Ultra High Temperature Anode Recycle Blower for Solid Oxide Fuel Cell

Department of Energy Award No.

DE-FE0031148

Prepared for DOE Kickoff Meeting

By Mohawk Innovative Technology, Inc.

Mohawk Innovative Technology, Inc.

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DOE Program Manager: Jason T. Lewis, Program Director

DE-FOA-0001735

“Solid Oxide Fuel Cell Prototype System Testing and Core Technology Development”

Dec 1 2017

Project Team

MITI

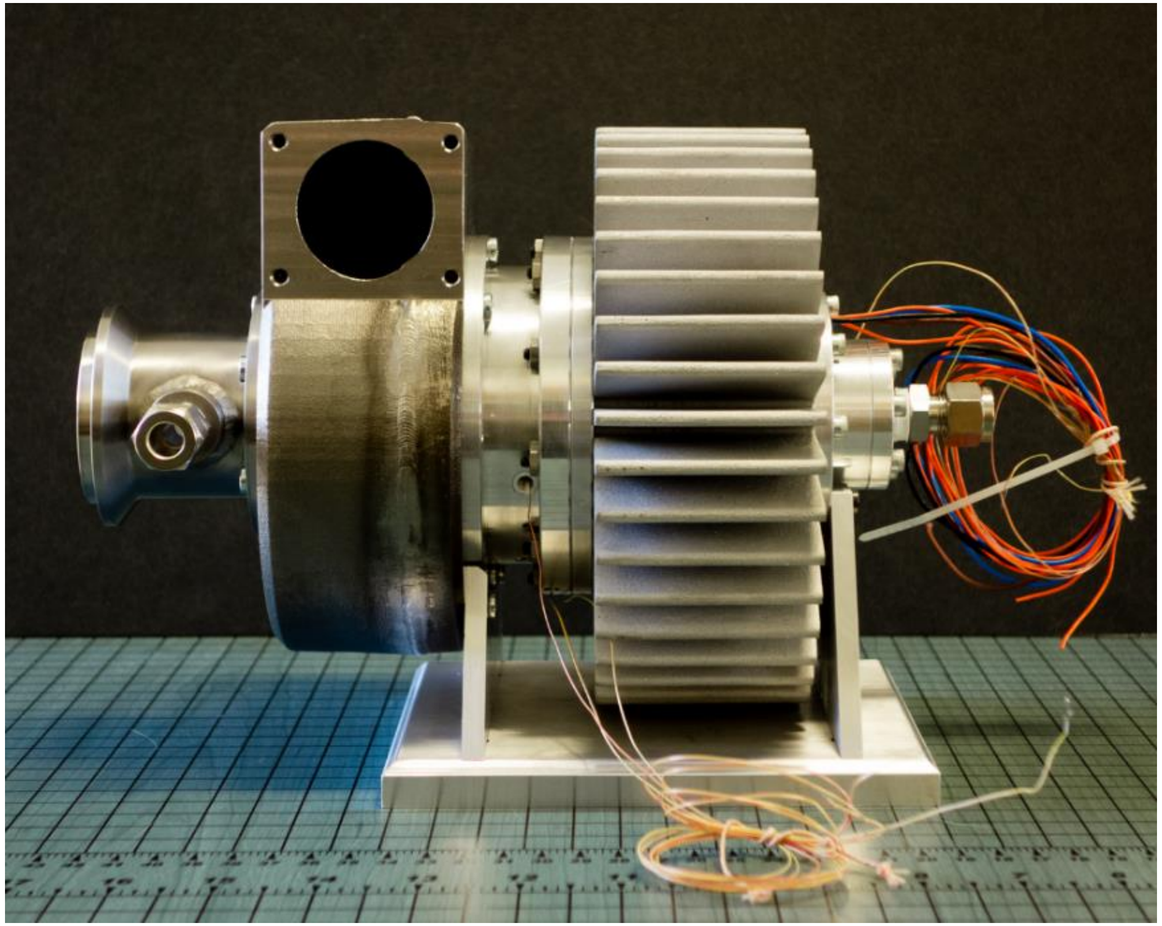
- Hooshang Heshmat, PhD
  - Principal Investigator
- Jose Luis Cordova, PhD
  - PM/Thermal Management
- James F. Walton II
  - Rotordynamics
- Garrett M. Davis
  - Aerodynamic Design

Team Background

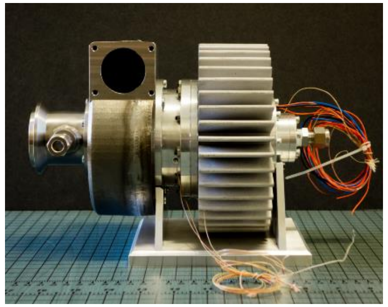
Mohawk Innovative Technology, Inc.

MITI Specializes in High-Speed, High-Temperature Oil-Free Rotating Machinery Technology

- Blowers
- Compressors
- Turbo-alternators
- Gas-Turbine Engines
- Flywheel Energy Storage
- And more



MITI's Completely Oil Free Blower & Compressor Technology

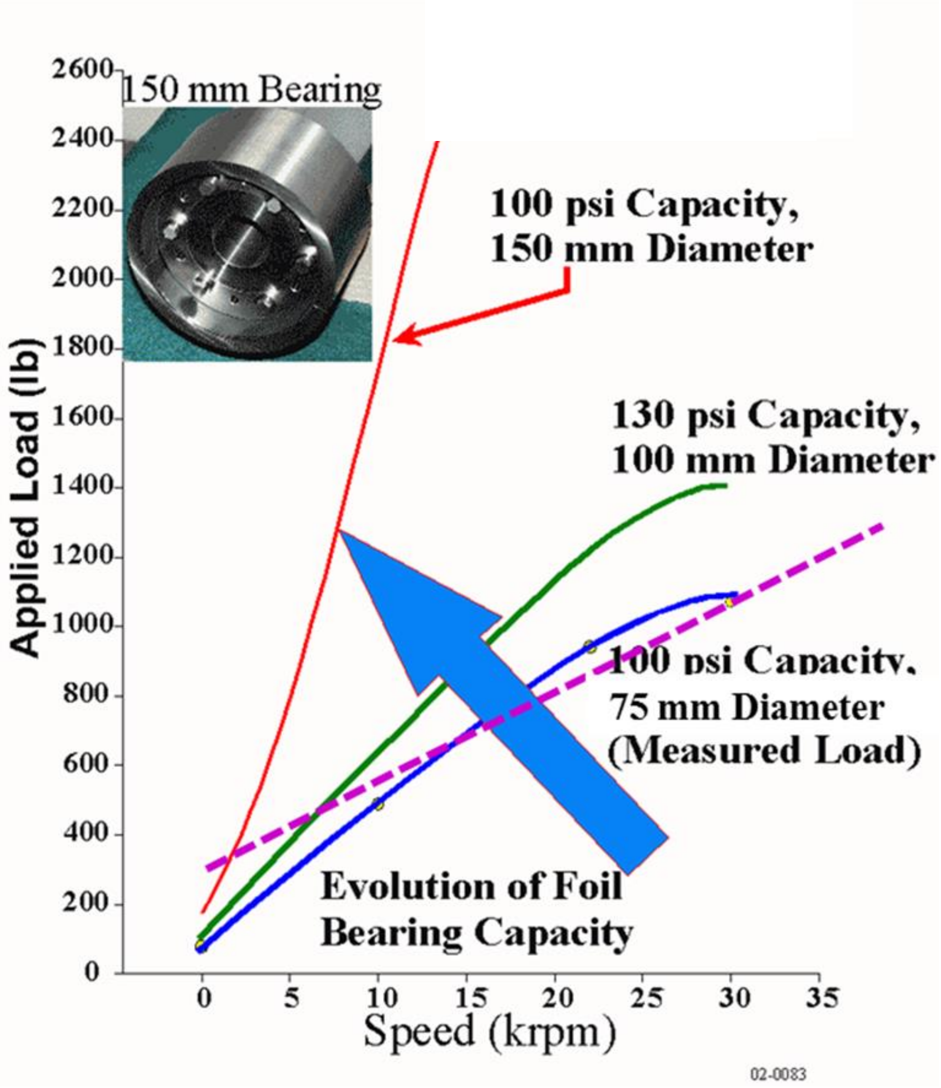





Hydrogen Blower	**Fuel Cell Anode Recycle Blower**	**Fuel Cell Compressor**	**Air Cycle Machine**	**Water Treatment Aerator**	**Hydrogen Pipeline Compressor**
1 kW	**1.5 kW**	**12 kW**	**30 kW**	**80 kW**	**200 kW**
360,000 rpm	**80,000 rpm**	**120,000 rpm**	**120,000 rpm**	**60,000 rpm**	**60,000 rpm**

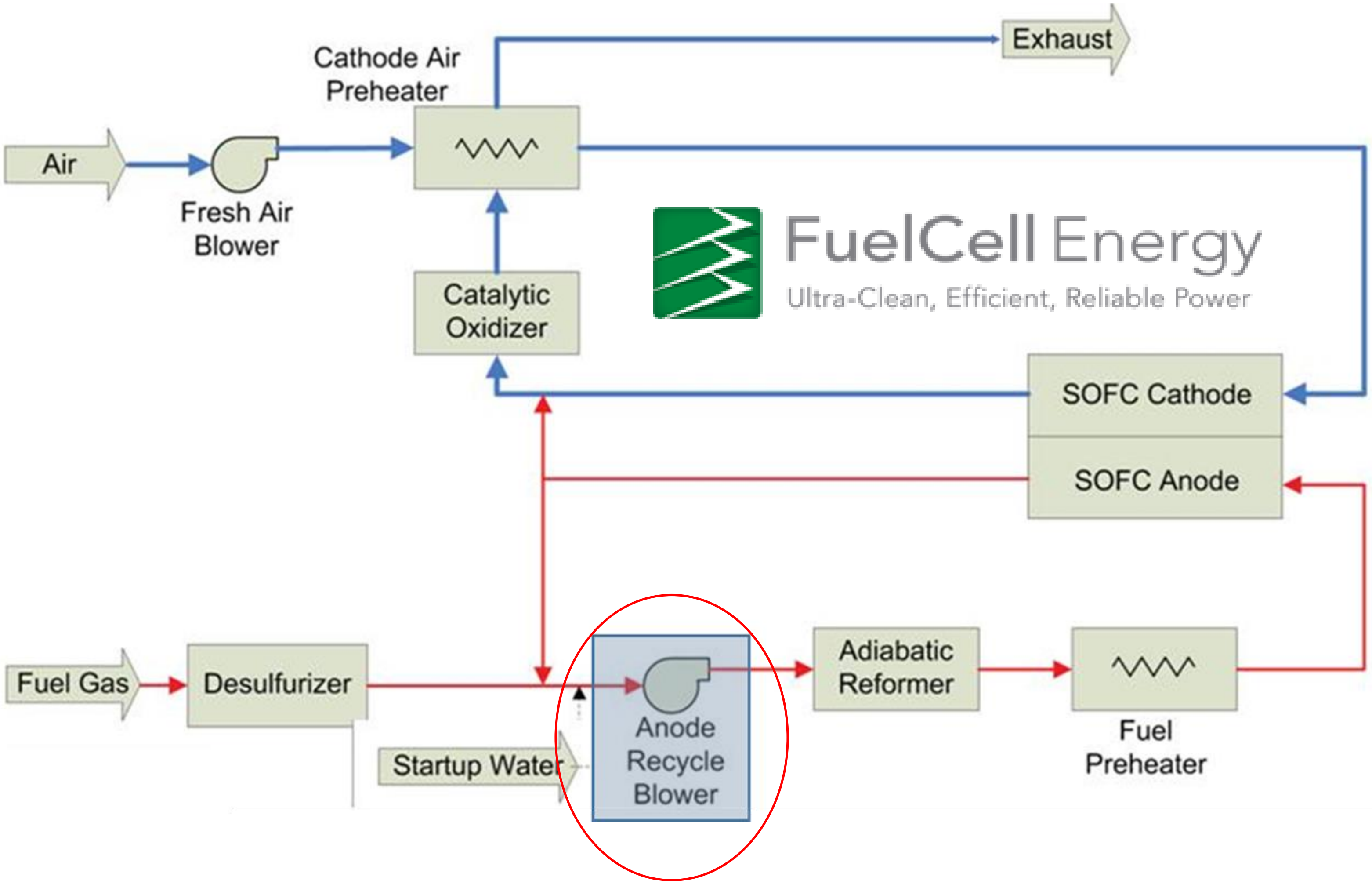
MITI's Compliant Foil Bearings Gen-V

Completely OIL FREE Technology
- High Load & High Temperature
- Sizes from 6 to 200 mm Diameter
- DN to over 6 Million
- Speeds greater than 700,000 RPM



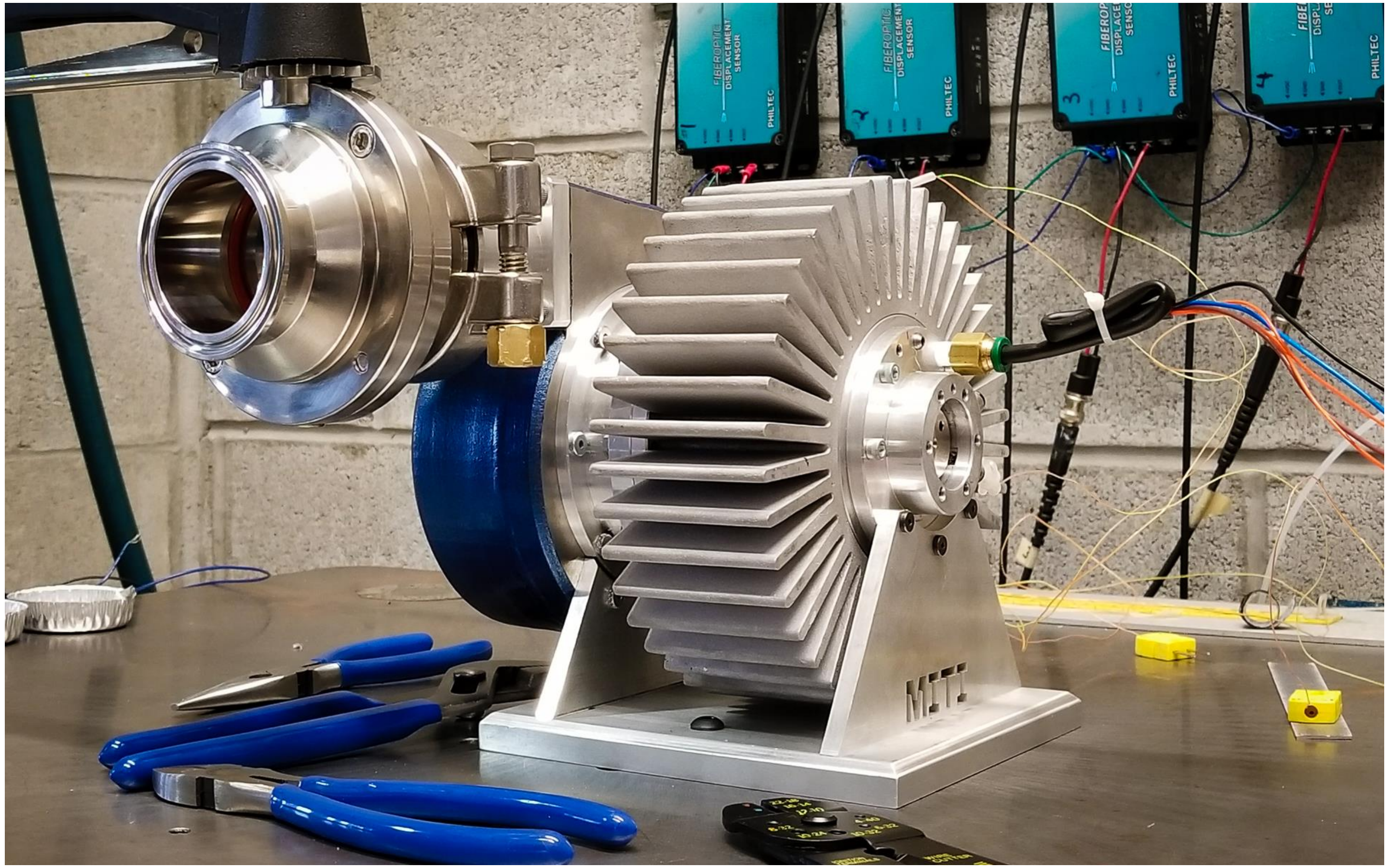
Project Overall Objective

- Develop ultra-high temperature anode recycle blower (UHT-ARCB) prototype that uses ***uncooled*** Solid Oxide Fuel Cell (SOFC) anode gas
  - Demonstrate successful operation of UHT-ARCB
  - Demonstrate that design can achieve TRL5
  - Determine fabrication methods to achieve commercial cost of < $110 per SOFC kWe
- Increase Efficiency and Reduce BOP
  - Recycle anode off-gas
  - Reduce external water supply used for fuel reforming
  - Elimination of heat exchangers
  - Reduce BOP footprint



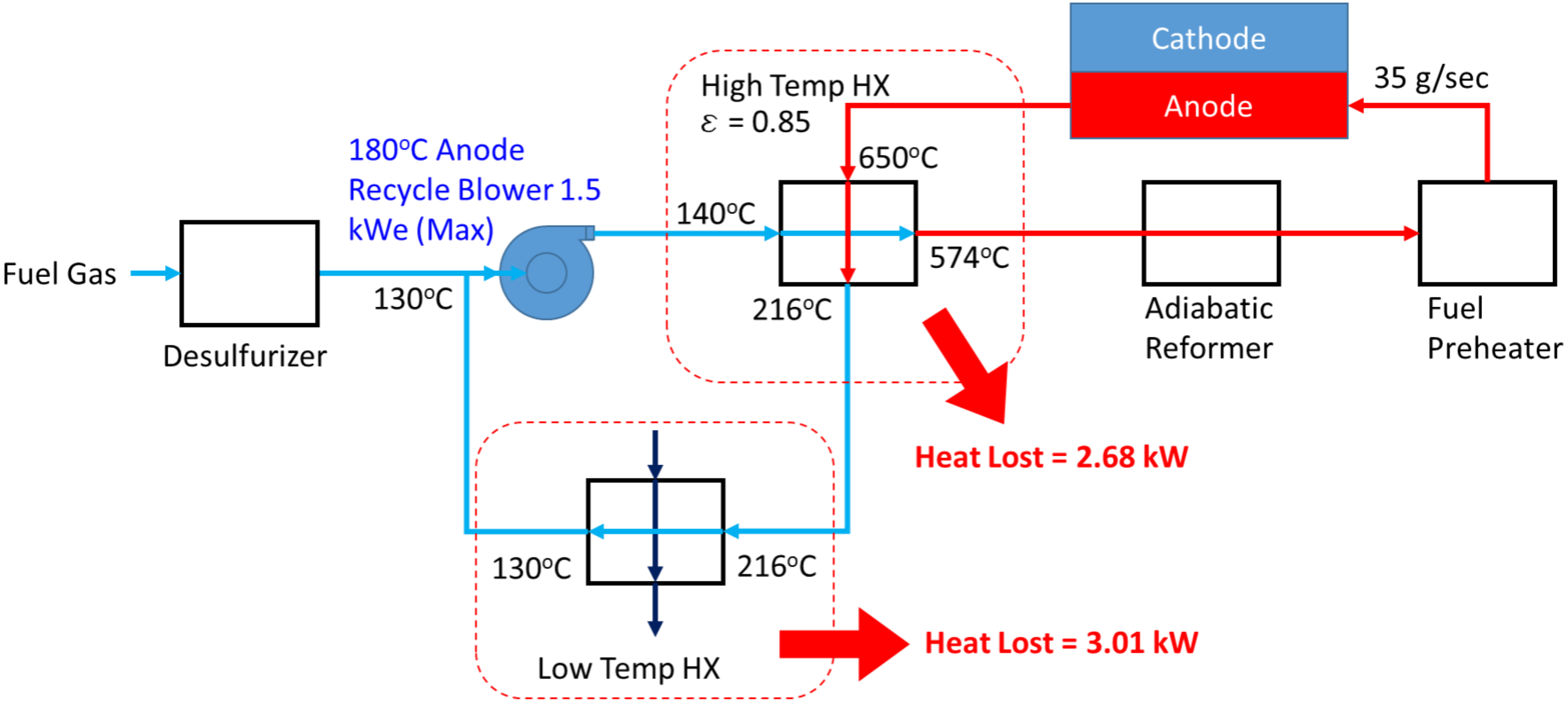
Leverage Precursor 180°C SOFC ARC

- Developed a 180°C Anode Recycle Blower for 100 kWe SOFC
  - DOE Award No.: DE-FE0027895
  - The prototype is currently undergoing performance testing
  - Eventual goal of that program is to test in an actual 100 kWe SOFC demonstrator by FuelCell Energy, Inc. (FCE)
- All the know-how obtained, particularly with regard to design for manufacturability and cost for commercialization will be leveraged.

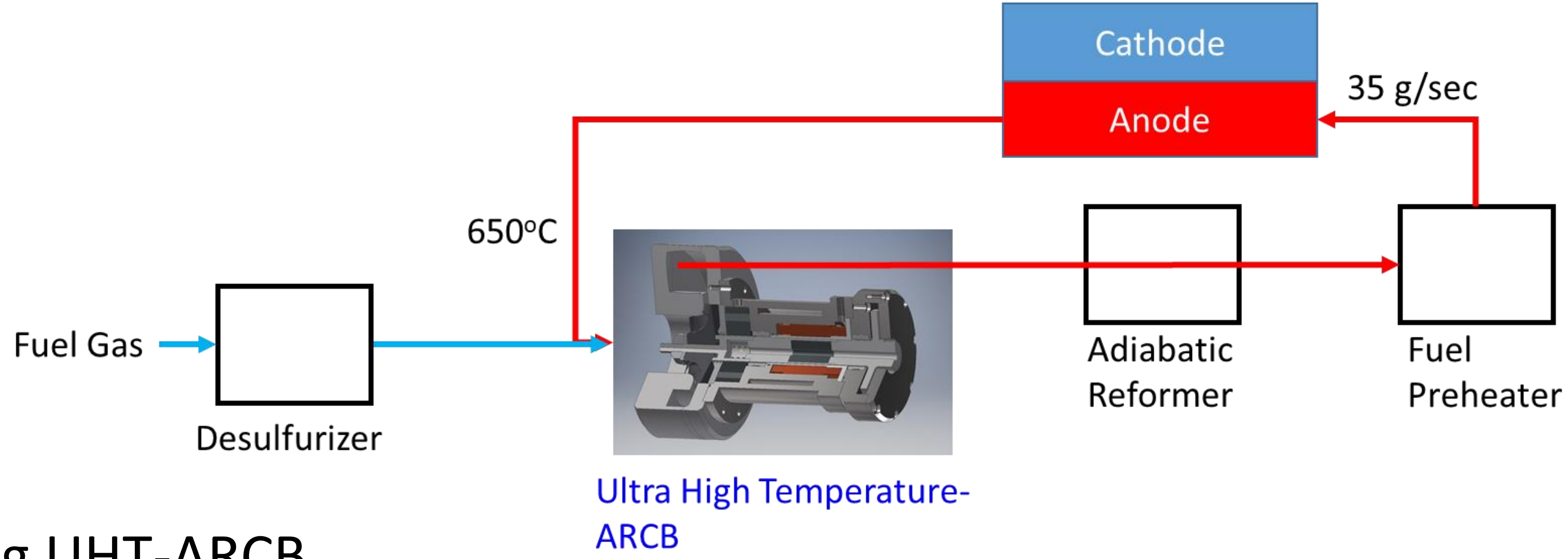


Advantage of UHT-ARCB vs. 180°C ARCB

- Current plan is to use 180°C ARCB under development.
  - This requires use of two heat exchangers (HX) to reduce gas temperature
  - This represents around 6 kW of thermal losses

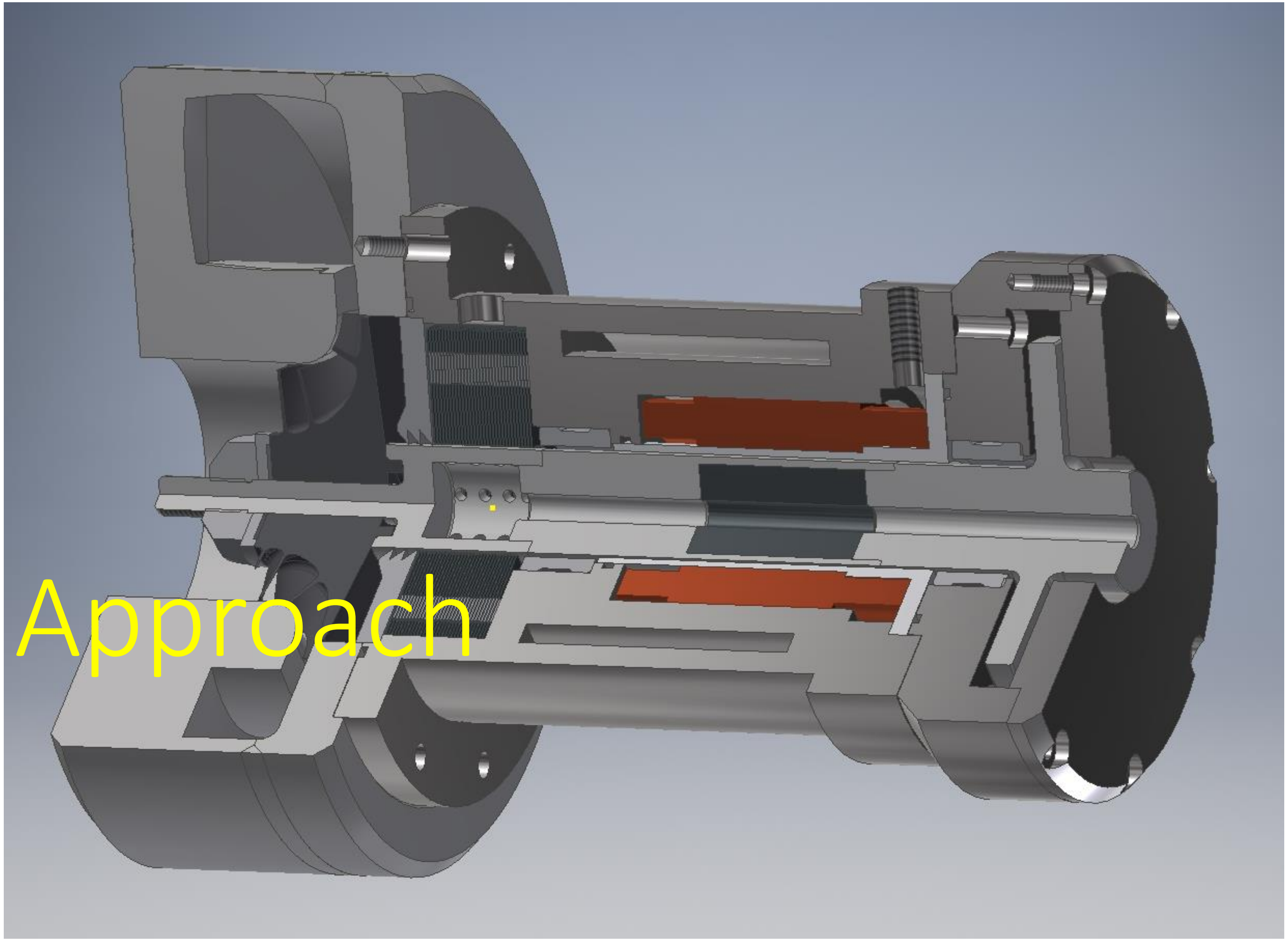


Advantage of UHT-ARCB vs. 180^{o}C ARCB



- Benefits of using UHT-ARCB
  - Reduced BOP by elimination of HXs and supporting piping, insulation.
  - Reduced pressure drop
  - Reduced thermal losses by ~6kW

Technical Approach



Project Structure

- Task 1: Project management and planning
  - Report Preparation
  - Kickoff and Annual Review Meetings
- Task 2: Definition of requirements
- Task 3: Design Proof-of-Concept System
  - Preliminary design
  - Detailed design and analysis
- Task 4: Hardware Fabrication and Assembly
  - Checkout tests
- Task 5: UHB-RCB Testing
  - Dynamic and high temperature test data
- Task 6: Final report and assessment of outcomes

Task 2: Definition of Requirements

- Operating conditions specified with input from FuelCell Energy Inc.
  - For this program, FCE has provided specifications and operating regimes at no-cost.
- Three operating regimes to consider
  - Start Up Transient
  - Nominal Operation
  - Rated Operation

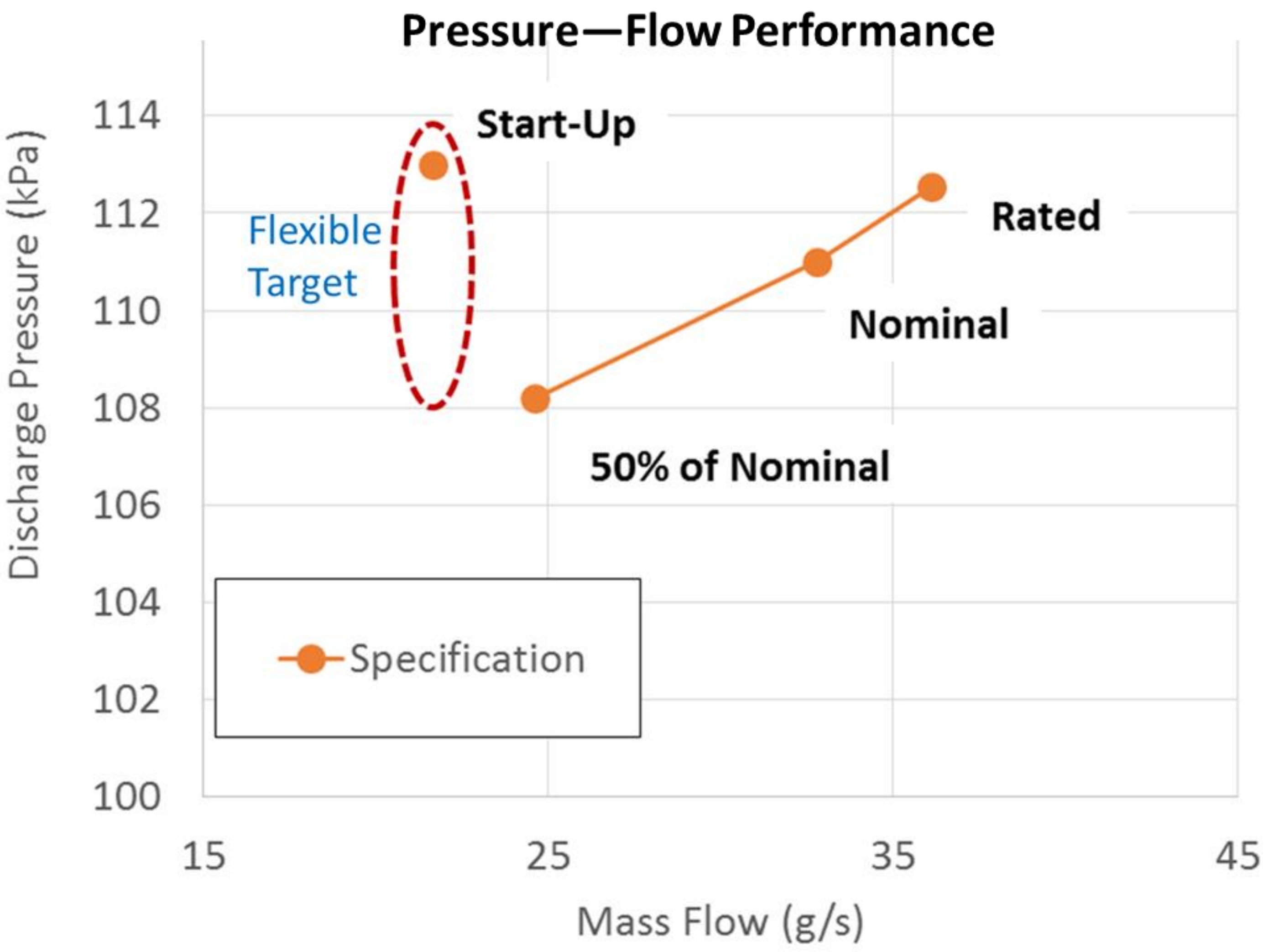
			Operating Regime		
Property	**Units**		**Nominal**	**Rated**	**Start-Up**
Temperature	**T**	**[^{o}C]**	**621**	**650**	**700**
Inlet Pressure	**P**	**[kPa]**	**103.9**	**103.9**	**103.9**
Mass Flow	**m**	**[kg/s]**	**0.033**	**0.036**	**0.22**
Pressure Increase	**ΔP**	**[kPa]**	**7.2**	**8.7**	**Unspecified**

Anode Recycle Gas Composition:

- **Mixture of Water Vapor, Methane, Carbon Dioxide, Carbon Monoxide, Hydrogen**

Task 2: Design Considerations

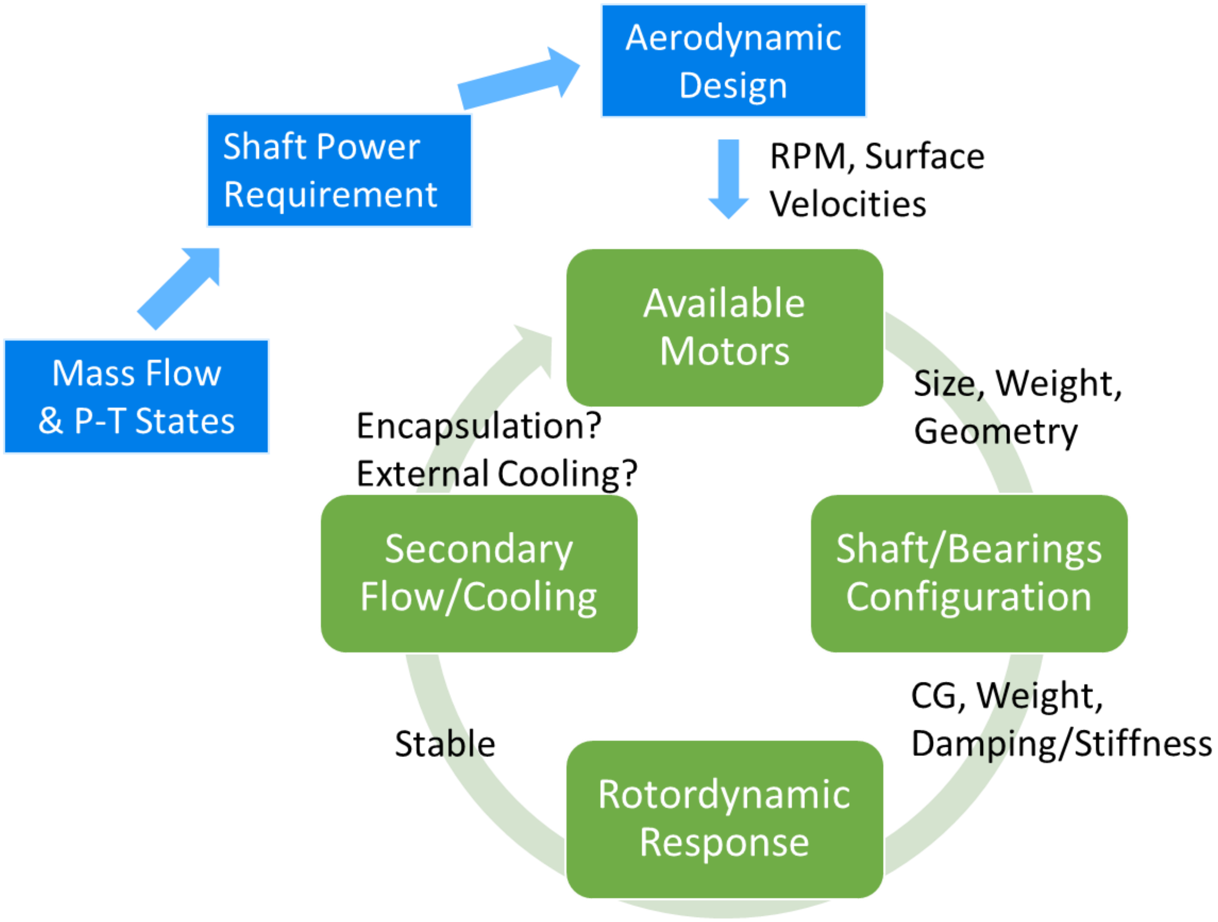
- Net Power Input < 3 kW
- Oil-Free Foil Bearing Design
  - No Lubricant Contamination
  - Low Power Loss Bearings
- Process gas (CH_4) for secondary gas path
- Process gas for housing cooling, with option for forced water/glycol loop necessary
- Economical Design
  - Low Capital Cost
  - Low Maintenance Cost
  - Low Operating Cost



Task 3: Design Process

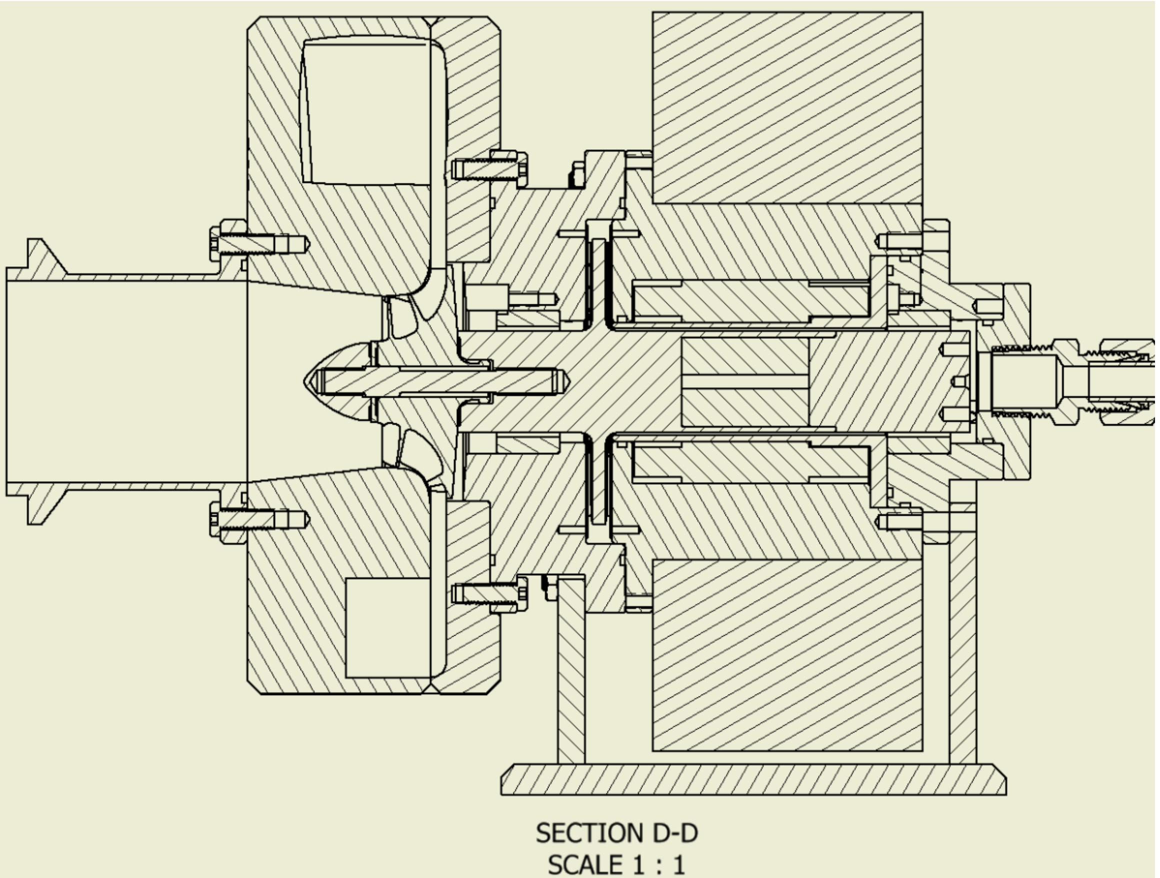
Oil-Free System Design Elements

- Motor/Power Electronics
- Fluid/Thermodynamic Analysis
- Aerodynamic Design
- Rotor-Dynamic Analysis
- Foil Bearing Design
- Thermal Management

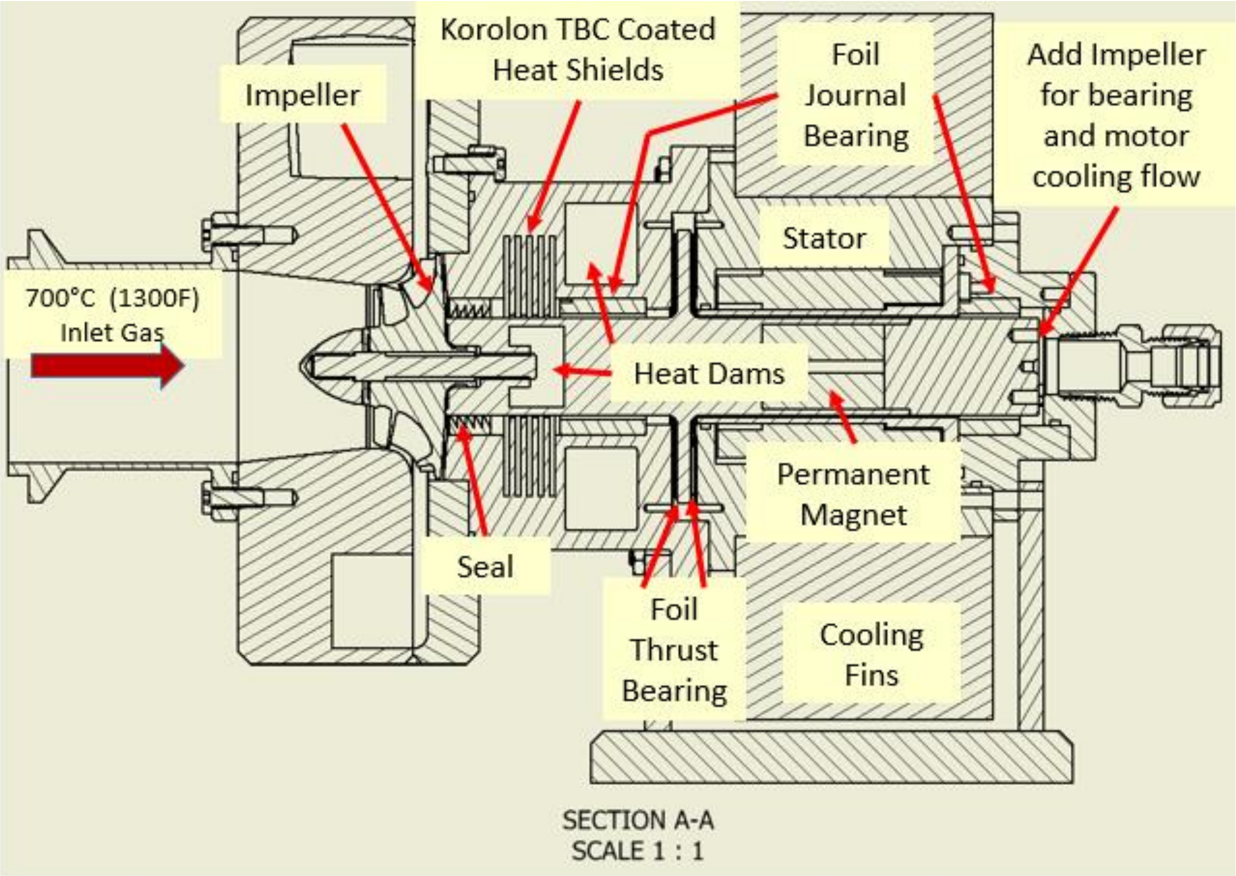


Task 3: General Layout

180^{o}C Precursor Anode RCB



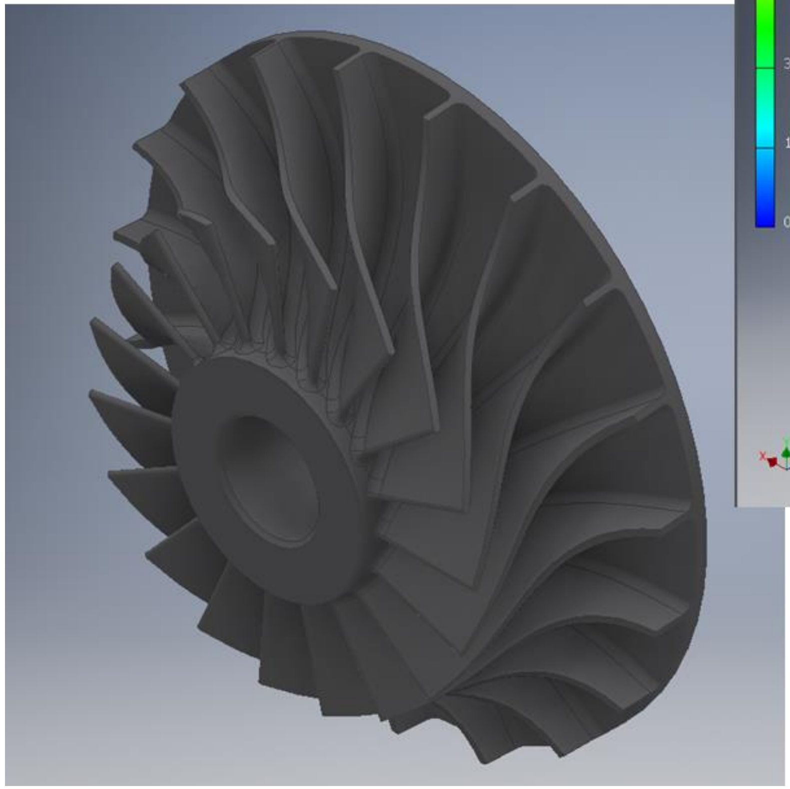
UHT-RCB

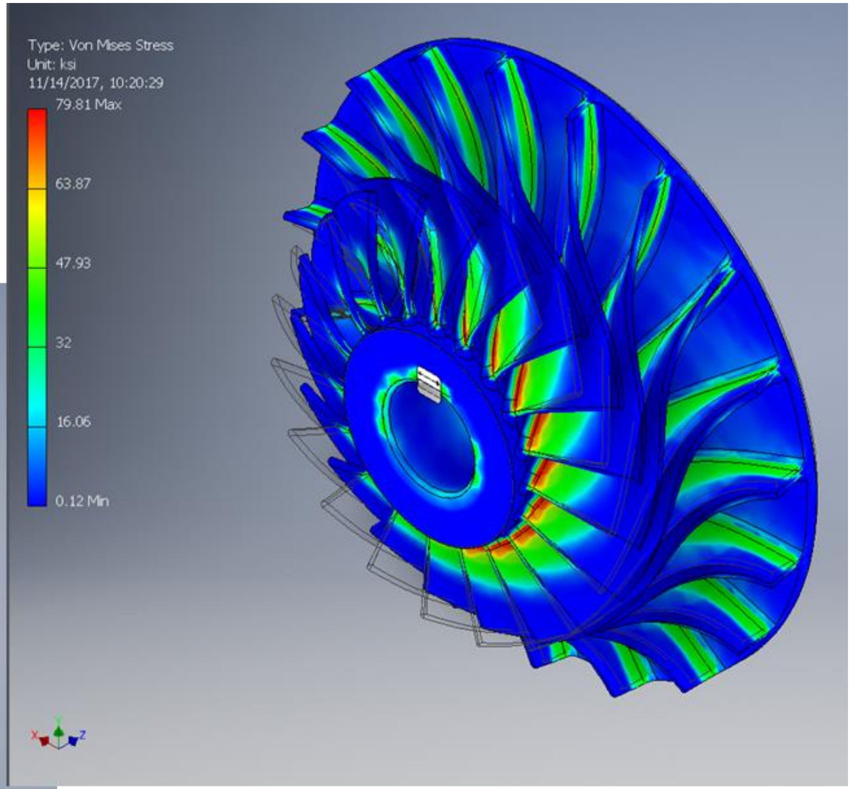


Task 3: Aerodynamic Design Summary

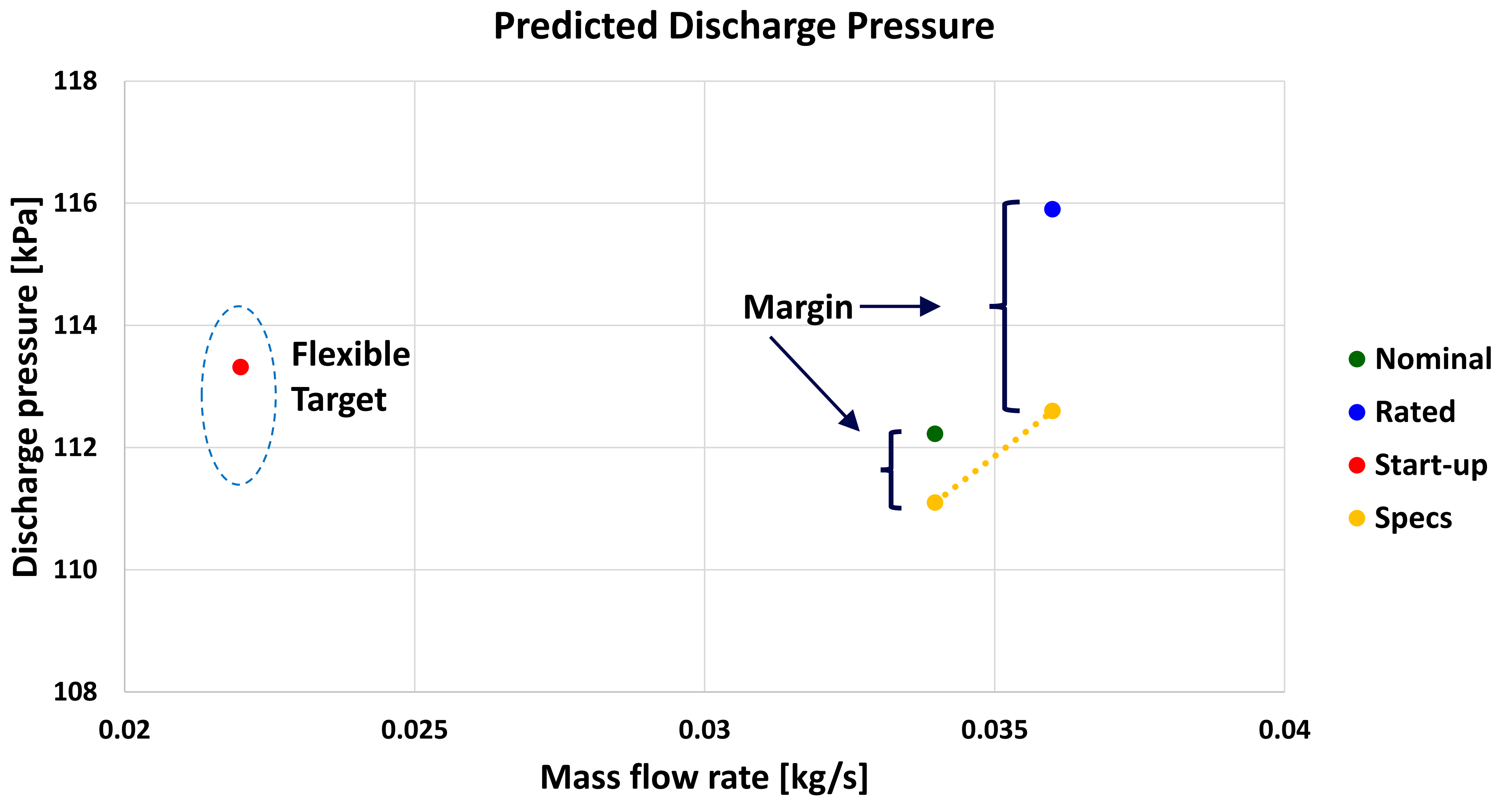
Preliminary Sizing Results

- Type = Centrifugal
- Diameter = 75 mm
- Operating Speed Range
  - 55 krpm < N < 80 krpm
- Adiabatic Efficiency > 70%
- Material: Rene 41





Task 3: Aerodynamic Design Performance



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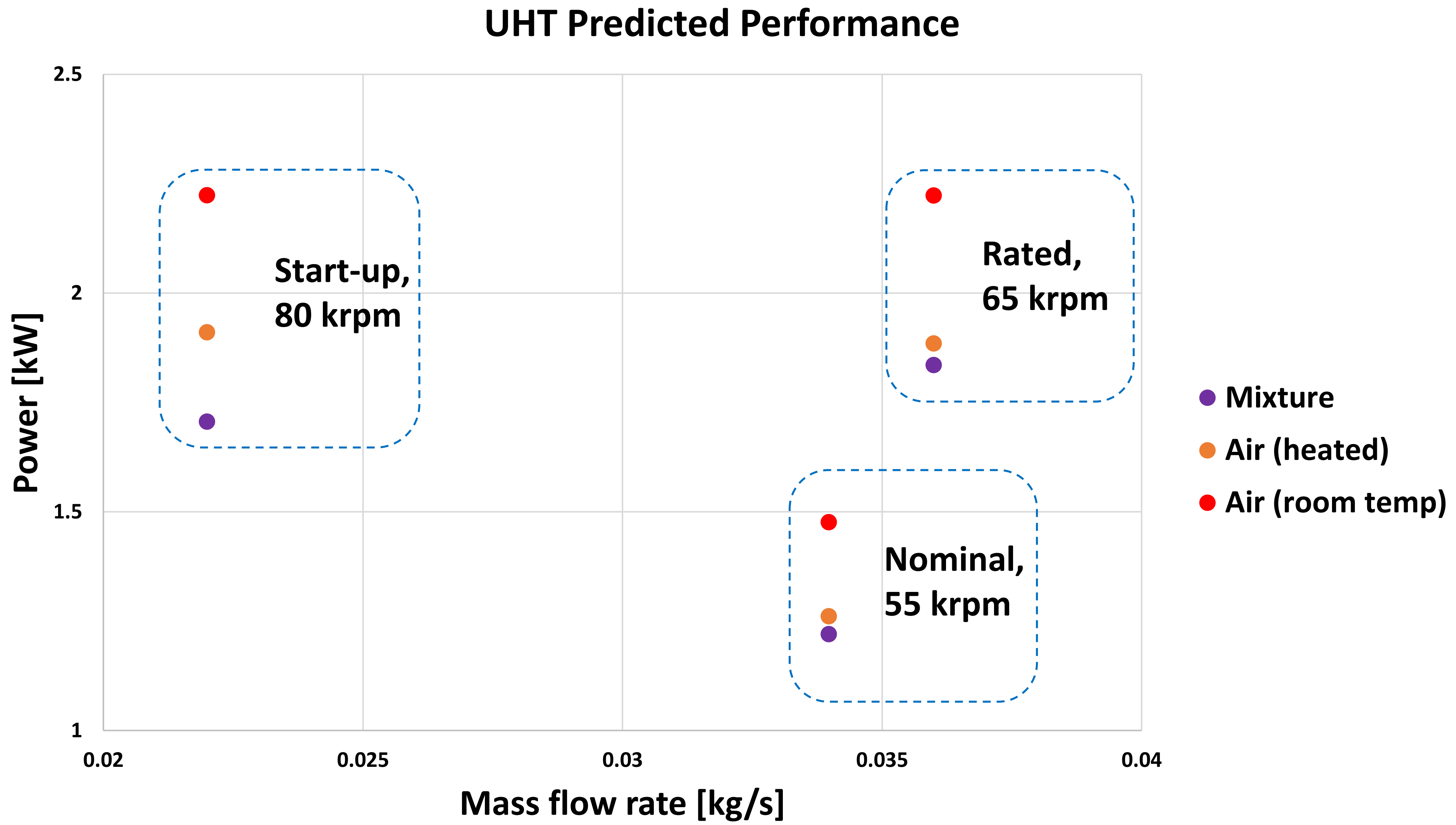

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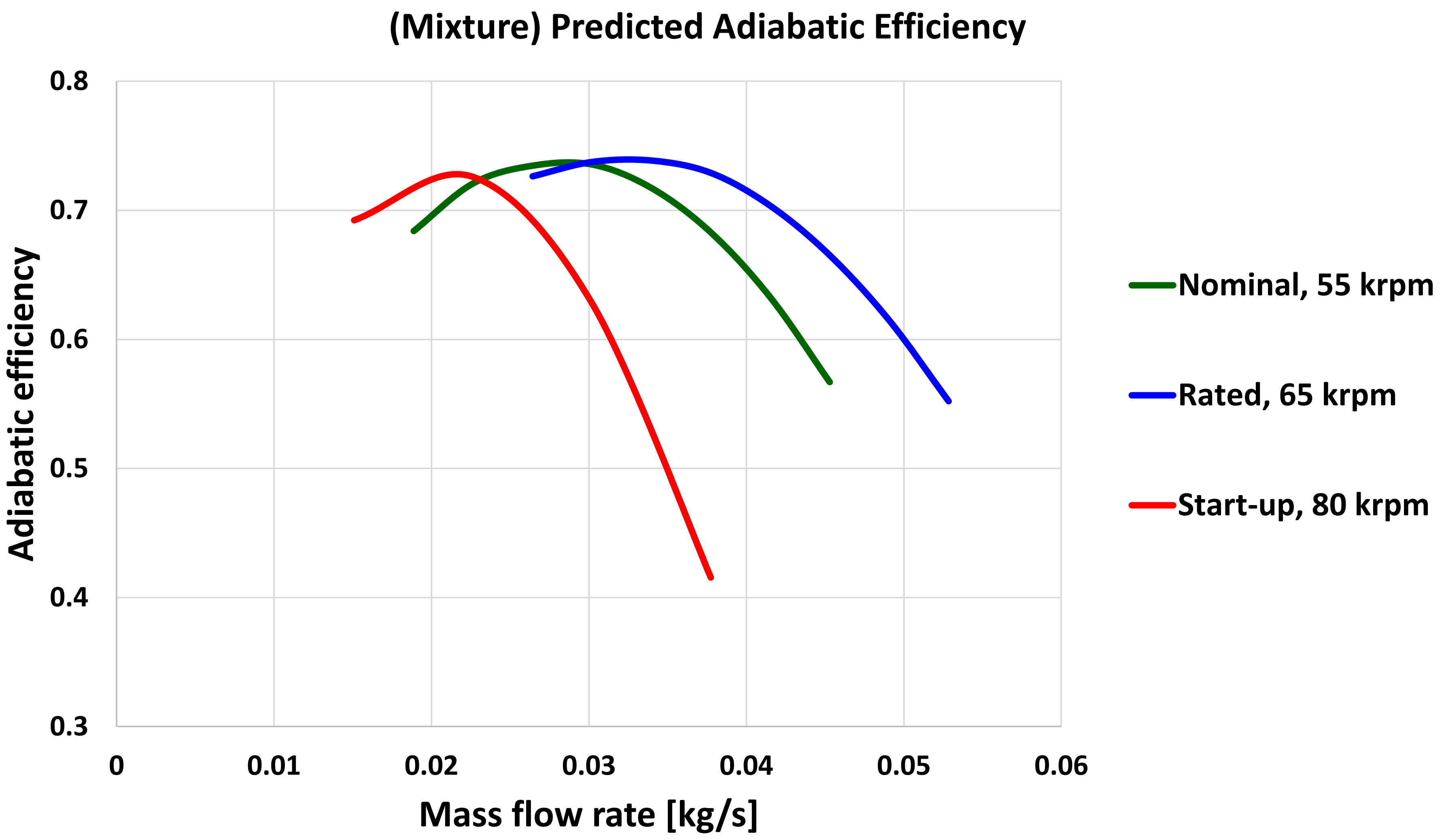


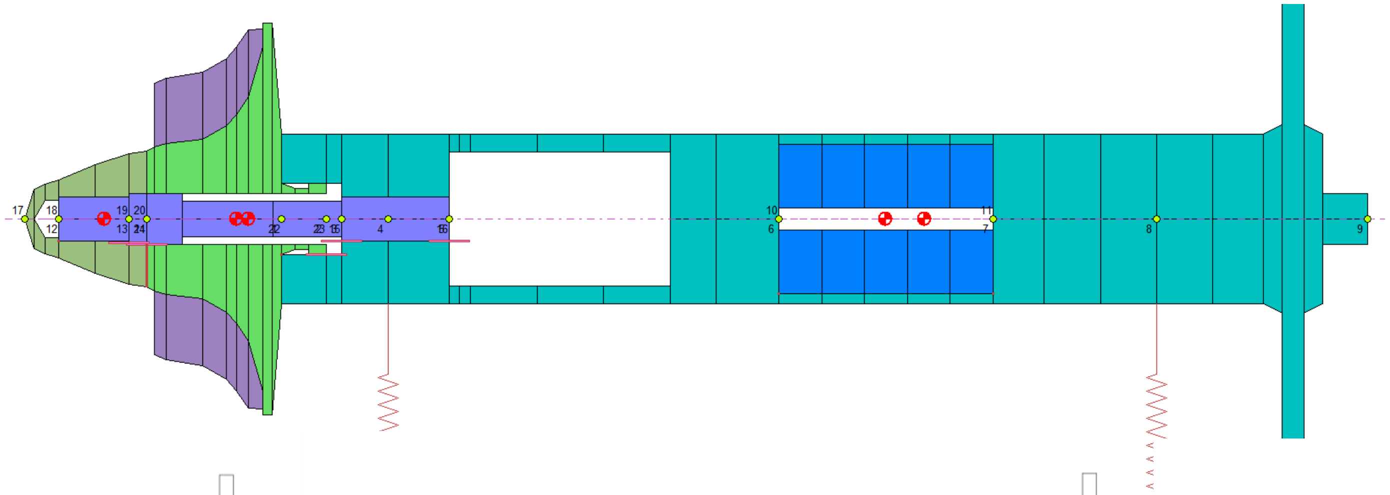
Task 3: Motor Selection

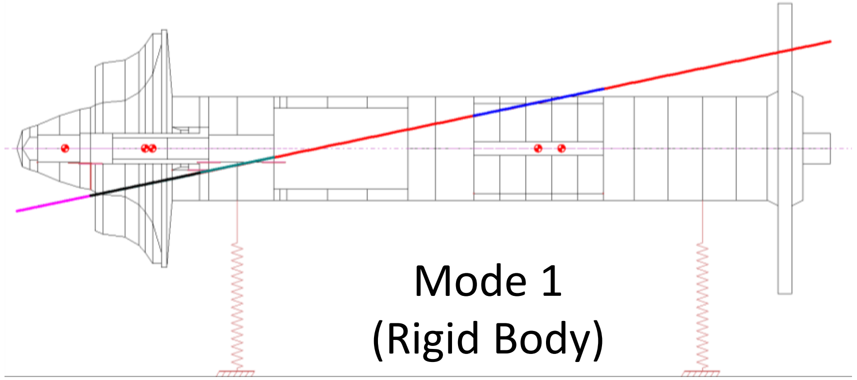
Permanent Magnet Motor

- Encapsulated Samarium Cobalt
- Permits Larger Air Gap
- Higher Efficiency

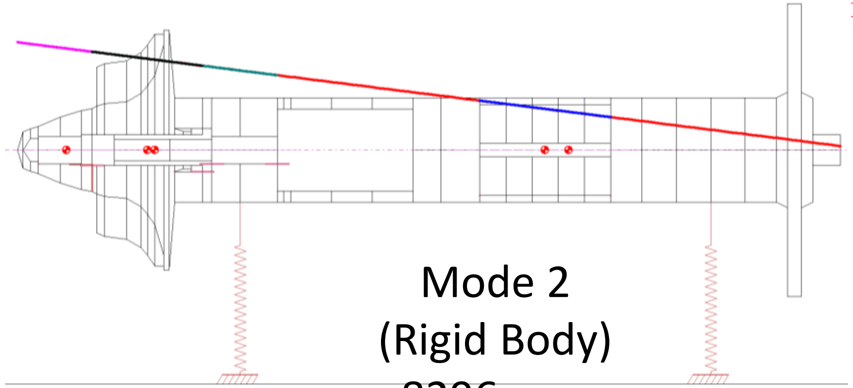
3 kW design based on previous 1.5 kW version

Task 3: Preliminary Rotordynamic Analysis

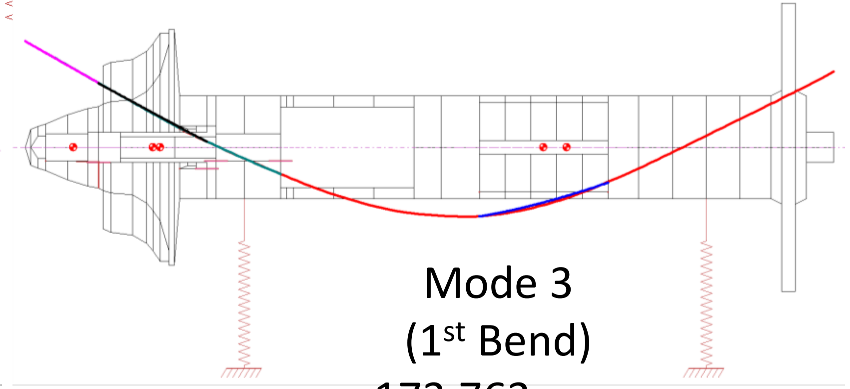




Mode 1
(Rigid Body)
7604 rpm



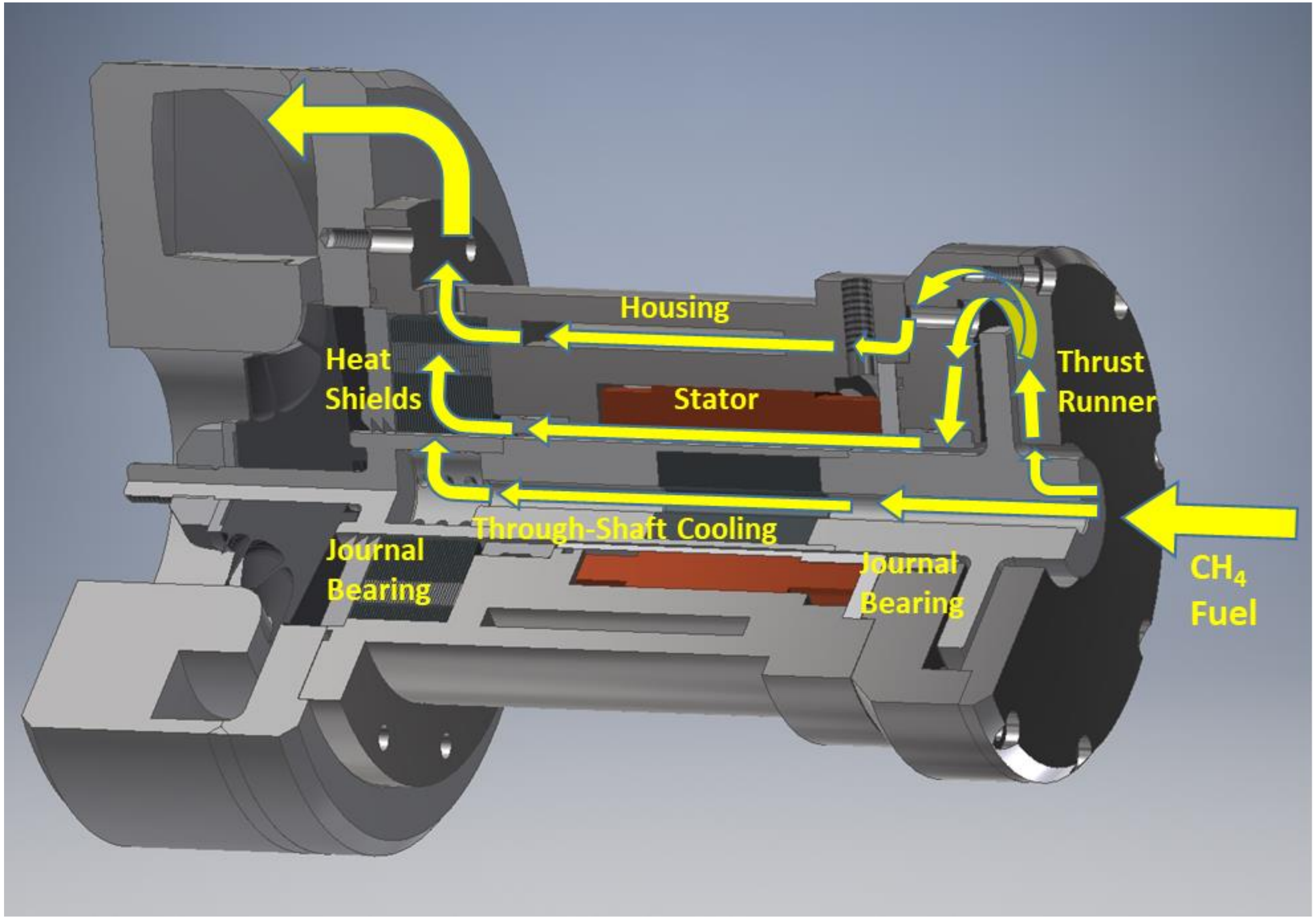
Mode 2
(Rigid Body)
8296 rpm



Mode 3
(1st Bend)
173,763 rpm

Task 3: Secondary Flow and Cooling Scheme

- A 100 kW fuel cell stack uses 3.14 g/sec of fresh CH_4.
  - Available CH_4 Conditions: T_i ~ 20^{o}C, P_i ~ 205 kPa
- The CH_4 can be used in the secondary flow for thermal management.
- Available CH_4 flow can remove up to up to 1.2 kW thermal an maintain motor in a safe temperature zone.

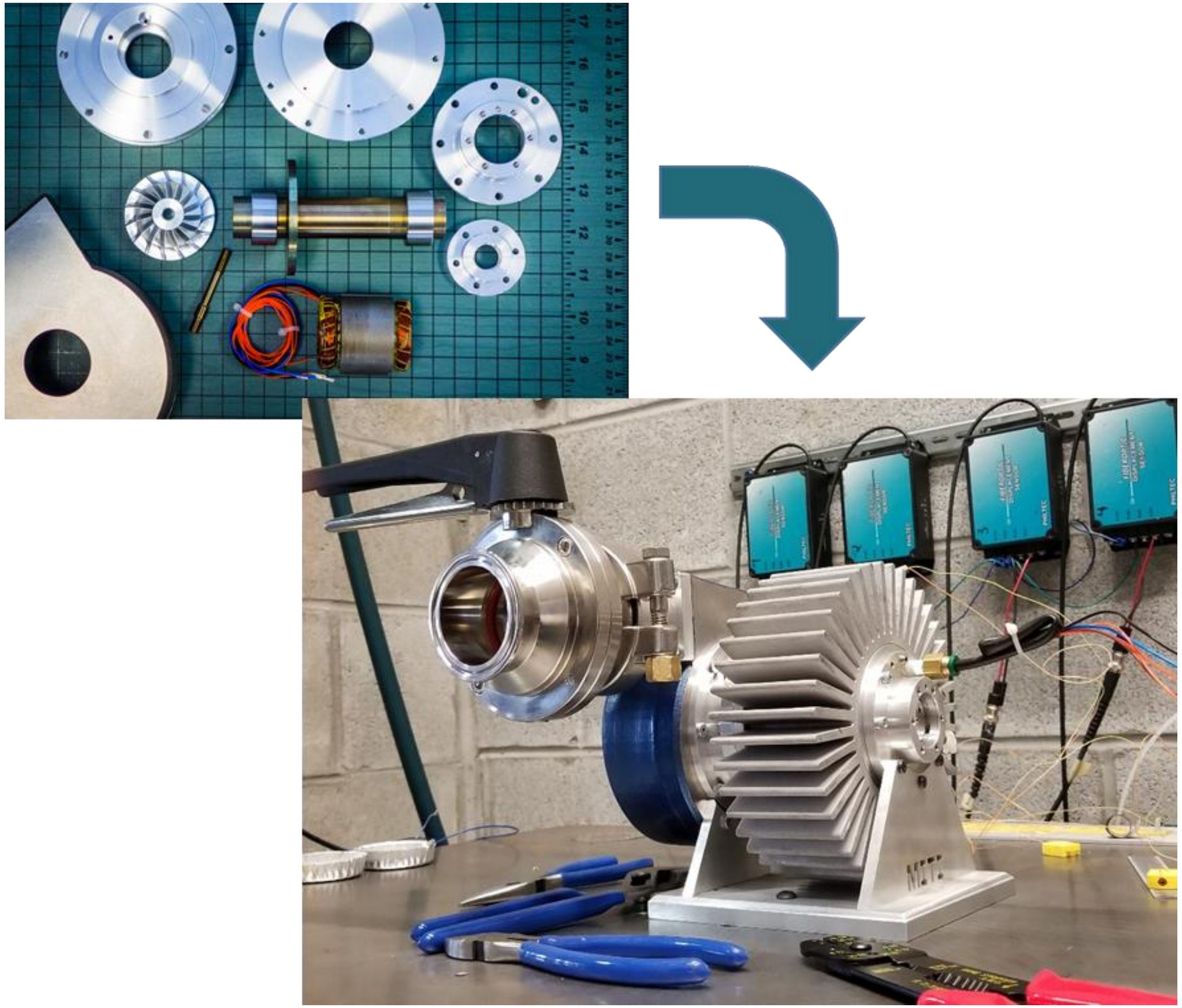


Task 3: Work in Progress

- Complete Preliminary Layout
- Detailed Design
  - Rotating Components
  - Housing
  - Bearings
  - Thermal Management
- Manufacturing & Assembly Drawings

Task 4: Hardware Fabrication and Integration

- Fabricate and Instrument Prototype
  - Vibration/Displacement Probes
  - Thermocouples/Pressure Transducers
- Preliminary and Checkout Tests
  - Validate Instrumentation Operation
  - Verify Motor/Controller Operation
  - Confirm Rotor Lift-Off Speed
  - Leak Check



Task 5: UHT-ARCB Testing

- Demonstrate ability to achieve full design speed
- Measure flow rate and pressure/temperature rise with room temperature air and high temperature (up to 700^{o}C) similitude gas and map performance characteristics
- Compare measured and design performance

Task 6: Assessment of Outcomes

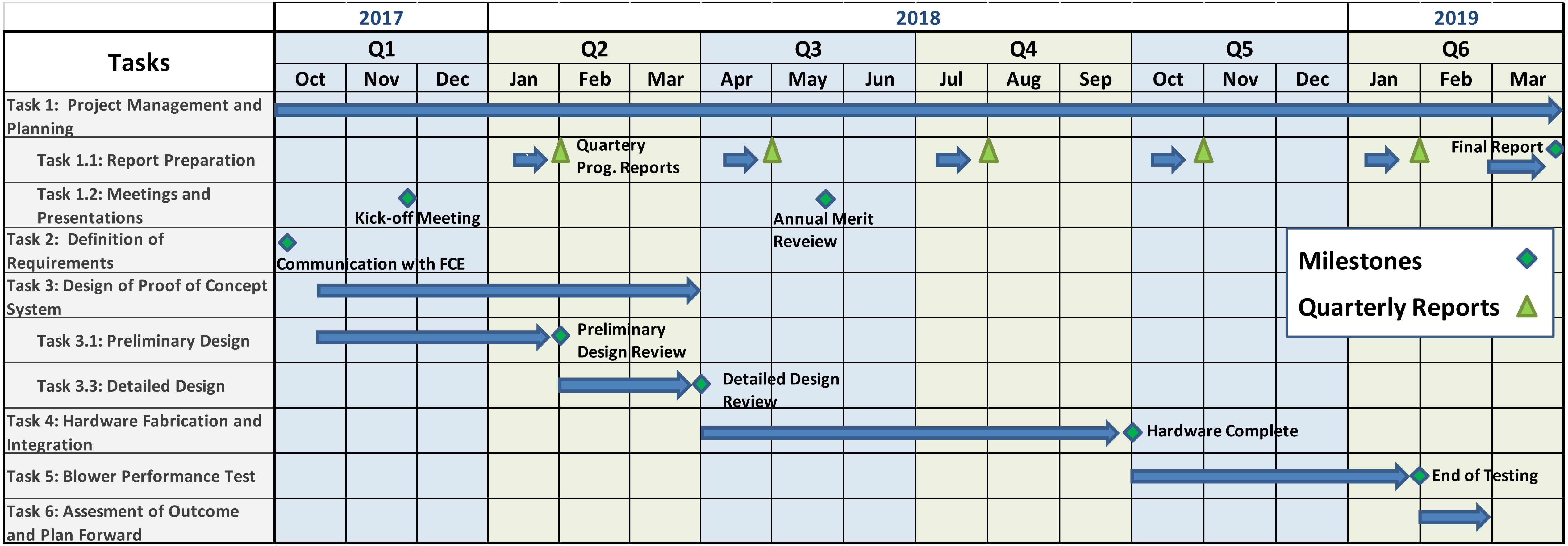
- Objectives:
  - Compare results to requirements
  - Assess scalability of technology
    - Explore design scalability up to flows for SOFCs with power output in the 10 MWe range and higher
  - Assess economic performance and compare to cost target of $110 per SOFC generated kWe
    - Estimated cost for 1 MW load meets or is less than the targeted cost of $40 per SOFC generated kWe

Task 6: Cost Considerations and Scalability

Projected Cost ***After Product Development:***

- Estimated Cost for First 10 Units
  - 3 kW: $12k - $15k / unit
  - 50 kW: $40k - $60k / unit

Project Schedule



Project Budget

Total Estimated Cost: $ 373,819.00

- 80% Government Share: $ 299,055.00
- 20% Recipient Share: $ 74,764.00

Risk Management

Main Risks Identified (R) and Planned Mitigation Strategies (M):

- **R: Thermal management: CH_4 cooling scheme may be insufficient**
  - ***M: Additional closed loop water/glycol (with stock radiator and pump)***
- **R: Schedule of long lead items: Motor Magnet procurement may cause prototype fabrication delay**
  - ***M: Handle motor set component procurement as a critical path step.***
  - ***M: Secure quotes from multiple vendors***
- **R: Prototype Fabrication Cost: Initial prototype low-volume cost may be high.**
  - ***M: Minimize part count***
  - ***M: Casting of as many parts as possible***
  - ***M: Material substitution where thermally possible***

Technology Readiness Level

- TRL Definitions
  - TRL 5 - System/subsystem/component validation in relevant environment:
  - TRL 6 - System/subsystem model or prototyping demonstration in a relevant end-to-end environment
- Prototype will be a high TRL 5 at end of Phase I
- Will achieve TRL 6 at end of an eventual Phase II

Status Summary

- Design Requirement Reviewed
- Preliminary Design and Layout Underway
- Detailed Design to Begin in Feb 2018
- Manufacturing to Begin Apr 2018

Thank You For Your Attention

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