costs.





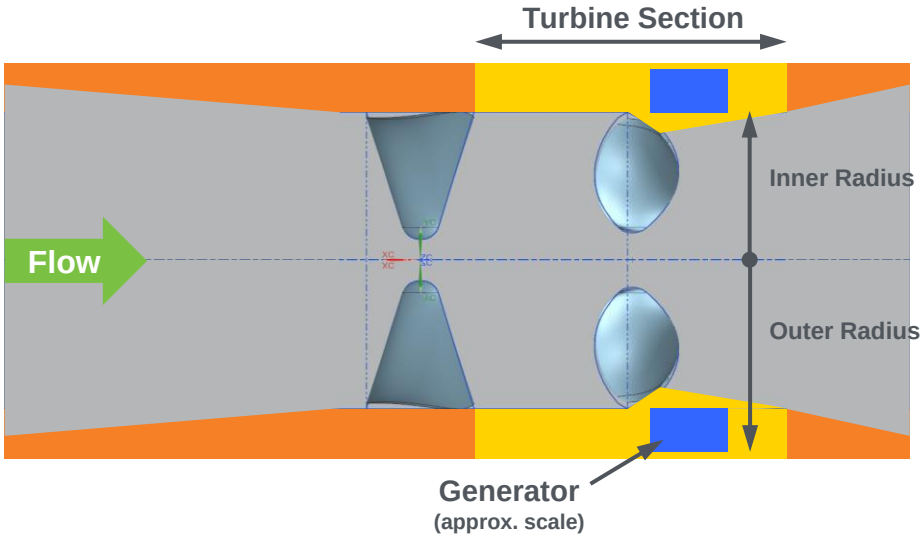



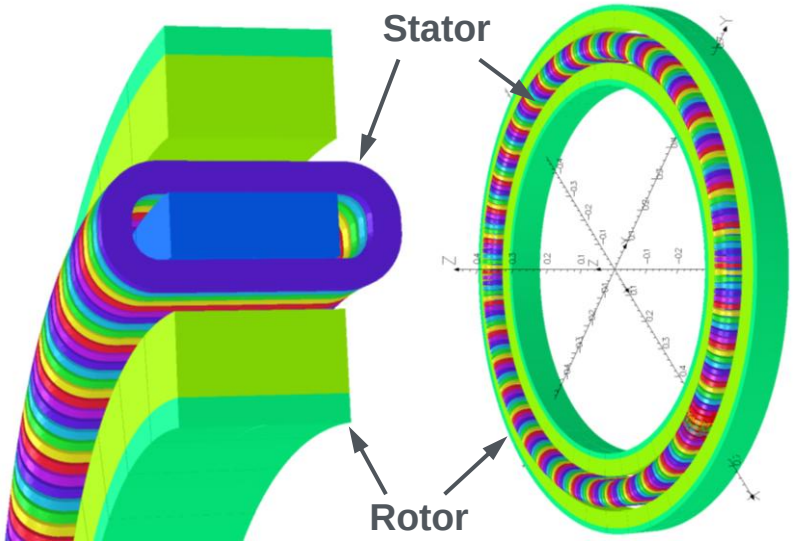



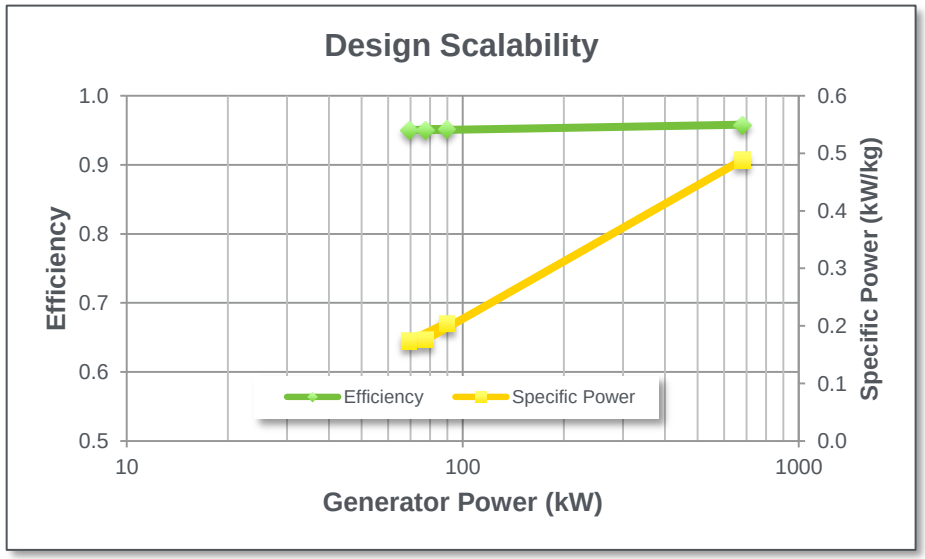
# General Atomics Optimized, Hubless Generator



- Optimized Design
  - High efficiency, ~95%
  - 6-phase/40 pole Gramme-ring stator winding
  - Halbach permanent magnet rotor
  - Automated design using multi-objective Gaussian process regression
- Scalable
  - Constant efficiency vs. scale
  - Specific power improves w/scale



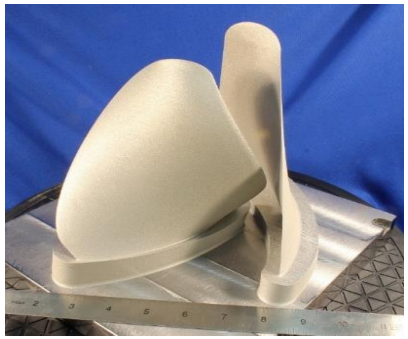



# Accomplishments and Progress



- Turbine Design Complete. CAD released for manufacturing.
- Work is continuing on the development and application of both powder bed fusion and directed energy deposition additive manufacturing (AM) processes. Work was accomplished on the fabrication of scaled components for both processes. The work on the fabrication of both rotor blade and inlet guide vane (IGV) designs using powder bed fusion processing has been performed, and the fabrication of two ½ scale parts is shown on the right. Current powder bed fusion systems are limited in size capacity and directed energy techniques are being investigated for full –scale and larger components.



- General Atomics has produced several generator designs using their design optimization tools and are iterating towards a final design
- Completed a cost benefit analysis that shows a positive return on investment for the implementation of health management technology
- Investigating material/manufacturing technologies for weight reduction and cavitation erosion resistance using multi-material concepts

# Project Plan & Schedule



- Project original initiation date and project planned completion date
  - Original Schedule: 01-May-2015 to 31-Mar-2017
  - Planned: 01-July-2015 to 31-Aug-2017
- Slipped milestones and slips in schedule
  - Contract initiation delays
  - Water tunnel availability for testing prototype
- Go/No-Go decision points for FY15
  - Task 1: A final turbine design report will be submitted to DOE. The design report will be reviewed to ensure that the turbine is suitable to additive manufacturing requirements while meeting overall design performance goals – efficiency, cavitation and cost to manufacture estimates.
  - Task 2: Process development samples consisting of no fewer than six passes and five layers and 75 mm in length will display less than 0.2 vol.% porosity in the as-deposited condition as measured by both macroscopic examination and x-ray computed tomography. Ensure Manufacturability of Turbine design.
  - Task 4: The cost benefit analysis and business case analysis need to justify the development and implementation of health management system (HMS) technology that will enable condition-based maintenance. Developing a HMS design that supports a return on investment of >3 and a payback period of <5 years will be the Go/No-Go decision criteria for the HMS portion of the total hydropower turbine system design.

# Project Budget



| Budget History | | | | | |
|---|---|---|---|---|---|
| FY2014 | | FY2015 | | FY2016 | |
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| | | $101.319k | $12.424k | $510.939k | $285.113k |

- Variances from planned budget and identify if/how the project plan was modified
  - none
- Portion of the project budget has been expended to date
  - 40%
- Other funding sources
  - none

# Research Integration & Collaboration

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

## Partners, Subcontractors, and Collaborators:

- CIMP3D
- GA

## Communications and Technology Transfer:

- Conferences: Material Science and Technology Conference 2016, Salt Lake City, UT
- Graduate student workforce development

# Next Steps and Future Research



## FY17/Current research:

- Complete Turbine manufacture with SHM system installed
- Test Prototype

## Proposed future research:

- Purchase and install GA rim-drive generator
- Install in a suitable field site for field testing
  - Performance evaluation in field
  - SHM system evaluation
  - Learning opportunity to improve and advance technology.
  - Training opportunity