Improving Cost and Efficiency of the Scalable Solid Oxide Fuel Cells Power System

Project ID: FE0031941

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Project Objective

Improving cost and efficiency of the scalable SOFC power system

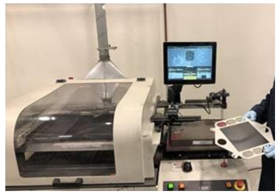
Overview

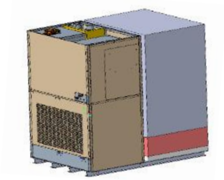
1. **3 year/$3.25M Project**
2. **Project Objectives**
    1. Develop analytical models and tools to optimize the Balance of Plant (BoP) design of a SOFC system.
    2. Design and develop the 20kW range fuel cell power system (FCPS) and build the small scale SOFC power system.
    3. Demonstrate the performance and durability of the 20kW FCPS for 5000 hours in a real-world environment at the University of Connecticut.
    4. Develop a cost model, complete techno-economic analysis (TEA) and demonstrate pathways to achieve sub-$1000/kW goals.
3. **Deliverables**
    1. BP1: 20kW System design, build and commissioning for demonstration at UConn
    2. BP2: 5000-hour demonstration, post-test analysis and TEA demonstrating pathways to achieve sub-$1000/kW goals

Project Structure

Columbus, IN

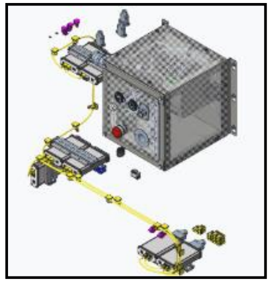
- Project Management
- Systems Modeling
- CFD Modeling
- Structural Analysis
- Design
- Experimental Testing





Malta, NY

- Advisement
- SOFC Stack and System assembly
- End of Line Testing



Fridley, MN

- Power Electronics development
- Control Module development
- Testing

UCONN Storrs, CT

- System demonstration
- Post-test analysis

Budget and Milestones

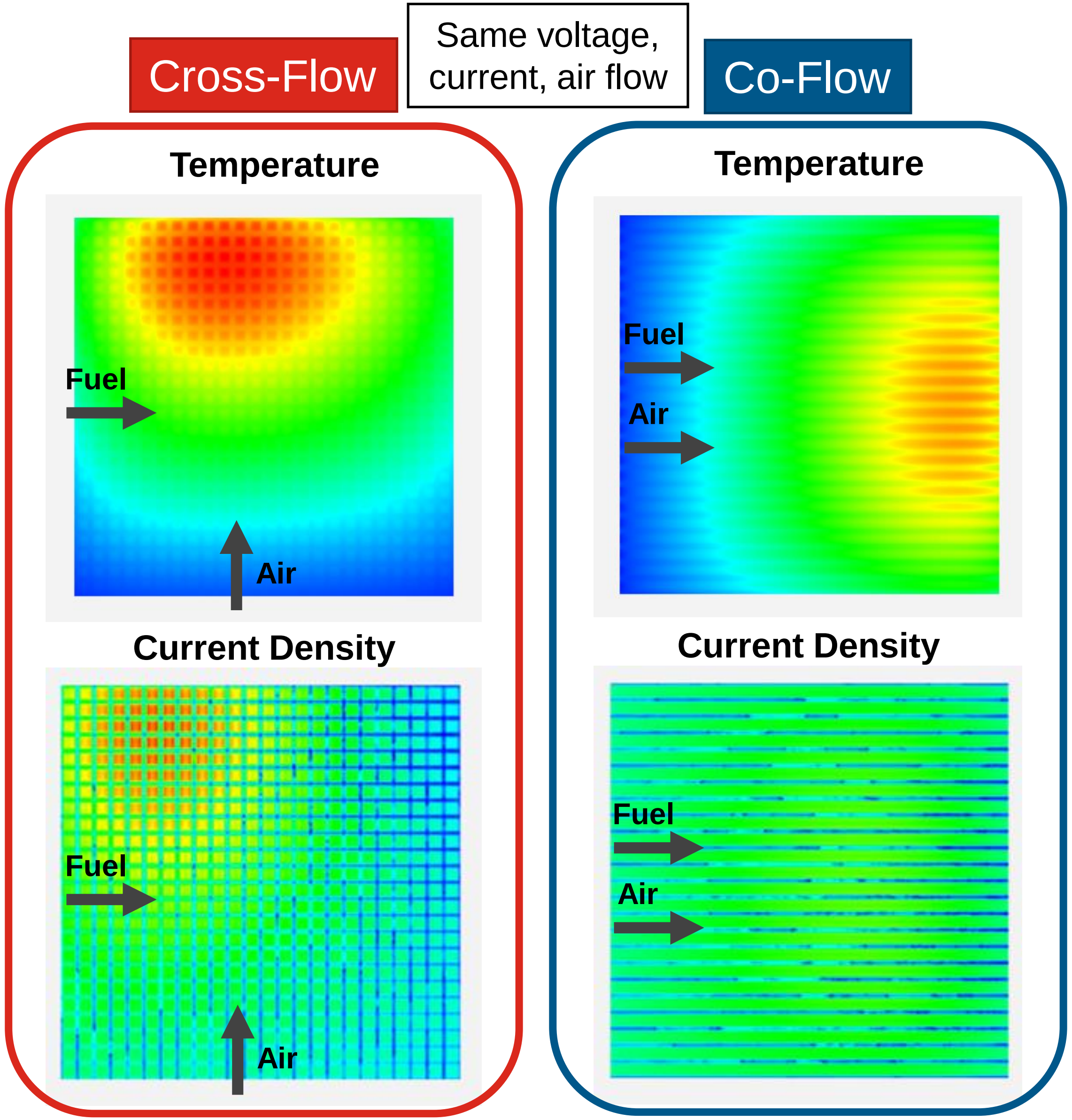
Complete
In Progress

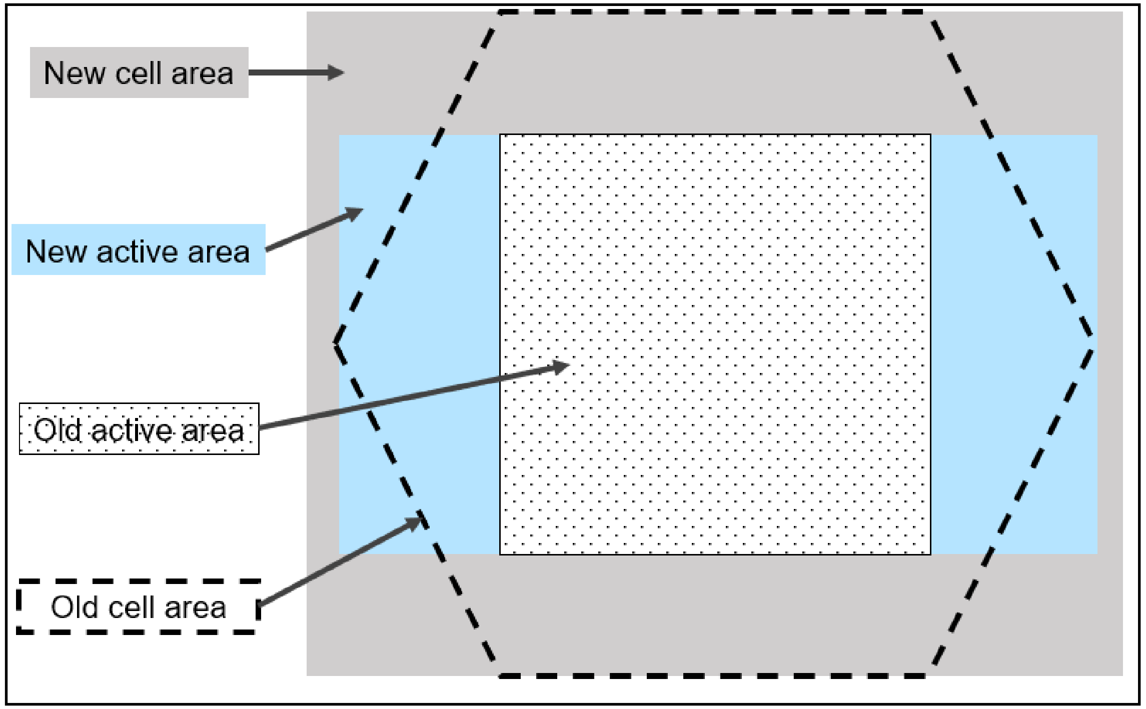
Budget

- Project Start Date: January 1, 2021
- Total Project Budget: $3,251,307
  - Total DOE Share: $2,601,046
  - Total Cost Share: $650,261
  - Total DOE Funds Spent*: $1,791,583
  - Total Cost Share Funds Spent*: $547,730
    - * As of December 31, 2022

Task	Milestone	Status
2.0	**M2: System requirements review and architecture definition**	Complete
3.0	**M3: Calibrated SOFC System Model**	Complete
3.0	**M4: Computational Fluid Dynamics (CFD) analysis complete**	Complete
3.0	**M5: Structural analysis complete**	Complete
4.0	**M6: Power electronics design qualified**	7-31-2023
5.0	**M7: Balance of Plant system defined**	Complete
6.0	**M8: Demonstration system design complete**	Complete
6.0	**M9: Demonstration system assembly complete**	7-31-2023
6.0	**M10: System commissioned at UConn** **Go/no-Go to BP2**	9-30-2023
7.0	**M11: 5000-hour test complete**	12-31-2024
8.0	**M12: TEA complete**	5-30-2025
8.0	**M13: Deliver Final Report to DOE**	6-30-2025

New Cell Design

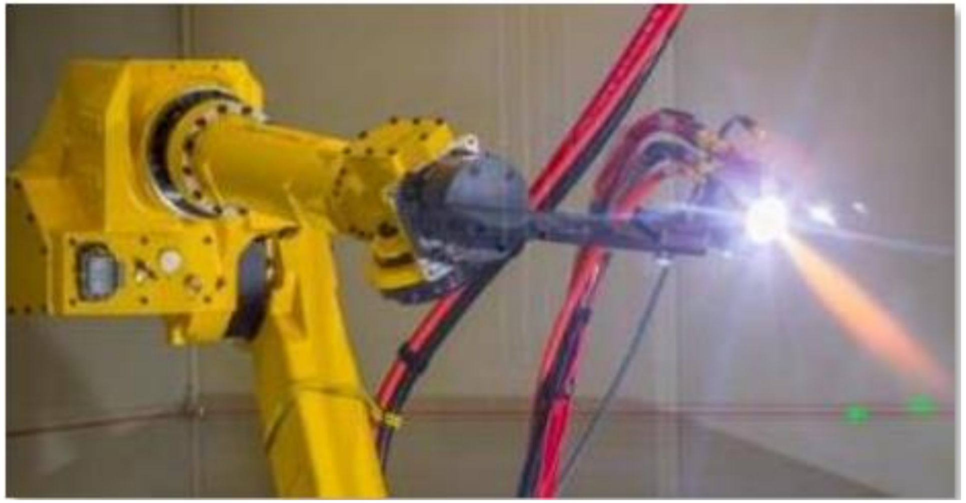


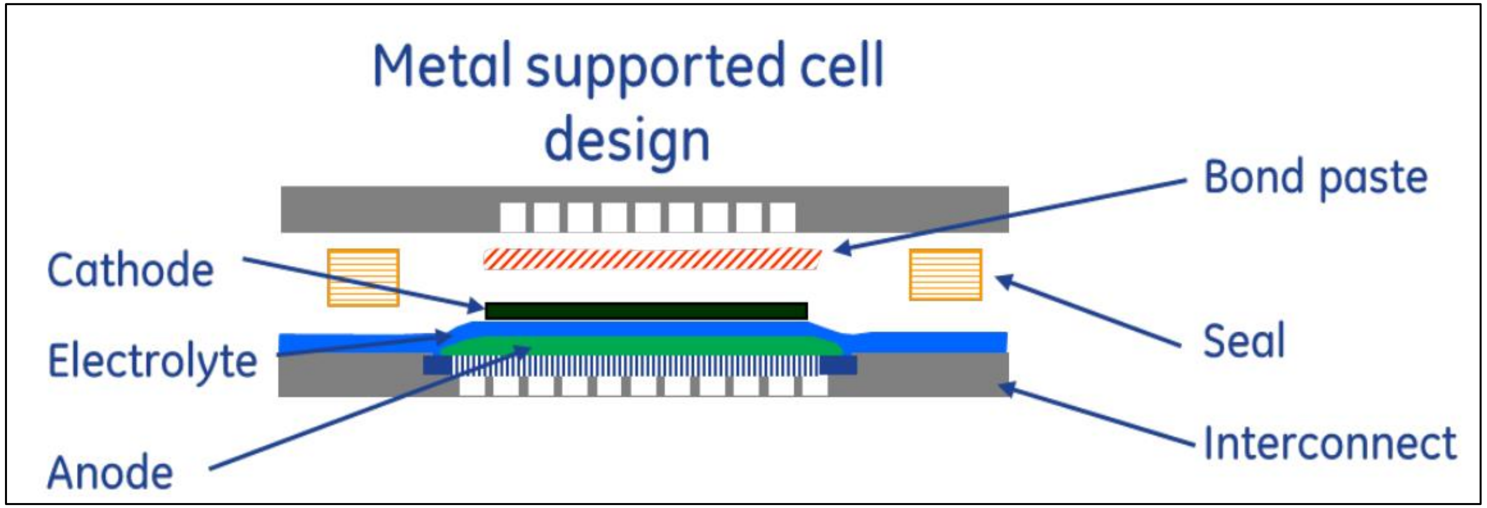


- Move to new cell designed in DE-FE0031971
  - 780 cm^2 active area co-flow design
  - Reduced degradation from improved thermal gradients and more uniform current density
  - Fewer cells for same stack power – improved \$/kW & kW/L

Cell Manufacture

https://arpa-e.energy.gov/sites/default/files/06_Shapiro_GEFC%20overview%20for%20ArpaE.pdf

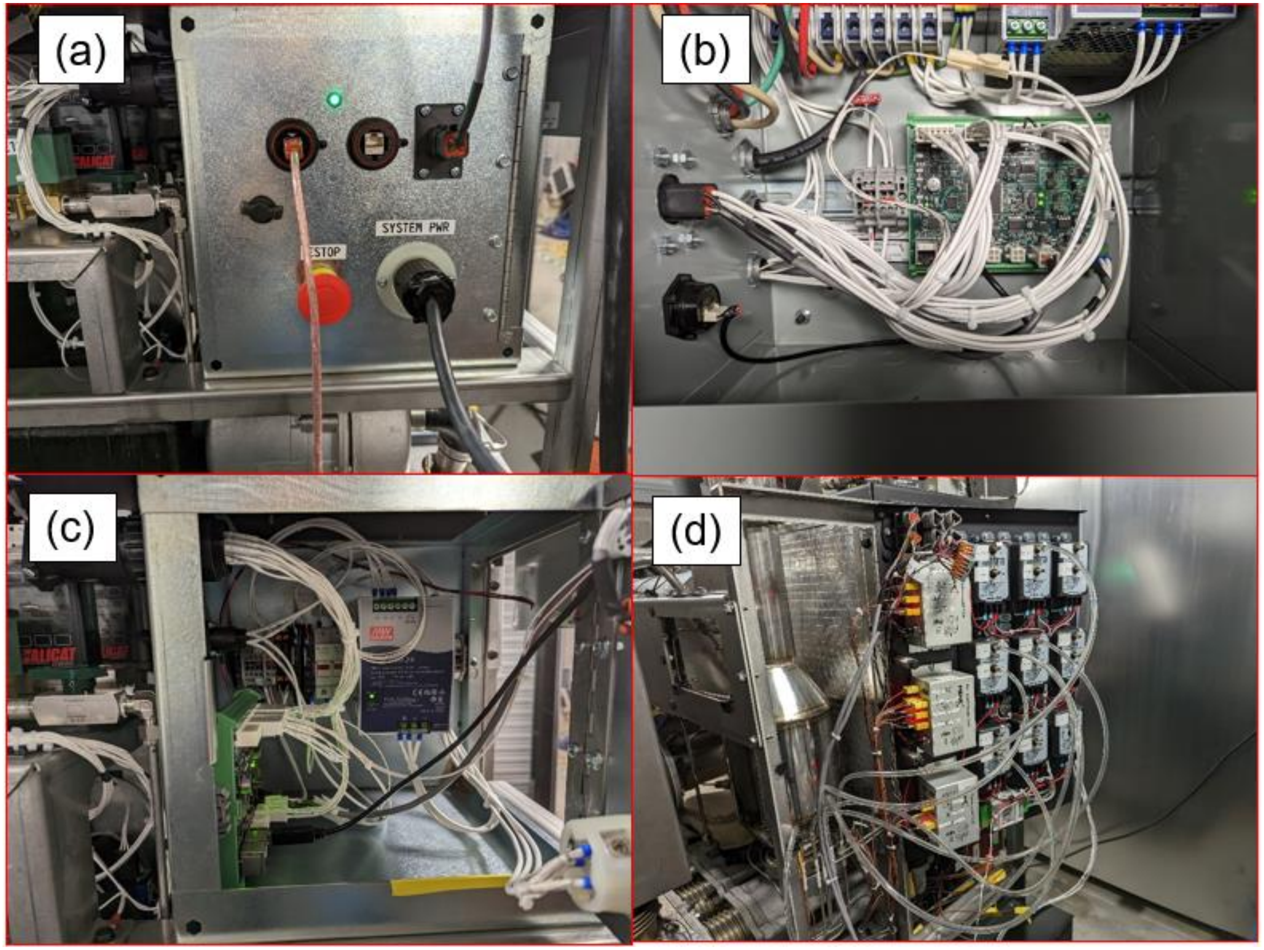




- Thermal spray used to form metallic substrate supported cell
- Quality control process based on 10 cell short stack test

D. Hickey et al. (2017). Stack Development at GE-Fuel Cells. *ECS Transactions*, *78*(1), 107–116.

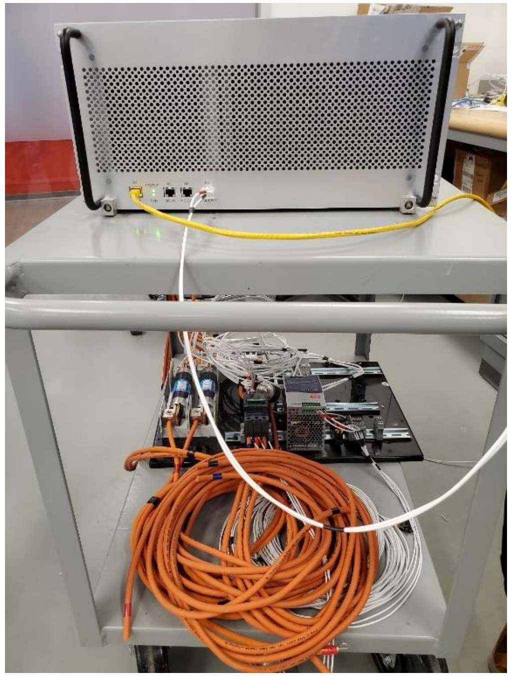
Electrical System

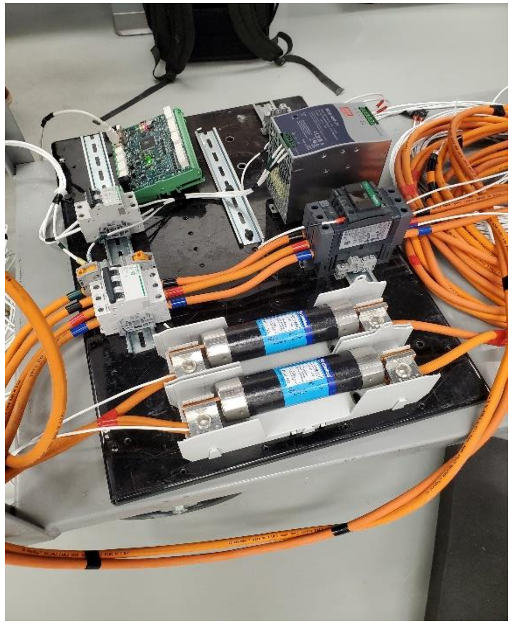


- Completed instrumentation wiring and initial checkout of the system controls
- Successfully tested mass flow, temperature, pressure sensors

Electrical System

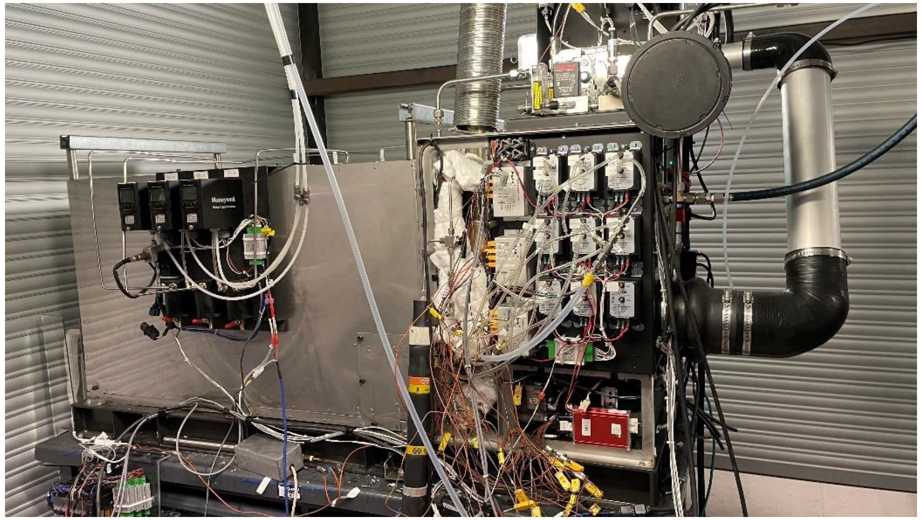
Upcoming tasks:
- Component characterization against DC power supply and grid simulator
- Supplier requirements validation
- Test against DC power supply and real utility grid with additional relay / breaker protections in place
- Validate Balance of Plant system controls state changes and protocol updates to accommodate Power Electronics
- Validate performance of Power Electronics against real fuel cell stack impedance



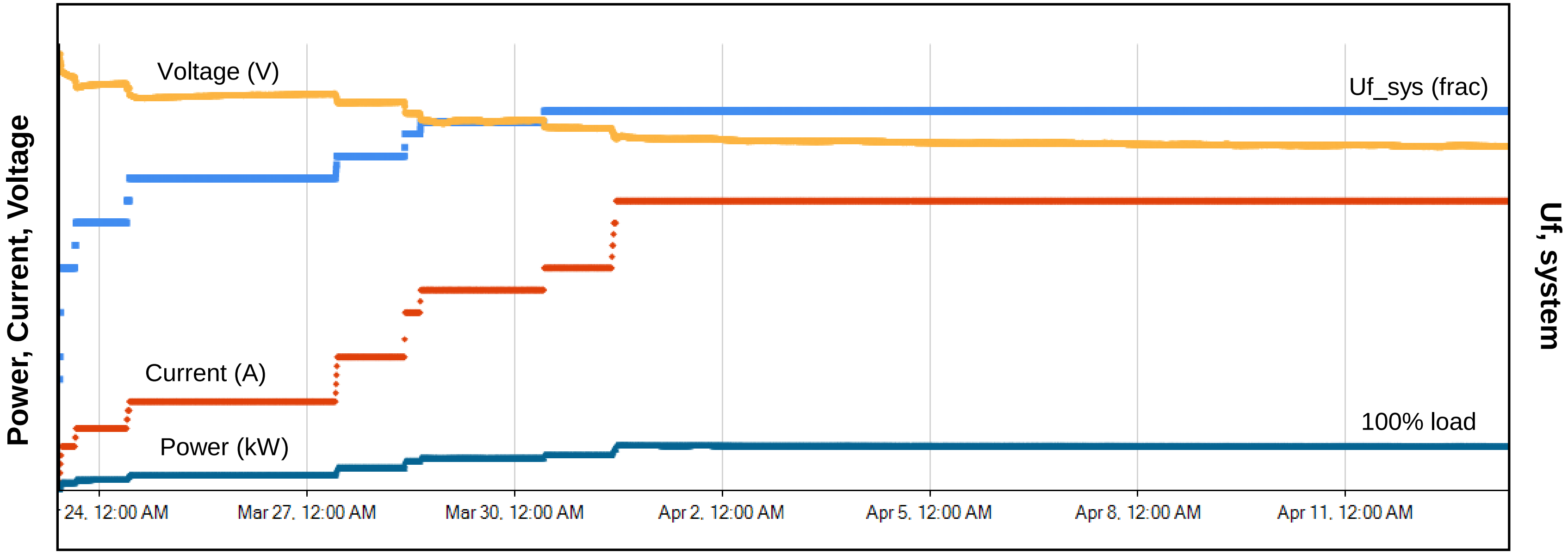


SOFC System Testing

- Compact system design: approximate dimension 750 mm x 700 mm x 1700 mm



Not SOFC system going to UCONN, but test learnings will inform UCONN testing.



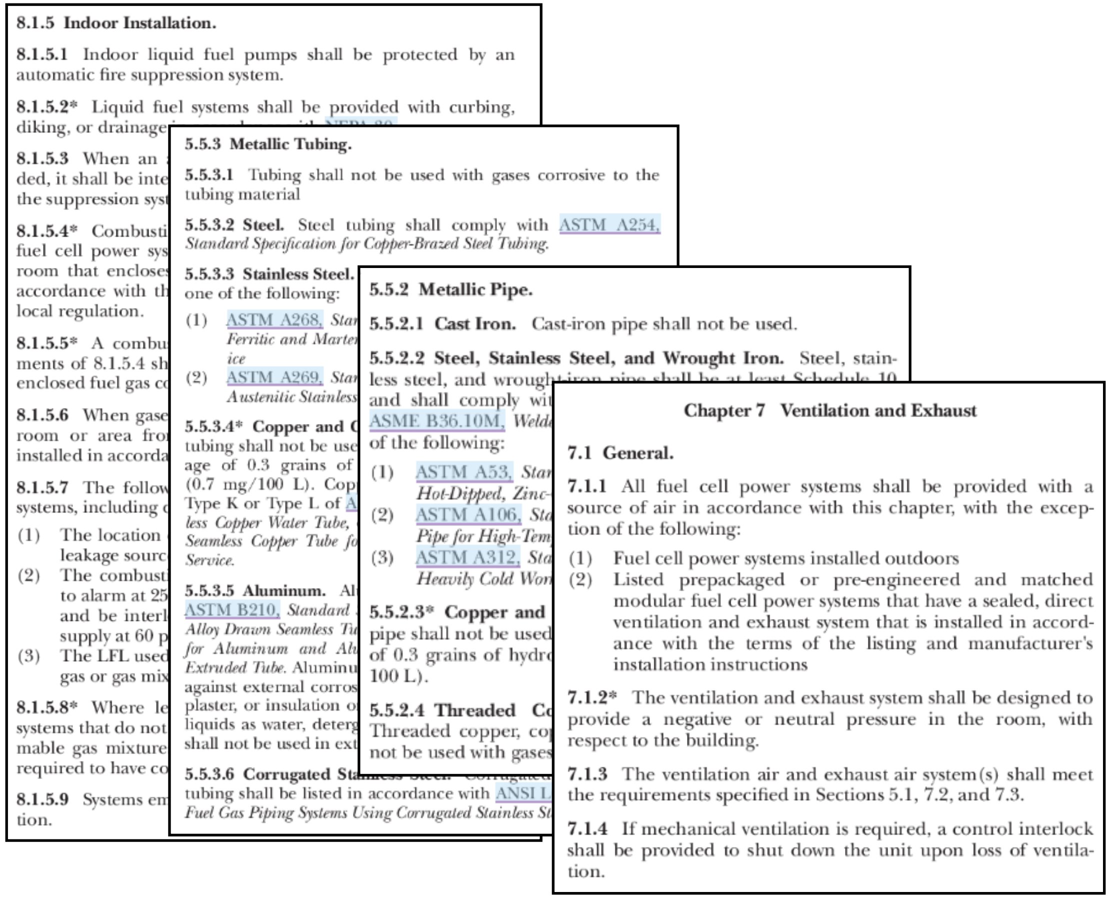
> 500 hours under load

> 300 hours at full load (20 kW DC)

Uf_sys = system fuel utilization

Installation Planning: Codes and Permitting

- Preparation work to secure permit at UCONN test facility:
  - Review and document compliance with relevant regulations
    - NFPA 54: National Fuel Gas Code
    - NFPA 853: Standard for the Installation of Stationary Fuel Cell Power Systems
  - Document system electrical layout, grid connection, and component certification (UL listing)



Selections from NFPA 54 and NFPA 853 regulations

NFPA = National Fire Protection Association

Overview of UCONN Lab and Test Capabilities

SOFC research and development activities include R&D at lower TRL's and systems evaluation and analysis at higher TRL.

- ✓ Cell component materials development and testing
- ✓ Electrochemical performance analysis
- ✓ *Long term performance and performance stability evaluation*
- ✓ *Hydrocarbon processing, cleanup and internal reforming*
- ✓ Airborne trace contaminants capture
- ✓ Metals, alloys and coatings for stack and BOP applications
- ✓ Corrosion under complex gas atmospheres

Electrochemical tests
High temperature corrosion
Electrode poisoning
Getter development and testing

Stack and systems performance testing, data analysis and characterization includes

- ➢ kW class system electrical test
- ➢ Utilization of hydrocarbon fuels
- ➢ Performance analysis
- ➢ Post test characterization
- ➢ Degradation process mechanistic evaluation
- ➢ Degradation mitigation approaches development and validation

10-20 kW system operation
Use of PNG
Long term performance analysis
Identification of degradation processes

Overview of UCONN Lab and Test Capabilities

- Full and half cell electrochemical test capability
- Cell component materials synthesis, characterization and testing
- Fuel reforming - internal and external utilization with fuel composition analysis
- Electrode poisoning from airborne contaminants; use of getters for contaminant capture
- Electrochemical impedance spectroscopy
- Structural analysis of cell, stack and BOP components
- Corrosion evaluation

Lab capabilities:
Electrochemical testing, cell fabrication, oxidation testing, hydrocarbon reformation, Transpiration and contaminant capture tests, and others
Characterization techniques:
XRD, SEM, EDS, FIB,TEM, EIS, ICP. Raman spectroscopy,

Fuel Quality Monitoring

Link System Customer Interface Gas Quality Postings - Chromatograph Daily

Pipeline: Algonquin Gas Transmission, LLC

Created.• 4/10/2023 1:00:53 PM

Gas Date: 4/9/2023

Device Id	Device Name	Data Timestamp	Data Quality	BTU (IT)/CF (BTUCF)	Specific Gravity	WOBBE	Carbon Dioxide (Mol $^{0}/0$)	Nitrogen (MOI $^{0}/0$)	Methane (MOI $^{0}/0$)	Ethane (MOI $^{0}/0$)	Propane (MOI $^{0}/0$)	I-butane (MOI $^{0}/0$)	N-butane (MOI $^{0}/0$)	(MOI pentane (Mol $^{0}/0$)	pentane (Mol	C2+	C4+ (Mol	C6+ (MOI	GPM C6+ (GPM)
00050-1S2	Burrillville_M/L	04/09/2023	Valid	1026	0.566	1364.	0.043	o. 282	97.730	1.900	0.043	N/A	0.001	N/A	N/A	1.945	0.001	N/A	N/A
00851-1S1	Cromwell-M/L	04/09/2023	Valid	1026	0.566	1365.	0.044	o. 244	97.799	1.870	0.041	0.001		1.949			0.037	o. 036	0.016
00050-1S3	Burrillville-30B	04/09/2023	Valid	1027	0.567	1364	0.045	o. 284	97.625	1.991	0.052	o. 001	0.002	N/A	N/A	2.046	0.003	o. 000	0.000

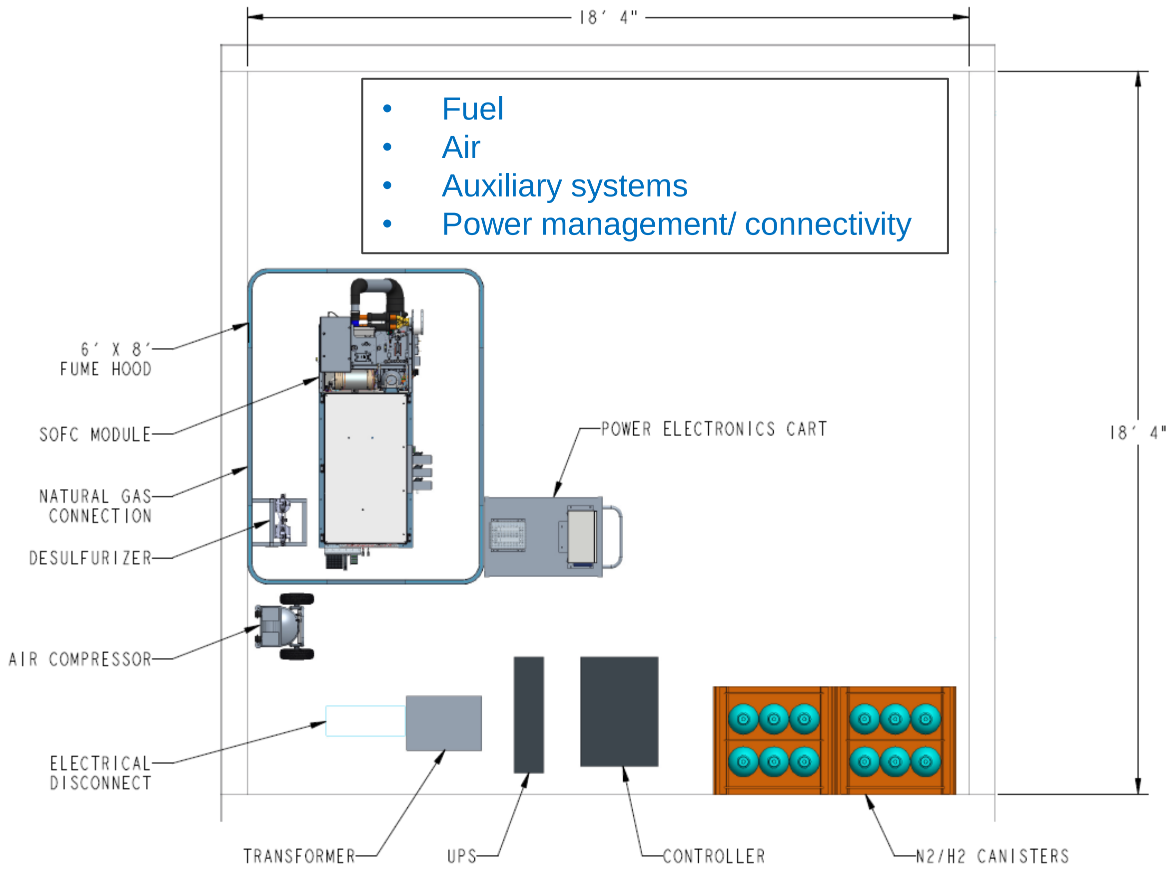
Gas Date: 4/14/2023

Device Id	Device Name	Data Timestamp	TOTAL SULFUR (Gr/100SCF)	H2O (Lb/MMCF)
00840-1S1	Hanover LN 26	04/14/2023	.15538	N/A
00320-1S1	Burrillville to End of Line - B	04/14/2023	.00753	2.908

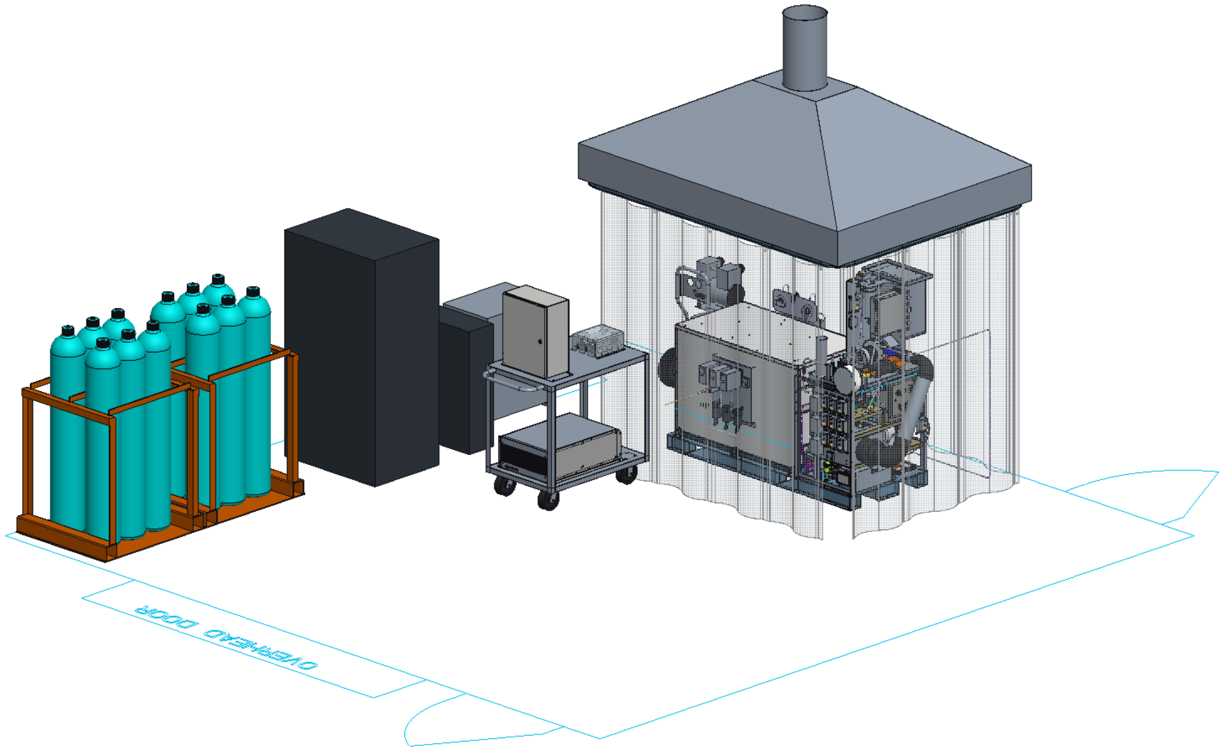
• Assessment of BTU	Impacts system efficiency
• Assessment of hydrocarbons	Impacts fuel processing
• Assessment of S	Impacts desulfurizer life

UCONN SOFC System Test Facility

- Worked with UConn team to come up interface installation requirements
- Developing CAD model to assist system setup

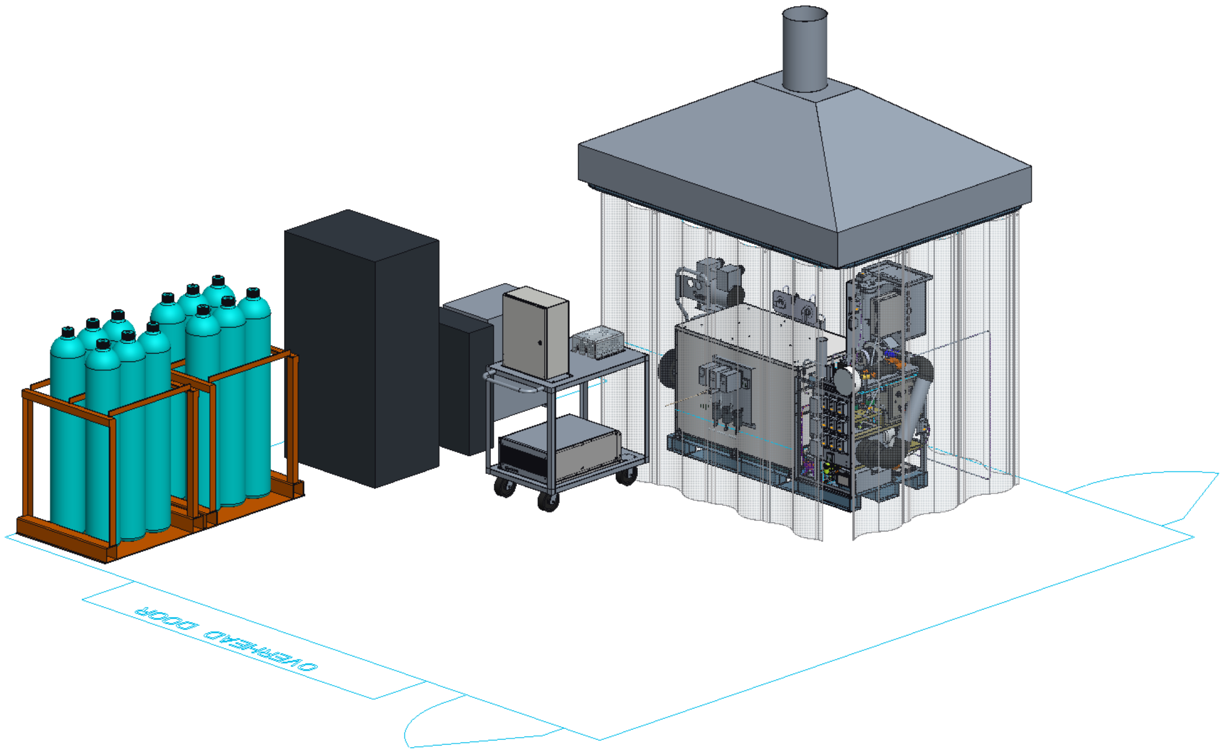


- Dedicated test area
- Dedicated utilities connection
- Dedicated data acquisition
- Dedicated electrical connectivity with grid



Commissioning Plan

Commissioning Plan
Installation of SOFC system at UCONN testing facility
System checks: • Calibration checks of flow sensors and valves • Calibration checks of sensors and instrumentation • System leak test • Electrical checks – Blowers, CPOX, Burner, etc.
Functionality checks: • Cold test of flows and pressure drop across components • Automated hot test – take system to full operating temperature followed by an automated shutdown • Test Emergency Stop (eStop) system
System performance check: • Bring system to full load to verify functionality and BOL specifications



Test Plan (Preliminary)

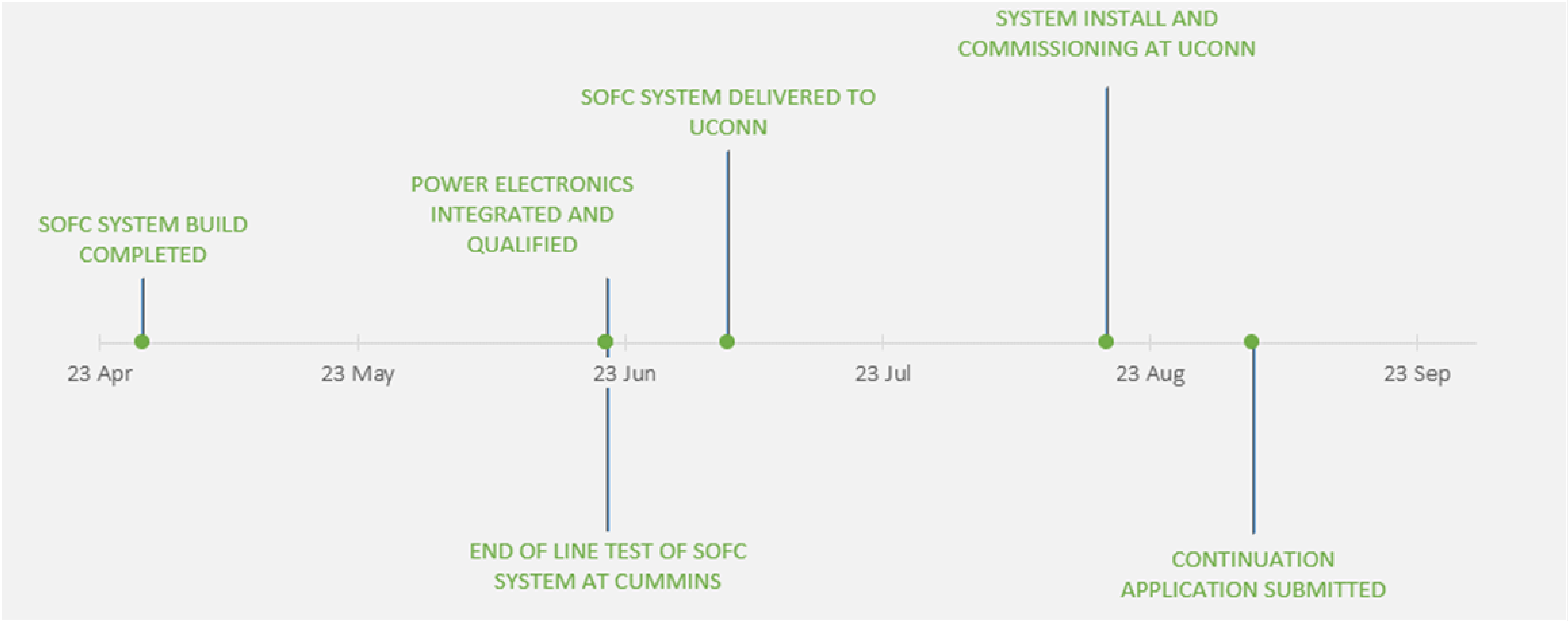
Objectives:

- 5000 hours continuous operation
  - Monitor system performance, collect key system parameter T, P, Voltage
- Post-test analysis
  - System tear down analysis, degradation assessment of key components, final summary

Testing Plan (Preliminary)	Comments
Start up system • Burner to warm system from ambient to operating temperature • CPOX for reducing gas on anode side	• Ensure OCV and group voltages are healthy and within specified tolerance
Add current demand in steps up to full load: • Step 1: 0 → 20 A (50% Uf_sys) • Step 2: 20 → 40 A (70% Uf_sys) • Step 3: 40 → 60 A (75% Uf_sys) • Step 4: 60 → 130 A (85-90% Uf_sys)	• Current increased in 4 A increments • Hold a current constant at each Step until steady and stable operation achieved • Perform regular gas analysis to ensure system operating within expected tolerances • Manage air flow to maintain stack ΔT within tolerances
Hold system at full operating power	

Uf_sys = system fuel utilization

Project Timeline: Next Steps



Acknowledgements

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- Mr. Drew O’Connell for his guidance as Program Manager
- Cummins Malta SOFC facility personnel:
  - Cell design, manufacture, testing
  - BOP and system design, assembly and testing
- UCONN for technical guidance on SOFC systems testing

Q+A


Cummins