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

Project ID: DE-FE0031941

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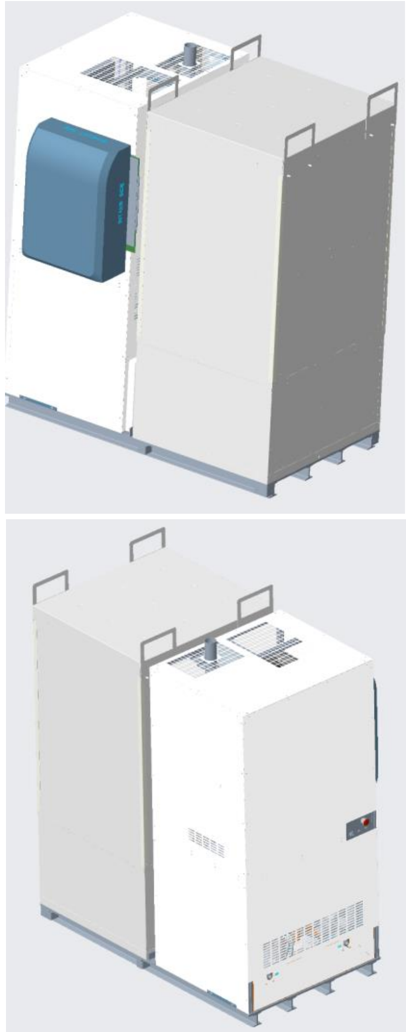
Project Objective

Improving cost and efficiency of the scalable SOFC power system

Overview

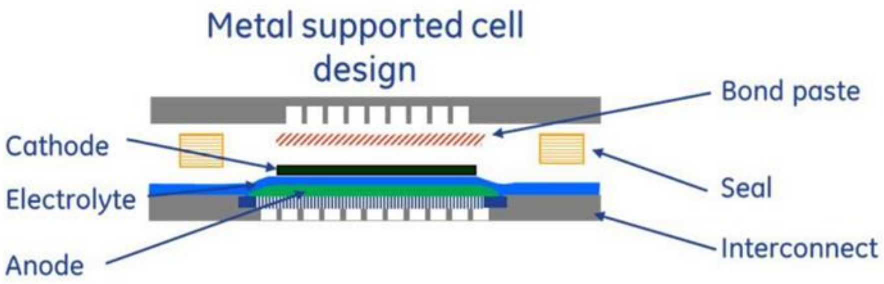
1. **3 year/$3.25M Project**
2. **Project Objectives**
    1. Develop analytical models and tools to optimize the Balance of Plant (BoP) design of a SOFC system.
    2. Design and develop the 20kW range FCPS and build the small scale SOFC power system.
    3. Demonstrate the performance and durability 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 (Jan'21–Jun'22): 20kW System design, build and commissioning for demonstration at UConn
    2. BP2 (Jul'22–Dec'23): : 5000-hour demonstration, post-test analysis and TEA demonstrating pathways to achieve sub-$1000/kW goals

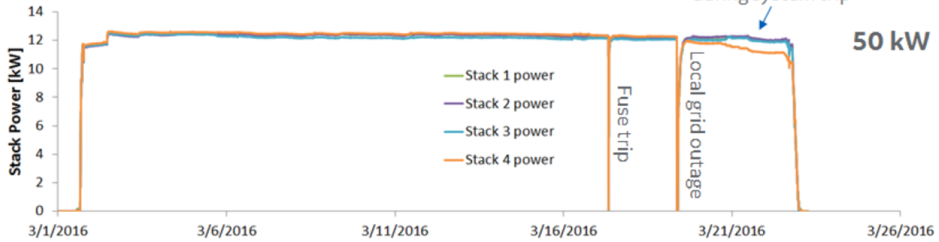


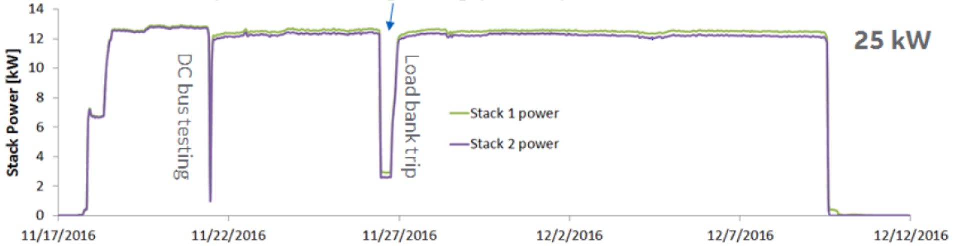
20kW module design

Solid Oxide Fuel Cell and Stack Technology

- Cummins SOFC technology is a proprietary metal supported cell design.
- 20 kW range Fuel Cell Power System will be build using demonstrated cell and stack technology (TRL 5)
- Flow channels have been optimized for flow uniformity and low pressure drop to achieve low parasitic losses







Data from 500-hour test conducted at Hudson Valley Community College (HVCC) in Malta, NY

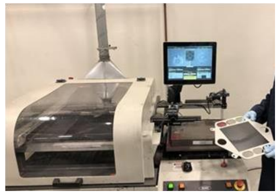
170 cell stack used in the 50-kW system test

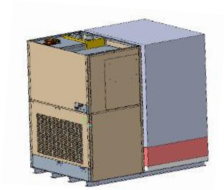
Reference: D. Hickey, M. Alinger, A. Shapiro, K. Brown, T. Striker, H. Wang, S. Gaunt, D. Kinsey and I. Hussaini, “Stack Development at GE–Fuel Cells”, ESC Transactions, V78N1 (2017) 107-116

Project Structure

Columbus, IN

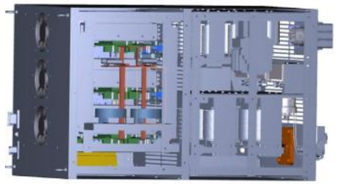
- Project Management
- Systems Modeling
- CFD Modeling
- Structural Analysis
- Design
- Experimental Testing





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

Project Milestones

Timeline and Budget

- Project Start Date: January 1, 2021
- Project Duration: 36 months
- Total Project Budget: $3,251,307

  Total DOE Share: $2,601,046

  Total Cost Share: $650,261

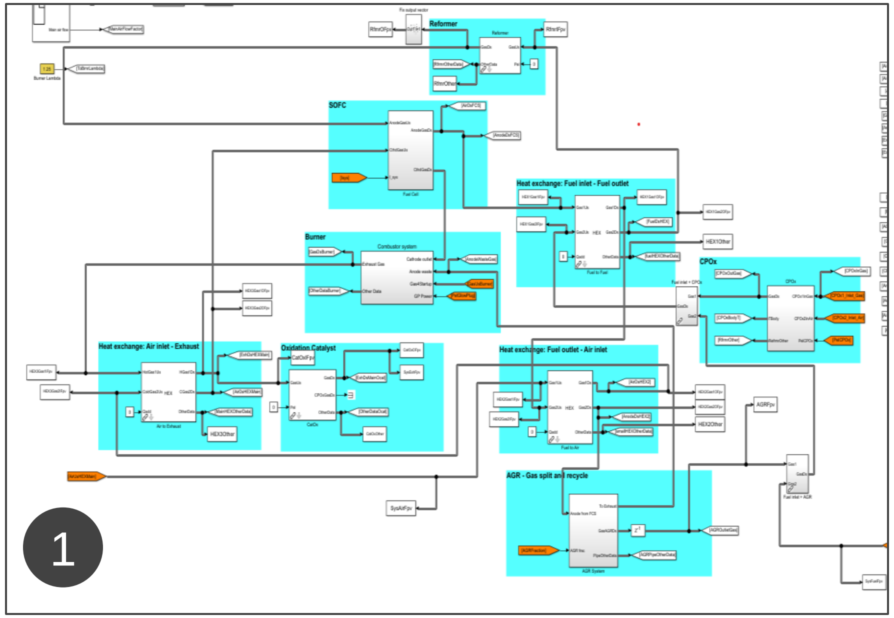
  Total DOE Funds Spent*: $630,150

  Total Cost Share Funds Spent*: $157,536

  * As of September 30, 2021

Task	Milestone	Status	Measure
1.0	**M1: Project kick-off**	Completed	Updated Project Management Plan Project kick-off presentation
2.0	**M2: System Requirements review and architecture definition**	Completed	System Requirements Report Architecture definition complete
3.0	**M3: Calibrated SOFC System Model**	Completed	System model calibrated to Baseline stack and system performance
3.0	**M6: Computational Fluid Dynamics (CFD) analysis complete**	Ongoing	Flammable gas analysis Flow distribution Analysis Thermal Analysis
3.0	**M7: Structural Analysis complete**	Ongoing	Hot and cold side BOP analysis Skid Analysis
4.0	**M4: Power Electronics design qualified**	Ongoing	Power Electronics design verified and validated
5.0	**M5: System Catalysts Defined**	Ongoing	CATOX and CPOX catalyst specification defined
6.0	**M8: Demonstration System Design Complete**	Ongoing	System design drawings and model released.
6.0	**M9: Demonstration system assembly complete**	Ongoing	20kW range Cummins SOFC power system build complete for demonstration End-of-line testing complete
6.0	**M10: System Commissioned at UConn** **Go/no-Go to BP2**	Ongoing	System commissioned at the host site demonstrating the functionality and meeting Beginning-of-Life (BOL) specifications
7.0	**M11: 5000-hour test complete**	Ongoing	20kW Cummins SOFC power system Demonstration Report – FCPS demonstration complete at the UConn test facility
8.0	**M12: TEA complete**	Ongoing	Complete TEA with costs for high volume manufacture demonstrating pathways to achieve sub-$1000/kW goals
	M13: Deliver Final Report to DOE	Ongoing	Final Report

System model development

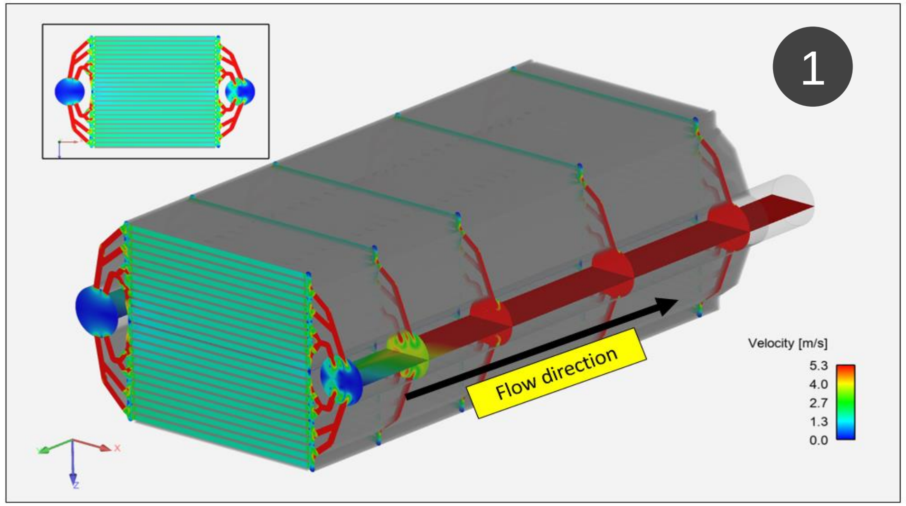


Component	Mode 1	Test	Sim	Pct delta%
Fuel Cell Stack	Ucell, V	0.747	0.71	**-4.69**
	Icell, A	80	80.00	**0.00**
	Psys, W	8.960	8.54	**-4.69**
	T Anode In, C	646	632.09	**-2.15**
	T Anode Out, C	767	751.19	**-2.06**
	T Cathode In, C	730	705.94	**-3.30**
	T Cathode Out, C	773	765.87	**-0.92**
	T Stack Body, C	768	767.51	**-0.06**
	dP Anode, kPa	1.8	1.90	5.53
	dP Cathode, kPa	1.19	1.19	0.22
	[H2] Anode Out, %	14.1	14.35	1.77
	[CO] Anode Out, %	7.2	6.22	-13.67
	[H2O[Anode Out, %	52.5	52.28	-0.43
	[CO2] Anode Out, %	26	27.07	4.10
	[CH4] Anode Out, %	0	0.00	

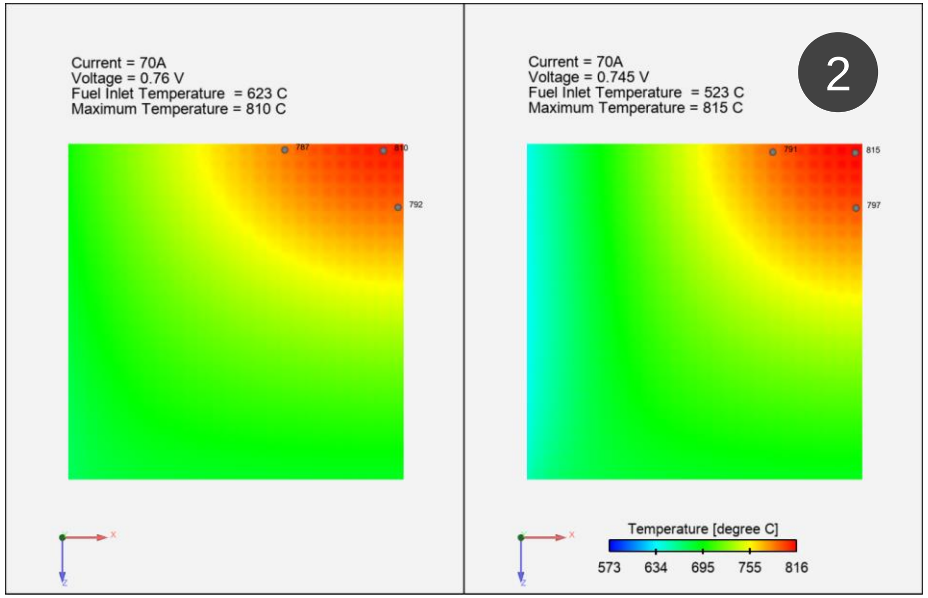
2

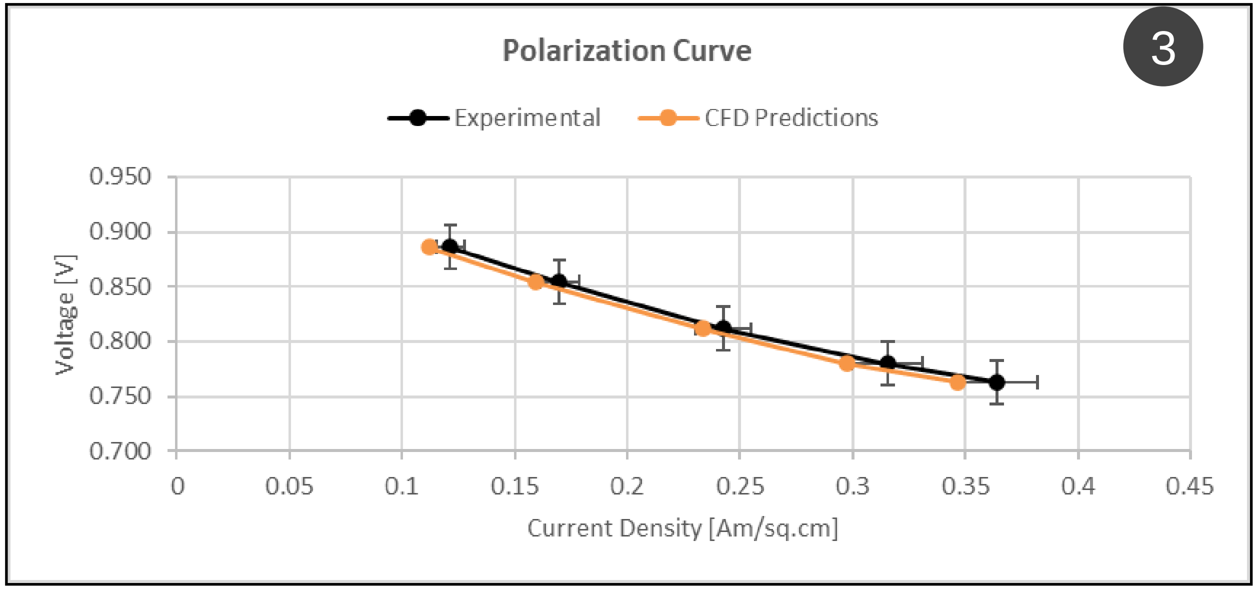
1. A full SOFC system Simulink model has been developed, incorporating various components including fuel cell stack, heat exchangers, burner, catalysts. Each component model will solve mass transfer, heater transfer and chemical reactions mathematically
2. The percentage differences in stack performance and temperature is within 5%. Meanwhile, the differences in pressure and anode out gas composition is also reasonable.

CFD model development

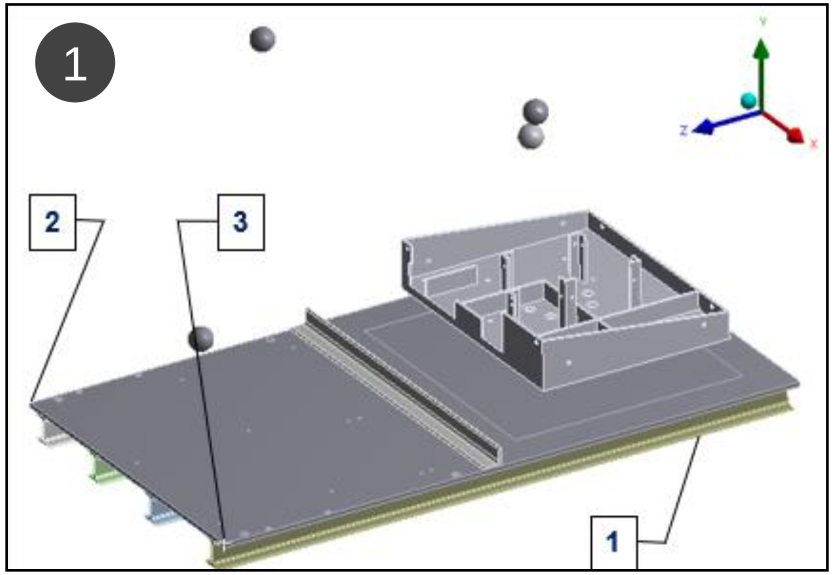


1. Stack CFD model has been developed to predict the cell-to-cell flow distribution across the stack consisting multiple fuel cells.
2. CFD model includes detailed electrochemistry of solid oxide fuel cell, which can be used to predict performance
3. The model input parameters are calibrated and validated against the test data. Results show model predictions match well when compared to the test data.

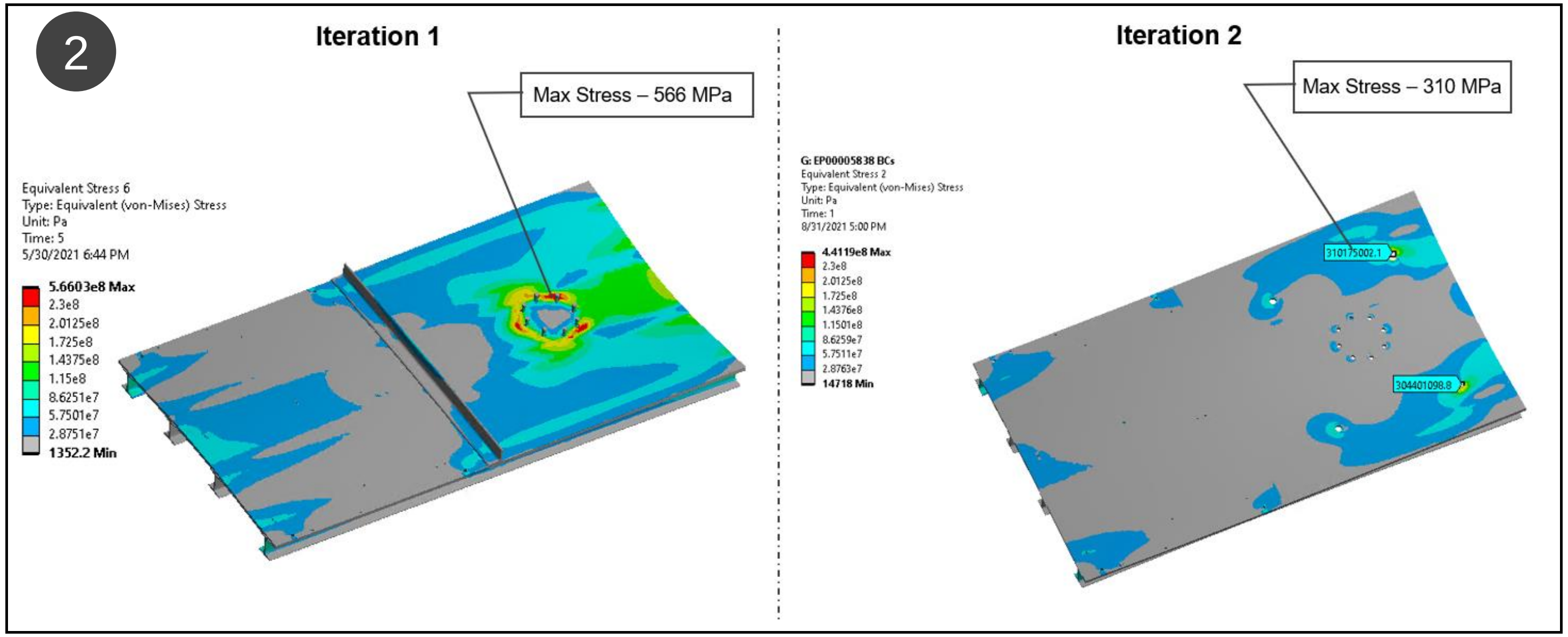




Structure analysis development

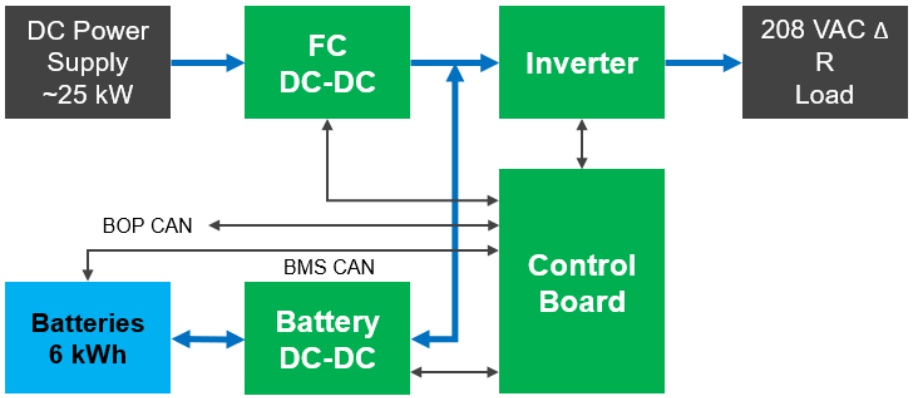


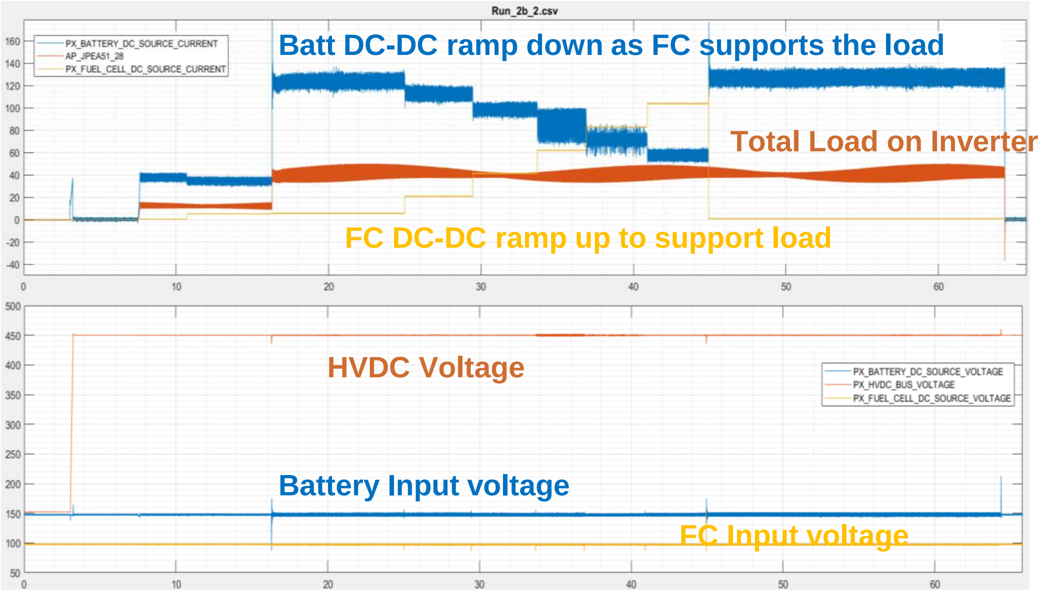
Label	Boundary Condition
1	Constrained in Y direction
2	Constrained in X, Z
3	Constrained in Z
N/A	Standard Gravity in Y direction



1. The ALD process has been set-up to study different mounting strategy for the stack
2. As example, with four additional mounting supports (iteration 2), stress values in the skid were seen to reduce as compared to the iteration 1.

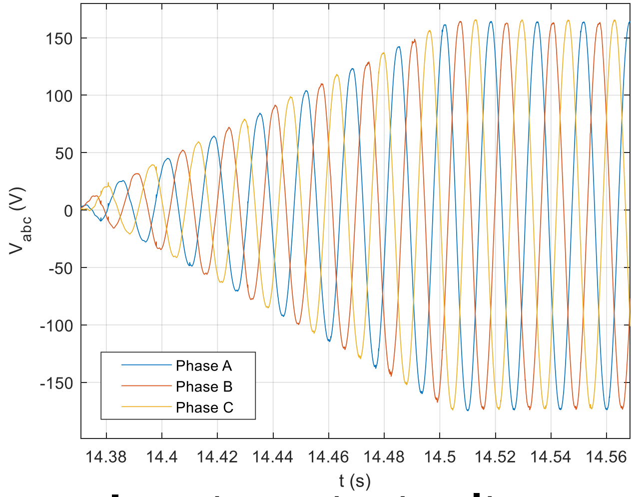
Power electronics development



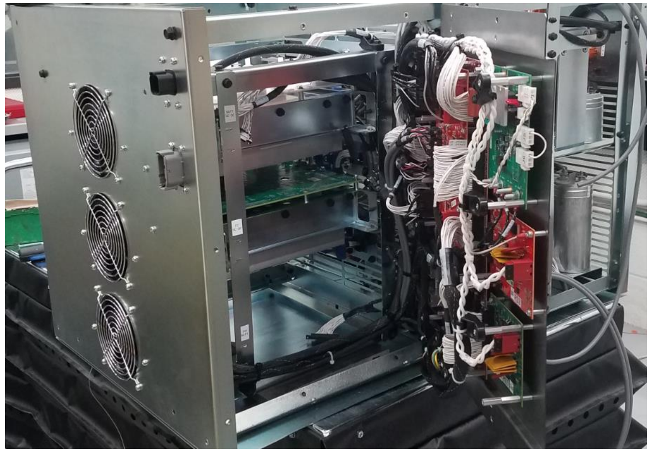


Verified operation

- Inverter creates 3-phase sine wave output and supports the load
- PE controls interface with Battery BMS for pre-charge and contactor closing sequence
- Battery DC-DC regulates HVDC voltage by boosting battery low voltage
- FC DC-DC provides current to HVDC link per FC BOP control current command sent over BOP CAN to control board
- When there is additional current available after supporting the load, FC DC-DC charges battery simultaneously
- FC current can ramp up to support the needed load (customer load + battery charge)
- In a test, battery can pick up 6 kW transient load in < 20 ms



Inverter output voltage

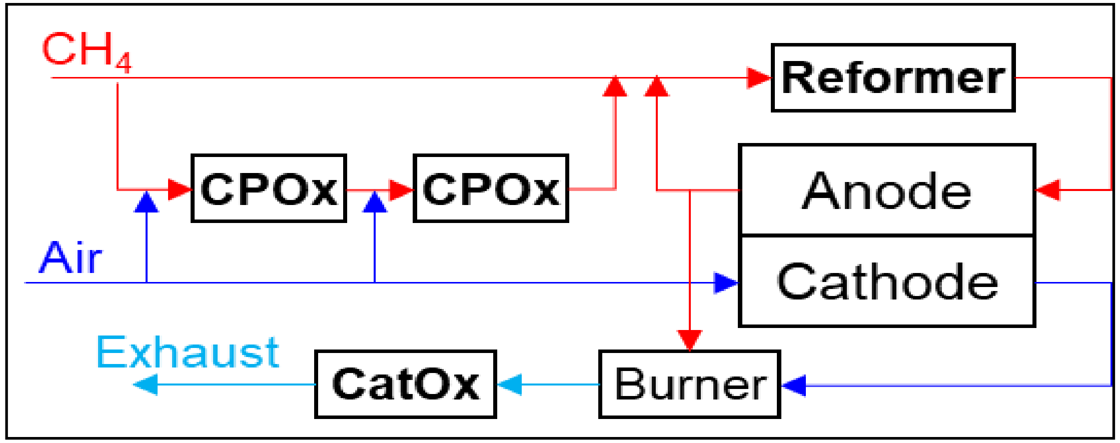


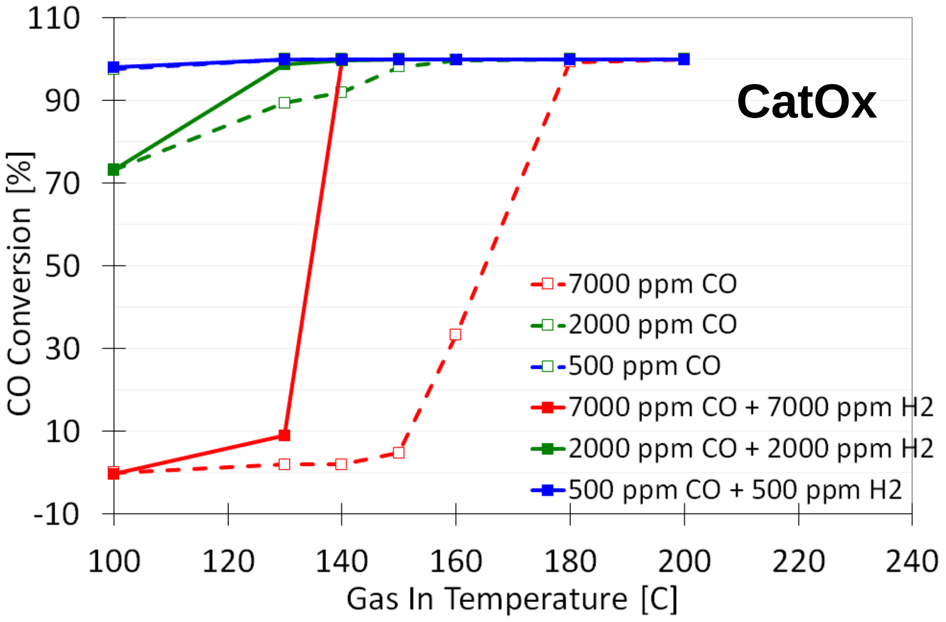
PE system in a closed package

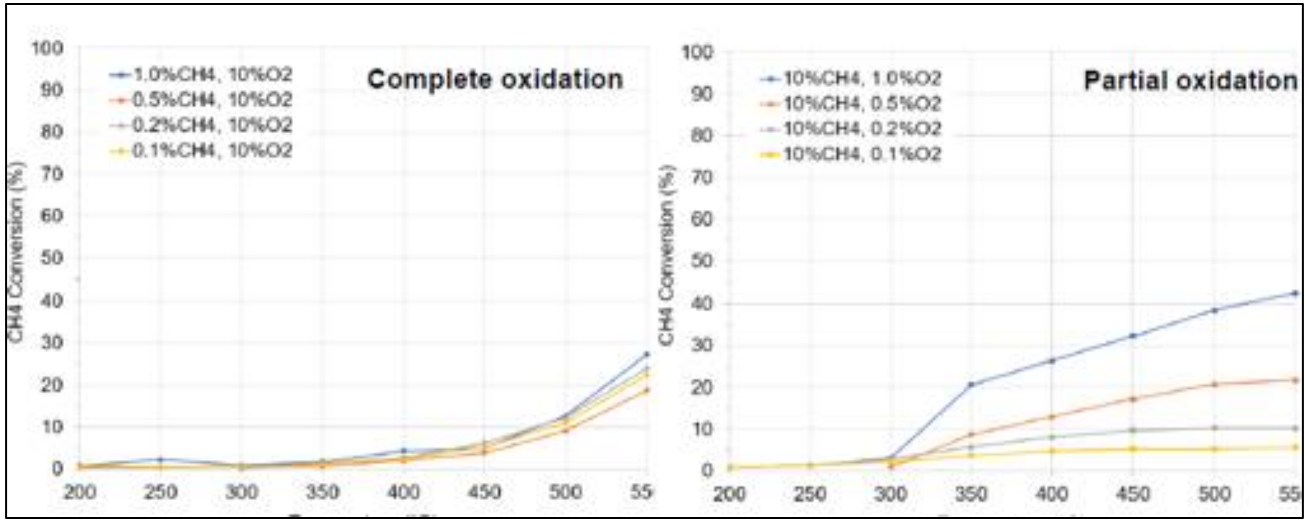
Catalyst development

3 catalysts components:

- **CatOx:** Catalyst selection and sizing completed
- **CPOx:** Characterization work completed. Model development ongoing.
- **Reformer:** Development ongoing.



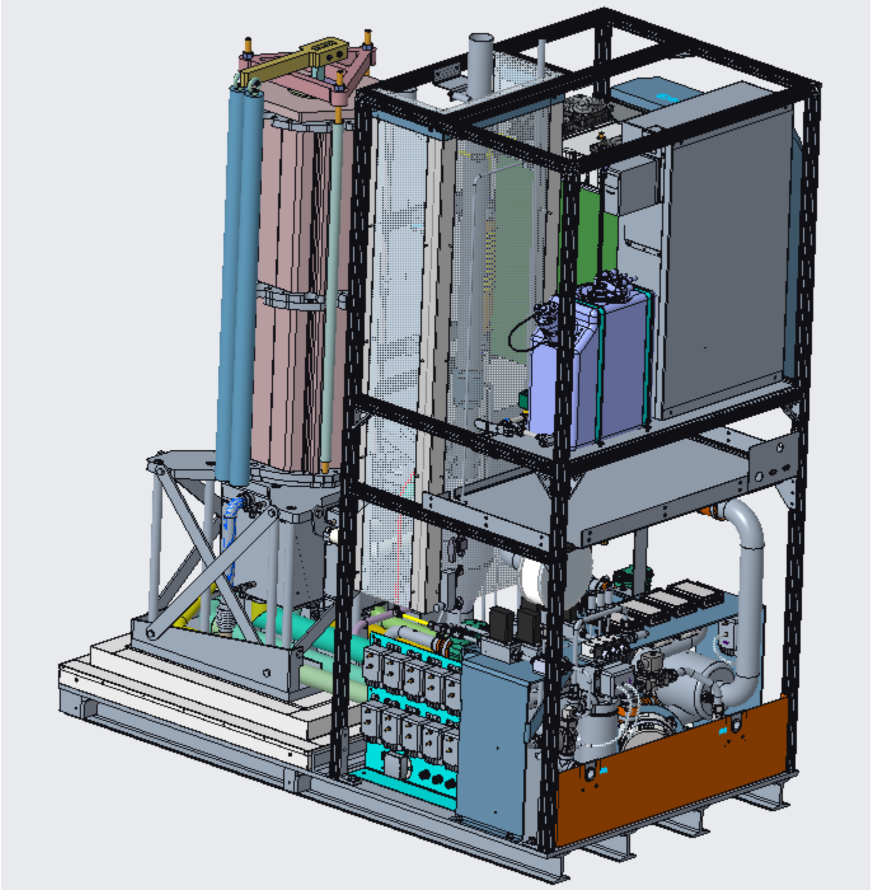




CPOx

System design

- Design and development of a 20kW range FCPS using the principles of Analysis Led Design (ALD) and targeted testing to optimize Balance of Plant (BOP) design. Baseline design has completed.
- Key Features of the Balance of Plant architecture includes:
  1) Anode Gas Recirculation (AGR) eliminating need of a steam generator
  2) Start-up burner and catalyzed partial oxidation (CPOx) to assist in start-up and shut-down
  3) Heat recovery from exhaust gases
  4) Catalytic Oxidation (CatOx) to clean the exhaust gases before venting to environment
  5) Leveraging automotive-derived components for the desired reliability and cost



20kW System

Next steps

- Complete system design and build
- System commissioning and 5000-hour demonstration at University of Connecticut.