Cummins PEM Fuel Cell System for Heavy Duty Applications

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DE-EE0009247

DOE Hydrogen Program
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AMR Project ID FC337

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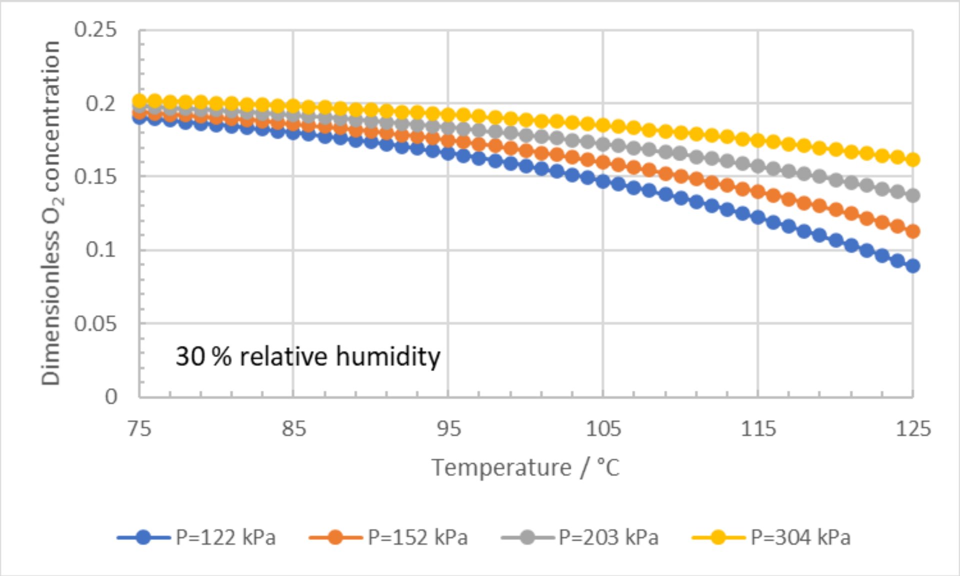
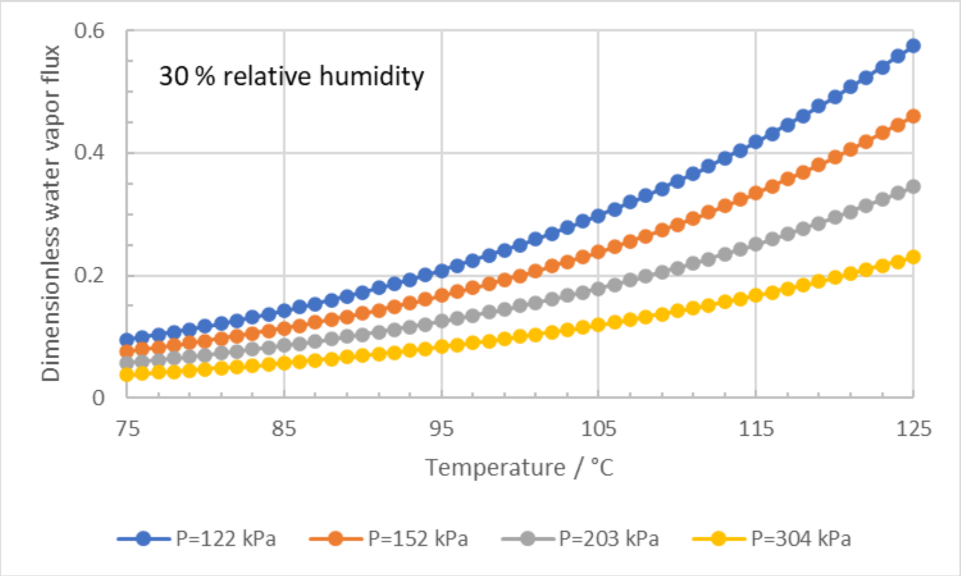
Project Goal

- Develop a mass produced PEMFC stack and system for heavy duty applications able to operate at temperatures ≥100°C to reduce the size of the radiator and lower activation losses
- Focus on key components enabling high temperature operation
  - Membrane/electrode assemblies (MEAs) based on ionomers tolerant to high temperatures
  - Electrically assisted air turbo-compressor (e-turbo) to limit oxidant dilution and increase the relative humidity
  - Micro-channel molded bipolar plates to achieve practical pressure drops and lower cost





Kinetics and ohmic losses are reduced by higher O_2 concentrations (ORR is a 1st order reaction) and lower water requirements to achieve higher relative humidities and ionomer conductivities

Overview

- Timeline and Budget
  - Project start date: 8/3/2021
  - Project end date: 8/2/2024
  - Total project budget: $3,750,000
    - DOE share: $3,000,000
    - Cost share: $750,000
    - DOE funds spent: $365,200 (as of Mar. 31, 2021)
    - Cost share funds spent: $102,083 (as of Mar. 31, 2021)
- Partners
  - Project lead (Jean St-Pierre, Cummins New Power Business Unit)
  - Partner organizations
    - Cummins Technology Center (stack and e-turbo testing, modeling)
    - Cummins Turbo Technologies (e-turbo prototype supplier)
    - Dana (bipolar plate supplier)
    - W. L. Gore (membrane supplier)
    - Argonne National Laboratory (data analysis)

Relevance/Potential Impact

- Demonstrate capabilities of recently available and high temperature compatible ionomers
- Leverage Cummins expertise in turbo-machinery for fuel cell applications
- Push the boundaries of compression molding technology with graphite/polymer composites
  - Form fine flow field channels and achieve practical pressure drops at high pressures

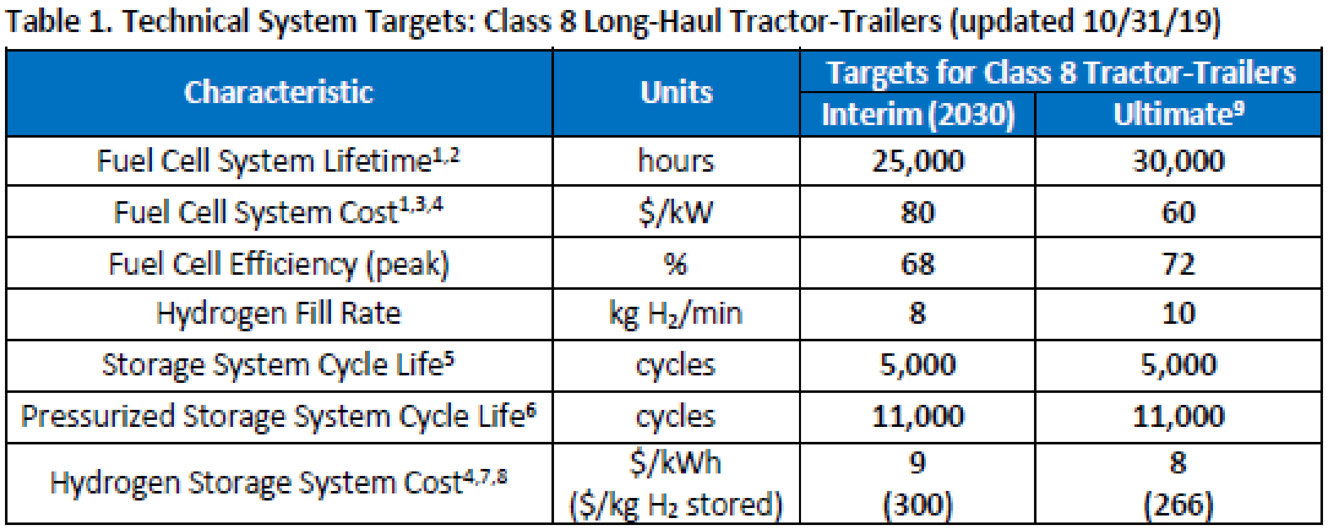


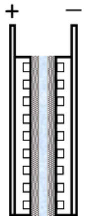
Table 1. Technical System Targets: Class 8 Long-Haul Tractor-Trailers (updated 10/31/19)

Characteristic	Units	Targets for Class 8 Tractor-Trailers	
		Interim (2030)	Ultimate[9]
Fuel Cell System Lifetime[1,2]	hours	25,000	30,000
Fuel Cell System Cost[1,3,4]	\$/kW	80	60
Fuel Cell Efficiency (peak)	%	68	72
Hydrogen Fill Rate	kg H_2/min	8	10
Storage System Cycle Life[5]	cycles	5,000	5,000
Pressurized Storage System Cycle Life[6]	cycles	11,000	11,000
Hydrogen Storage System Cost[4,7,8]	\$/kWh (\$/kg H_2 stored)	9 (300)	8 (266)

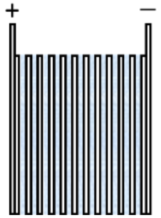
Hydrogen Class 8 Long Haul Truck Targets, U.S. Department of Energy, Record # 19006, October 31, 2019

DE-FOA-0002229, p. 20: “Furthermore, demonstration of stacks operating at higher temperature (≥ 100 °C, for heat rejection) and stack designs that would decrease the cost of BOP and power electronics components are desirable.”

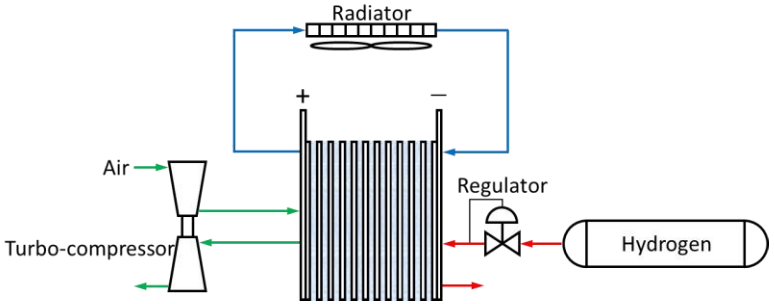
Approach



1. Cell



2. Stack



3. System

- Membrane/electrode assembly material selection, design, and performance verification
- Bipolar plate design and performance verification

Period 1

Aug. 2021 to Jan. 2023

- 1 kW stack build and performance verification

- 1 kW stack build and duty cycling verification (5000 h)
- 100 kW stack build and performance verification

Period 2

Feb. 2023 to Aug. 2024

- E-turbo prototype performance verification
- System model development and analysis
- Stack projection costs

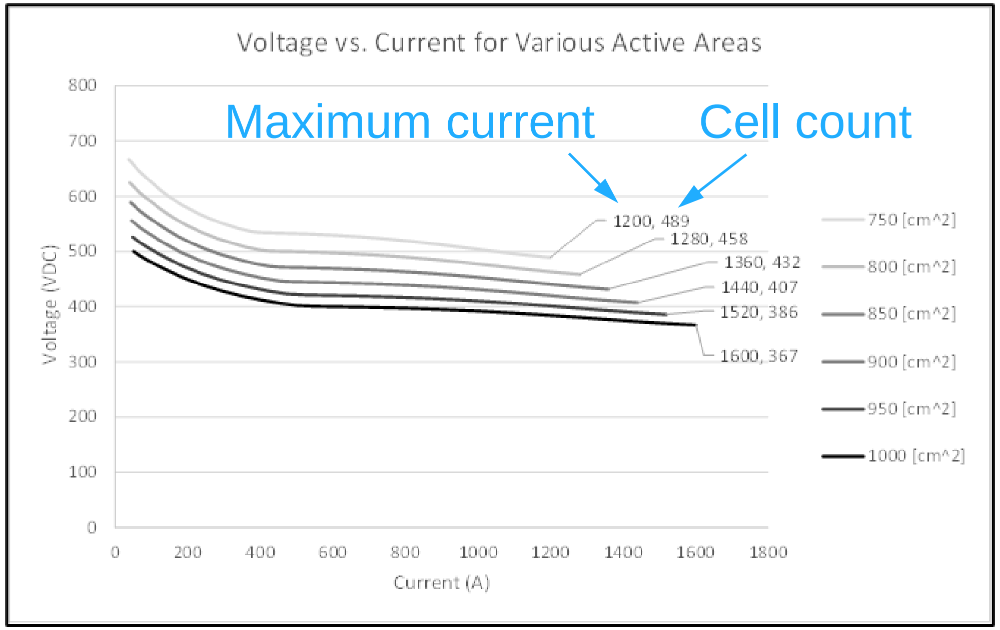
Approach

Detailed in Accomplishments and Progress

Milestone/deliverable (as of Apr. 25, 2022)	Due date	Completion extent
1.101. Fuel cell stack cell active area defined based on analysis of expected product requirements	Q1	100%
1.102. HD fuel cell system product requirements defined for use in setting 100 kW modular PEMFC stack design and requirements	Q2	100%
1.212. Bipolar plate design released for 100 kW HD stack based on validation of design specifics via non-electrochemical coupon tests	Q3	90%
1.215. Stack model report released which meets stack requirements as laid out in the product requirements document	Q4	50%
1.224. Bipolar plate delivered for short stack test which meets design requirements related to dimensional tolerance (+/- 0.3 mm of general dimension and +/- 0.05 mm of thickness), through plane electrical conductivity (<0.08 ohm cm^2), and permeation rates of gas (<0.001 ccm/cm^2 at 40 psi N_2) and coolant (target and test method to be developed) as well as passes pneumatic pressure testing at 250 kPa and successful CFD prediction of pressure drop across the plate	Q5	
1.235. MEA prototype for short stack test delivered which meets design requirements related to dimensional tolerance as well as passes functional inspection compared to specifications in the product requirements document including catalyst loading (<0.3 mg PGM/cm^2) and performance (0.75 V at 0.3 A/cm^2, peak power 0.80 W/cm^2)	Q5	
Go/No-Go. Successful demonstration of a 1 kW HD PEMFC short stack as indicated by meeting the following metrics: 1) Performance (0.75 V at 0.3 A/cm^2, peak power 0.80 W/cm^2) 2) Successful testing at high temperature (>100 °C) and pressure (>250 kPa) 3) Short term degradation (<10 mV/1000 h at 0.4 A/cm^2) 4) Cost review	Q6	
4.101. Fuel cell system specifications, including compressor, humidifier and cooling system requirements, defined for heavy duty applications in the range of 200-300 kW	Q7	
4.301. Air compressor validated as demonstrated by meeting pressure, flow rate, and power requirements specified in the HD fuel cell system model	Q8	
5.401. Fuel cell stack manufacturing cost targets, including at high-volumes of 100,000 units/year, identified based on results of studies on roll-to-roll MEA production, BPP production line, stack hardware & endplates, and automated stacking process	Q9	
6.101. 5,000 hours MEA demonstrated on a short stack using a relevant drive cycle intended to test peak performance at 100 °C, achieving a degradation rate of <15 mV/1000 h	Q10	
6.601. Validation of 100 kW stack prototype complete meeting performance target (0.73 V at 0.3 A/cm^2 and peak power of 0.75 W/cm^2) at rated and peak power conditions of current densities, temperature, pressure, humidity conditions, stoichiometries, and cooling requirements	Q11	
7.101. Final report completed and delivered to DOE	Q12	

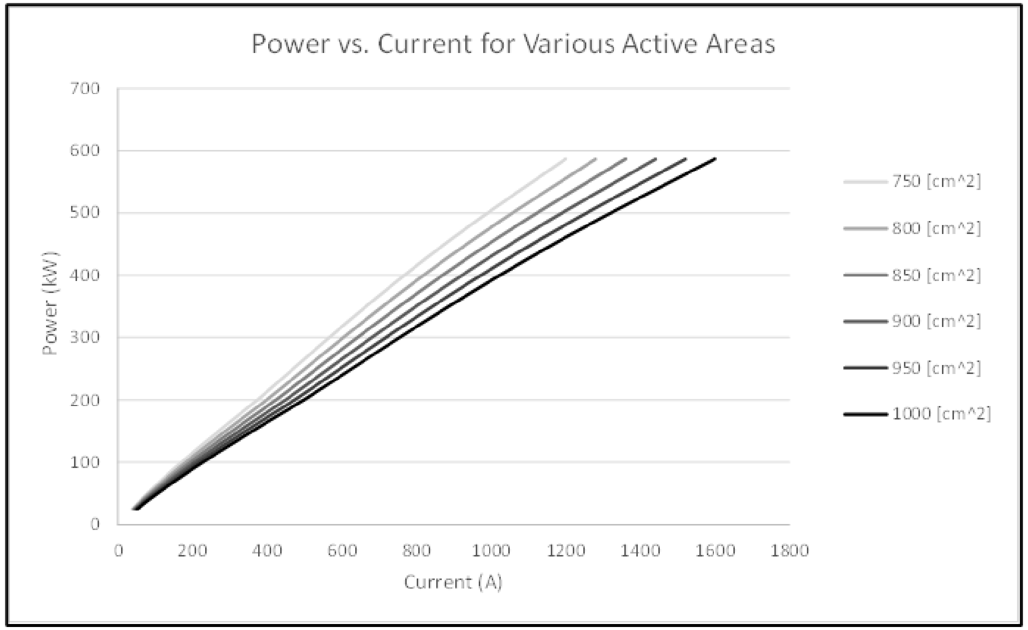
Accomplishments and Progress

- Accomplishments were not reported in 2021 (project start date: 8/3/2021)
- Cell active area (900 cm^2, milestone 1.101) and stack design and requirements (milestone 1.102) were determined using (this slide and the next 3 slides for selected details)
    - system (DC to DC voltage converter voltage limits, etc),
    - manufacturing (press size, etc),
    - and stack components design and cost (bipolar plate, MEA) considerations



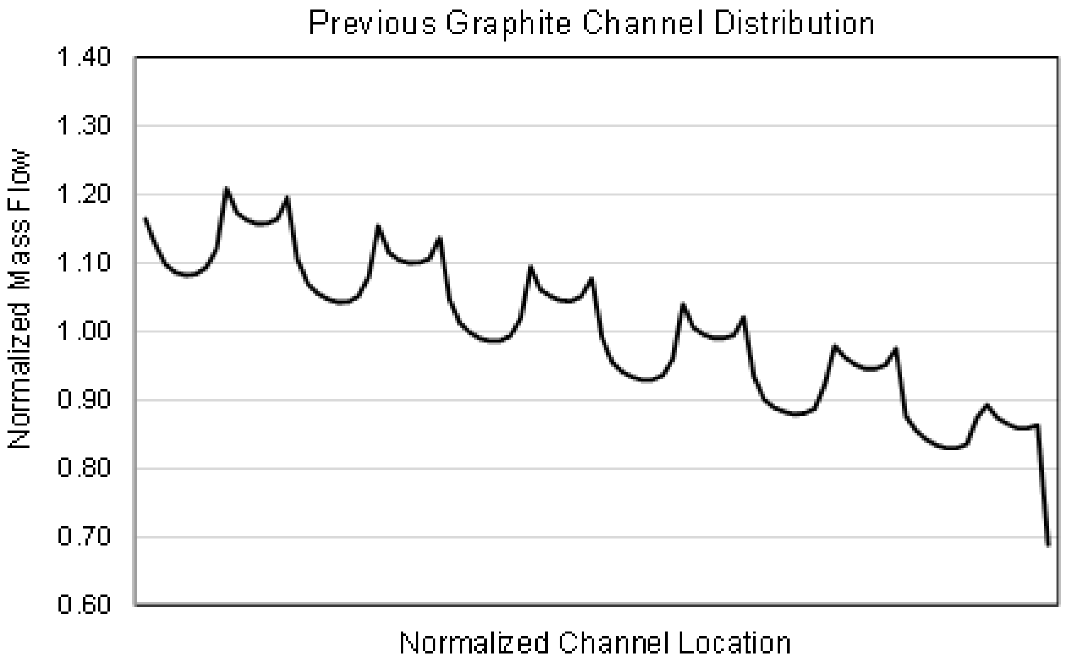
Maximum current

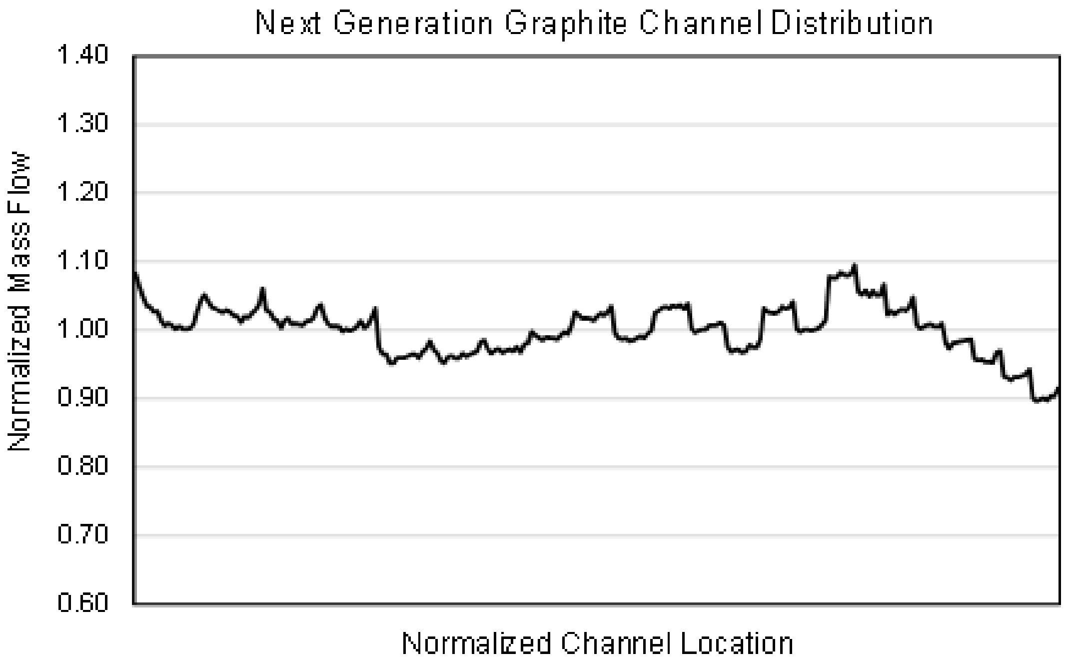
Cell count



Accomplishments and Progress

- Reduced the anode flow variation between channels from ±20 % to ±10 %
  - A more uniform flow distribution maximize material utilization and minimize degradation
    - Lower mass transfer losses
    - Reduced risks of high current density hot spots and starvation regions

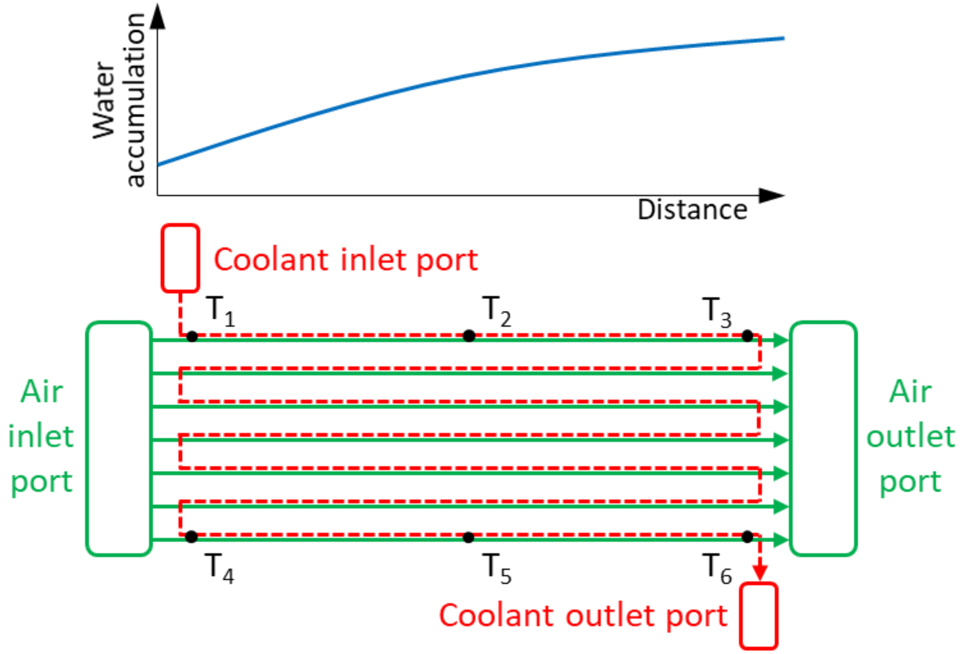




Accomplishments and Progress

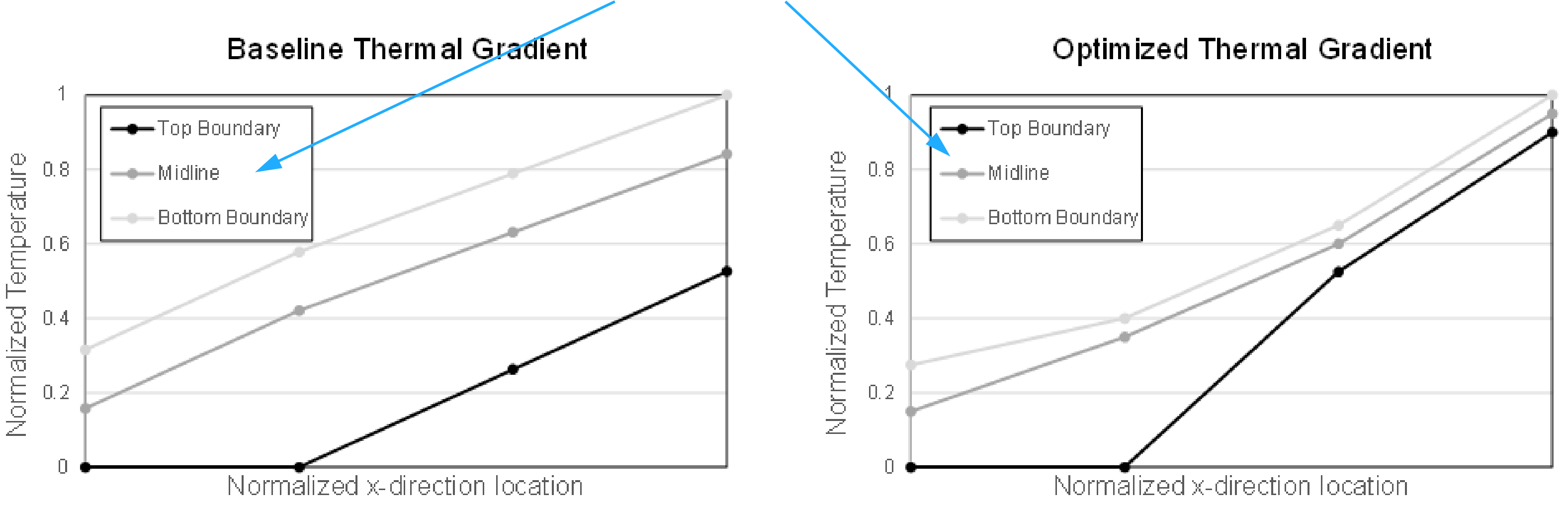
- Optimized the coolant temperature distribution to more uniformly manage water accumulation near the air outlet region with air and coolant manifolds located on different sides of the active area perimeter
  - The limited active area perimeter constrains manifold locations creating design challenges
  - A conceptual example of unoptimized air and coolant flow fields ($T_1 \approx T_2 \approx T_3 < T_4 \approx T_5 \approx T_6$) shows a mostly vertical temperature distribution unable to effectively manage water accumulation along the horizontal direction (ideally $T_1 \approx T_4 < T_2 \approx T_5 < T_3 \approx T_6$) leading to dehydration and flood zones

Unoptimized air and coolant flow fields



Footprint width of all flow field channels

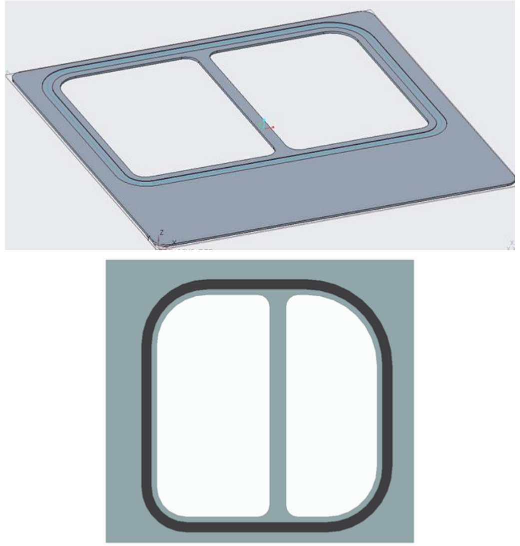
(top and bottom boundary: outermost channels, midline: center channel)

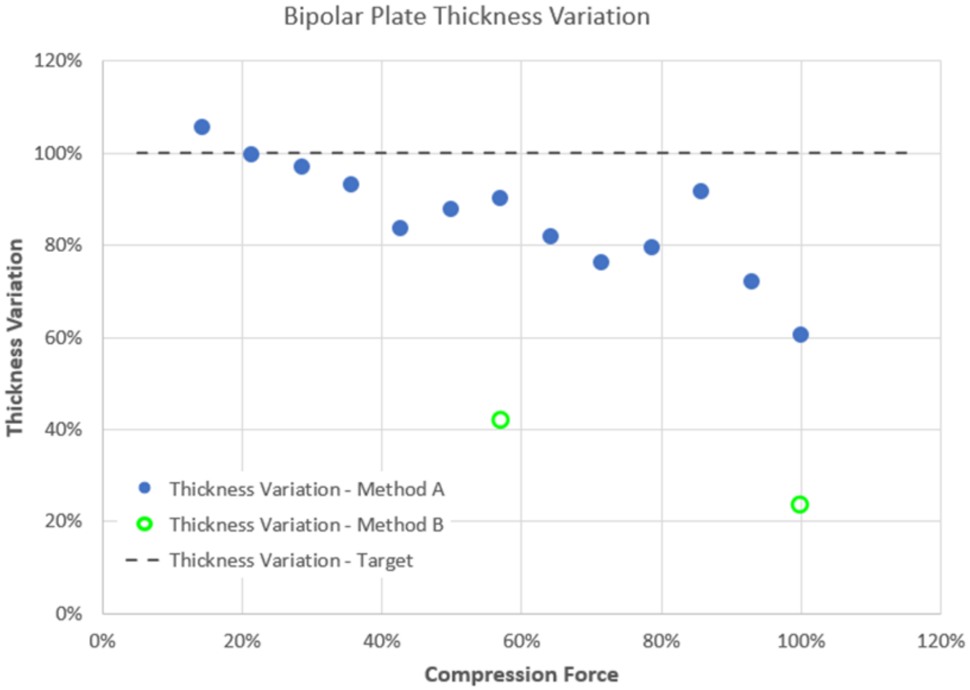


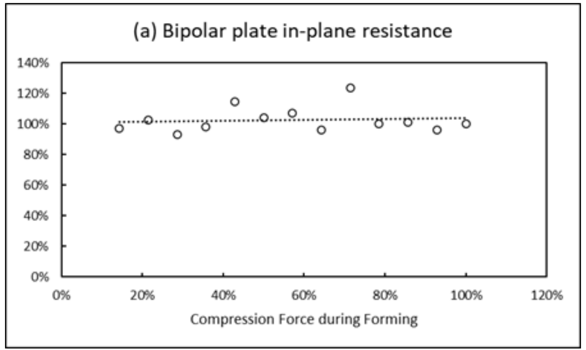
Accomplishments and Progress

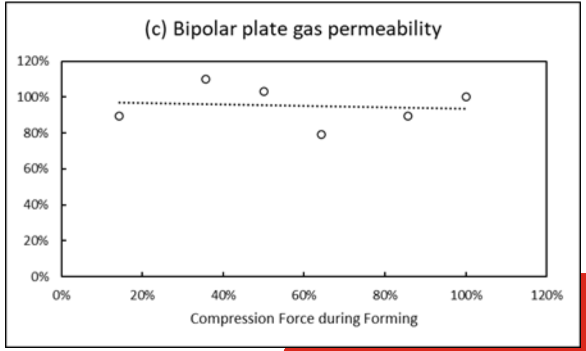
- The pressure and active area requirements exceeded the established practice (low pressures, 500 cm^2 active area) and led to several bipolar plate composite design and manufacturing process revisions
  - Developed manifold coupons for pressure burst test with different wall thicknesses
    - Form-dependent and anisotropic strength characteristics complicate numerical analysis by FEA
  - For lower molding pressures, plate samples met the thickness variation target and key characteristics were unaffected
    - Legacy press capability and larger plate active area resulted in lower compression forces

Manifold wall test coupons (symmetric and asymmetric)









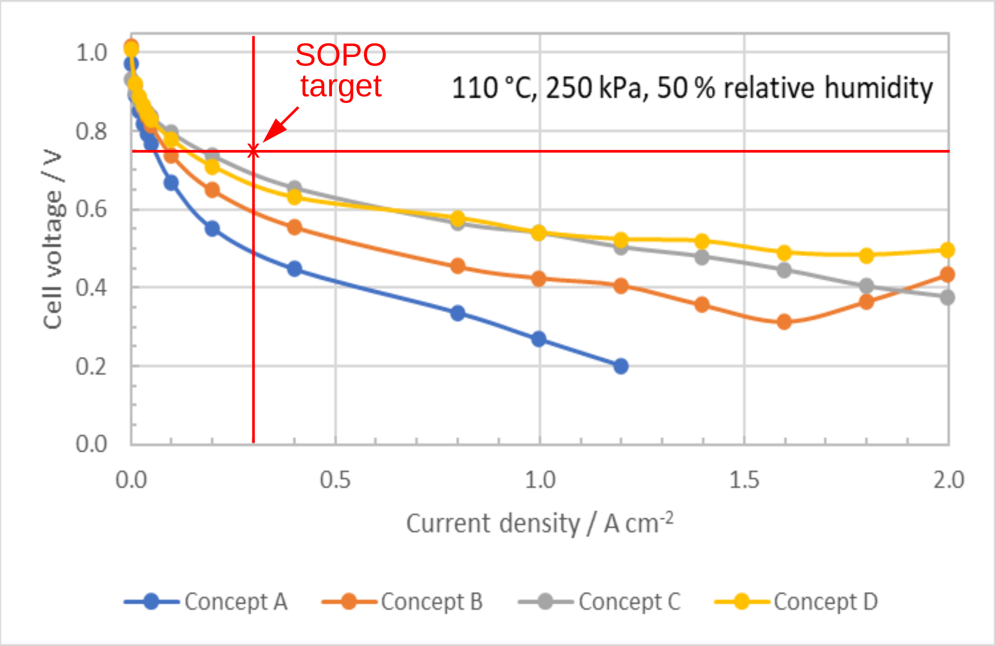
Accomplishments and Progress

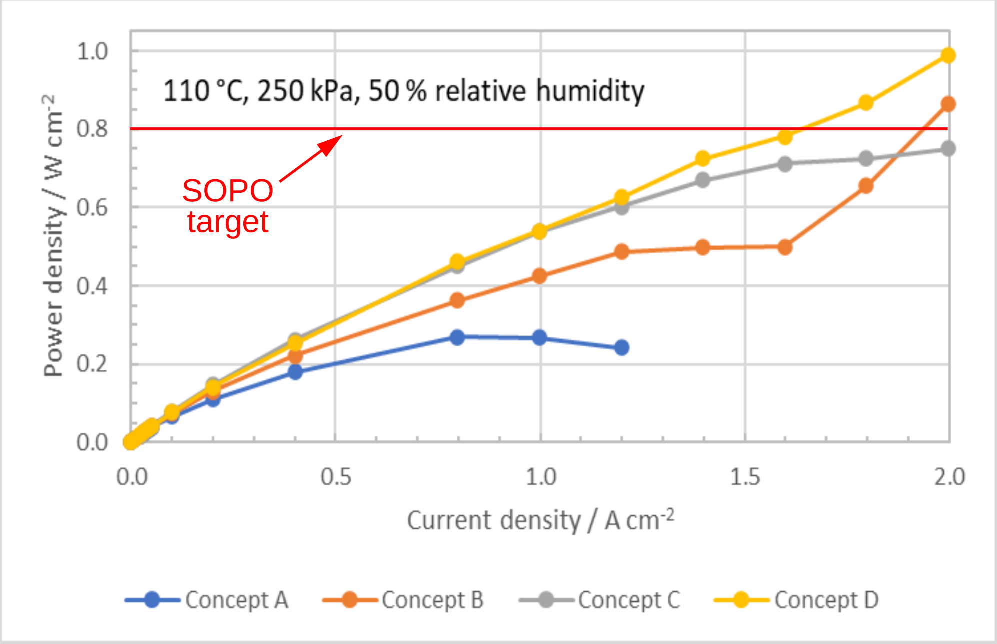
- As a prelude to milestone 1.235, MEA prototype for short stack test delivered
  - The membrane selection was completed
  - Test stations for MEA designs screening were modified to accommodate higher pressures and temperatures
  - An initial list of MEA designs including catalyst and ionomers for membrane integration was prepared
  - Several cell concepts embedding different MEA designs were tested (next slide)

Membrane ID	Thickness (µm)	Reinforcement	Stabilizer
Gore-1	15	ePTFE	Enhanced chemical stabilizer
Gore-2	8		Chemical stabilizer

Accomplishments and Progress

- First cell concepts embedding both selected Gore membranes showed that
  - the performance between concepts widely varies (~270 mV at 1 A cm^{-2})
  - the best concept has a voltage that is ~55 mV lower than the 0.75 V at 0.3 A cm^{-2} target
  - two cell concepts exceeded the 0.8 W cm^{-2} target





Accomplishments and Progress

<u>Responses to previous year reviewers' comments</u>

"The project seems to lack any fundamental aspect related to understanding performance and material degradation. The team should work with the national laboratory M2FCT consortium to fill that void."

- The team was invited to join the M2FCT consortium. The NDA is under negotiation (slide 15)

"A weakness is the lack of a clear approach to achieve the aggressive requirements that often have non-complementary traditional solutions (high temperature and high cell voltage to meet heat rejection and efficiency versus low temperature and low cell voltage generally used to achieve durability."

"It might be beneficial to add a collaboration with some of the catalyst durability projects or groups to ensure success."

- The team is leveraging recent developments in high temperature tolerant ionomers and durable catalysts. The integration of these and other solutions in an MEA is viewed as proprietary. An invention disclosure is currently being prepared and others are expected. Also, testing is completed under worse case scenario conditions as high temperatures are maintained at a constant level. This situation occurs intermittently in the field (duty cycle) and is application dependent. Three catalyst projects are relevant (FC323, FC326, FC327). These projects will be considered as potential catalyst suppliers

"The project will demonstrate a full stack plus turbo-compressor. However, to assess durability, it is recommended that a complete system, including humidification, be designed and tested as these play integral roles in demonstrating system durability."

- Although this is a sensible and relevant suggestion, the durability of a complete system is out of scope

Collaboration and Coordination

Collaborator	Organization type	Relationship	Role
Cummins New Power Business Unit	Industry	Prime and sub-contractor	Project management Stack and MEA design MEA and stack testing CFD, performance, and system modeling
Cummins Technology Center	Industry		Stack testing Modeling and CAD support E-turbo testing Techno-economic analysis
Cummins Turbo Technologies	Industry	Supplier	E-turbo prototype supplier
Dana	Industry	Supplier	Bipolar plate supplier
W. L. Gore	Industry	Supplier	Membrane supplier Membrane characterization data
Argonne National Laboratory	National Laboratory	FFRDC	Data analysis

Remaining Challenges and Barriers

- Tooling development for molded bipolar plates requires significant resources and time
    - Bipolar plates alternatives were planned
- M2FCT NDA has not yet been executed delaying project support by DOE FFRDCs
    - Negotiations are ongoing to resolve the last issue

Proposed Future Work

Remainder of FY 2022

- Complete bipolar plate compression molding process tooling and commissioning (milestone 1.212)
- Continue the screening of cell concepts increasing performance and prolonging life at high temperatures (milestone 1.235)
- Continue 1D model development to facilitate the analysis of the 1 kW stack test data for the go/no go decision (milestone 1.215)
  - Focus given to features enabling predictions at higher temperatures and pressures
- Complete and commission the hydrogen laboratory at Cummins Technology Center in preparation for the 1 kW stack test (milestone 1.235)

Summary

Category	Characteristic	Units	Period 1 SOPO targets	Status
1 kW stack	Cell voltage at 0.3 A cm^{-2}	V	0.75	~0.67
	Power	W cm^{-2}	0.8	>0.8
	Temperature	°C	>100	110
	Pressure	kPa	>250	250
	Short term degradation rate at 0.4 A cm^{-2}	μV h^{-1}	10	?
	System cost at 100,000 units/year	\$ kW^{-1}	[a]	?
Bipolar plate	Areal tolerance	mm	±0.3	?
	Thickness tolerance	mm	±0.05	<0.05
	Through-plane electrical conductivity	ohm cm^{2}	<0.08	<0.08
	Gas permeation rate at 40 psi N_2	standard cm^{3} min^{-1} cm^{-2}	<0.001	<0.001
	Coolant permeation rate	TBD [b]	TBD [b]	?
	Successful pressurization test	kPa	250	?
	Pressure drop prediction accuracy	kPa	[c]	?
MEA	Total PGM loading	mg cm^{-2}	<0.3	0.5

[a] for review purposes only

[b] method and target to be developed

[c] target not defined

Q+A