High Temperature Anode Recycle Blowers for Solid Oxide Fuel Cell

DOE Award No.: DE-FE0027895

21st Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting

Mohawk Innovative Technology, Inc.

U.S. DEPARTMENT OF ENERGY

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Overall Program Objectives

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

Team

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- Project Manager

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- Principal Investigator

Jose Luis Cordova, PhD
- Program Manager
- Aero-Thermal Analysis

Leonard Darcy
- Design Engineer
- Testing

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Hossein Ghezel-Ayagh, PhD
- Director SECA Program
- FCE Project Manager

Stephen Jolly
- SOFC systems engineering
- Operations manager

Andrew Ethier
- Process Engineer

Team Background

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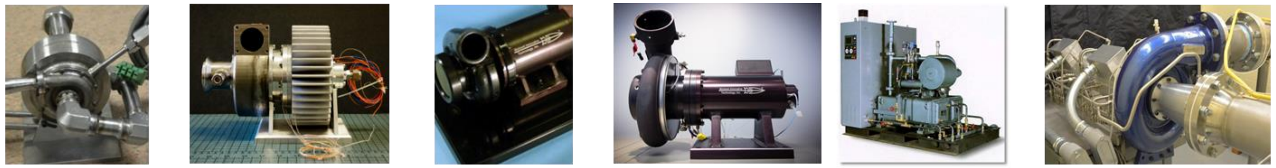
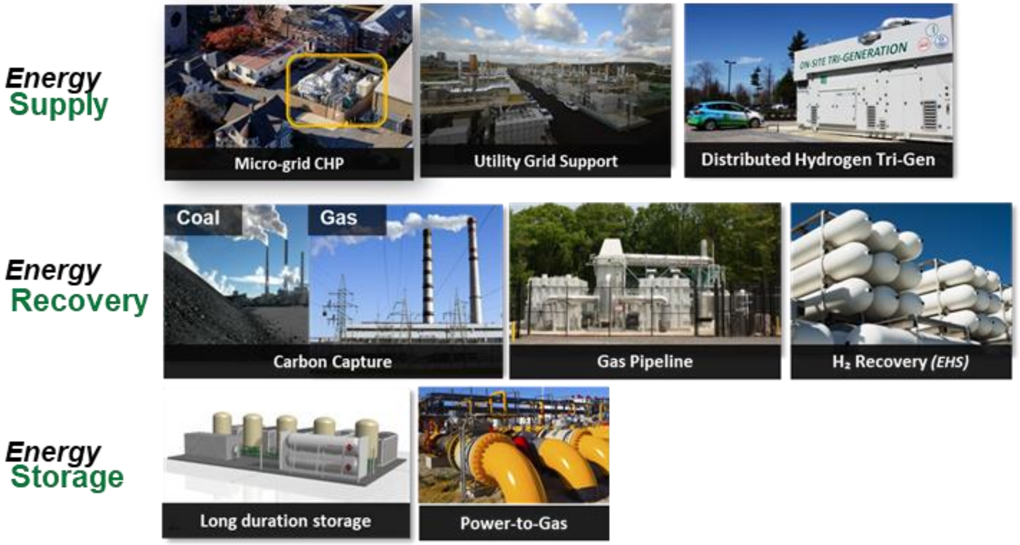
- Specializes in ultra-high speed, oil-free turbomachinery for power generation, waste heat recovery, refrigeration and energy storage, etc. Develops blowers, compressors, gas turbine engines, turbochargers, etc.

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



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	80-100 kW	135 kW	200 kW
360,000 rpm	80,000 rpm	120,000 rpm	60,000 rpm	77,000 rpm	60,000 rpm
H2, H2+H20	CH4, CO, CO2, etc. to 700°C	Air	Air	Air	H2



MITI’s Anode Recycle Blowers for SOFCs

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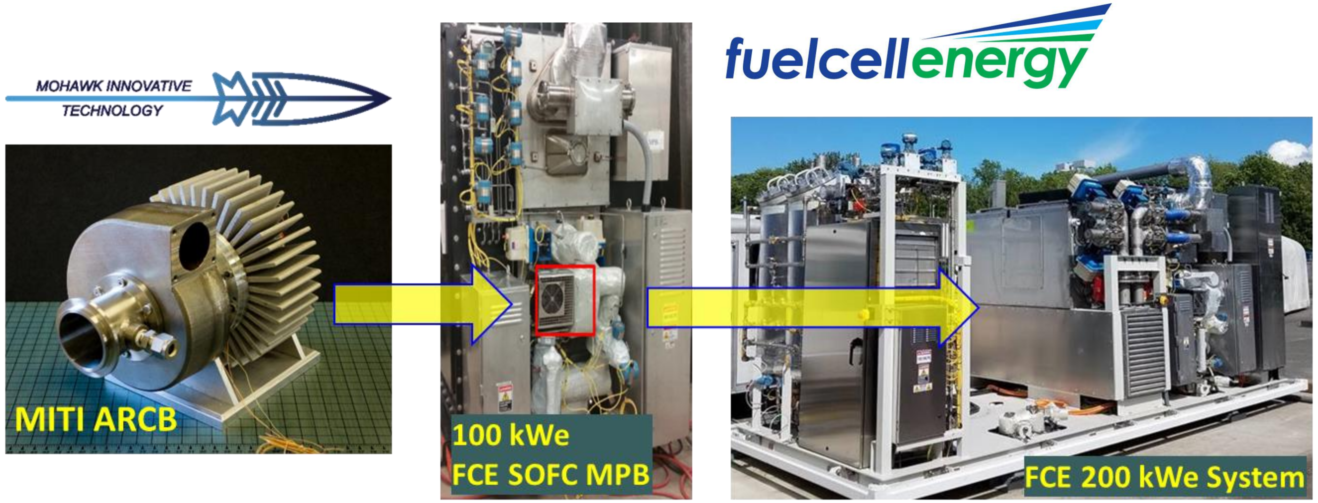
- **High Temperature (HT) Anode Recycle Blower for Solid Oxide Fuel Cell—Phase II**
  - Award No.: FE0027895
  - Performance Period: 10/01/2016 - 03/31/2020
  - Total Phase I & II Budget:
    - DOE: $2,098,408
    - MITI Cost Share: $ 569,443

Phase II Deliverable Unit

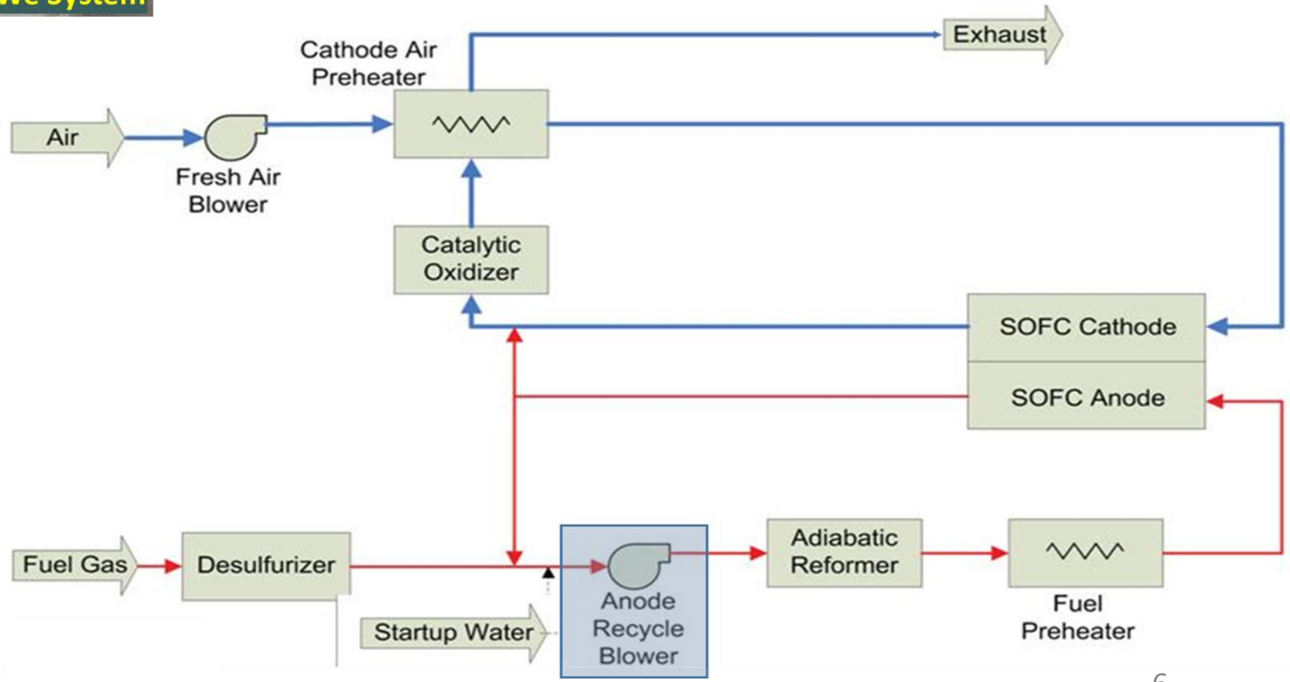
Phase I Prototype and Testing

How it all fits together

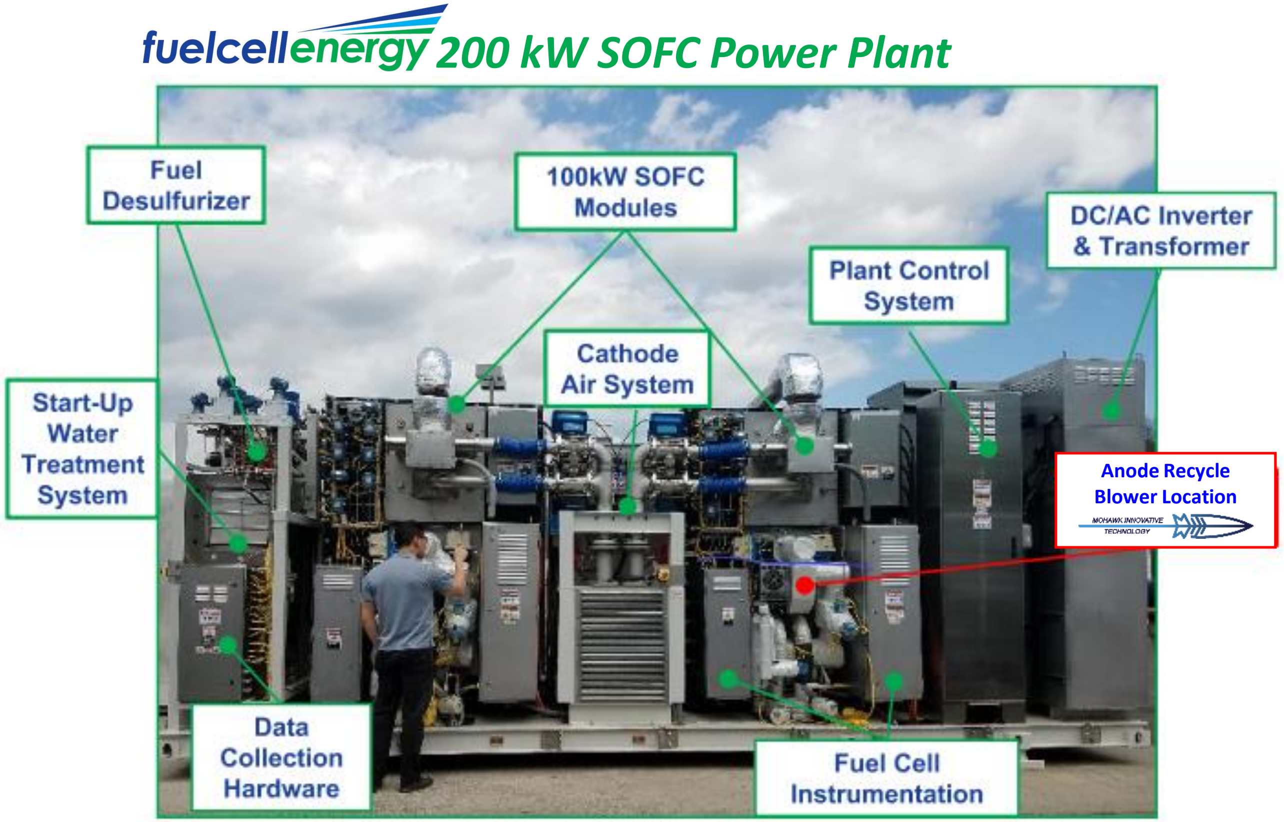


- Typical SOFC stacks operate with fuel utilization in the range of 70–85%.
- Recycling anode exhaust gases improves the stack efficiency.

- 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



Test Site: FuelCell Energy 200 kW SOFC Plant



Slide courtesy of FuelCell Energy, Inc.

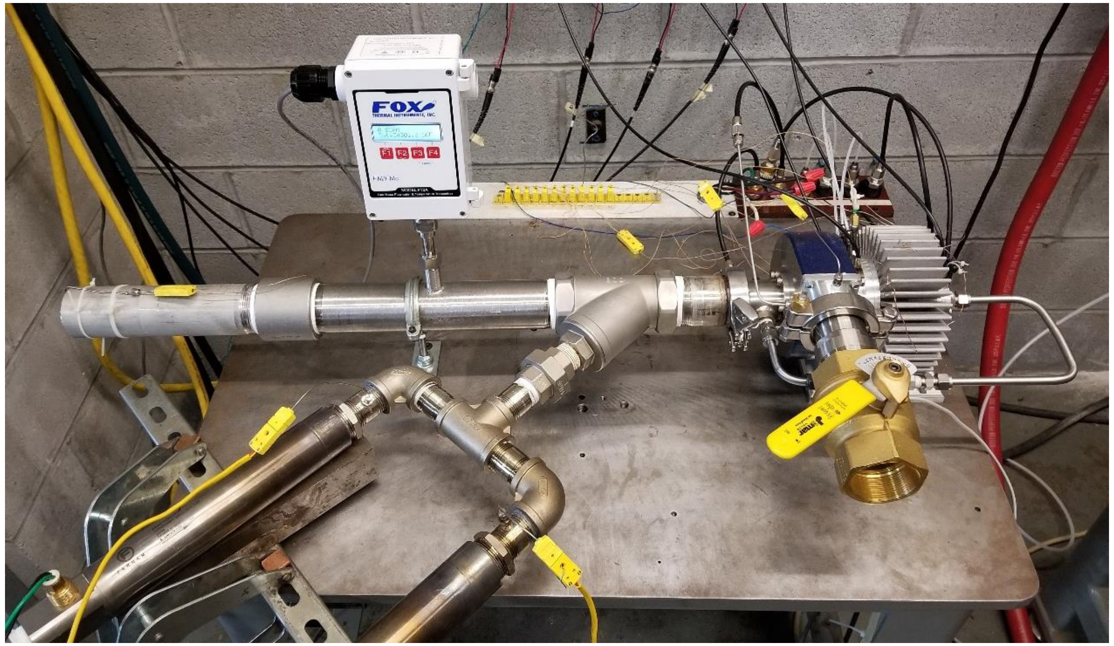
- Solid Oxide Fuel Cell Power plant
  - Façade contains 2 – 100kW Module Power Blocks (MPBs)
- MPB A & B operated from 4/9/19 to 9/5/2019 in Pittsburgh at Clearway Energy.
- Unit returned to Danbury CT to resume operation of MPB-B starting on 5/11/2020.
- Currently operating at Danbury CT FuelCell Energy, Inc. facility to fulfill operational goals to the D.O.E.
- Mohawk Blower operational start up date planned for September 1, 2020.

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, CO_2, H_2, CH_4
  - Inlet temperature: up to 180 ^{O}C
- Low power consumption
  - < 1.5 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

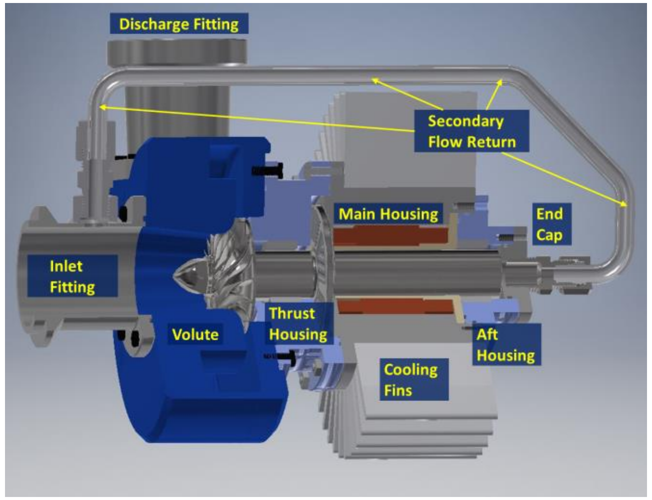
HT ARCB—Where we left off last meeting…

- ***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***



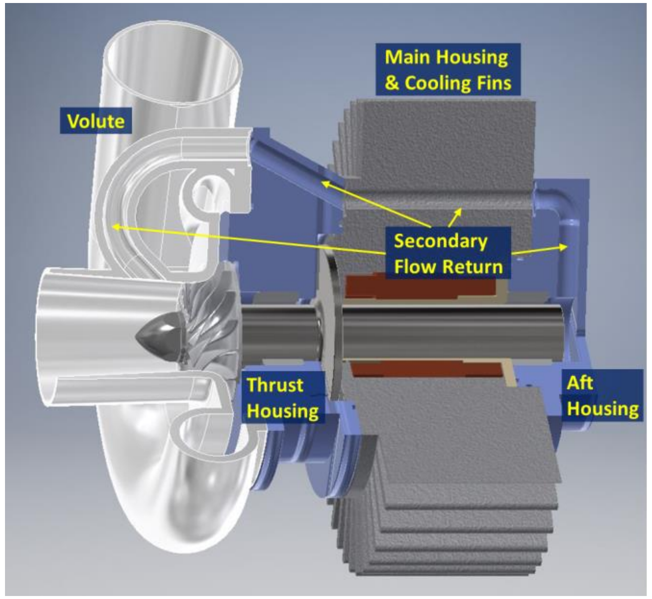
Phase II Objectives: Design for Manufacturability

Test Prototype:
- Many Parts and Fasteners
- Laborious Assembly



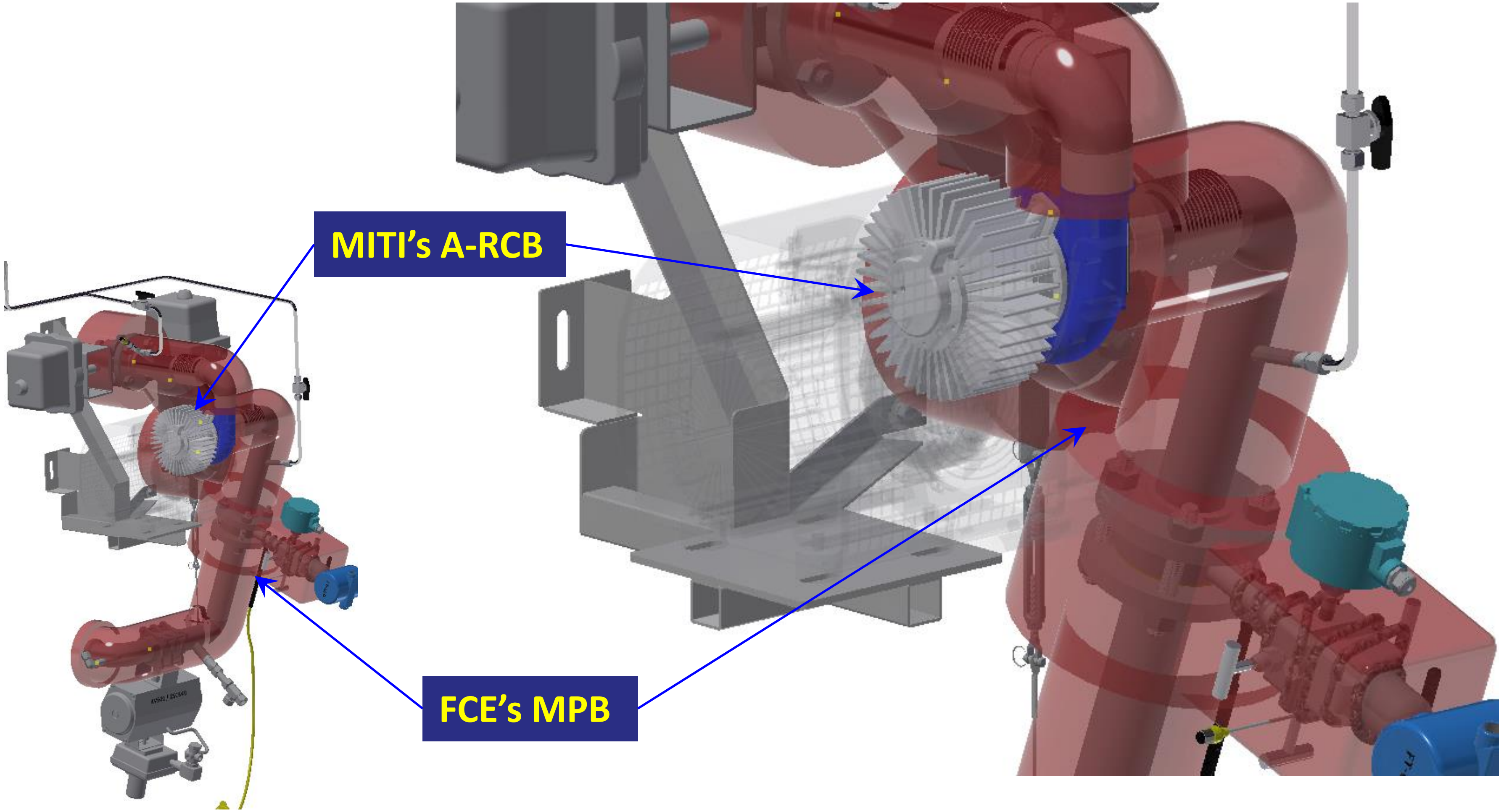
4 Production Prototypes

Production Prototype:
- Castings & Integral Features ⇔ Reduced Part Count, Few Assembly Operations, Lower Cost



MITI – FCE Interface

Cooperation between MITI and FCE to define interface between A-RCB and fuel cell modular power block (MPB).



HT ARCB Hardware Fabrication

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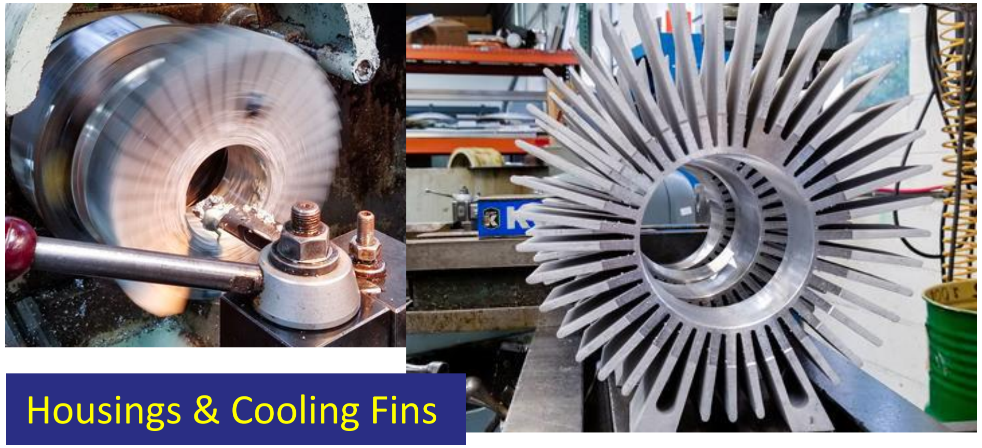
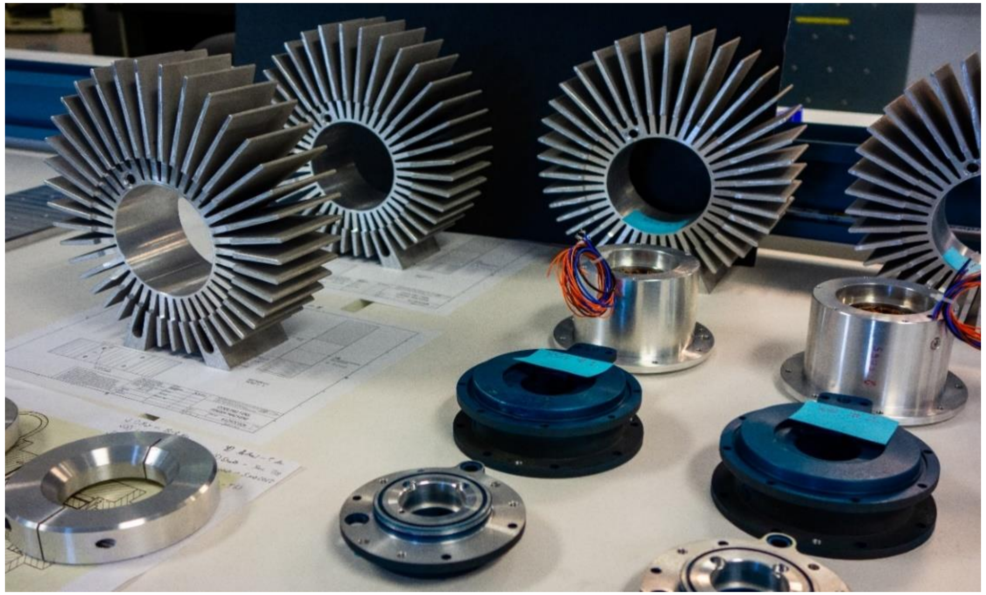

Housings & Cooling Fins

Shafts

Compliant Foil Bearings

Volutes

Impellers on Shafts

HT ARCB Full Assembly

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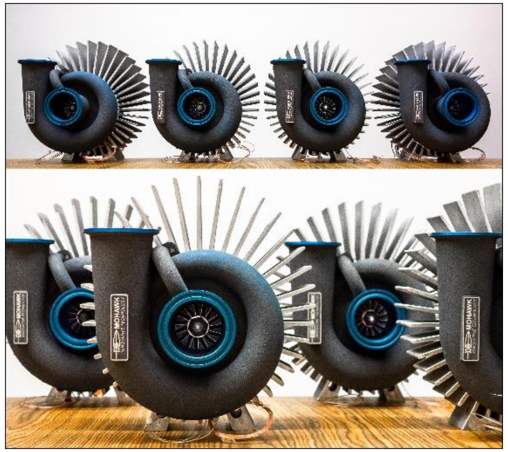
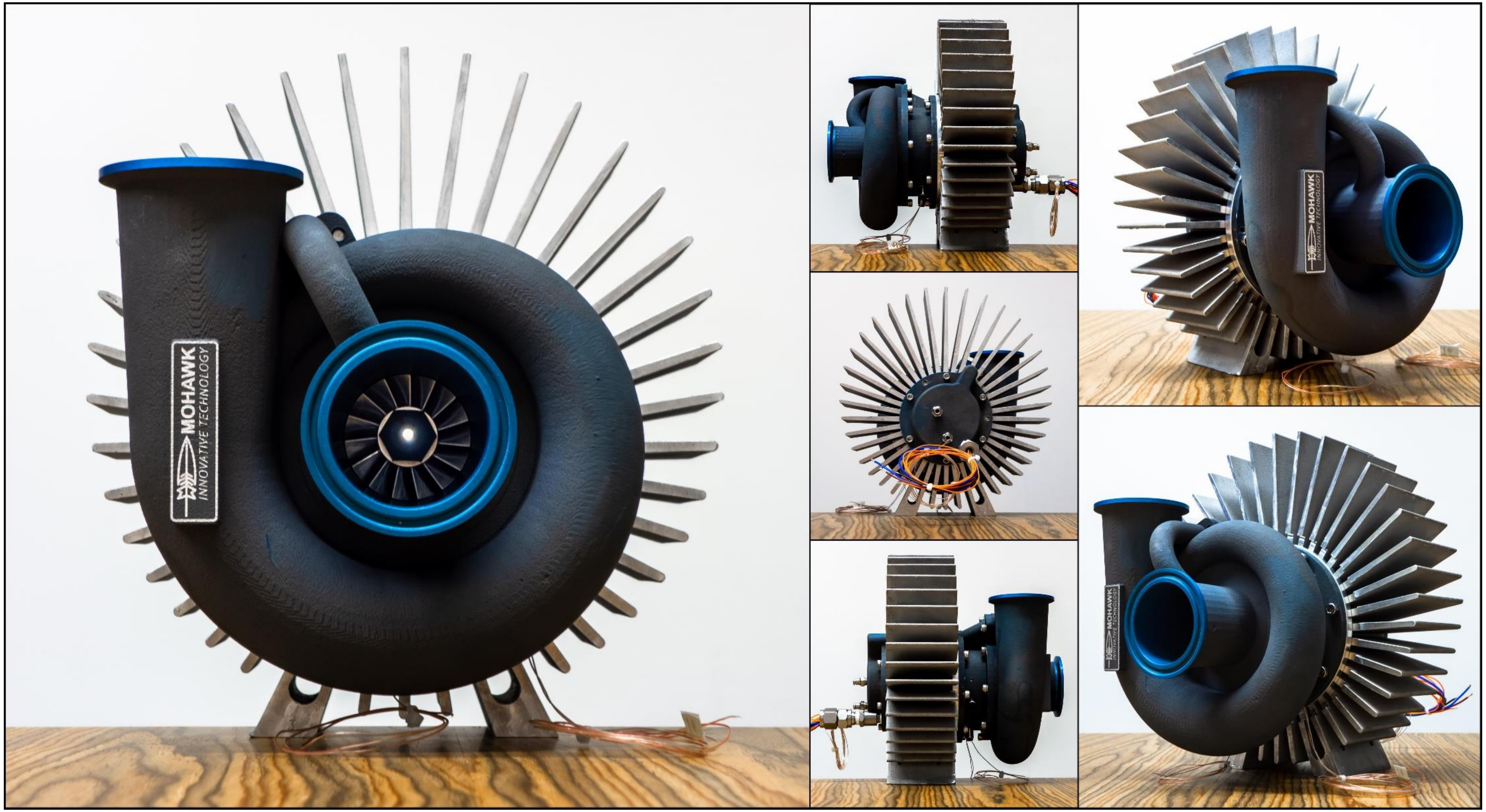
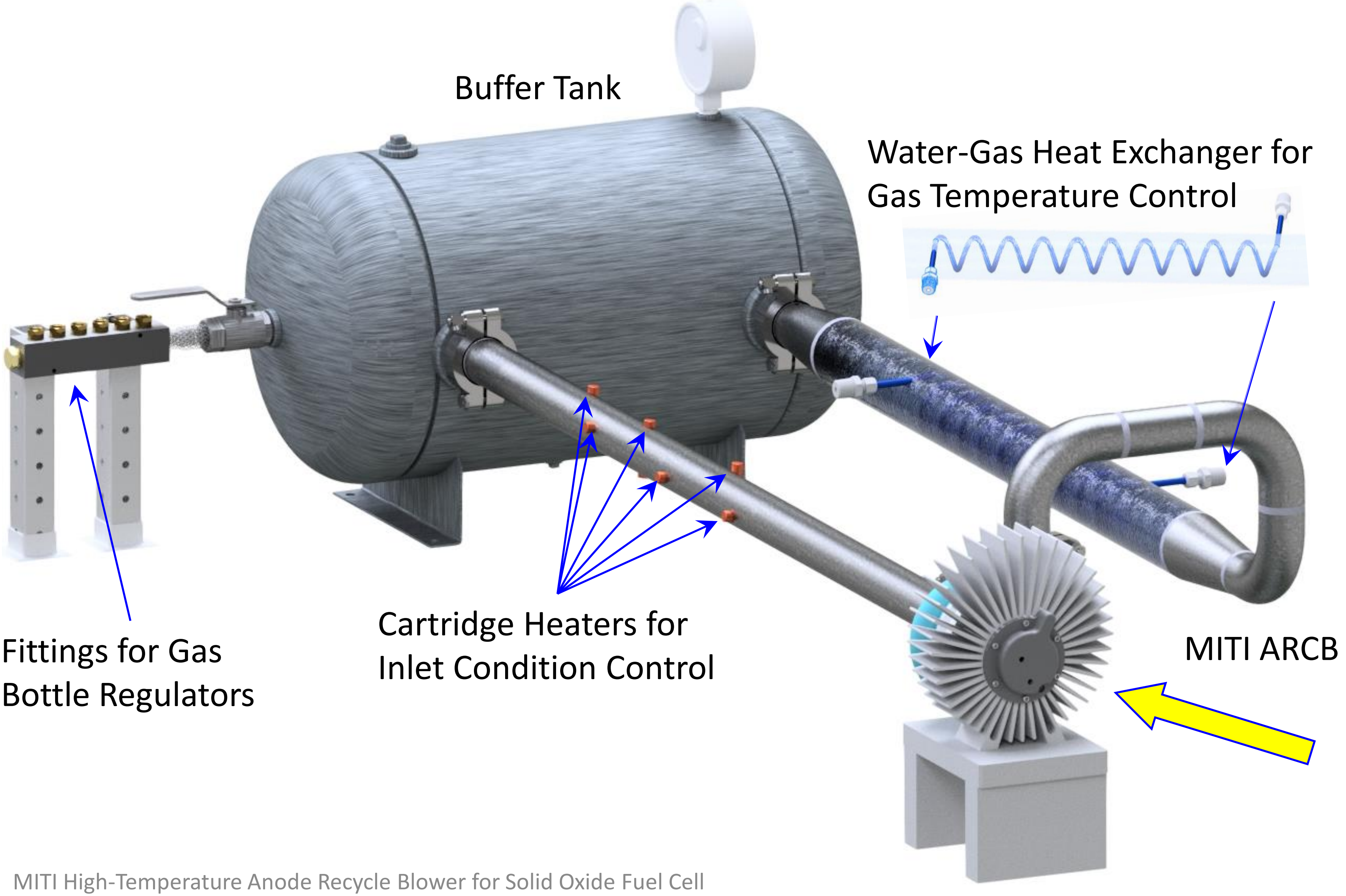
4 X Production Prototypes Completed





Accelerated Life Test Loop Design



- **Test Loop Assembly Started**
- **Beginning of testing mid-August 2020**

HT ARCB Phase II Timeline

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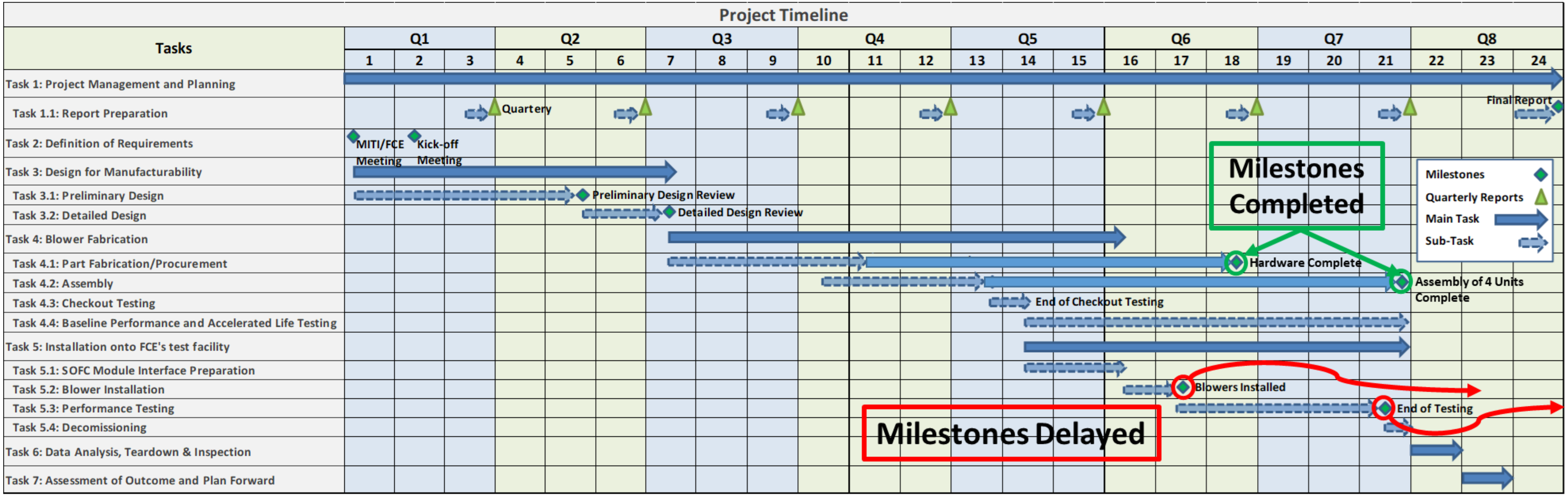


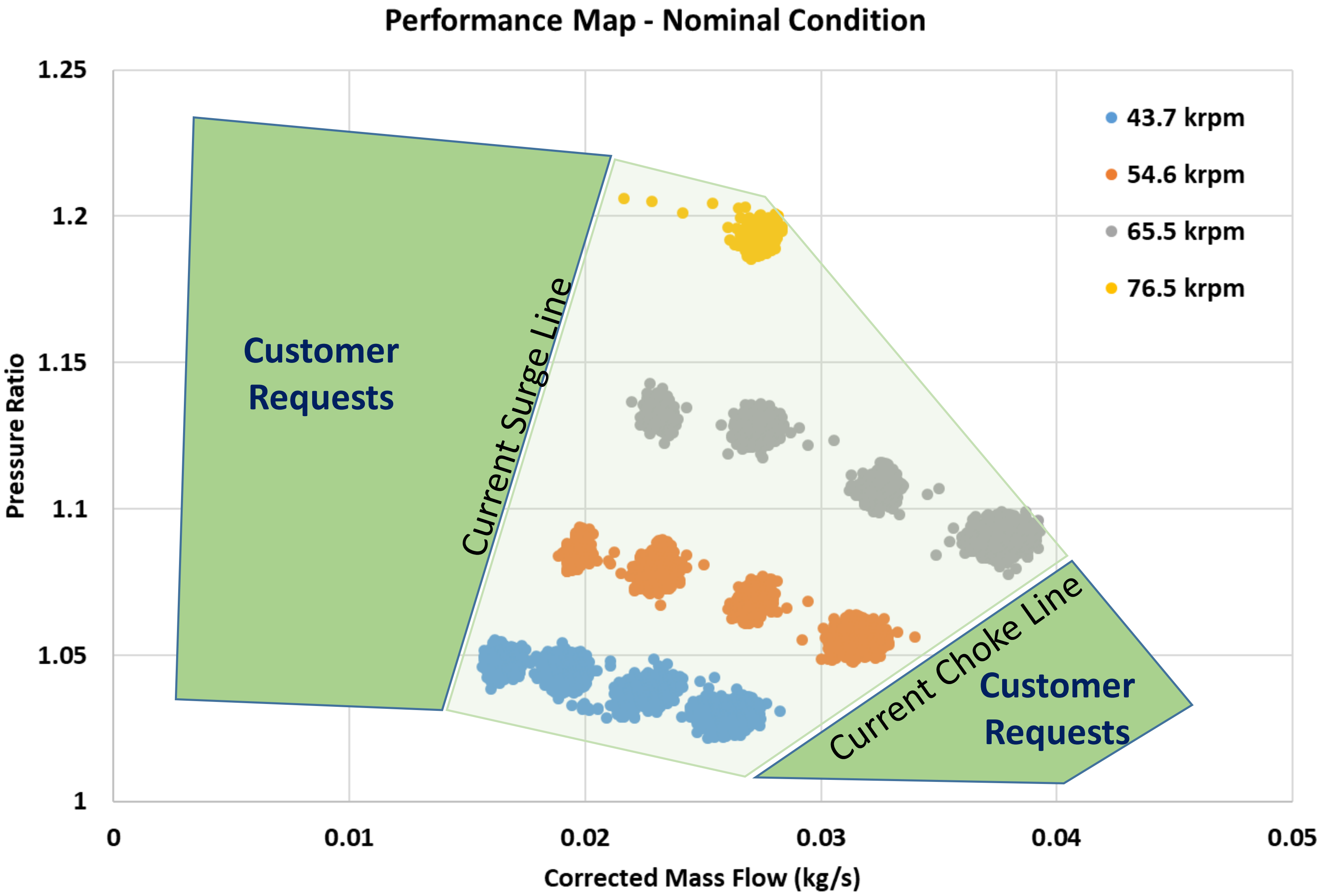
- **Project is on budget, but recovering from time delays**
- **One Year No Cost Time Extension Granted by DOE.**
- **New End Date: 3/31/2021**

HT ARCB Commercialization Considerations

- 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

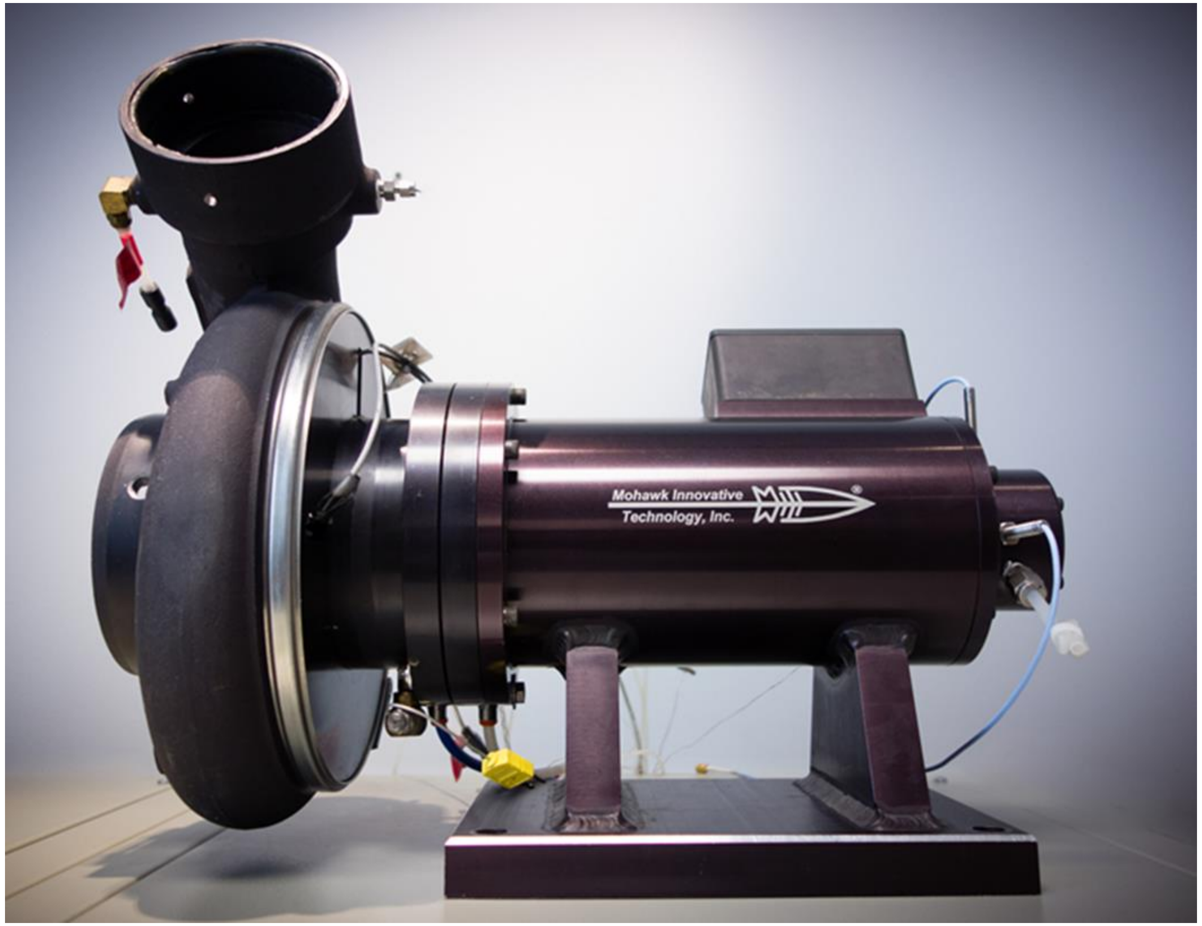
Broaden Commercialization: Scaling

- **Question: what to do to extend current design to cover more of the compressor map—beyond current choke and surge lines?**
- **Max Power Approach:**
  - **Use same motor (max power 1.5 kW)**
  - **Follow compressor scaling-laws to resize only the impeller and volute to meet different flows and pressures**
  - **Advantage: no motor, housing or bearing redesign**
  - **Exploring rapid 3D printing for production of impellers and volutes (DOE Grant DE-SC0020793)**



Mega-Watt Design Scalability

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



Recently-Developed 80 kW Oil-Free Blower by MiTi

100x Scalability Assessment

100 kW *Present* Design

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

10 MW Scaled Design

- Type = Centrifugal
- Diameter = 125 mm
- Operating speed range
  - N ≈ 50 krpm
  - $\dot{m} \approx 1.5$ kg/s
  - CDP ≈ 126 kPa
  - Power ≈ 50 kW
- Efficiency > 87%
- Material selection
  - Stainless Steel

Thank you for your attention!

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