High Temperature Anode Recycle Blowers for Solid Oxide Fuel Cell

DOE Award Nos.: DE-FE0027895 & DE-FE0031148

U.S. Department of Energy's 2019 Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting

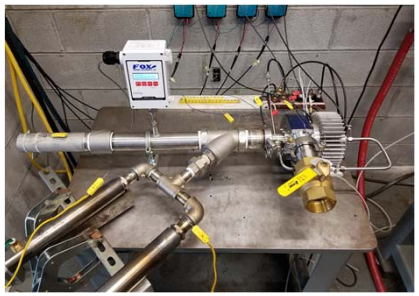
Mohawk Innovative Technology, Inc.

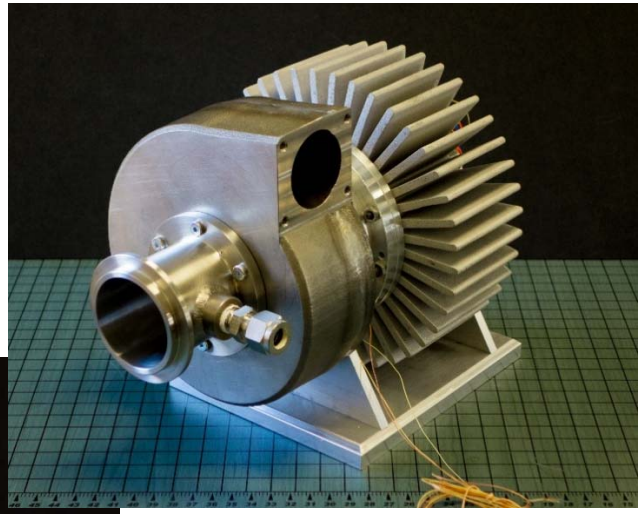
U.S. DEPARTMENT OF ENERGY

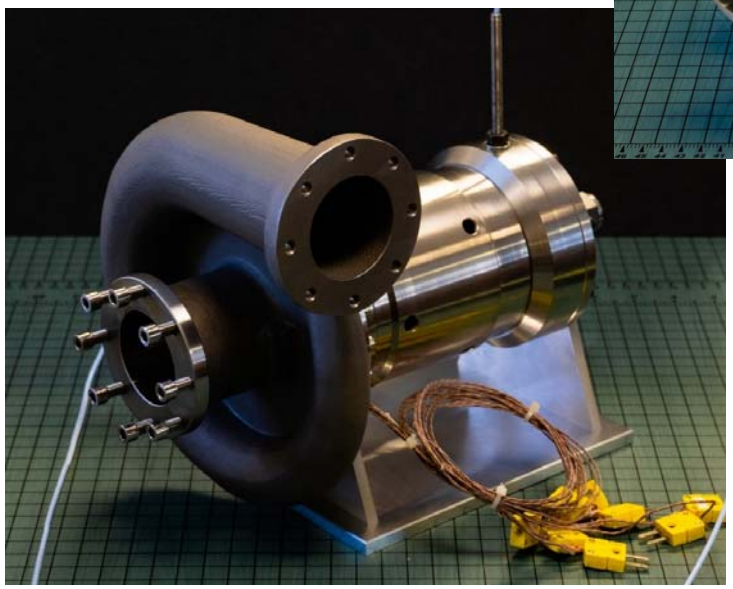
MOHAWK INNOVATIVE TECHNOLOGY

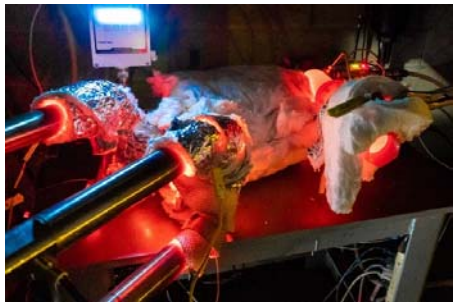
Overall Program Objectives

- To develop scalable Oil-Free High-Temperature Anode Recycle Blower (ARCB) technology for SOFC power plants
- Achieve TRL 7 (during Phase II) by demonstrating performance and life through testing in a real SOFC power plant









Team Background

MOHAWK INNOVATIVE TECHNOLOGY

- Hooshang Heshmat, PhD
  - Principal Investigator
- Jose Luis Cordova, PhD
  - Program Manager
  - Thermal Management
- Luke Montesano
  - Design Engineering
  - Testing

fuelcellenergy

- Hossein Ghezel-Ayagh, PhD
  - FCE Project Manager
- Stephen Jolly
  - SOFC systems engineering
  - Operations manager
- Micah Casteel, PhD
  - Mechanical blower integration

U.S. DEPARTMENT OF ENERGY

Steven R. Markovich

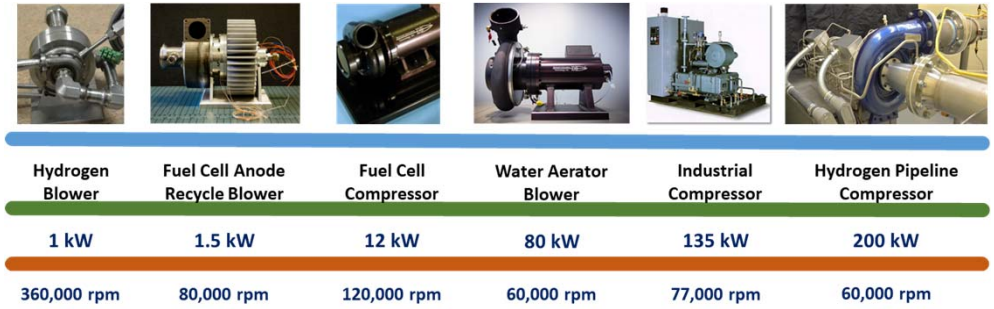
Advanced Energy Systems Team
Office of Fossil Energy, NETL

- Project Manager

Team Background

MOHAWK INNOVATIVE TECHNOLOGY

- Specializes in ultra-high speed, oil-free turbomachinery for power generation, waste heat recovery, refrigeration and energy storage, etc. Develops blowers, compressors, gas turbine engines, turbochargers, etc.



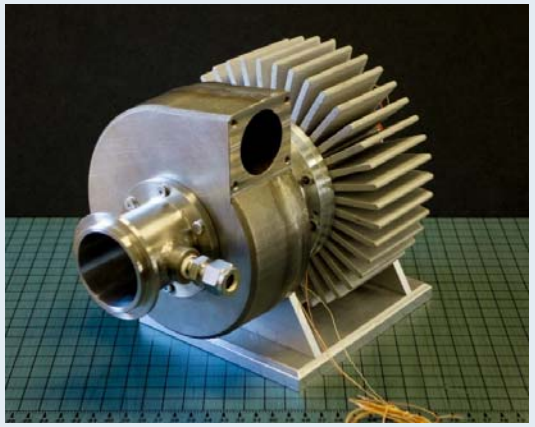
fuelcellenergy

- Integrated fuel cell company that designs, manufactures, installs, operates, and services stationary fuel cell power plants. Develops technologies for energy supply, recovery and storage.

MITI's Anode Recycle Blowers for SOFCs

- **High Temperature (HT) Anode Recycle Blower for Solid Oxide Fuel Cell—Phase II**
  - Award No.: FE0027895
  - Performance Period: 10/01/2016 - 03/31/2020
  - Total Phase I & II Budget:

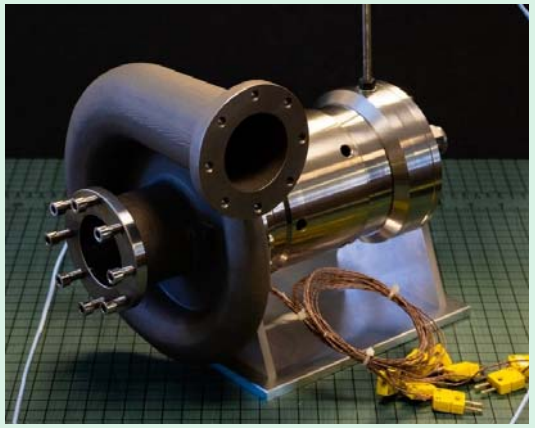
DOE	**$2,098,408**
MITI	$ 569,443
Total	$2,667,851



HT: Max T_{in} = 180 ^{O}C

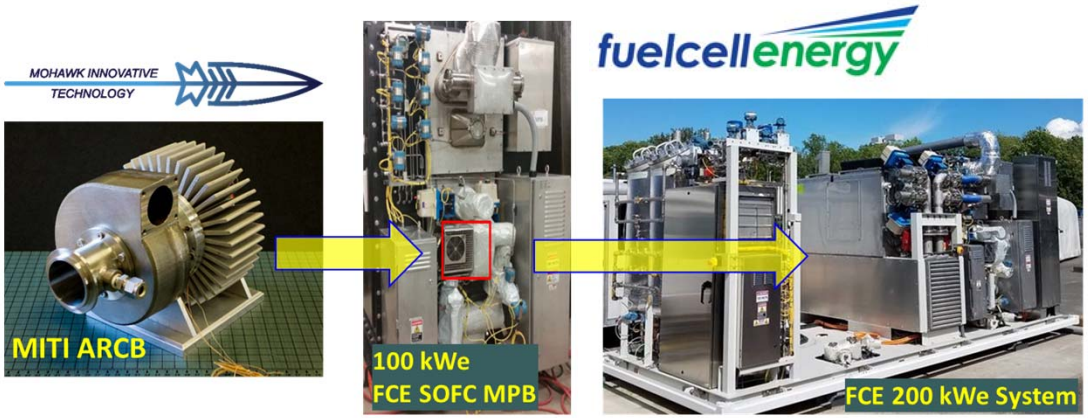
- ***Ultra High* Temperature (UHT) Anode Recycle Blower for Solid Oxide Fuel Cell—Phase I**
  - Award No.: FE0031148
  - Performance Period: 10/01/2017 - 03/31/2019
  - Phase I Budget:

DOE	**$ 299,055**
MITI	$ 74,764
Total	$373,819



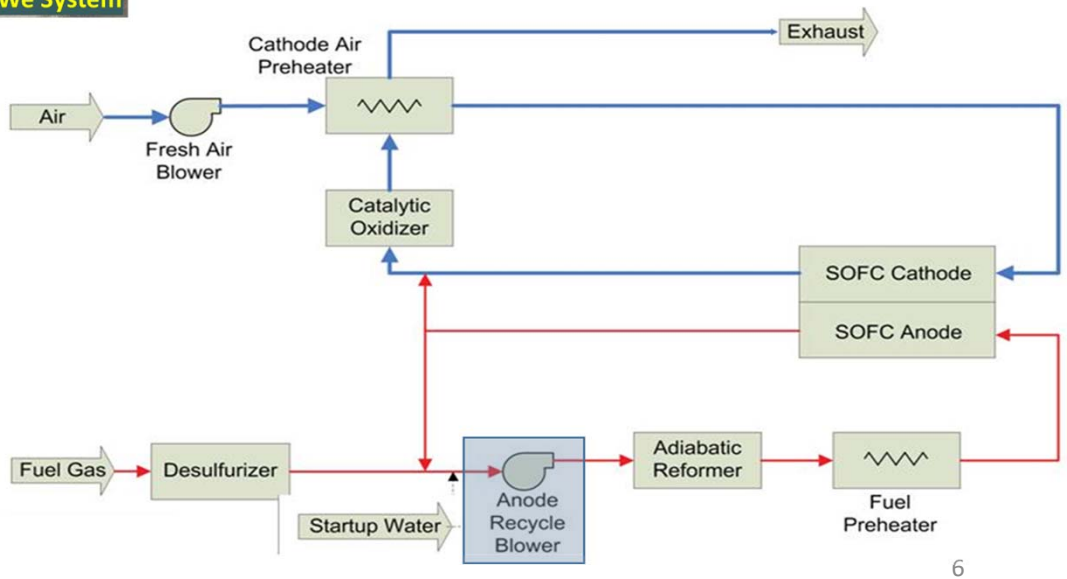
UHT: Max T_{in} = 700 ^{O}C

How it all fits together

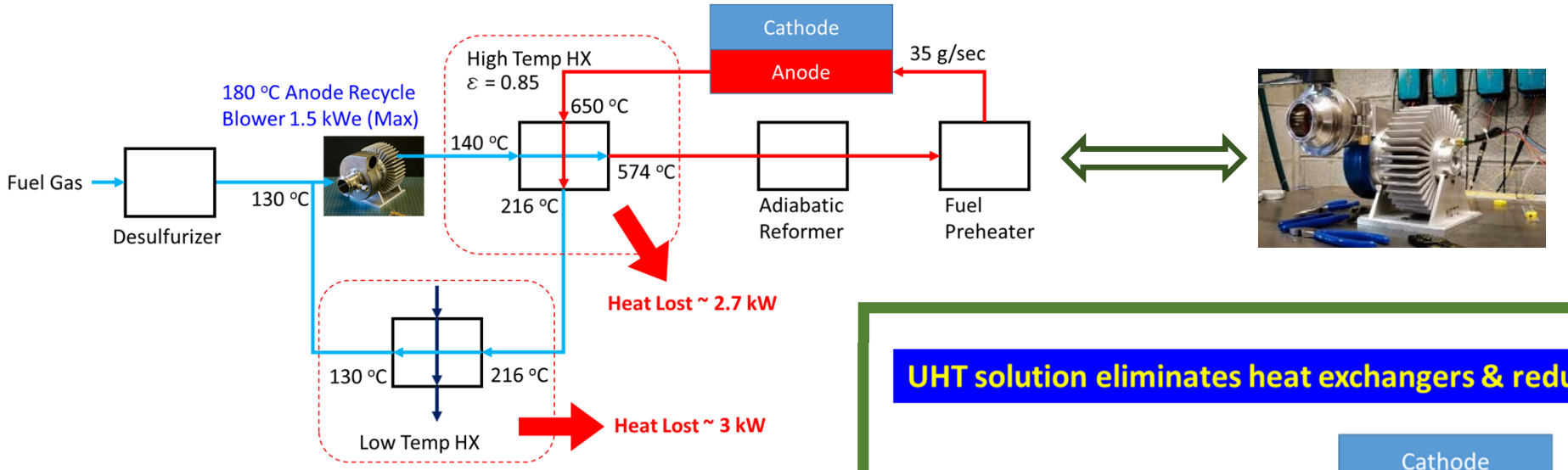


- Typical SOFC stacks operate with fuel utilization in the range of 70–85%.
- Recycling anode exhaust gases improves the stack efficiency.

- The ARCB recirculates a fraction of the depleted anode exhaust to the fuel-cell inlet
- This also provides water vapor to the anode feed gas to assist methane reformation and inhibit carbon deposition



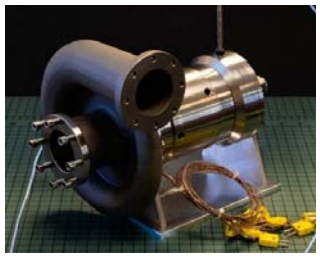
How it all fits together

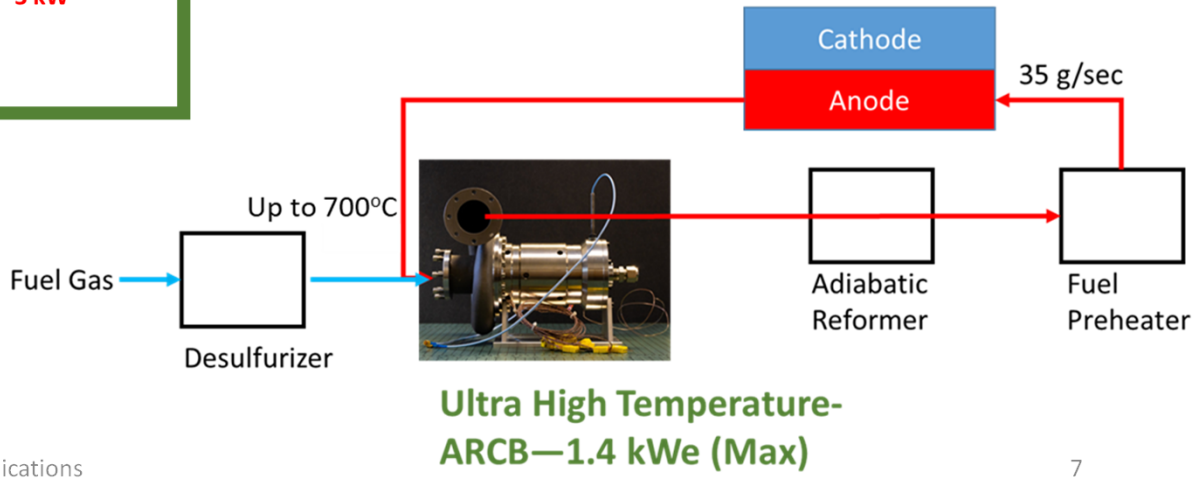


HT

UHT solution eliminates heat exchangers & reduces losses

UHT



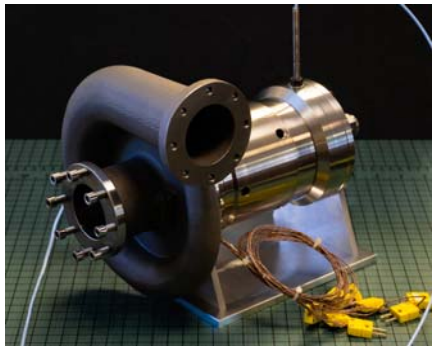


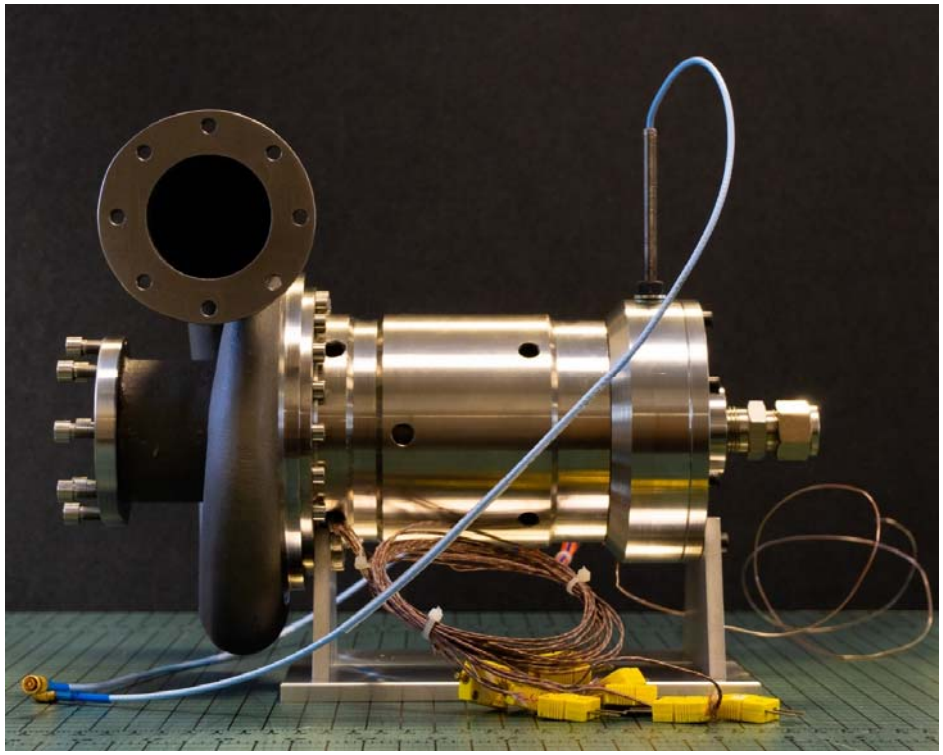
Ultra High Temperature-ARCB—1.4 kWe (Max)

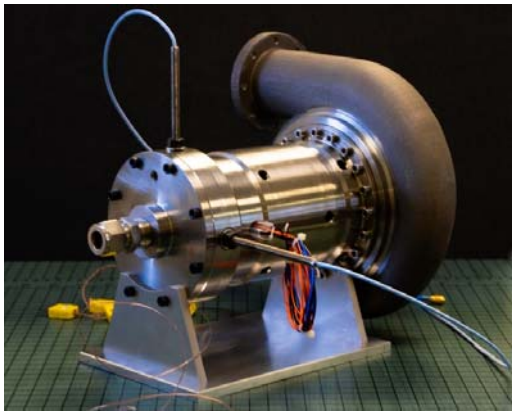
Definition of Requirements

- Operating regimes specified by FCE require a high turn-down ratio engine
  - Flow rate: 0.02 to 0.04 kg/sec
  - Pressure increase: < 10 kPa
  - Gas composition: variable mix, primarily consisting of water vapor, CO2, H2, CH4
  - Inlet temperature:
    - HT: up to 180 ^{O}C
    - UHT: Up to 700 ^{O}C
- Low power consumption
  - HT: < 1.5 kWe
  - UHT: < 1.4 kWe
- Oil-free foil bearing design
  - No lubricant contamination
  - Low power loss bearings
- Economical design
  - Low capital cost
  - Low to no maintenance cost
  - Low operating cost

UHT ARCB Full Assembly





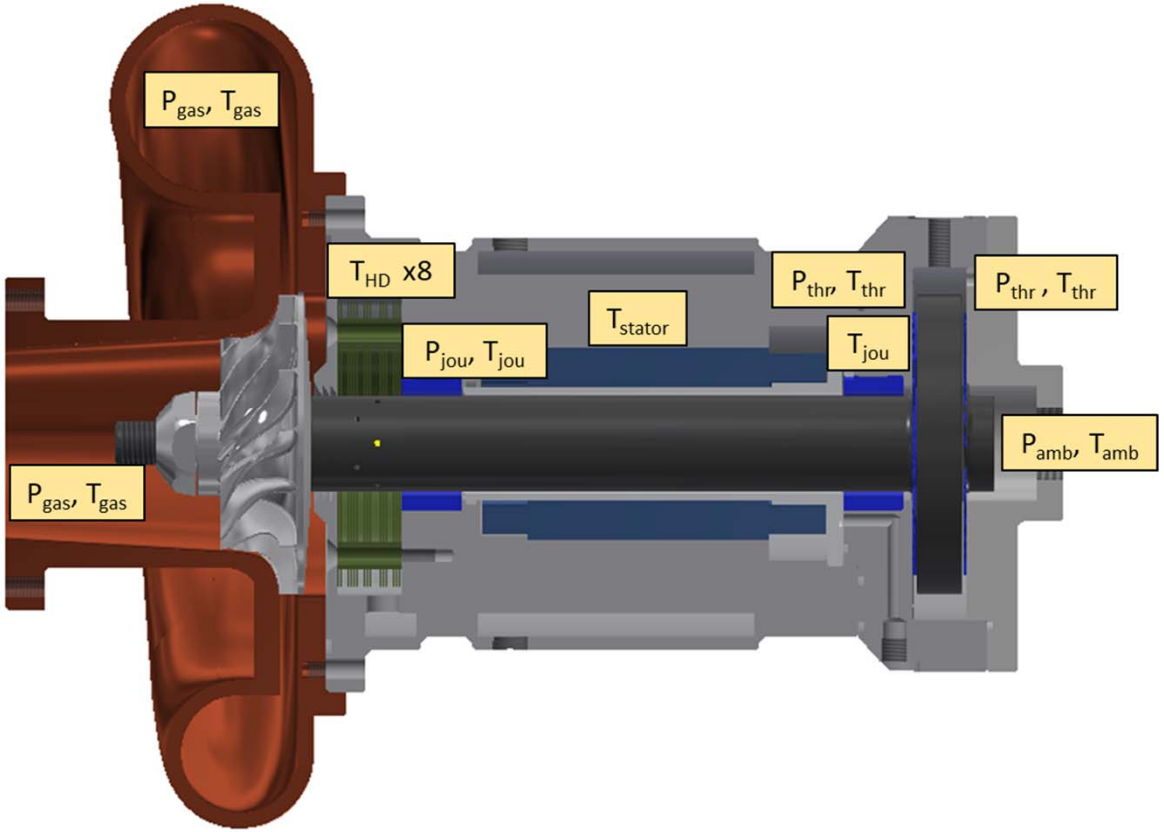


UHT Instrumentation Schematic

LabView-based continuous monitoring

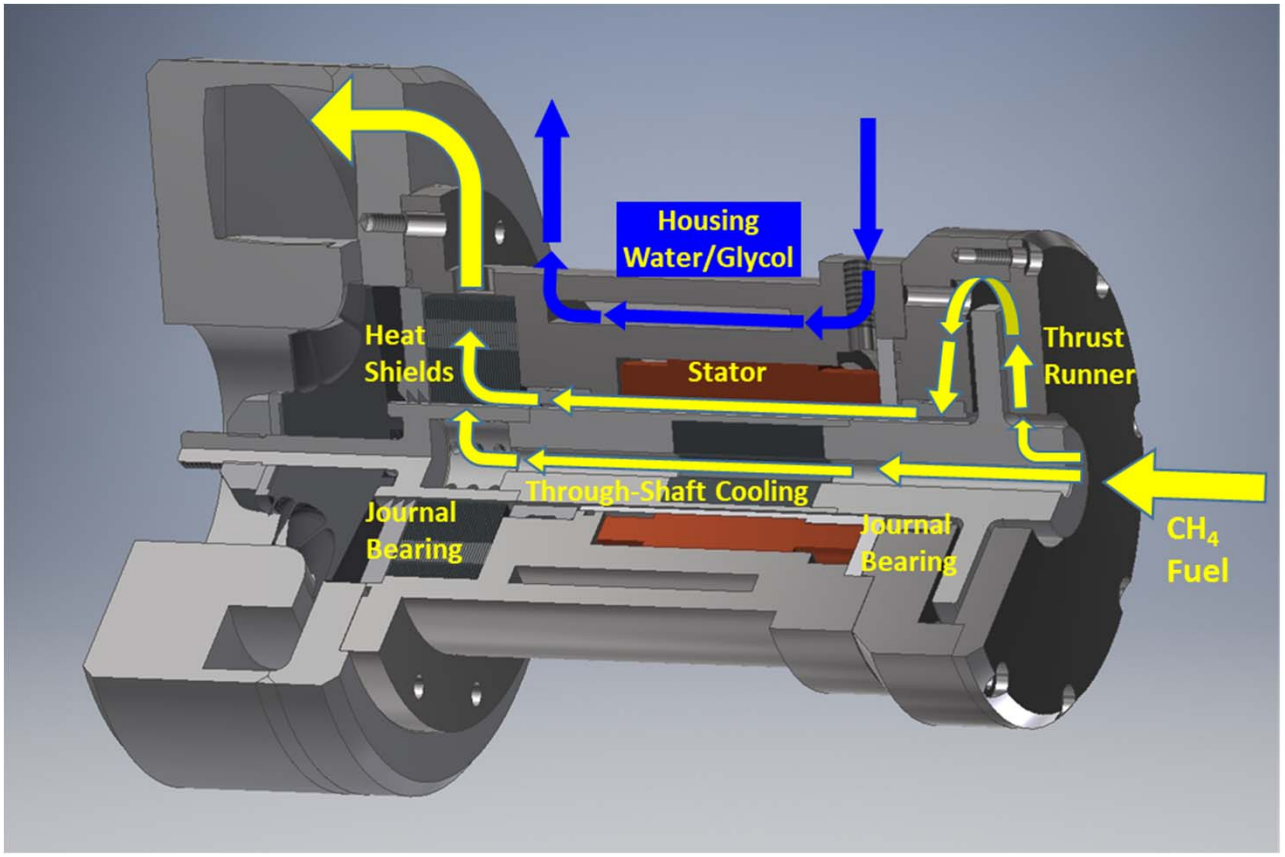
Transducer list:

- 6 pressure transducers
- 16 thermocouples
- 4 shaft displacement probes



UHT Secondary Flow and Housing Cooling

- A 100 kW fuel cell stack uses ~3 g/sec of CH_4.
  - Available CH_4 Conditions:
    - T_i ~ 20°C
    - P_i ~ 205 kPa (abs)
- 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 of heat and maintain motor in a safe temperature zone.
- Housing can be cooled with an external water/glycol loop

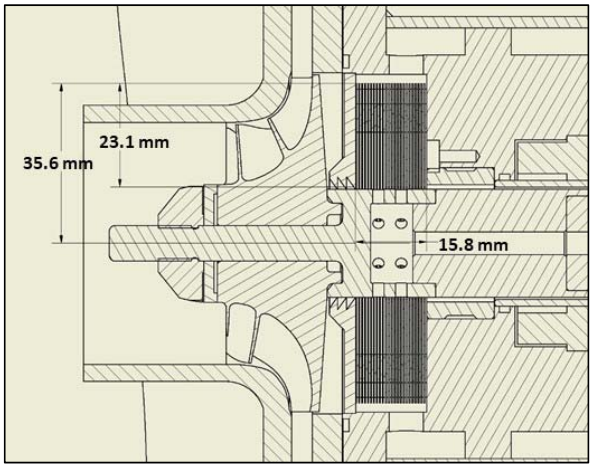


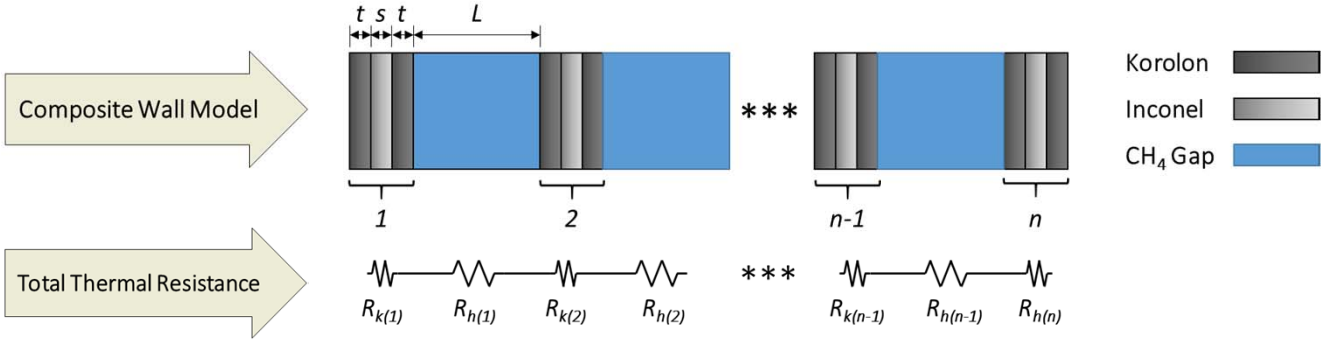
UHT Secondary Flow and Housing Cooling

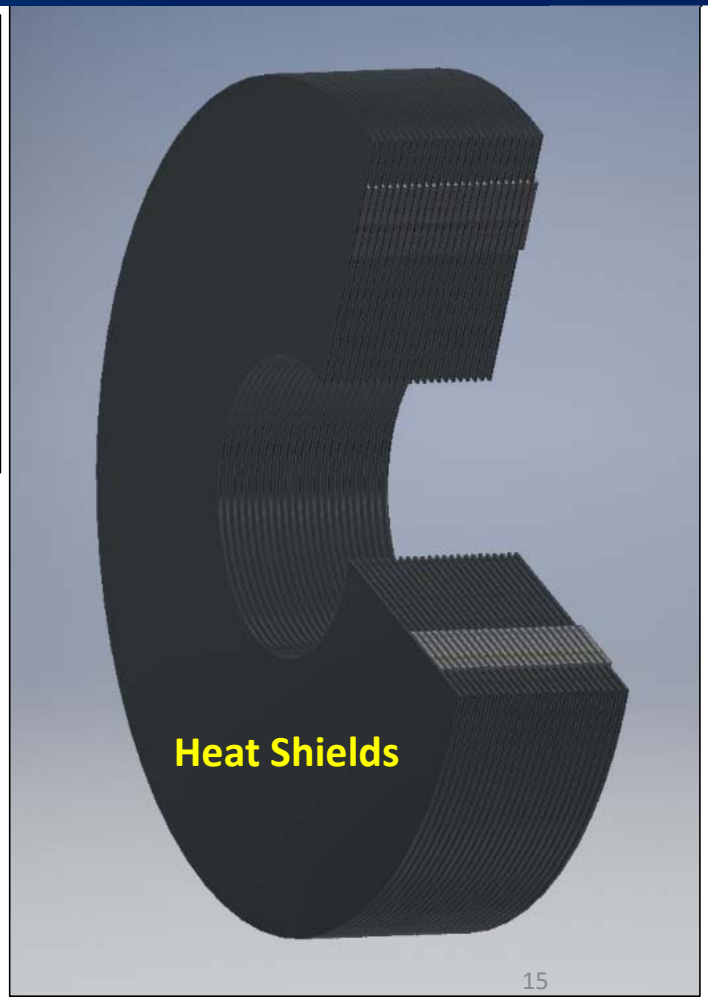
MOHAWK INNOVATIVE TECHNOLOGY

Dual Purpose Heat Shields

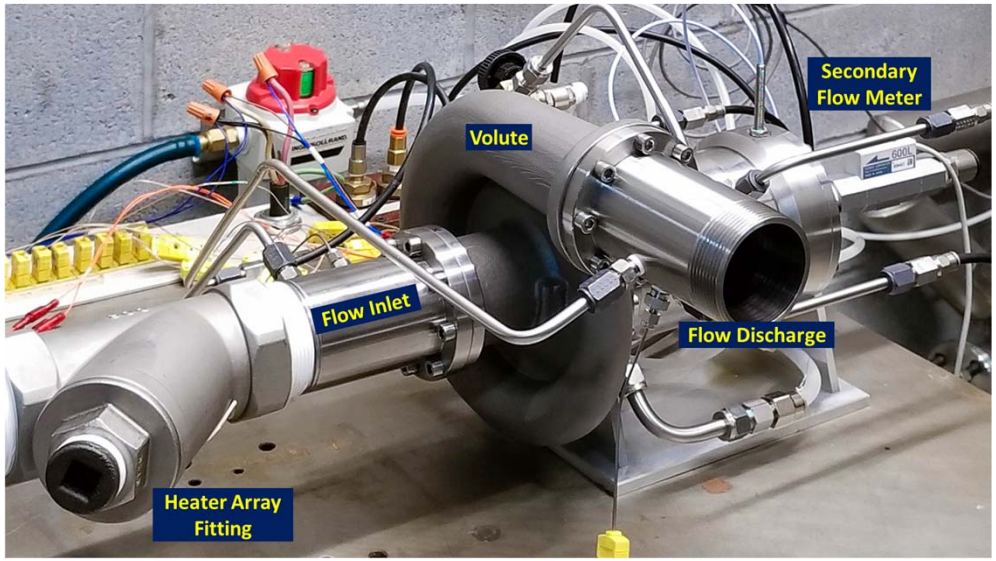
- Turn Secondary Flow Radially
- Provide Large Thermal Barrier Between the High Temperature Aero Zone and the Motor Section
- ***MITI's KOROLON 1350™***

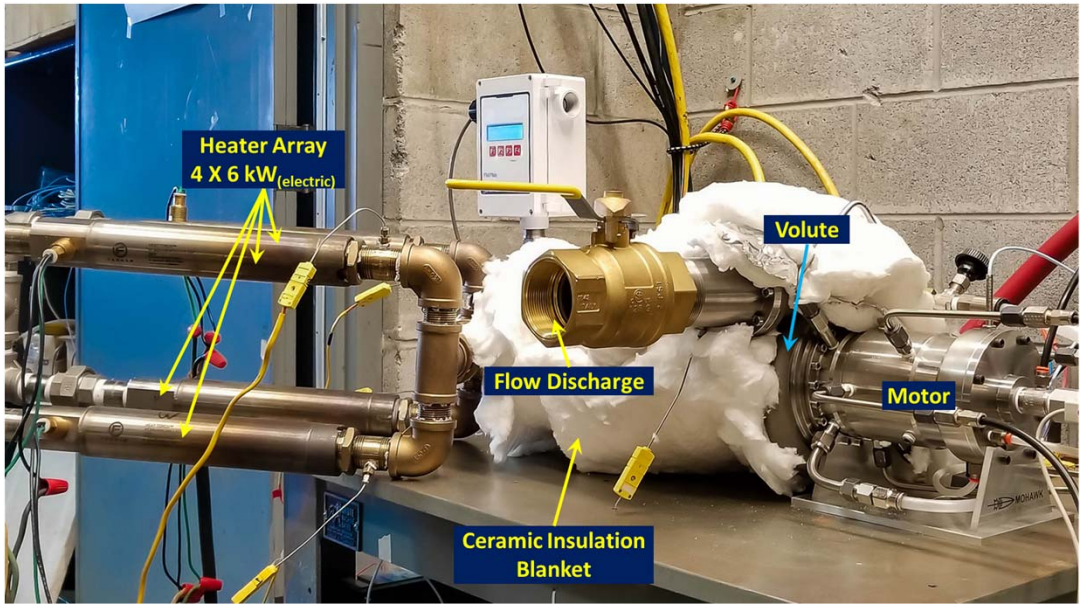






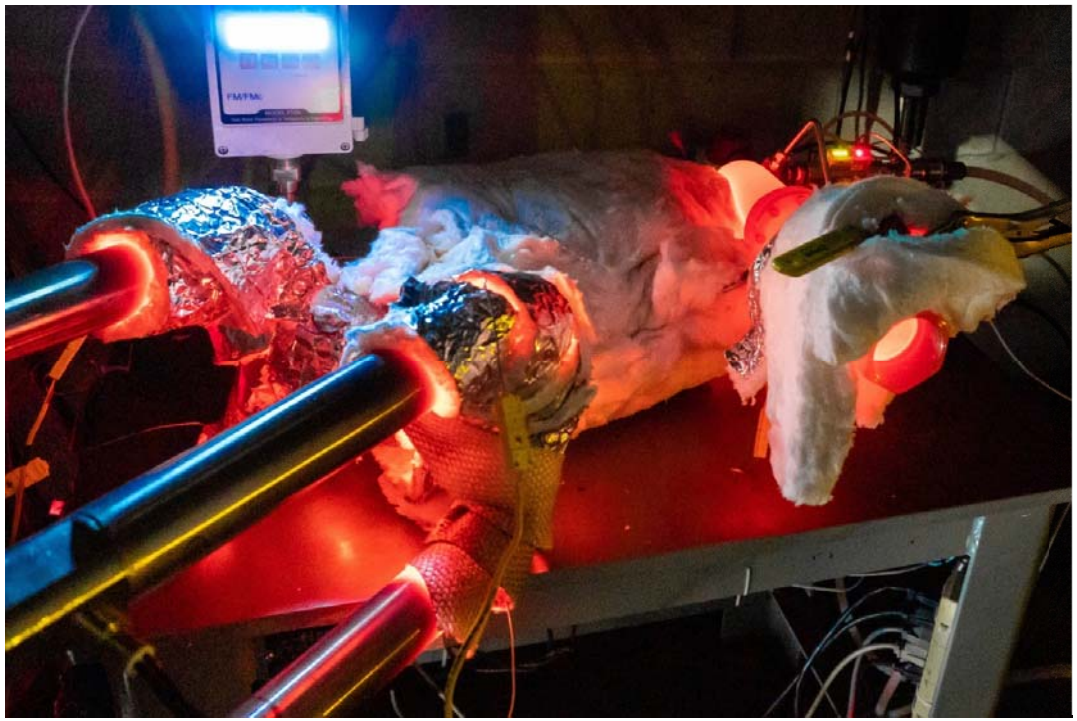
UHT ARCB Test Cell

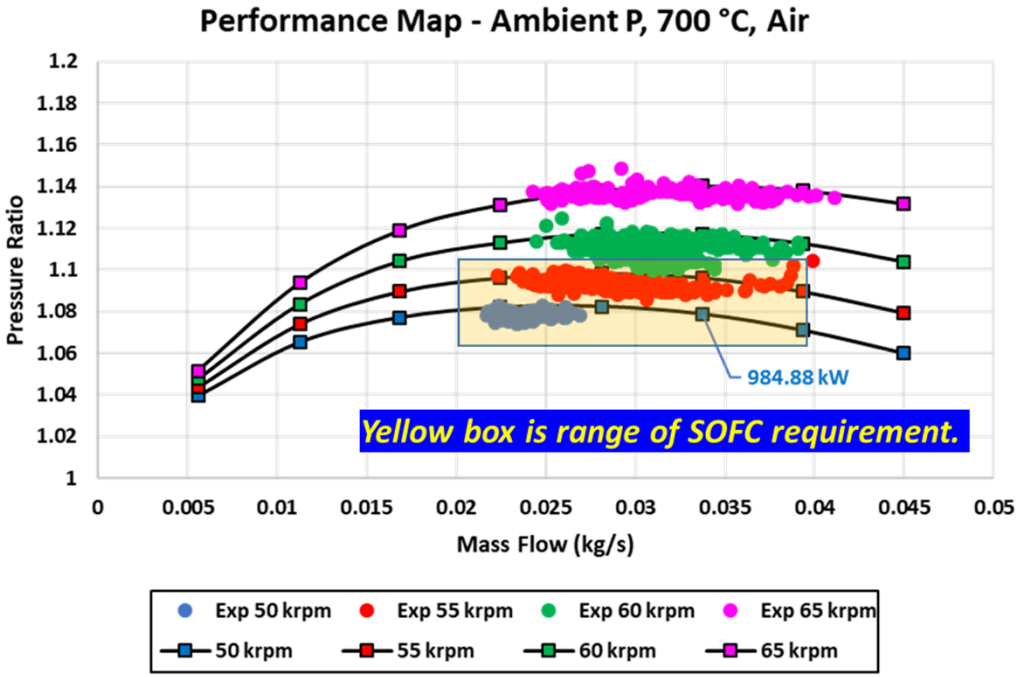




UHT ARCB Testing

Testing with air at 700 ^{O}C. Photo taken with 1 sec exposure

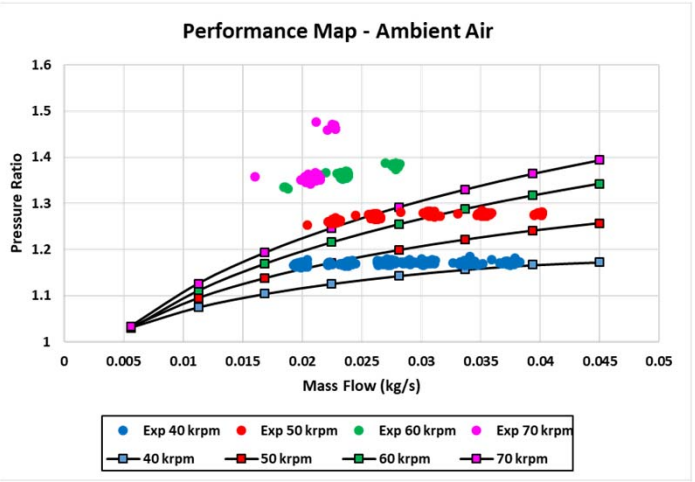


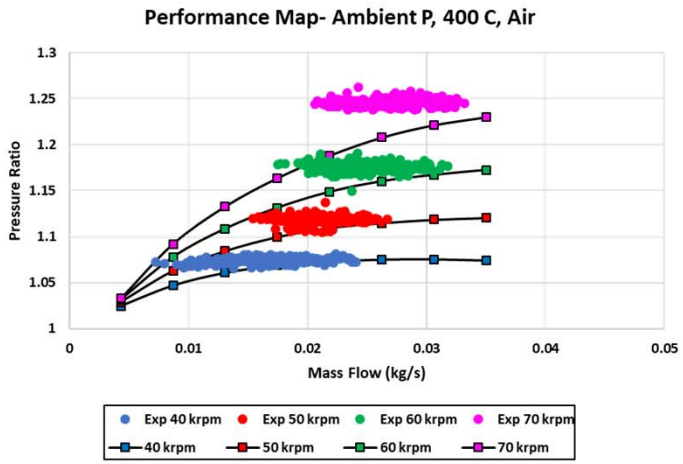


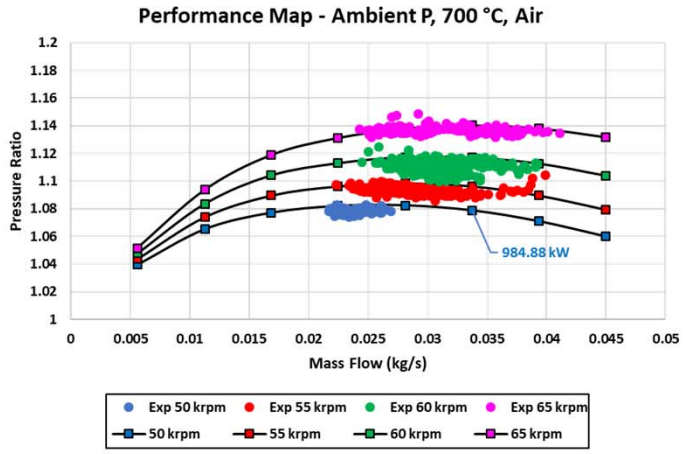
UHT ARCB Performance Map

MOHAWK INNOVATIVE TECHNOLOGY

Comparison of Experimental to Design Performance





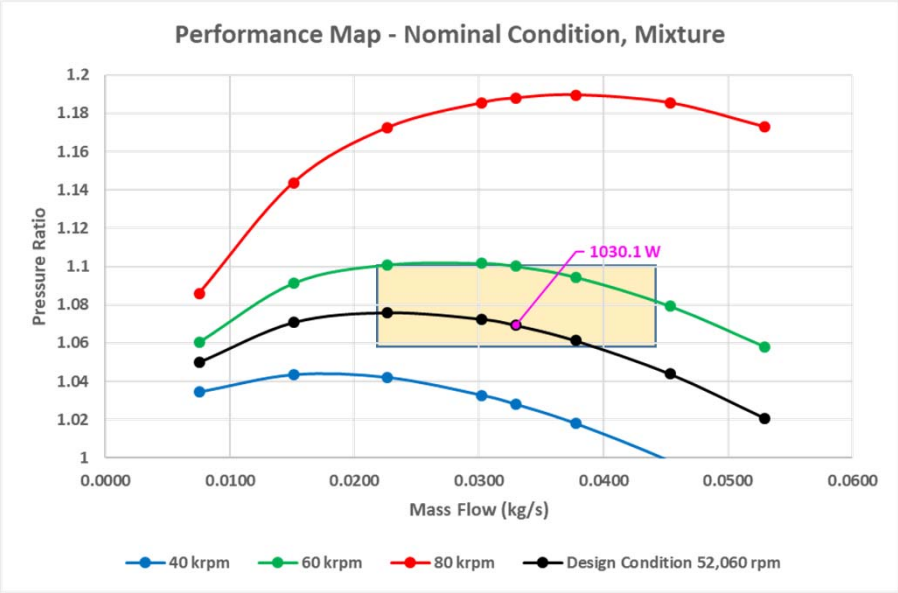


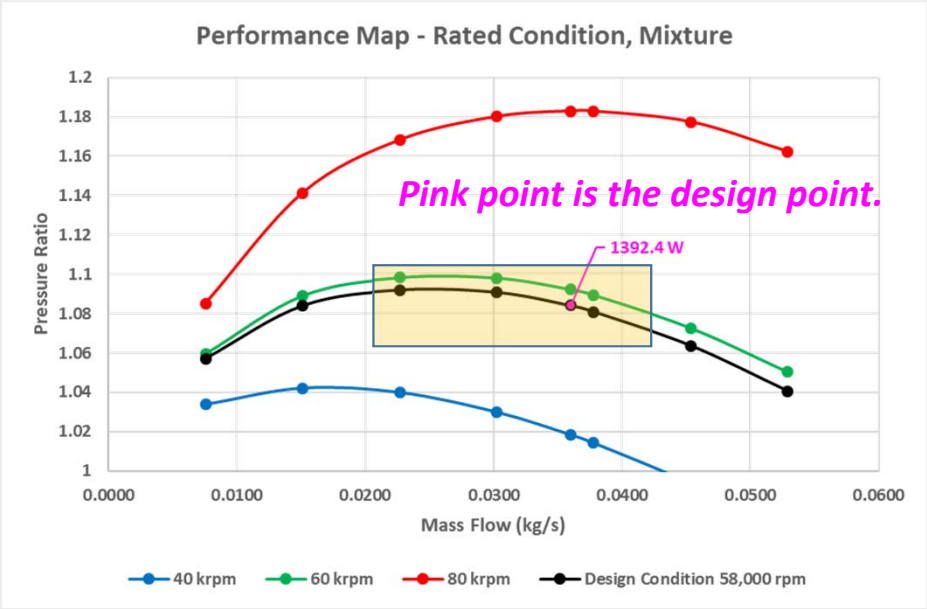
Agreement between theoretical performance and experimental data is best at conditions closest to the design condition.

UHT ARCB Performance Map

MOHAWK INNOVATIVE TECHNOLOGY

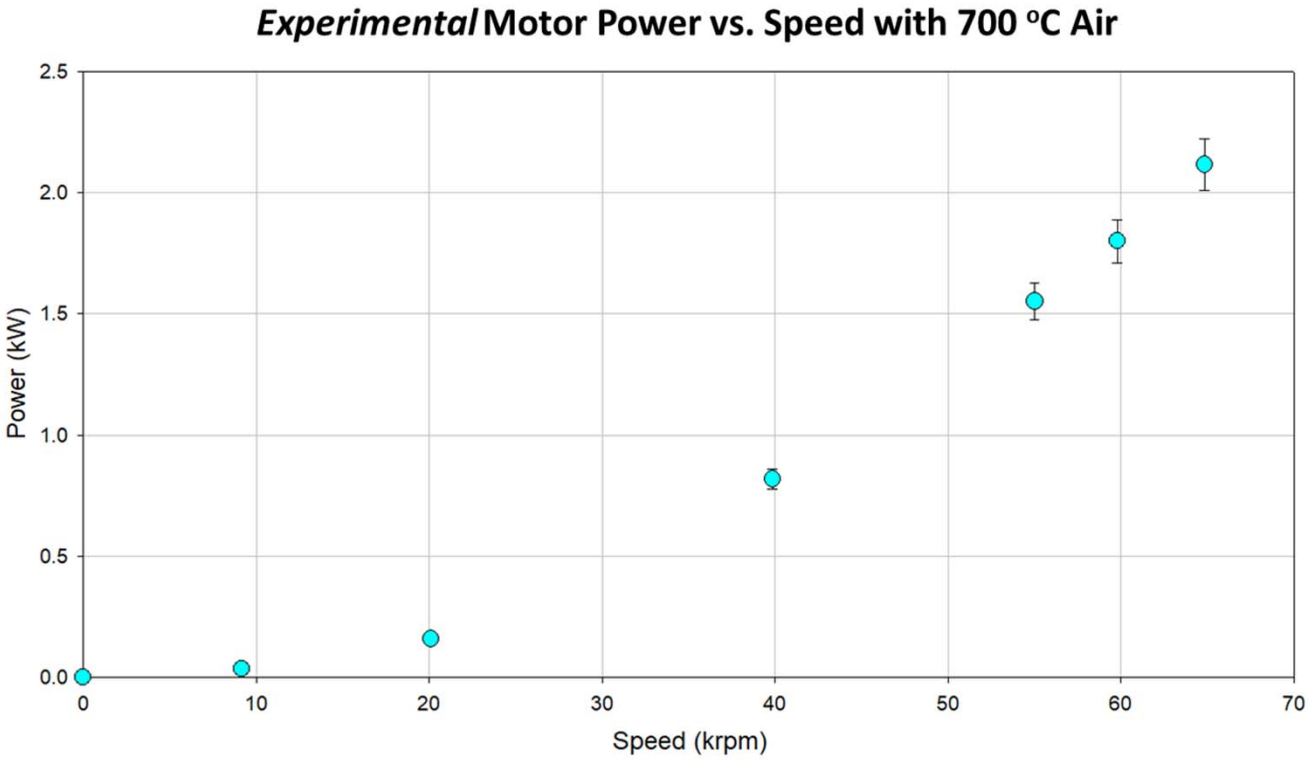
Design Performance in Anode Recycle Gas Mixture





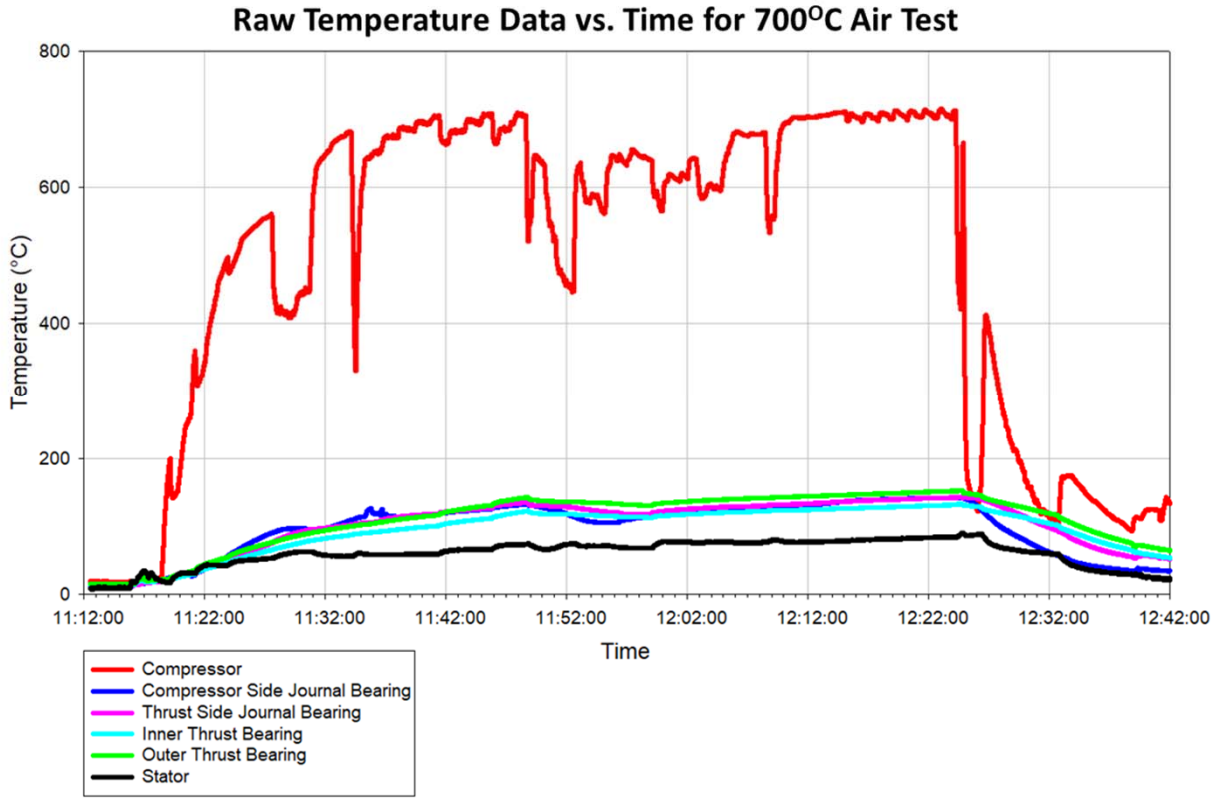
UHT ARCB Motor Power

- Results from testing at 700 °C inlet temperature condition ***in air***
- Motor power maxed at 2.4 kW for pressure ratio of 1.14 and flow of 40 g/sec, well above design specification.
- With anode recycle gas mixture, the projected power at rated condition will be under 1.4 kW.

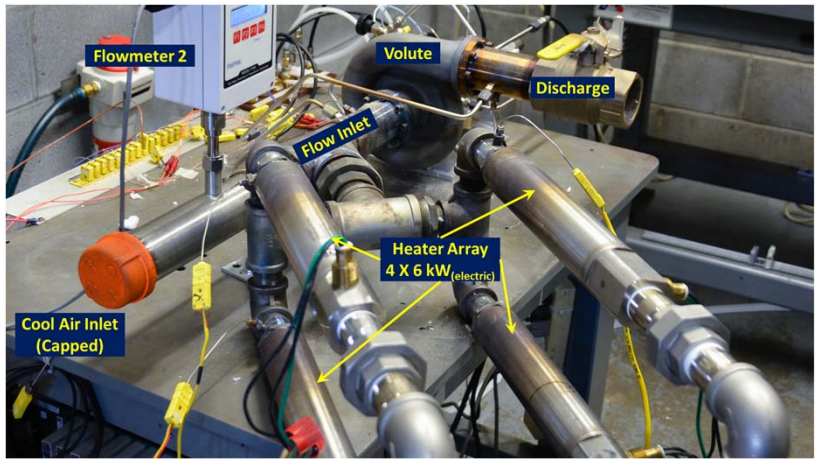


UHT ARCB Thermocouple Data

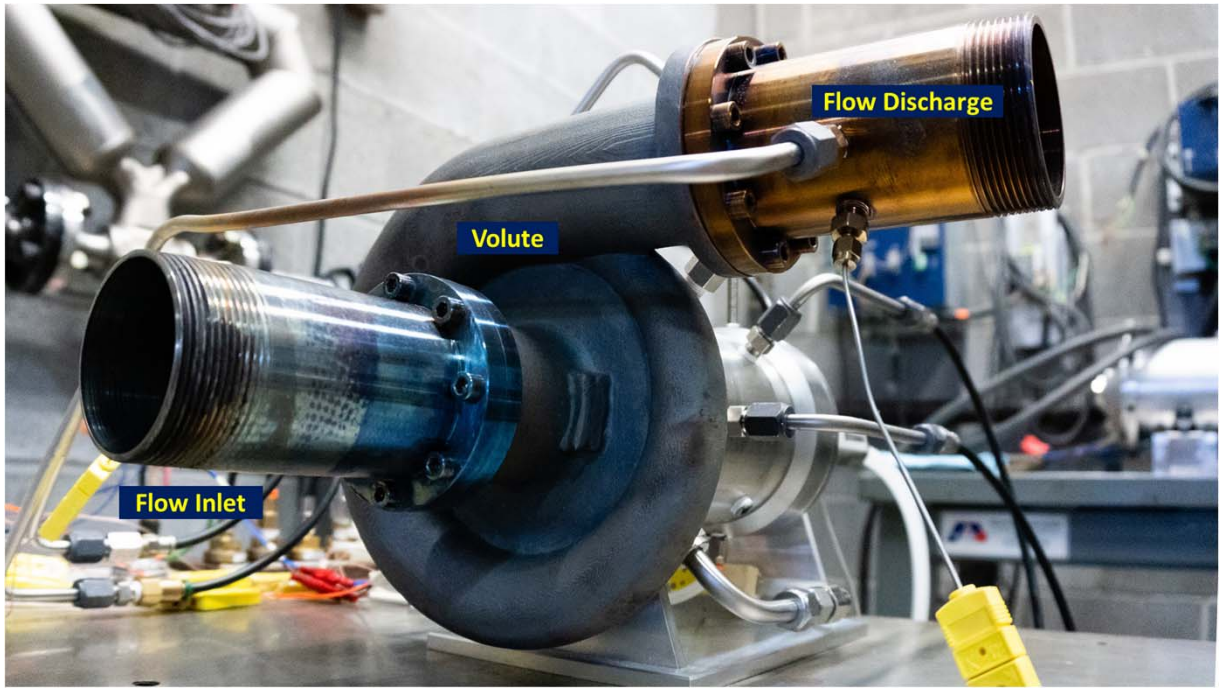
- Thermocouple raw data with time on the x-axis
- The red trace is the compressor inlet temperature
- The black trace is the stator temperature
- Other traces are journal bearing and thrust bearing temperatures



UHT ARCB Post Test Condition

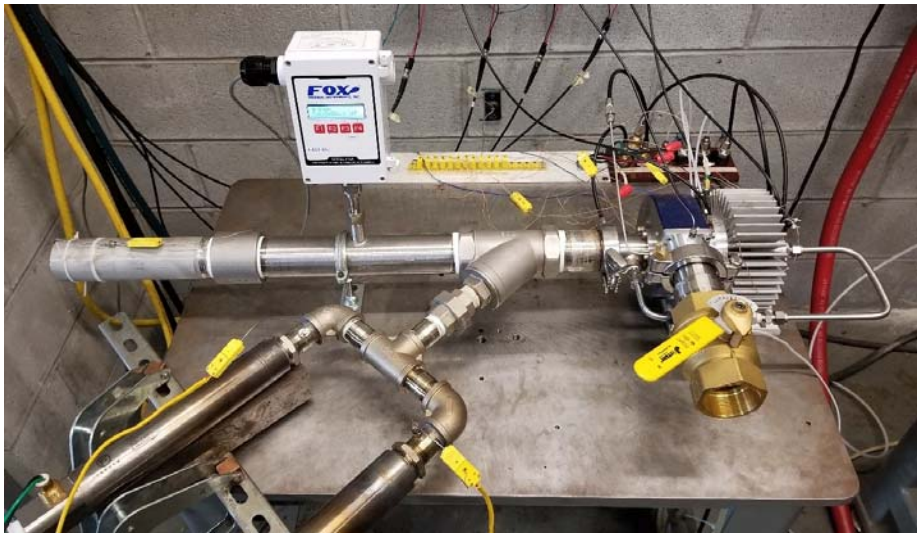


Unit is a bit discolored after testing, but fully operational!



HT ARCB—Where we left off last meeting…

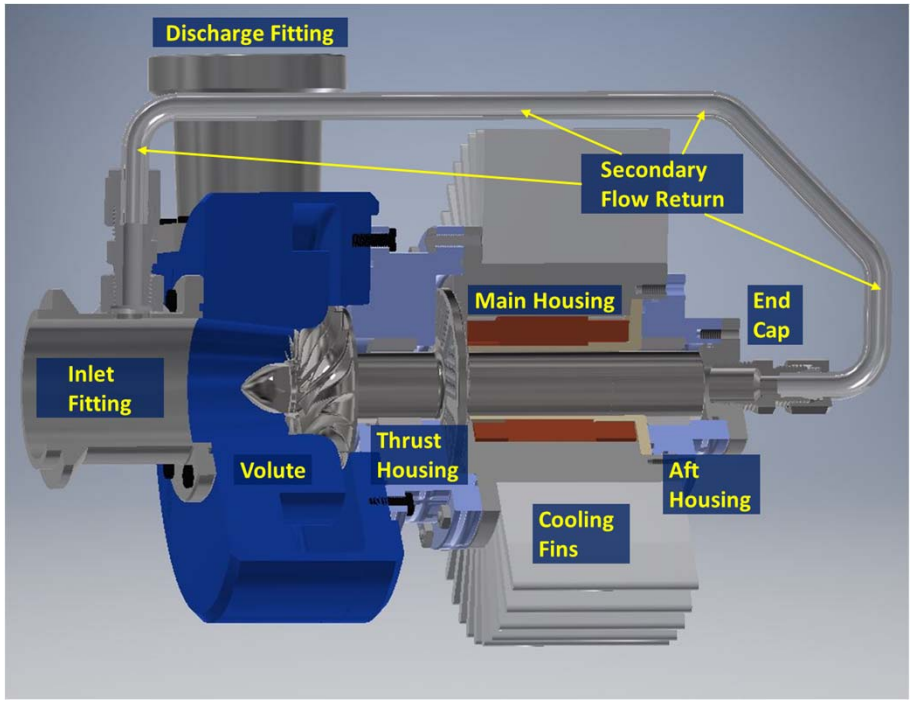
- ***Phase I***—Ended on Mar 31st 2018
  - Developed HT (up to 180°C) Anode Recycle Blower for 100 kWe SOFC
  - The prototype was completed and subjected to full performance tests
  - Prototype has achieved TRL 6
- ***Phase II***—Started on Apr 1st 2018
  - Integrate four units following design for manufacturability principles
  - Deliver two units for test on prototype 100 kWe SOFC demonstrator developed by FuelCell Energy, Inc. (FCE) under DOE Award DE-FE0026199
  - Perform accelerated life testing at MITI
  - ***Objective: Demonstrate TRL 7***



Phase II Objectives: Design for Manufacturability

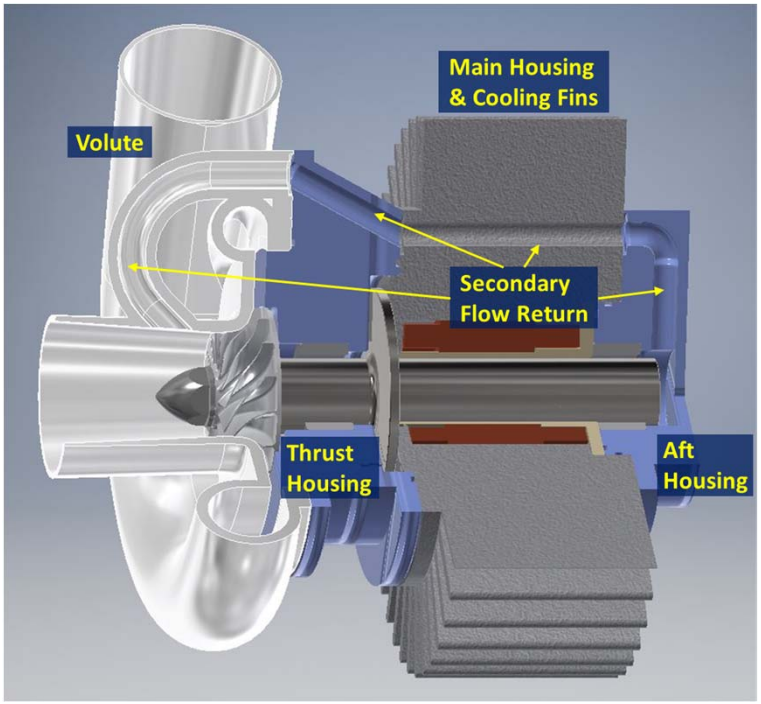
Test Prototype:

- **Many Parts and Fasteners**
- **Laborious Assembly**

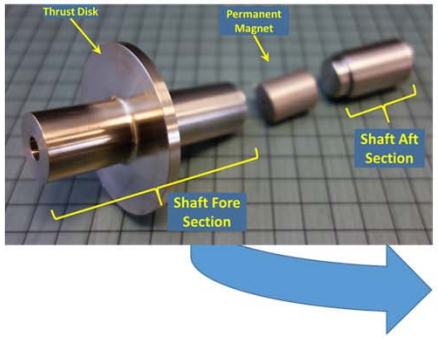


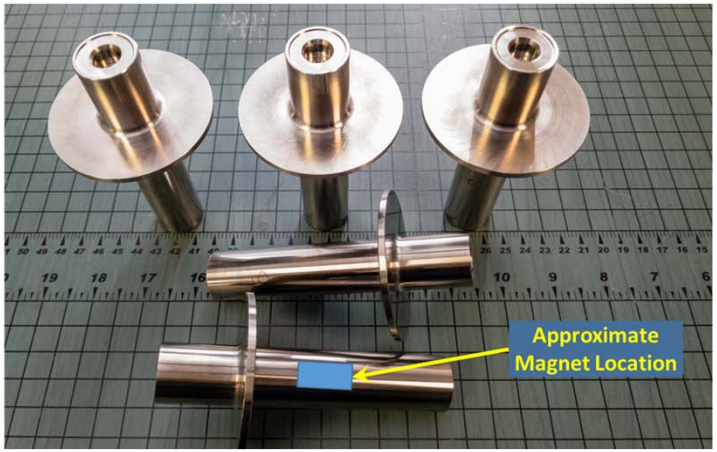
Production Unit:

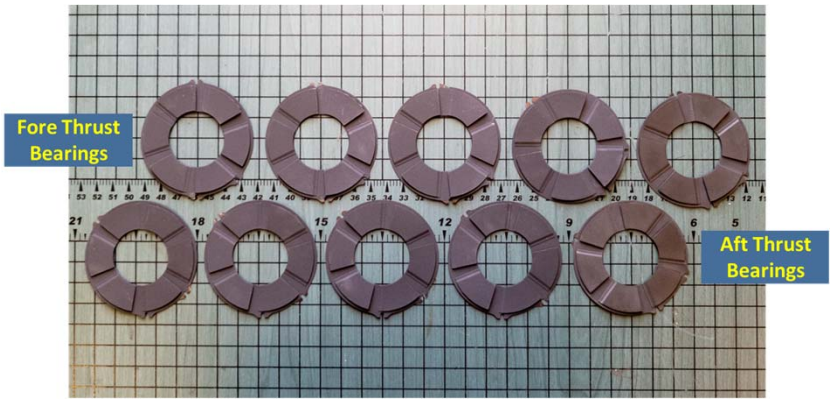
- **Castings & Integral Features ⇔ Reduced Part Count, Few Assembly Operations, Lower Cost**

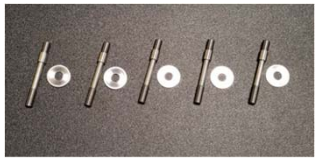


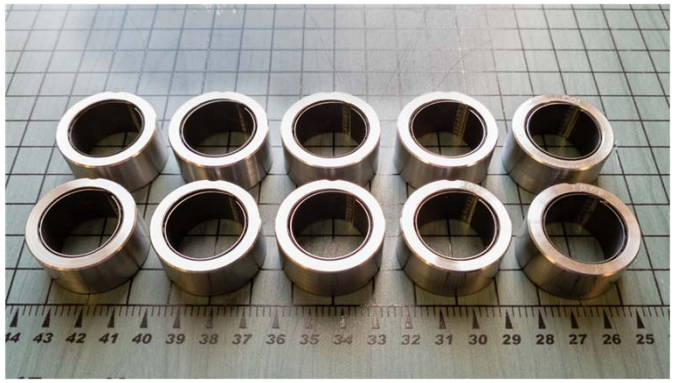
HT ARCB Hardware—Rotors and Bearings











HT ARCB Hardware—Housings