High-Temperature Anode Recycle Blower for Solid Oxide Fuel Cell

Department of Energy Award No.: DE-FE0027895

Prepared for the 19th Annual Solid Oxide Fuel Cell Project Review Meeting

By Mohawk Innovative Technology, Inc.

U.S. DEPARTMENT OF ENERGY

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Overall Project Objectives

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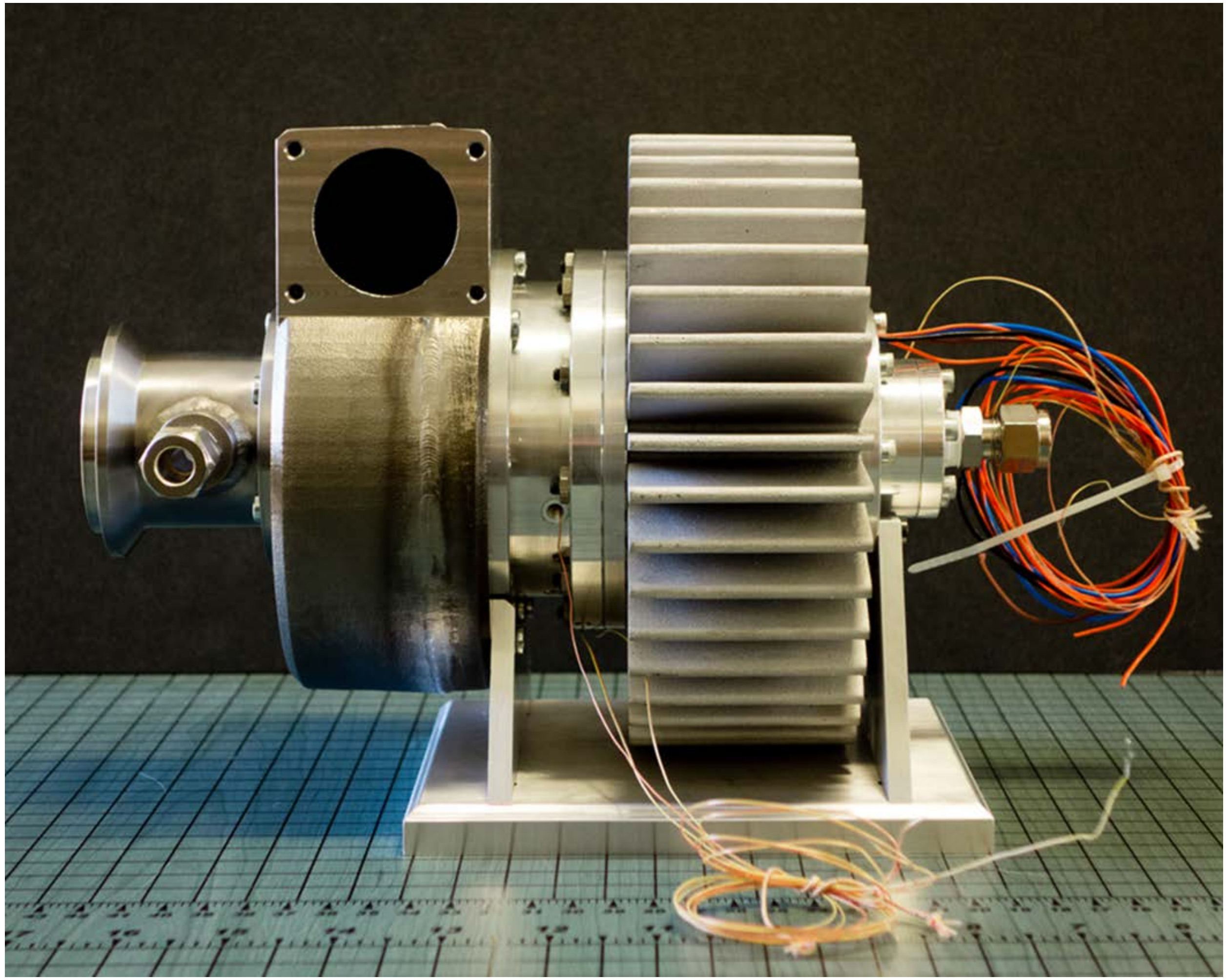
- To develop scalable Oil-Free High-Temperature Anode Recycle Blower (ARCB) technology for SOFC power plants
- Achieve TRL 7 by demonstrating performance and life through testing in a real SOFC power plant



Team Background

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- 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.

Hydrogen Blower	Fuel Cell Anode Recycle Blower	Fuel Cell Compressor	Water Aerator Blower	Industrial Compressor	Hydrogen Pipeline Compressor
1 kW	1.5 kW	12 kW	80 kW	135 kW	200 kW
360,000 rpm	80,000 rpm	120,000 rpm	60,000 rpm	77,000 rpm	60,000 rpm

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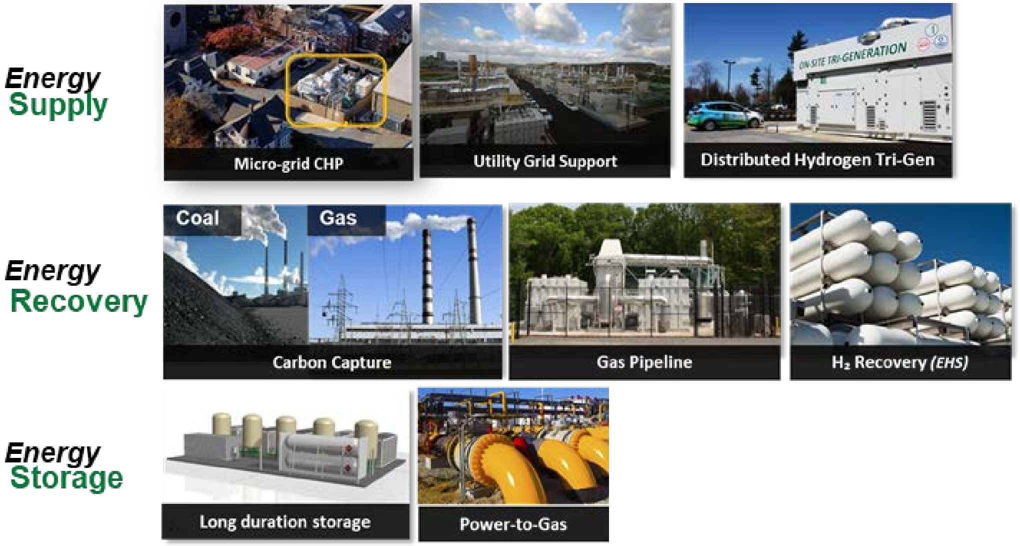
- Integrated fuel cell company that designs, manufactures, installs, operates, and services stationary fuel cell power plants. Develops technologies for energy supply, recovery and storage.



Team Background

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

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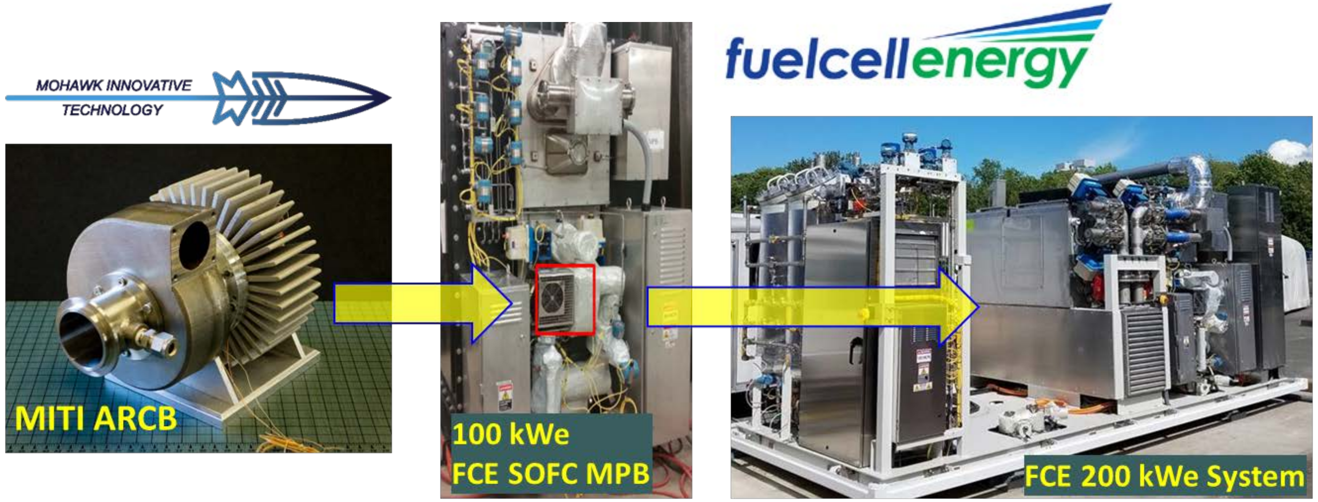
- Hossein Ghezel-Ayagh, PhD
  - FCE Project Manager
- Stephen Jolly
  - SOFC systems engineering
  - Operations manager
- Micah Casteel, PhD
  - Mechanical blower integration
- James Kim
  - SOFC system operations and data analysis

Project Structure

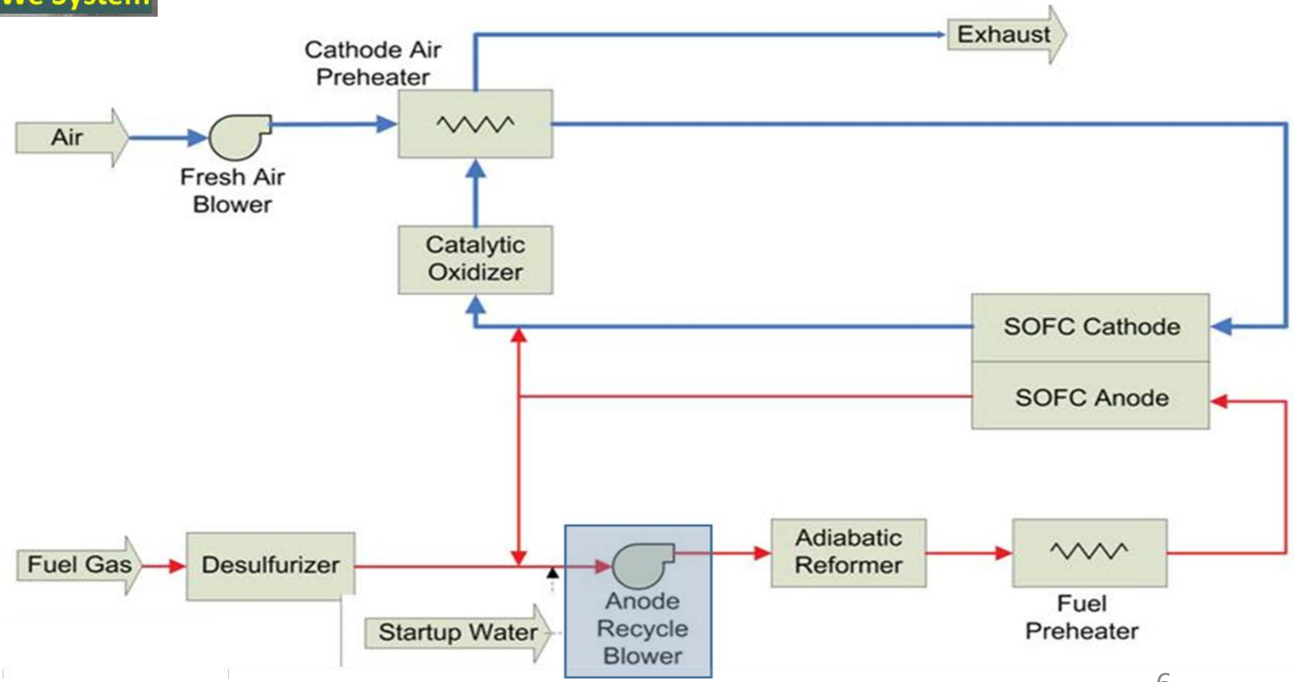
- ***Phase I***—Ended on Mar 31st 2018
  - Developed a 180°C Anode Recycle Blower for 100 kWe SOFC
  - The prototype is complete and has been fully tested
- ***Phase II***—Started on Apr 1st 2018
  - The goal is to integrate four units following design for manufacturability principles
  - Deliver two units for test on prototype 100 kWe SOFC demonstrator developed by FuelCell Energy, Inc. (FCE) under DOE Award DE-FE0026199

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



Definition of Requirements

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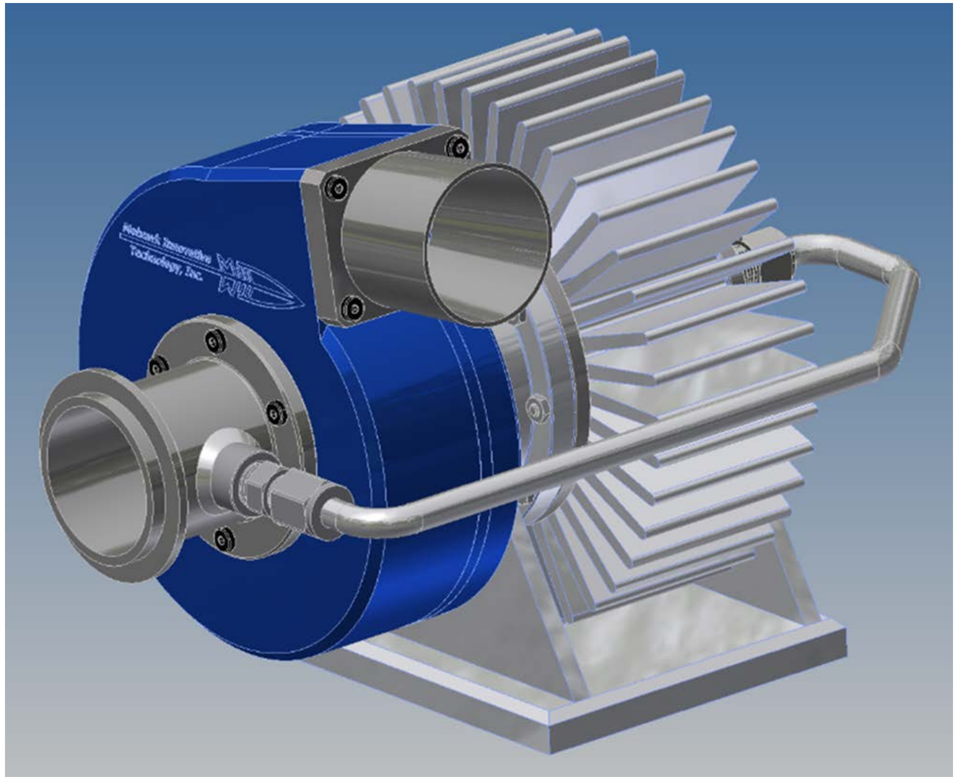
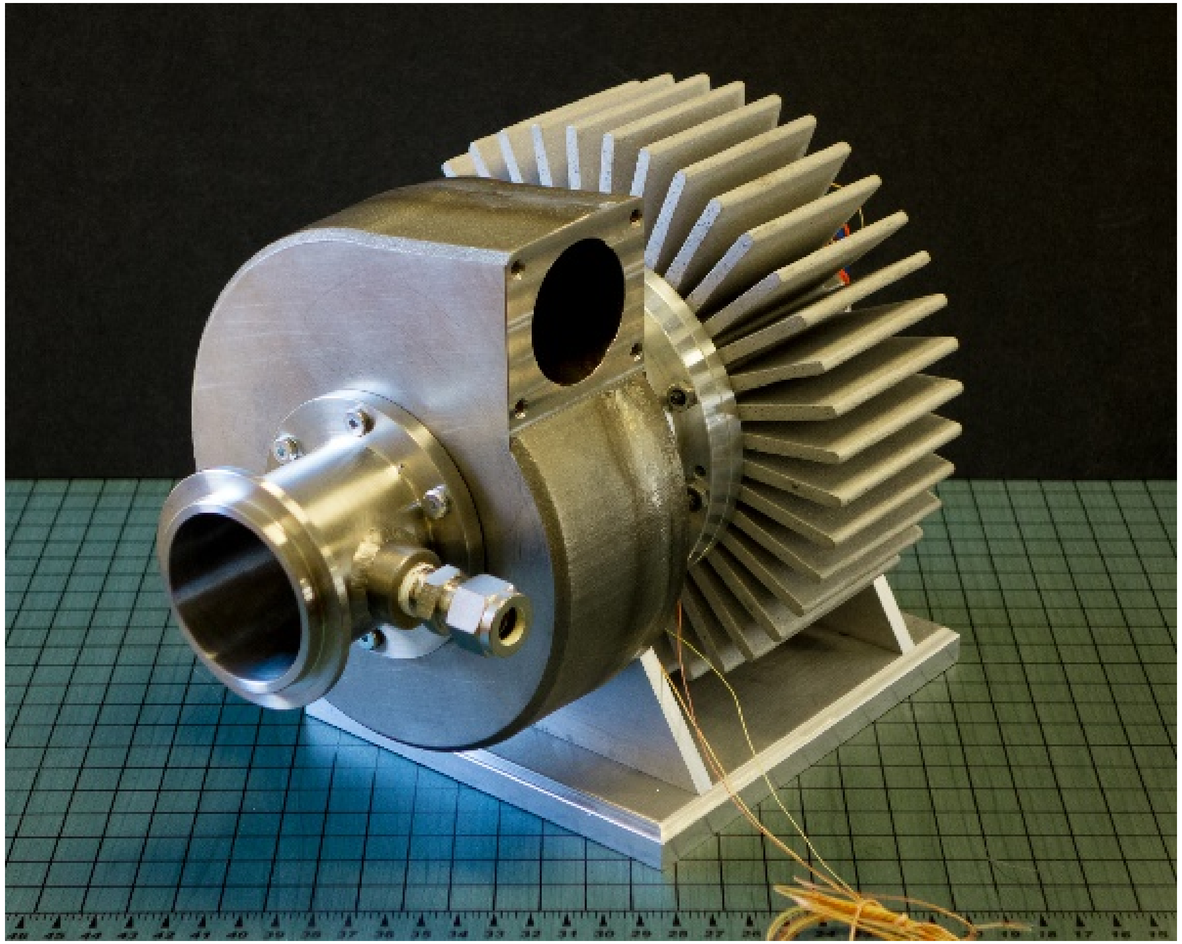
- Three main operating regimes specified by FCE:
  - Start-up transient
  - Nominal operation
  - Maximum rated
- These require a high turn-down ratio engine
  - Inlet temperature: Up to 180^{o}C
  - Flow rate: 0.02 to 0.04 kg/sec
  - Pressure increase: < 10 kPa
  - Gas composition: variable mix, primarily consisting of water vapor, CO_2, H_2, CH_4
- Magnet and stator element must be encapsulated



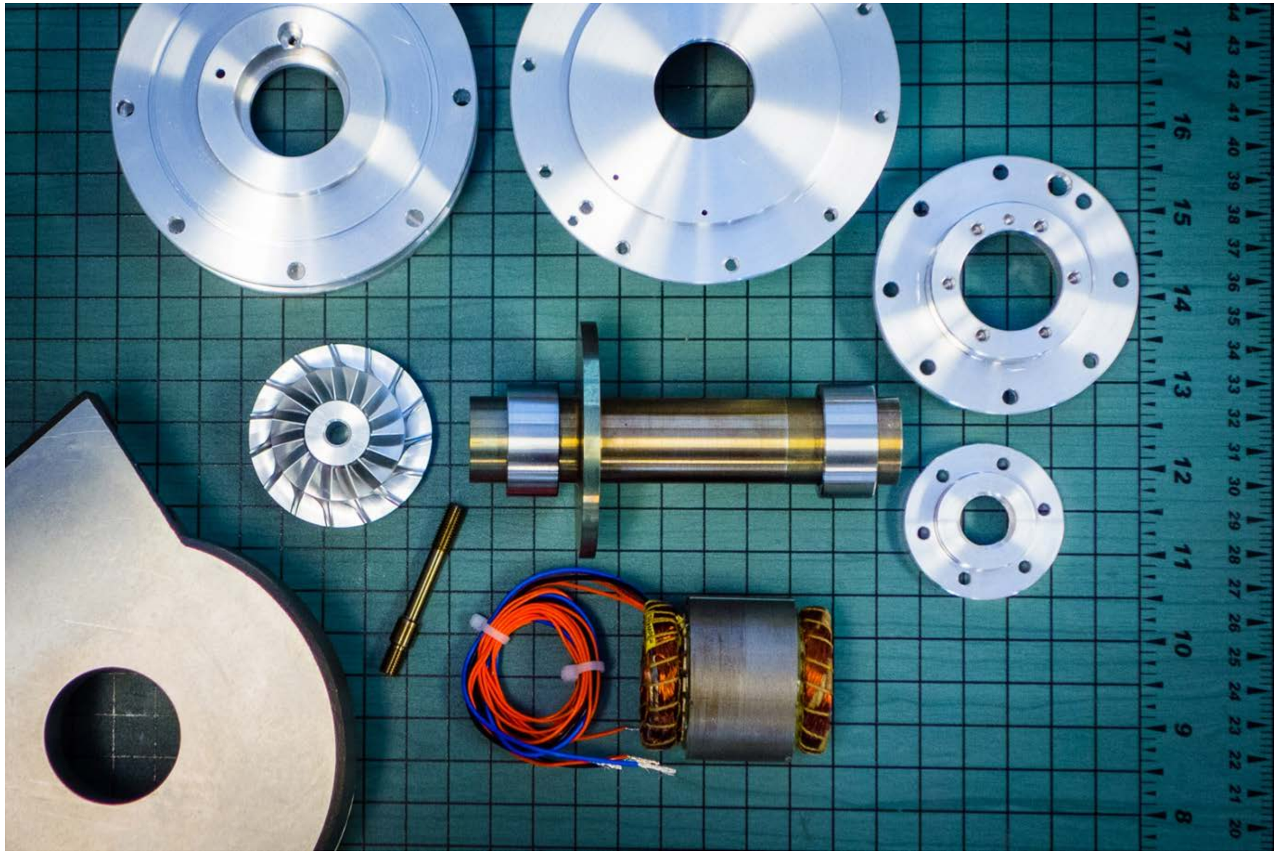
Other Design Considerations

- Net power input < 1.5kW
- Oil-free foil bearing design
  - No lubricant contamination
  - Low power loss bearings
- No external cooling
- Economical design
  - Low capital cost
  - Low to no maintenance cost
  - Low operating cost

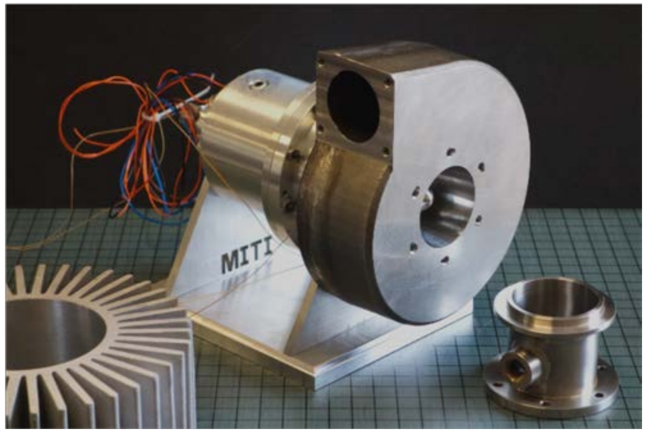


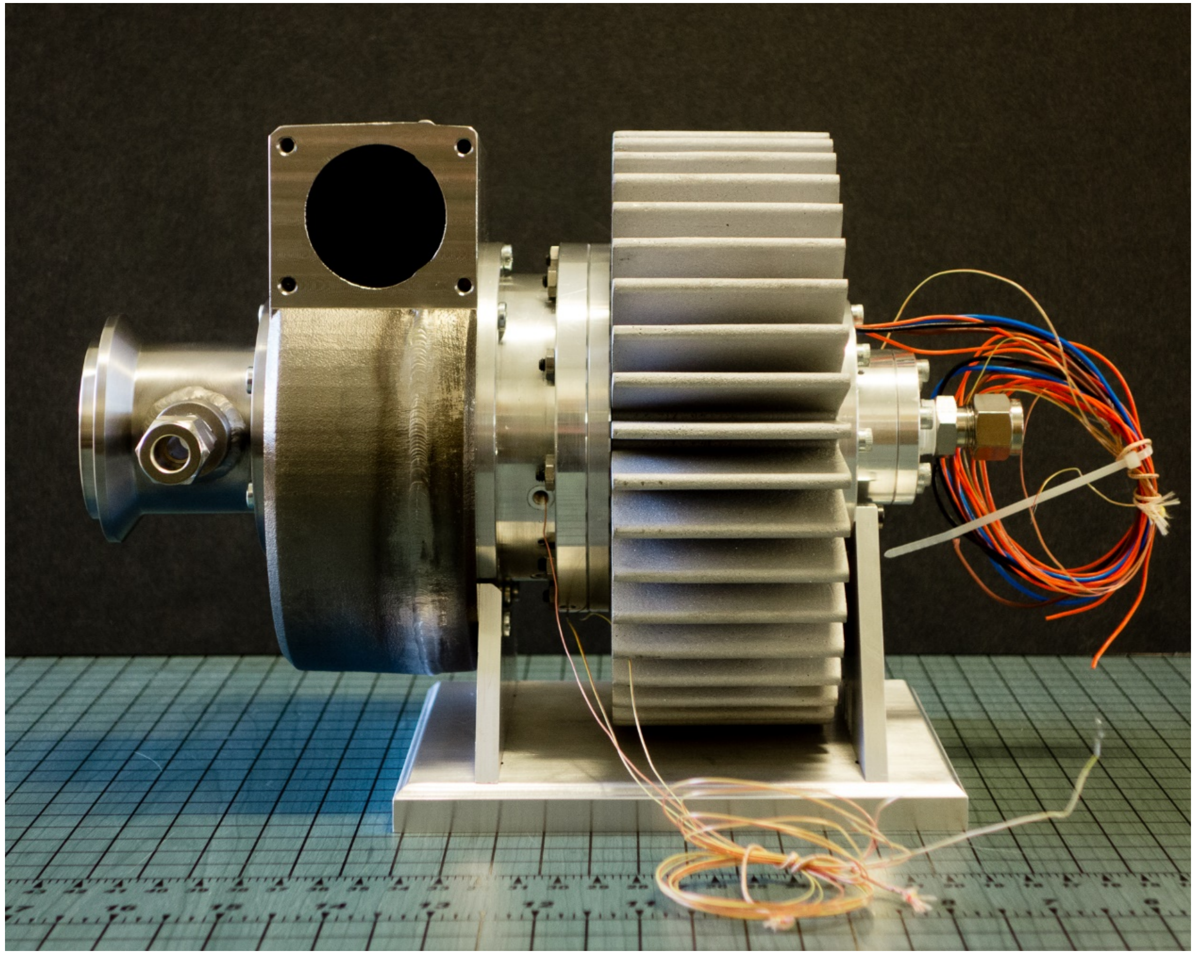
Where we left off last meeting…

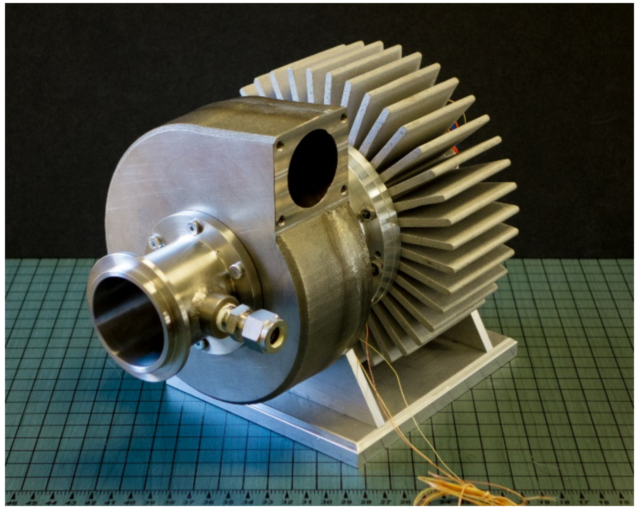
- Fabricate parts and assemble prototype blower
- Instrument prototype
  - Temperature
  - Pressure
  - Flow
  - Power
  - Monitor rotor motions
- Preliminary tests
  - Verify instrumentation operation
  - Verify motor/drive operation
  - Confirm rotor smooth operation



Full Assembly







Blower Testing

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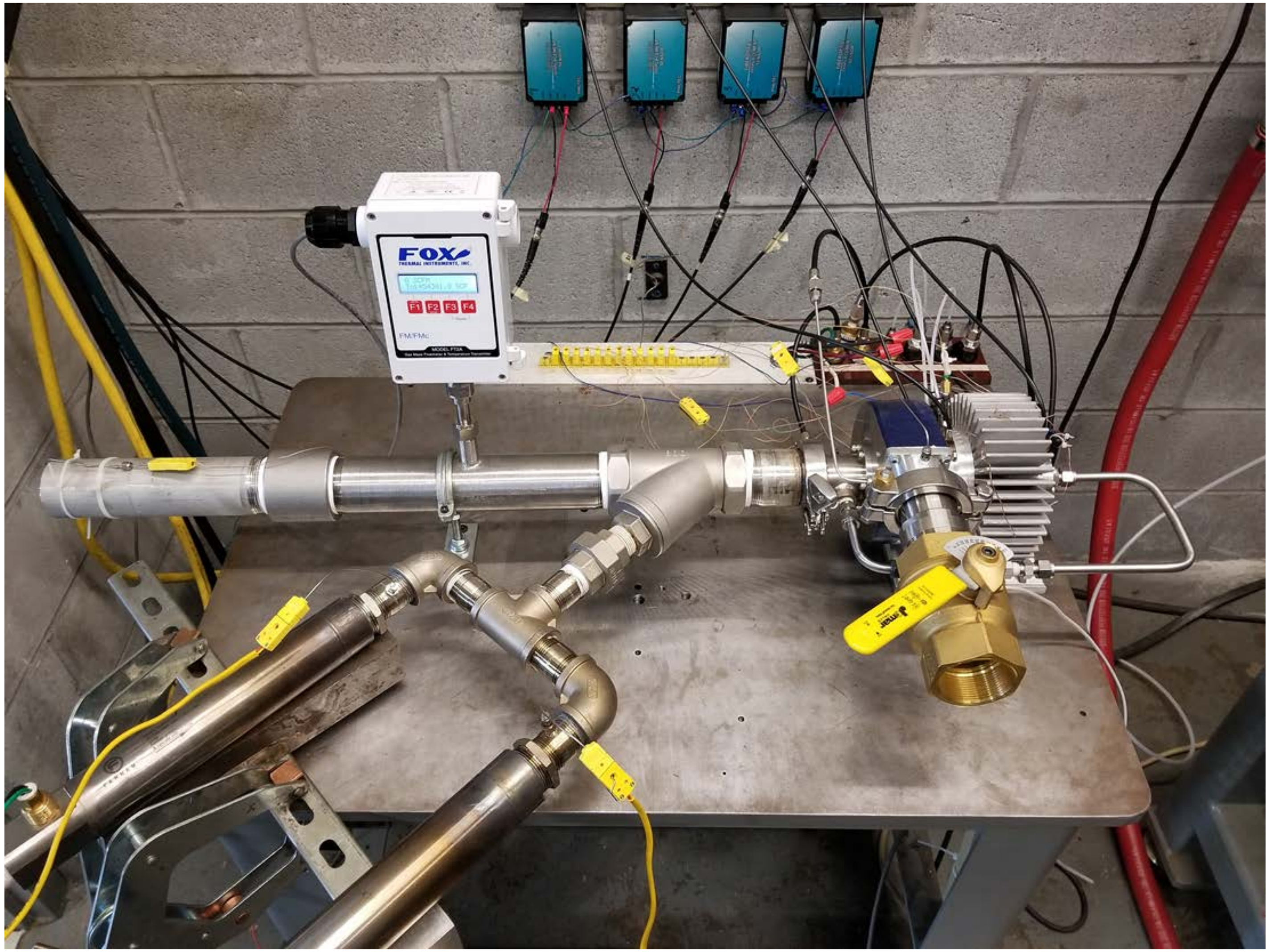
- Demonstrate full speed operation
  - Rotordynamic stability
  - Thermal stability
- Obtain performance maps
  - Pressure vs. flow at multiple speeds
  - Multiple inlet temperatures

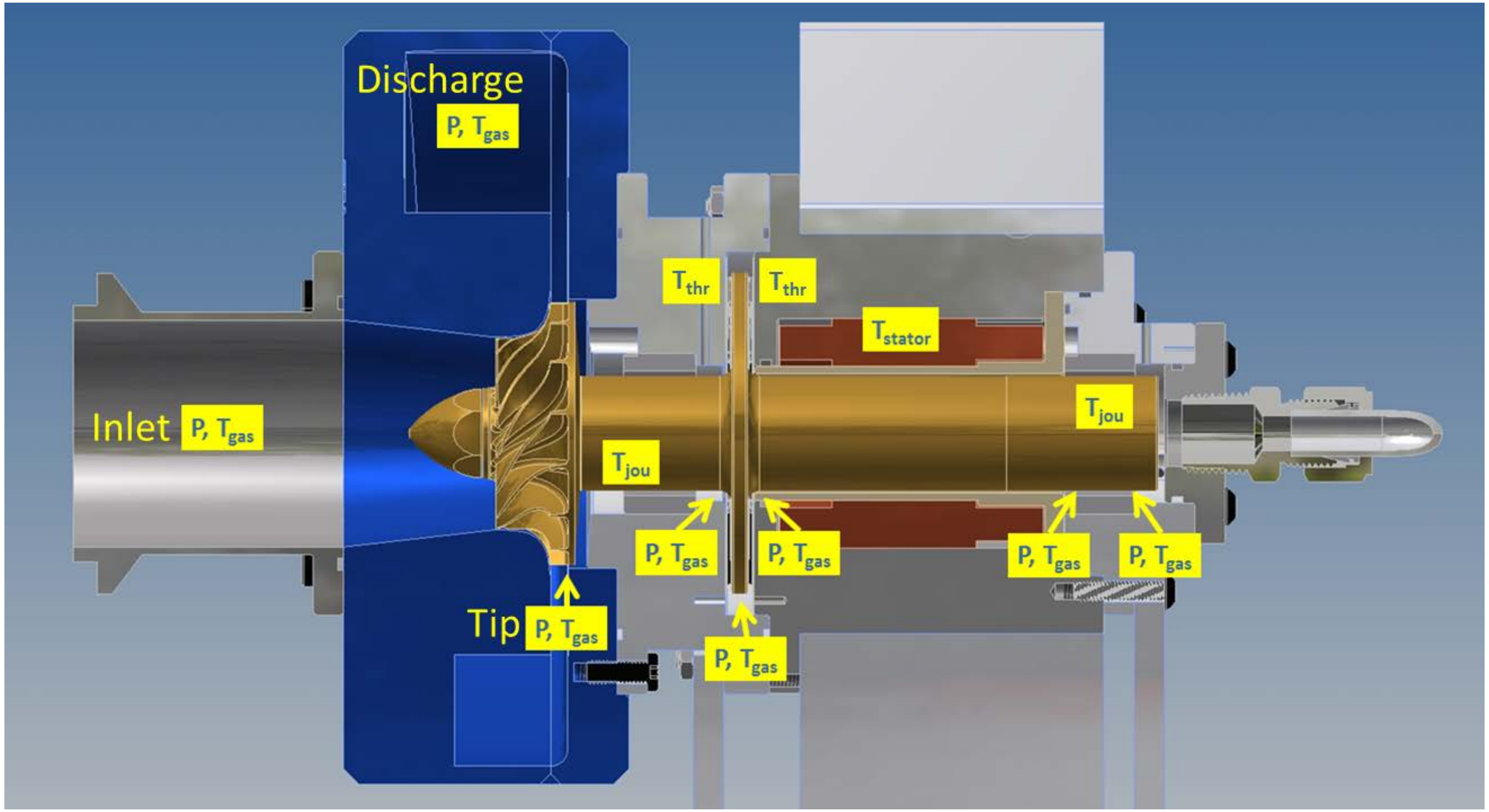


Instrumentation Schematic

LabView-based continuous monitoring

Transducer list:

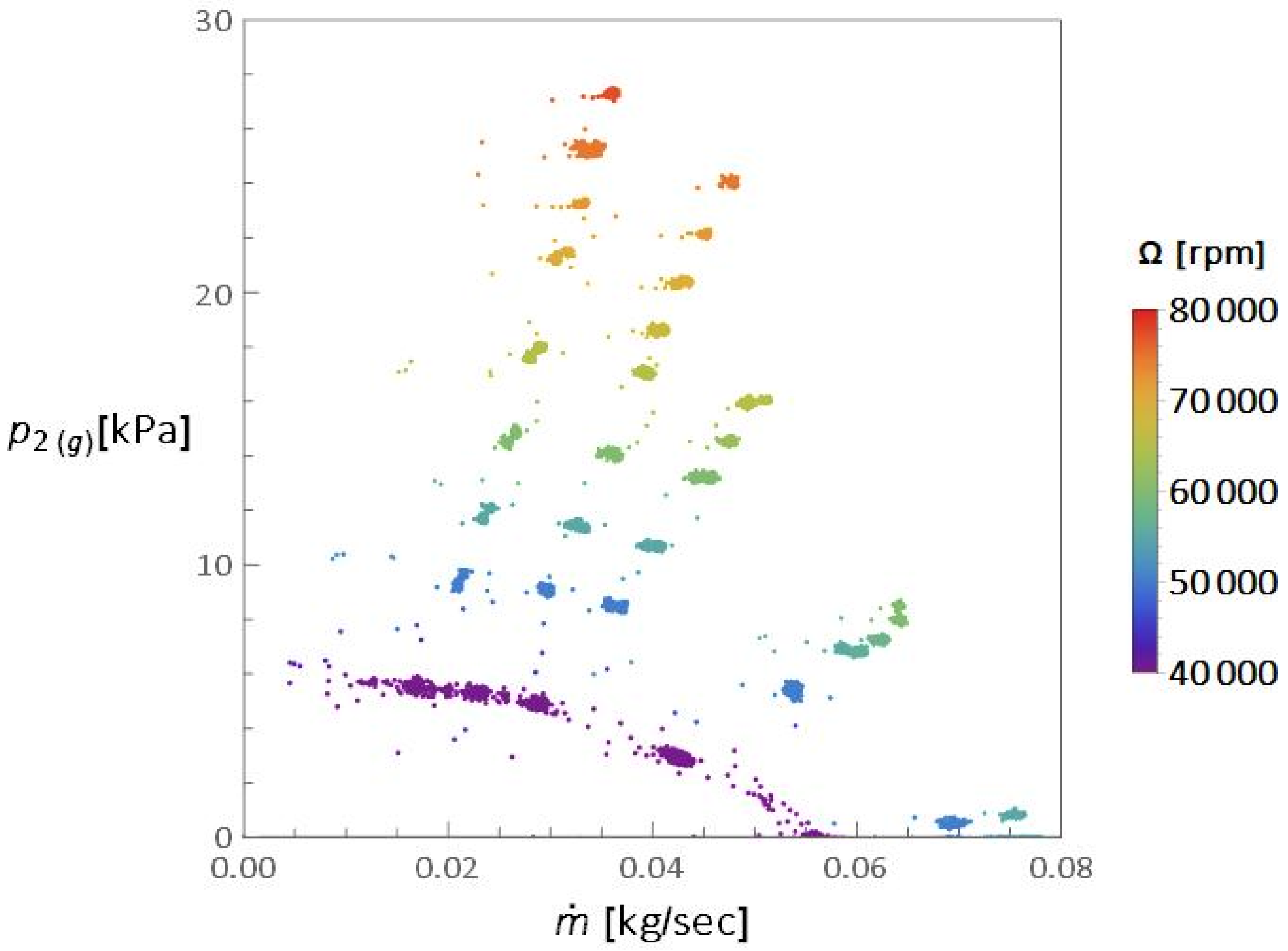
- 8 pressure transducers
- 13 thermocouples
- 4 or 5 shaft displacement probes



Performance Maps

- Pressure and flow mapping with multiple air inlet temperatures
  - 25ºC, 100ºC, 150ºC, 180ºC, 200ºC
- Air (molar mass 29 kg/kmol) imposes greater demands than the anode recycle gas mixture (max molar mass 22.9 kg/kmol).
- Speed was varied from 40000 to 80000 rpm.

Sample performance map at ambient temperature



Non-Dimensional Performance Map

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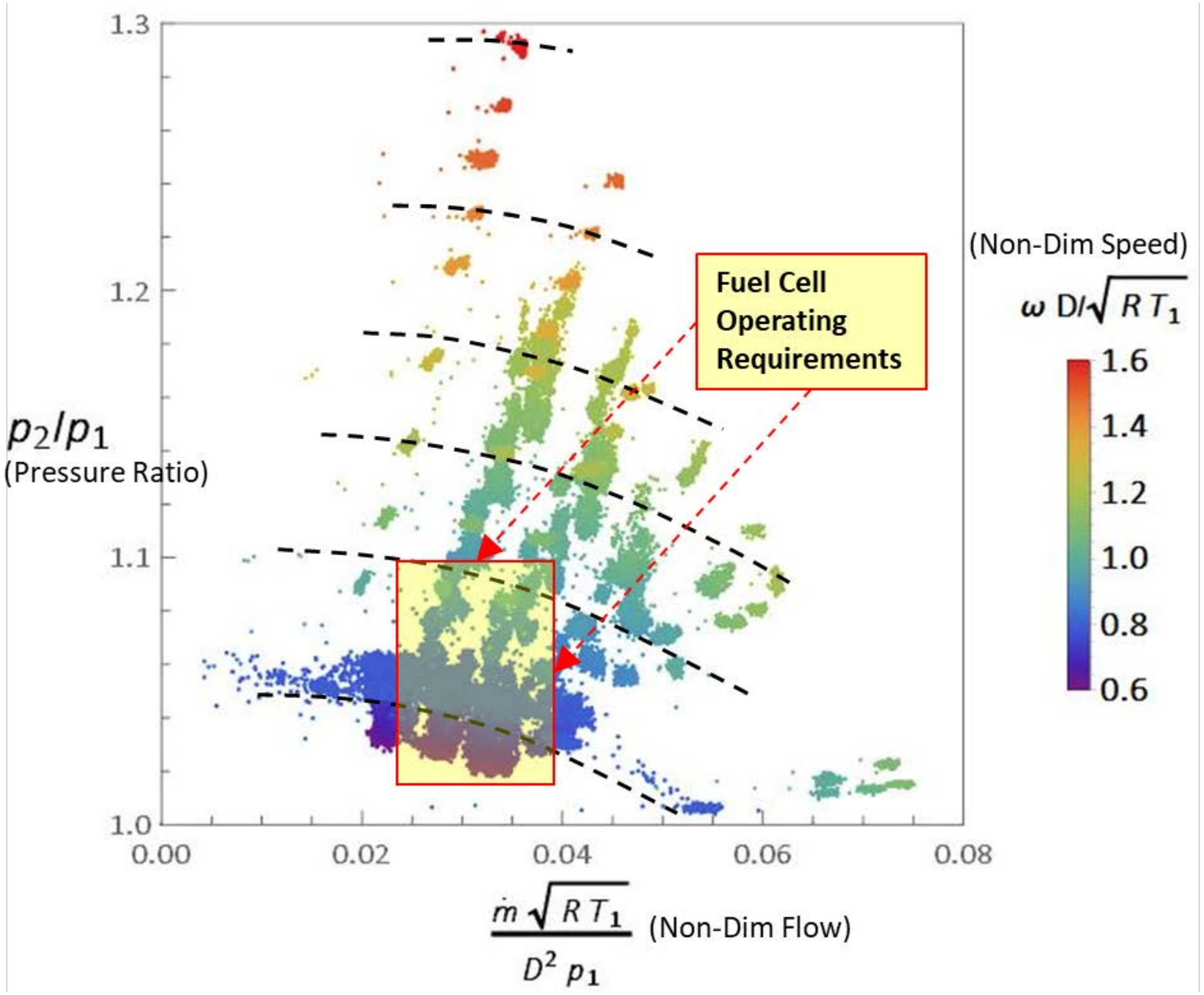
- Non-dimensional analysis used to reduce the experimental data
- Blower performance exceeds specified operating requirements



Mega-Watt Design Scalability

- Design scalability for higher capacity SOFC applications assessed
  - MITI design capability has been demonstrated from 1kW to multi-megawatt systems
  - MITI has demonstrated oil-free blowers from 1 to 200kW
  - Scalability to high-temperature applications: 650°C (1200°F)

Recently-Developed 80 kW Oil-Free Blower by MiTi

100x Scalability Assessment

100 kW *Present* Design

- Type = Centrifugal
- Diameter = 55mm
- Operating speed range
  - 40krpm < N < 80krpm
  - $\dot{m} \approx$ 35g/s
  - CDP ≈ 100kPa
  - Power < 1.5kW
- Efficiency > 85%
- Material selection
  - Aluminum 2618

10 MW Scaled Design

- Type = Centrifugal
- Diameter = 125mm
- Operating speed range
  - N ≈ 50krpm
  - $\dot{m} \approx$ 35g/s
  - CDP ≈ 126kPa
  - Power ≈ 50kW
- Efficiency > 87%
- Material selection
  - Stainless Steel

Technology Readiness Level (TRL)

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- TRL Assessment
  - TRL 6 – Prototype validated in a relevant environment
  - TRL 7 – System prototype validated in an operational system
- Prototype has achieved TRL 6
- Technology will achieve TRL 7 at end of Phase II

Phase II Objectives

- Design Improvements
  - Leverage Phase I prototype design
  - Introduce improvements identified during Phase I
  - Fully incorporate design for manufacturability and assembly methodology to redesigned units
    - Reduce part count and part cost
    - Make provisions for ease and automation or assembly
    - Goal is to facilitate eventual volume production and commercialization
- TRL 7 testing
  - Integrate multiple anode recycle blowers
    - 1 for accelerated life (at MITI)
    - 2 for installation at 200 kWe SOFC (at FCE)
    - 1 backup unit
  - Installation and parametric testing at FCE’s 200 kWe SOFC
    - Approximately 1500hr testing

Commercialization Considerations

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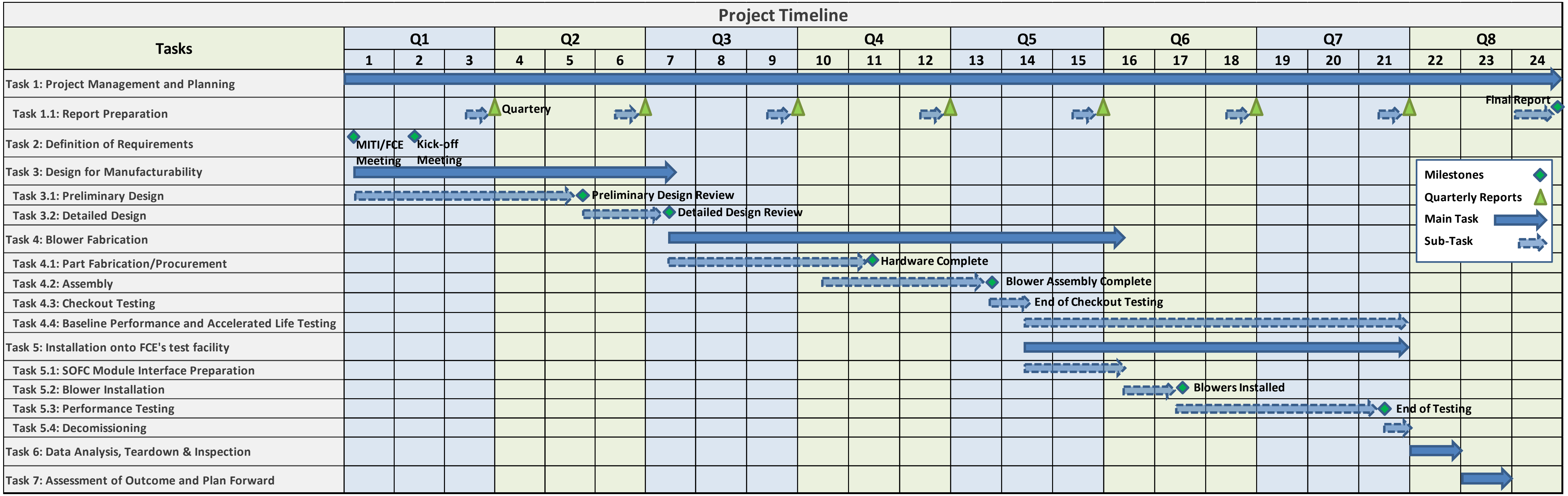
- Estimated cost ***after development*** for first 10 units
  - 1.5 kW: $10k - $15k / unit
  - 50 kW: $40k - $60k / unit
- Estimated cost after development for 100 units
  - 1.5 kW: $6k / unit
  - 50 kW: ≈ $20K / unit

Timeline


Project Timeline
Tasks
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
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Task 1: Project Management and Planning
Task 1.1: Report Preparation
Quartery
Final Report
Task 2: Definition of Requirements
MITI/FCE Meeting
Kick-off Meeting
Task 3: Design for Manufacturability
Task 3.1: Preliminary Design
Preliminary Design Review
Task 3.2: Detailed Design
Detailed Design Review
Task 4: Blower Fabrication
Task 4.1: Part Fabrication/Procurement
Hardware Complete
Task 4.2: Assembly
Blower Assembly Complete
Task 4.3: Checkout Testing
End of Checkout Testing
Task 4.4: Baseline Performance and Accelerated Life Testing
Task 5: Installation onto FCE's test facility
Task 5.1: SOFC Module Interface Preparation
Task 5.2: Blower Installation
Blowers Installed
Task 5.3: Performance Testing
End of Testing
Task 5.4: Decomissioning
Task 6: Data Analysis, Teardown & Inspection
Task 7: Assessment of Outcome and Plan Forward
Milestones
Quarterly Reports
Main Task
Sub-Task

Questions and Discussion

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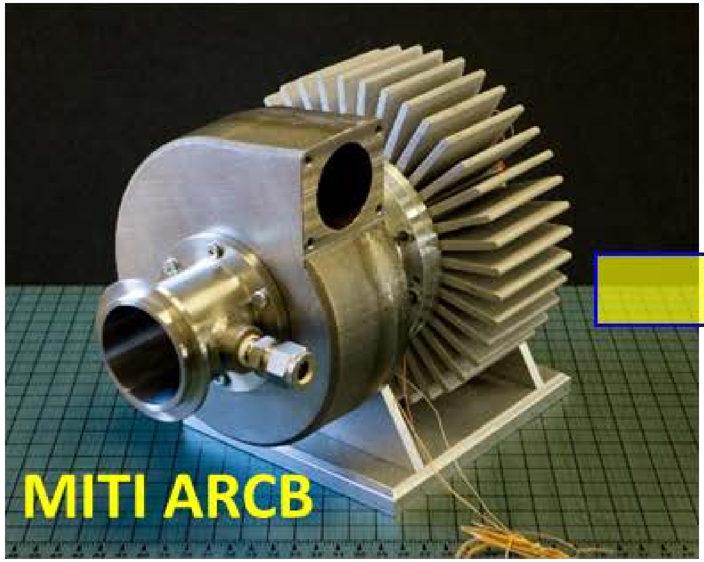

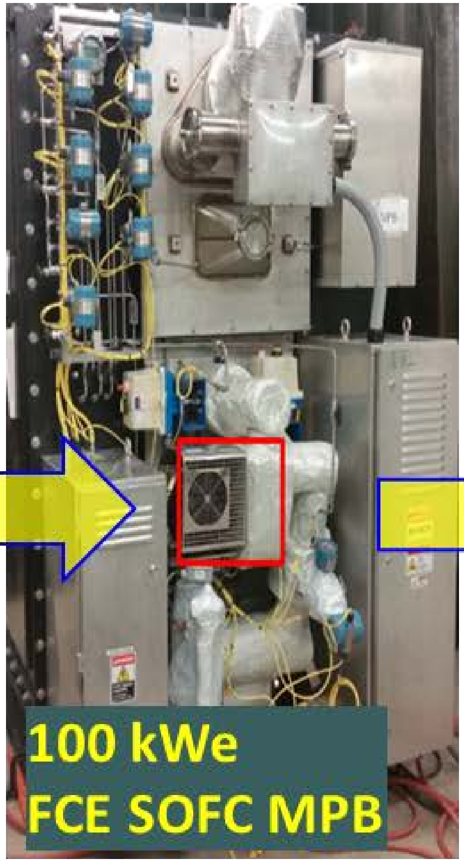

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Thank you for your attention!

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