Project ID: FC338

Domestically Manufactured Fuel Cells for Heavy-Duty Applications

DE-EE0009248

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Presenter: Karen Swider Lyons

DOE Hydrogen Program: fc338_lawler_2022_o
2022 Annual Merit Review and Peer Evaluation Meeting
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U.S. DEPARTMENT OF ENERGY

MILLION MILE FUEL CELL TRUCK

Project Overview
– Fuel Cells for Heavy-Duty Applications

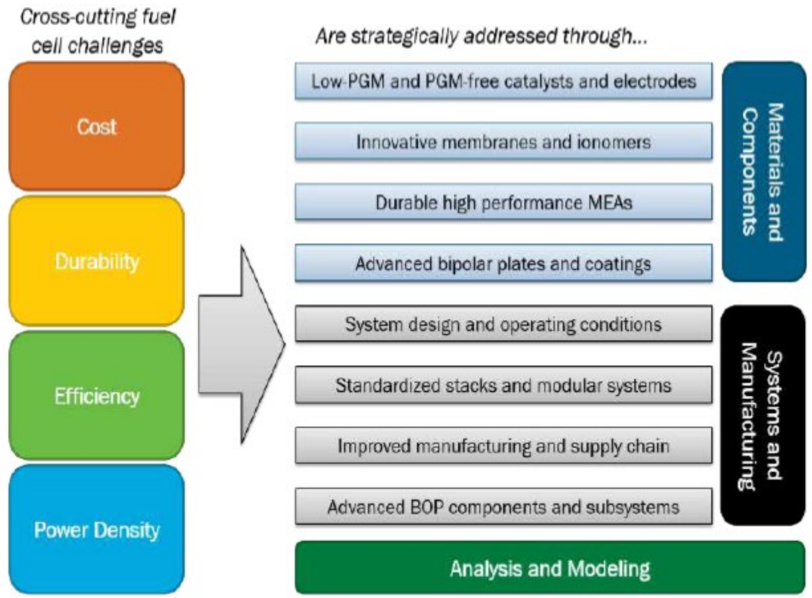
Funded by Department of Energy, Fuel Cell Technology Office
Related to M2FCT – Million Mile Truck
3 year, 2 phase $3.6M research and development program to achieve these performance targets:

Technical System Targets: Class 8 Long-Haul Tractor-Trailers

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
		Interim (2030)	Ultimate
Fuel Cell System Lifetime	[hours]	25,000	30,000
Fuel Cell System Cost	[$/kW]	80	60
Fuel Cell Efficiency (peak)	[%]	68	72

DOE Hydrogen and Fuel Cells Program Record 19006: Hydrogen Class 8 Long Haul Truck Targets (energy.gov);
Targets are under development for marine, rail, mining and aviation applications

- Phase I- 5 kW stack/system made with high volume manufacturing
- Phase II – 100 kW stack/system made with high volume manufacturing
- Significant advancements in stack life towards DOE 2030 goal of 25,000 hours
- Progress toward total system efficiency target of 68%
  - Specific MEA performance targets
- Reduce stack cost to $80/kW by reducing Pt loading and utilizing DFM & automation



Project Goal

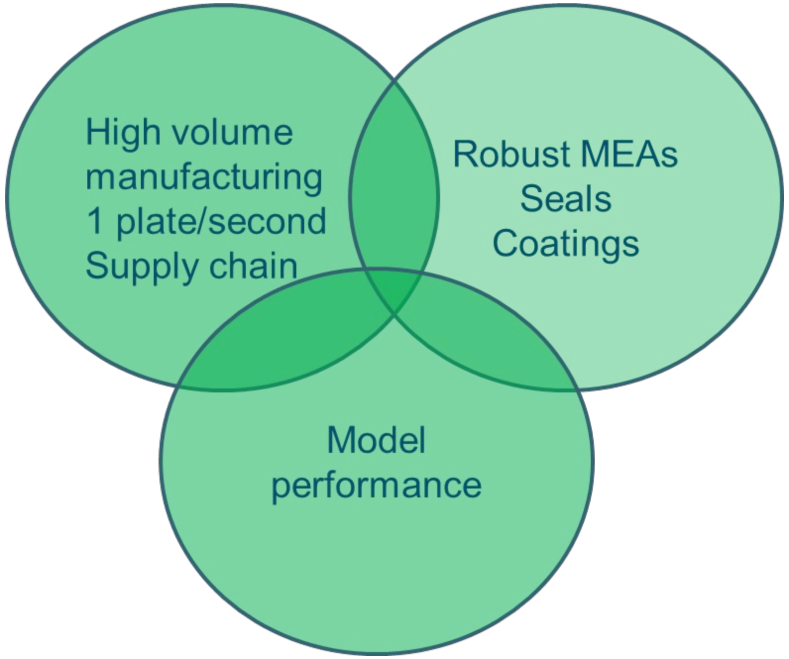
Create high performance, robust fuel cells that can be domestically manufactured in high volumes

Correlate data from high volume fuel cell to ANL/DOE model.

Research challenge:

Validate existing models and AST data for small single cells with stacks made using high volume manufacturing

Materials must be available in the supply chain



Underpinning technologies

- Robust coatings for metal bipolar plates
- Rapidly-applied, robust seals
- High performance MEAs
- High performance, efficient compressor
- Cell voltage monitoring

Programmatic Overview

Timeline and Budget

- Project Start Date: 10/01/2021
- Phase I end date: 03/30/2023
- Phase II end: 09/30/2024

- Total Project Budget: $ 3,642,181
  - DOE Share: $2,687,181
  - Cost Share: $955,000

  Phase I budget
  DOE Share: $1,392,774
  Cost Share: $495,000
  - DOE Funds Spent: ~$150,000
  - Cost Share Funds Spent: 26%

Contributors

PI: John Lawler

- Karen Swider Lyons
- Phil Schoch – liaison to modeling
- Gün Erlat
- Jonathan Rosen
- Kevin Mease
- Steve Buelte
- Robert Hoyt
- Amit Chaugule
- Mani Ramani
- Chuck Carlstrom
- Chris Rainford

Partner organization

Argonne National Laboratory

- Rajesh Ahluwalia
- Xiaohau (Joshua) Wang

25 years
of innovation

258
granted patents

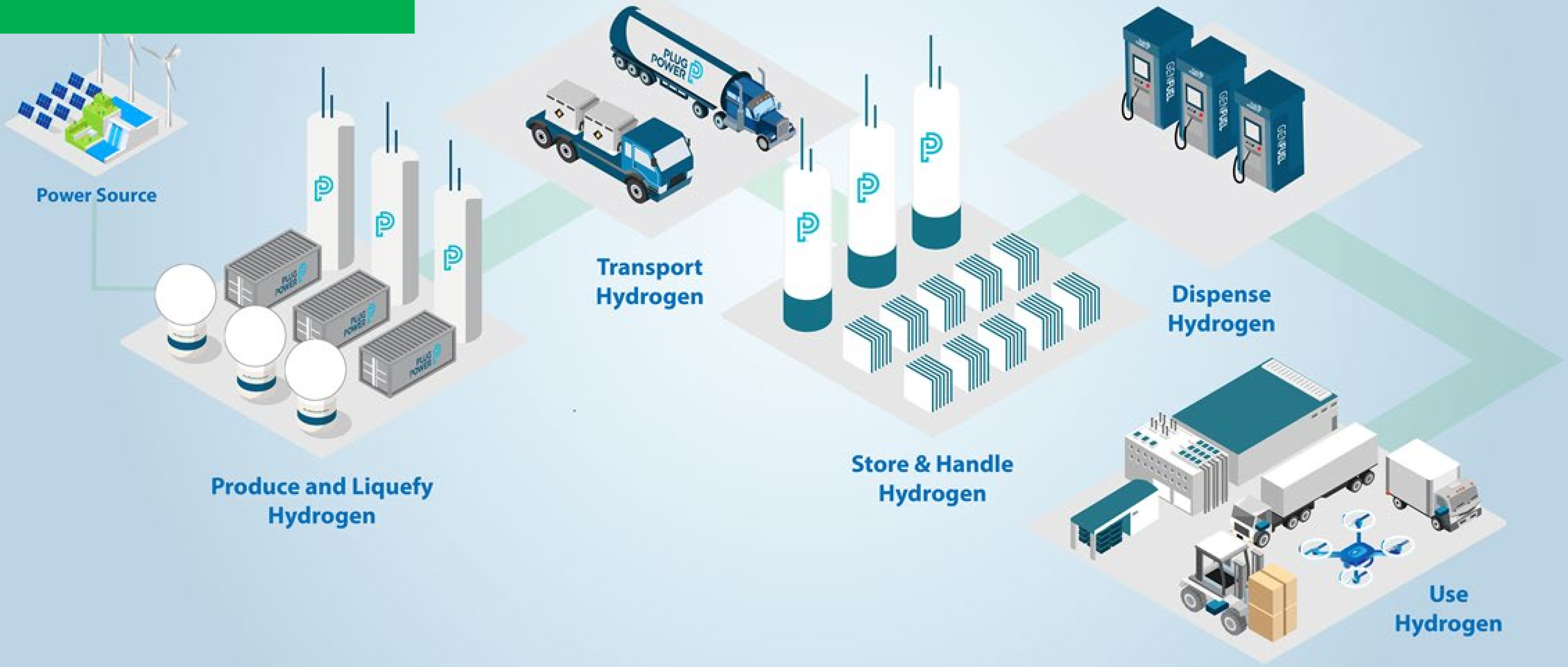
40+ tons
of hydrogen
consumed daily

60,000+
systems in service

832 million
hours of operation

2,800+
employees

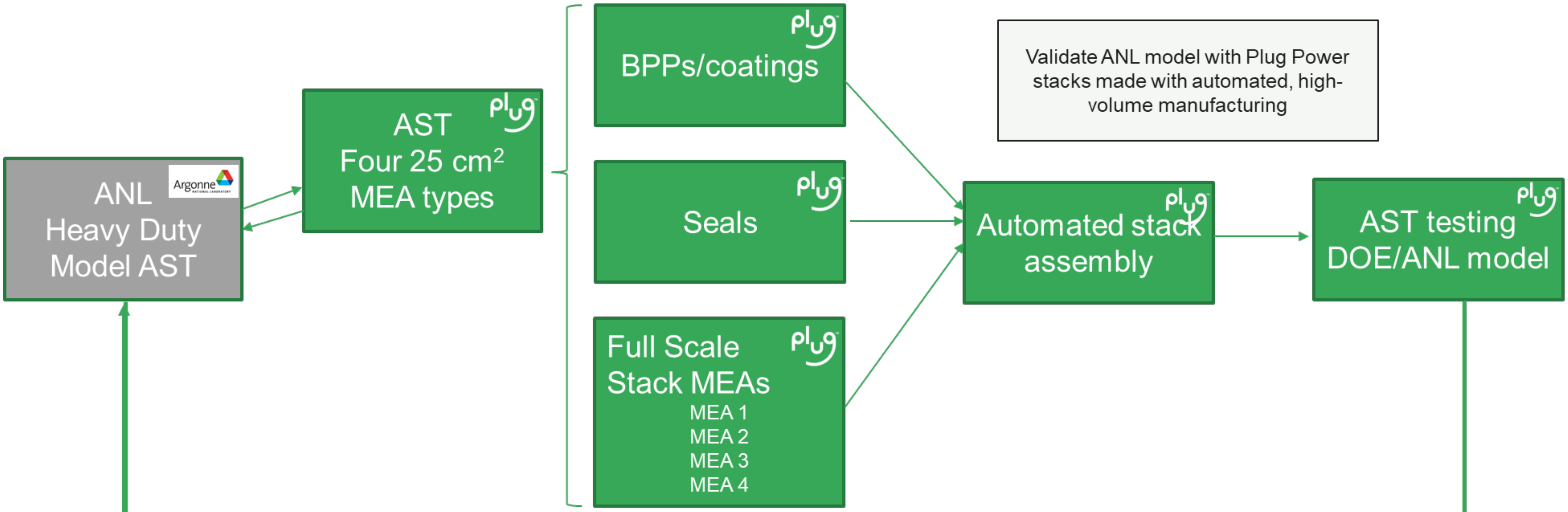
PLUG INTEGRATED Solutions Ecosystem



Approach

Phase I program: 5 kW stack

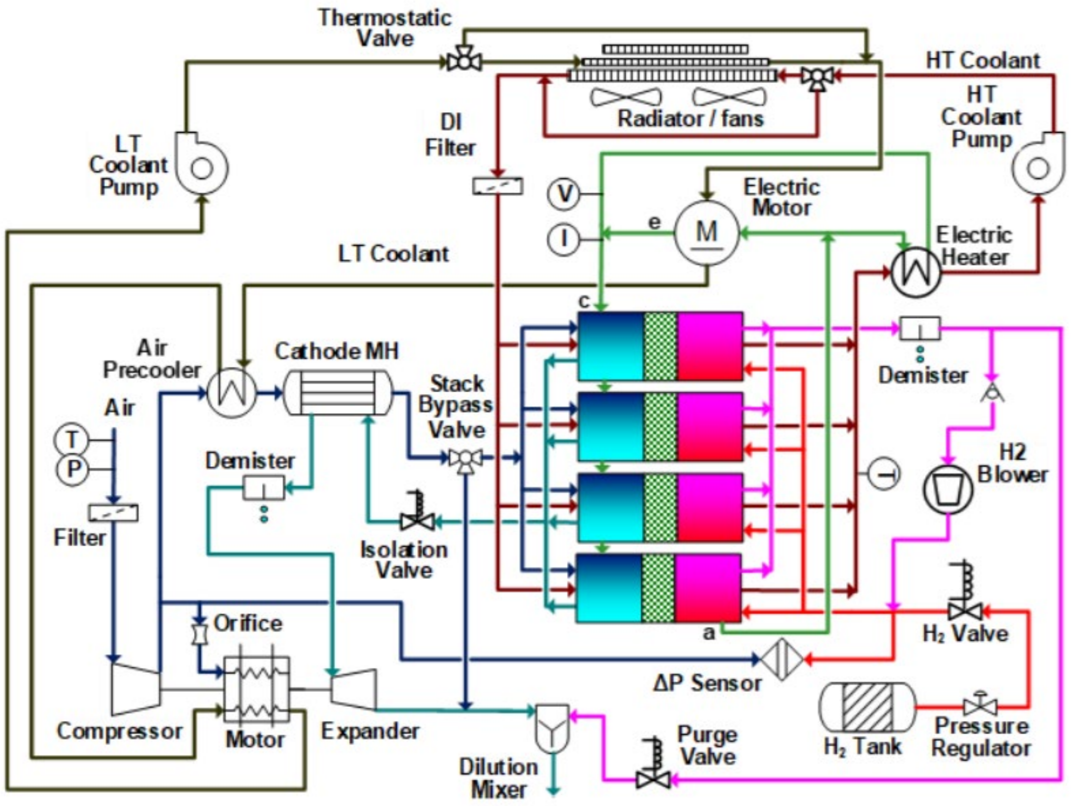
Phase II program: 100 kW stack



Plug Power will select 4 MEAs available at high volume
Plug Power - Run DOE recommended AST in 25 cm^2 cells
Plug Power - Create 5 kW stacks using high volume methods
Plug Power - Execute AST methods on full stacks with each MEA
ANL - Compare Plug Power stack results to ANL model results
ANL update model to full stack results
ANL publish any changes to AST validated against stacks

Approach: System modeling and analysis

- ANL leads the system modeling and analysis component of the program.
- Based on 50 cm^2 single cells
- Apply ANL model to 5 kW stack built with high volume manufacturing methods



Project Deliverables and SMART Goals

Complete 5 kW short stack demonstration by Q6 (4-2023)

- stack durability based on voltage degradation after AST developed by M2FCT group.
- seal durability by building stack, leak test, disassemble, shuffle parts, build and leak test again.

GO/NO GO DECISION POINTS

Go/No Go Number	Goal Description	Milestone Verification Process (What, How, Who, Where)	Qtr.
G1.1	Demonstrate 5kW stack	Demonstrate 5 kW stack and map performance on 100Kw test stand	Q6
G1.2		Establish Stack Leak Metrics (< 2 CC Nitrogen/Min/Plate @ 3 [Atm])	Q6
G1.3		Achieve power density requirement of 840 mW/cm^2 @ 0.769V	Q6
G1.4		Demonstrate: I-V curves at 70-75-80-85c coolant inlet temp, < 10 Degree C Delta-T @ 3 [Atm] Cathode inlet	Q6
G1.5		Estimate stack voltage at 25k hour EOL by AST simulated operation cycle (ASTWG) (CC, Vcell Vs. t)	Q6
G1.6		Plot AST, 100h, AST (CC, Vcell Vs. t)	Q6

Supporting technologies

- Coatings
- Seals
- Robotic assembly

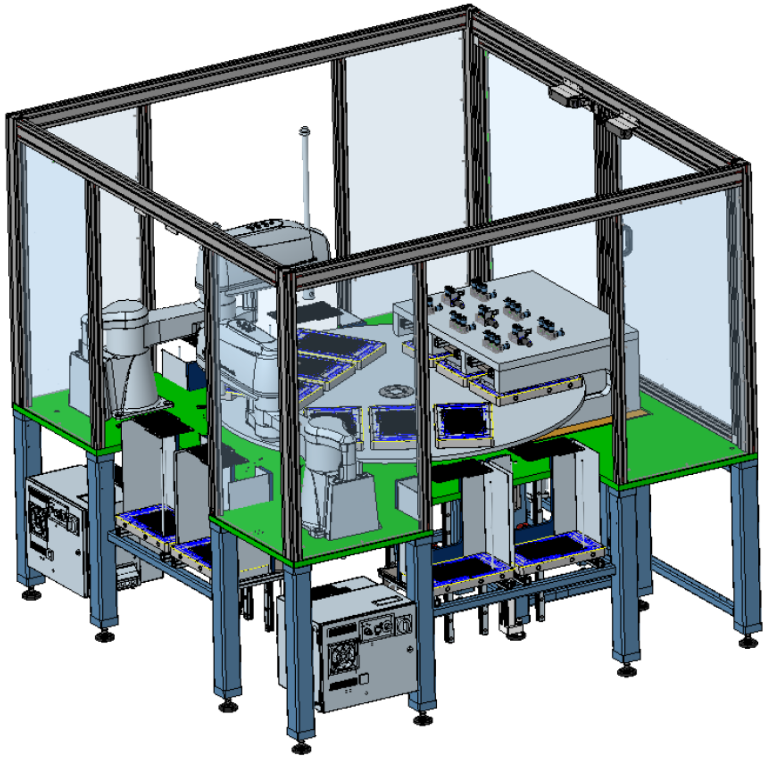
Based on DOE single cell measurements of Umicore MEA.
Now 830 mW cm^{-2}

Accomplishments and Progress: Specification of System for High-Speed Automated Leak Detection And Stacking

System was specified.

- Worked with vendor to develop a fully automated system for module leak check and repeat unit stacking
- Manifold system with interchangeable dies
- Integrated MEA bar code scanning, database management, 1hr unattended operation.

Specifications created Plug Power's prototype leak-test system



3D overview

MEA Specification Development

Operating Conditions	**A/cm²**	**V**
Beginning of life performance (A/cm^2 @ V)	1.08	0.769 V
End of life performance (A/cm^2 @ V)	1.08	0.7
Lifetime (h)	25,000	
Start/stop cycles during lifetime	5000	
Normal operating cell temperature (°C)	65 C	
Stack Inlet / Outlet (°C)	55	75
Max T (°C)	90 C	
Cold start temperature (°C)	-30	
Fuel composition (H2 wt%)	99.85%	
Fuel flow mode	Recirculated	
Inlet Pressure (kPa(a))	200	
Outlet Pressure (kPa(a))	180	
Inlet relative humidity (%)	50	
Stoichiometry	1.3-1.4	
Oxidant	Air	
Oxidant flow mode	Single Flow-through	
Inlet Pressure (kPa(a))	180	
Outlet Pressure (kPa(a))	135	
Inlet relative humidity (%)	60-85%	
Stoichiometry	1.8 - 2.2	

Internal and external MEA developers engaged to make high performance MEAs <u>available at high volumes</u>

- Chemistries evaluated for performance and life
- Final MEA formulations TBD
- Vendor-specific results will be shared with originator
- Normalized results will be openly shared *while protecting vendor IP and confidentiality*

Metal Bipolar Plates & Coatings

Approach

All materials & coatings must be compatible with high volume manufacturing and meet cost goals

- Understand the impact of the plate (material and fabrication process, with or without coatings) on the fuel cell performance (life, reliability) and,
- Evaluate promising material systems (substrate/coating) that may improve performance

In-situ (stack, single cell) and as ex-situ (corrosion, ICR) tests

Results:

Results to date for interfacial contact resistance (ICR -ASR) and corrosion tests for our baseline metal plate material in flat sheet and formed states.

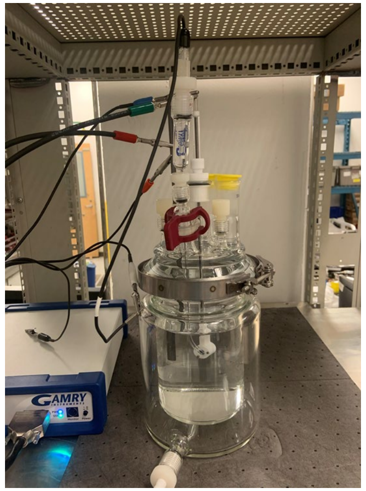
Characteristic	Units	DOE Targets	Flat Metal/Coating	Formed Metal/Coating
Corrosion, anode	$\mu A / cm^2$	< 1 and no active peak	PASS	PASS
Corrosion, cathode	$\mu A / cm^2$	< 1	PASS	In Progress
Areal Specific Resistance	$Ohm\text{-}cm^2$	< 0.01	PASS	In Progress

Similar comparison in performance for the baseline and alternative metal plate/coating systems we're evaluating will be provided in upcoming reports.

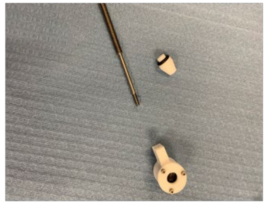
[1] https://www.energy.gov/sites/default/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf

Corrosion Cell – Potentiostatic/Dynamic Testing

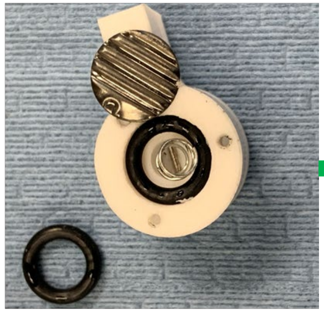
2021 Corrosion Cell



Assembled sample



Sample holder details



- Unsatisfied seal with gasket
- Unreliable contact

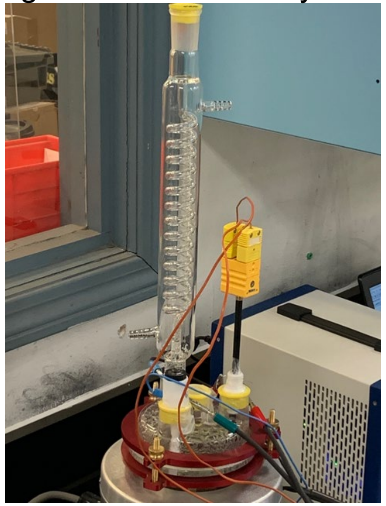
Program focus on coatings corrosion

See back up slides for more information

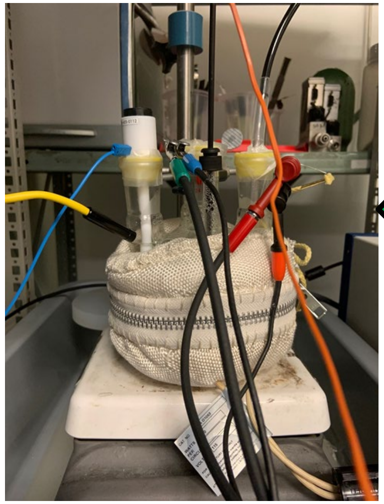
2022 Corrosion Cell

- Eliminated concerns with pitting corrosion
- Enhanced repeatability in I_{corr}/E_{corr}
- Working electrode stability improved
- Masks vs unmasked studies

Improved Concentration Control for long term run/ICP Analysis



Improved Temp Control and testing at 80 C

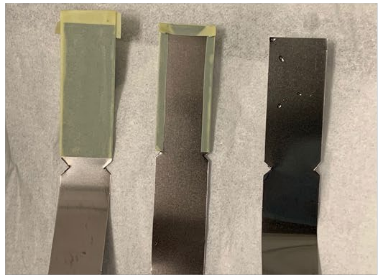


Hydroflex® relative hydrogen electrode

Sample as WE

Graphite CE later replaced with Pt

316L or samples with homogenous surface

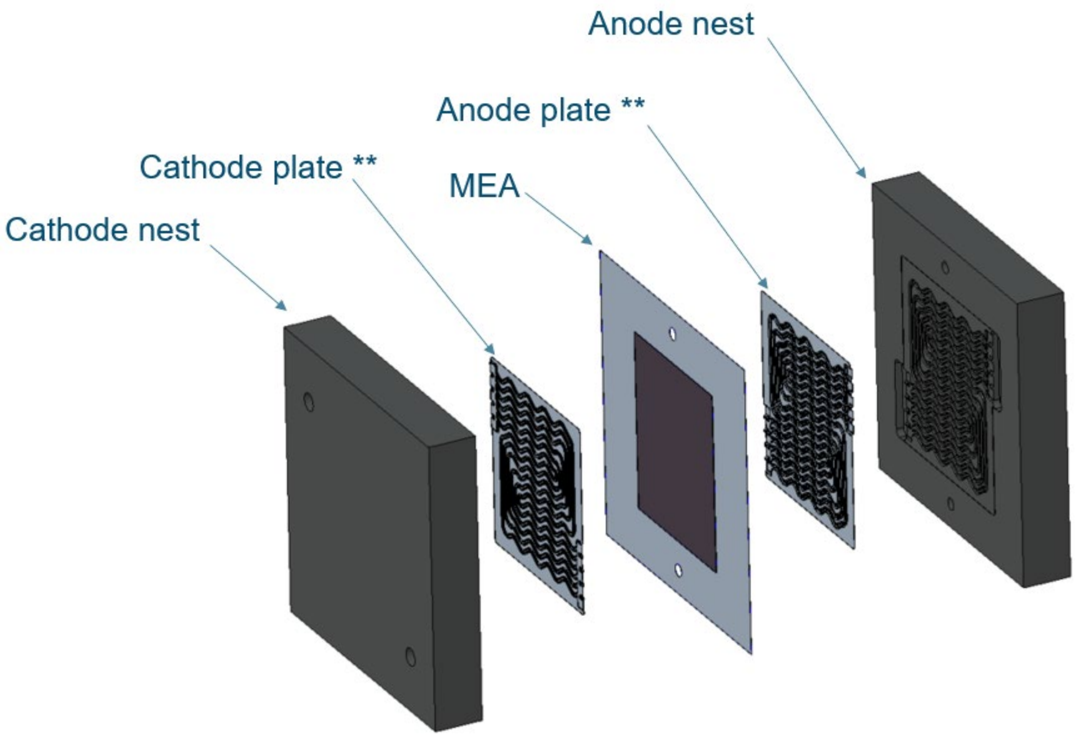


Coated sample

Single Cell Testing of Metal Plate Durability

Status:

- Design complete
- Materials Procurement in progress.
- Testing to start in Q3 ’22.



Demonstration of improved seals

Investigated a new material compatible with automated sealing in 200 units consisting of 5 different types of systems.

No significant differences in their performance out to 2000 hours (at the time of this report) compared to historical data

The new seal material outperformed the existing material clearly in stack designs.

Testing is ongoing, and all systems are currently running and performing well.

Responses to Previous Year Reviewers' Comments

Approach
- 2021 Issue: the presentation lacks specifics on materials in the MEAs
- 2022 Response: This will likely be a concern again for this year as we are still in the process of obtaining materials. For next year, we will work with MEA developers to release select data.

Progress
- 2021 Issue: N/A Program was briefed last year, 6 months before the start.
- 2022 Response: We are 2Q underway and don't have a lot of data yet, but we expect a lot of results in Q4-6 of the program.

Collaboration
- 2021 Issue: Purpose of ANL collaboration is not clear, and not clear how this relates to other Plug projects. Need more collaborations.
- 2022 Response: Sharpened collaboration with ANL. Plug working to validate ANL model will help all heavy-duty programs. Plug is now attending and engaged in AST meetings and other M2FCT program meetings.

Alignment with DOE goals
- 2021 Issue: Need more information on how Plug is building stacks to determine the impact on DOE goals.
- 2022 Response: Focus on what materials/components are available for high volume manufacturing

Recommendations for future work/scope
- End of life voltage is unreasonable. Changed to 1.08 A cm-2 at 0.769 V (830 mW cm^{-2})– will look at impact of real materials on stack efficiency
- No information provided for the public good. This concern will hopefully be alleviated by focusing on validating the ANL model, which benefits all DOE and fuel cell programs. Also building out U.S. based manufacturers for high volume fuel cell manufacturing.

Collaboration and Coordination

- Biweekly meetings of ANL and Plug Power
- ANL presentation to Plug Power Fuel Cell Group meeting – April 29, 2022
- Plug Power participation in AST Working Groups and M2FCT meetings

Response to DOE RFIs on supply chain and manufacturing

Briefing to DOE labs on findings.

- BNL
- NREL
- ORNL

Present Challenges and Barriers

It takes a long time to do a long endurance program

- Meeting efficiency and endurance goals with materials and methods for high volume
- Supply chain delays
  - Delivery of MEAs in volume
  - Delivery of high-volume manufacturing equipment during project timeframe
- Long endurance performance (e.g., premature failures)
- Accuracy of AST methods

Actual Challenges and Barriers to meeting M2FCT barriers will be better known in 12 months

Proposed Future Work

- Focus on stack variables vs performance, durability and cost
  - MEAs
    - Pt type and loading
    - Gas diffusion media
    - Membranes
  - Sealing
    - Ability to apply at high rates
    - Curing time
    - In field durability vs chemical and mechanical properties
  - Bipolar plate coatings
    - Corrosion resistance
    - Resistance

Build up capability for U.S. based high-volume manufacturing

Cost analysis (cost of development, ownership, etc)

Relevance/Potential Impact

Project fully focused on meeting DOE goals for Class 8 and heavy duty vehicles

Technical System Targets: Class 8 Long-Haul Tractor-Trailers

Characteristic	Units	Targets for Class 8 Tractors-Trailers	
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Targets are under development for marine, rail, mining and aviation applications

Broader Relevance to DOE goals

Plug Power is fully committed to the production and use of green hydrogen

- Achieve the Hydrogen Shot goal of $1 for 1 kg hydrogen in 1 decade – **will support expanded uses and applications.**
- Lower greenhouse gas emissions and criteria pollutants – **will help eliminate diesel vehicles.**
- Create good-paying jobs in the United States –**supporting U.S. based manufacturing.**
- Strengthen U.S. manufacturing – **promoting U.S. manufacturing base and supply chain.**
- Build clean energy infrastructure – **this project directly support the build out of the green hydrogen infrastructure.**
- Support energy, environmental, or social justice – **Plug Power has a full commitment advancing opportunities to maximize EJ40 and community outreach.**
- Provide pathways to private sector uptake – **this program helps accelerate the transition to Plug Power existing customers**

Summary

- Project underway for high-volume manufacturing capability to create fuel cells that eliminate diesel engine emissions and provide strategic energy independence.
- Shared progress on
  - MEA selection
  - Development of corrosion testing and initial results
  - Sealing

- Complete Phase 1 program in next 10 months (March 2023)
  - Demonstrate 5 kW stacks made at high volume using low-cost materials
  - Compare to DOE heavy duty vehicle performance targets

Back up

Publications and Presentations/Technology Transfer

No public presentations or publications October 1, 2021- April 25, 2022

- Abstract submitted for July 2022 Gordon Conference
- Abstract submitted for Fall 2022 ECS meeting, Atlanta GA

Technology Transfer – none to date

Awards – none to date

Method for Electrochemical Testing for Corrosion

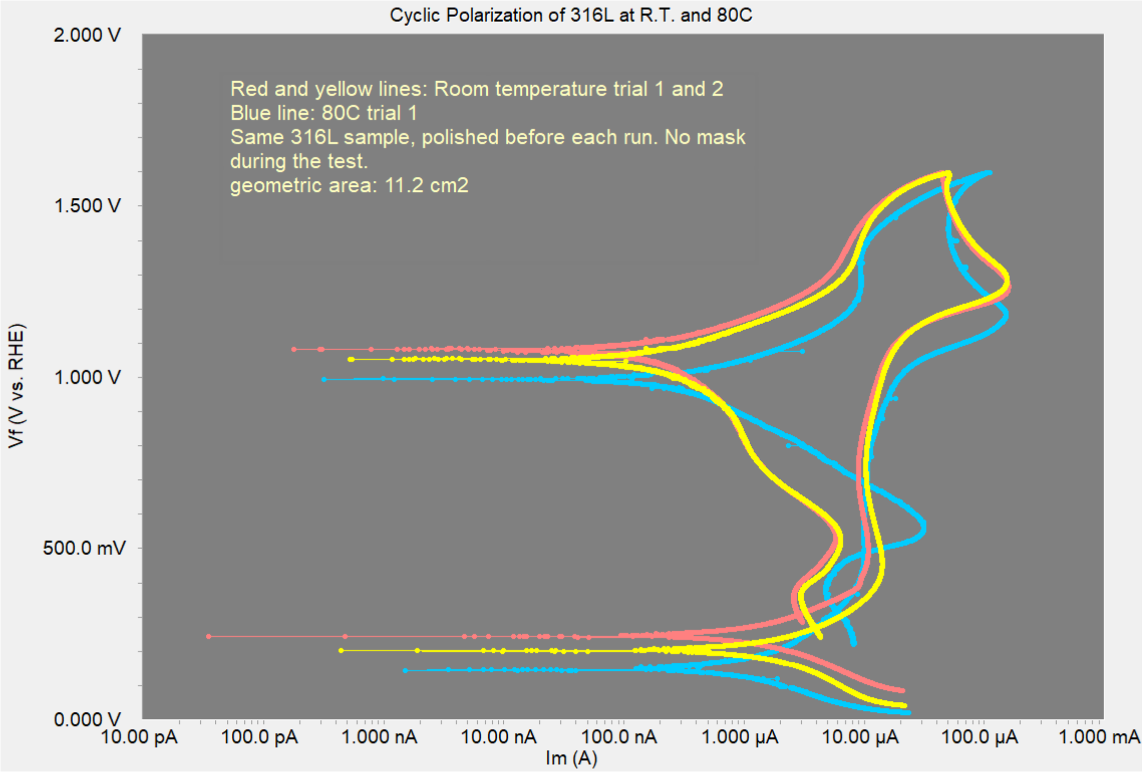
- Potentiodynamic
  - pH3, 0.1ppm F^-, 80^{o}C, de-aerated (Check with R.T. Pt CV)
  - From OCV-0.2V to 1.6V then back to OCV
  - 10mV/min scan rate
  - Purpose:
    - identify the redox peaks
    - check the coating integrity
    - Screening materials
  - Check points:
    - If there is oxidation and reduction peak at voltage <1V, and is the peak related to the substrate?
    - Use peak current between 0 to 1V to evaluate anode corrosion, need less than 1uA/cm^2

- Potentiostatic
  - pH3, 0.1ppm F^-, 80^{o}C, aerated
  - 1.0V vs. RHE (equal to: 0.6V vs. Ag/AgCl)
  - Run time: 24 hour+ after stabilized
  - Purpose:
    - Plate durability test
  - Check points:
    - If the corrosion current is less than 1uA/cm^2
    - If the current is stable
  - For postmortem tests
    - ICP for Fe^{2+} release rate
    - ICR change with coating degradation

The maximum measured corrosion current density must meet DOE 1uA/cm^2 target, and maintain reasonable corrosion resistance at voltage higher than 1V

Validation of corrosion method

- All pol curves are consistent in stainless steel corrosion behavior
- There is a good alignment on the chromium dissolution voltage with literature.



pH3 H_2SO_4 + 0.1ppm F^- @ 80C, 0.167mV/s scan rate, RHE
Ecorr 0.146V vs. RHE

Voltage conversion: 0 V vs. SCE is about 0.42V vs. RHE (pH3)

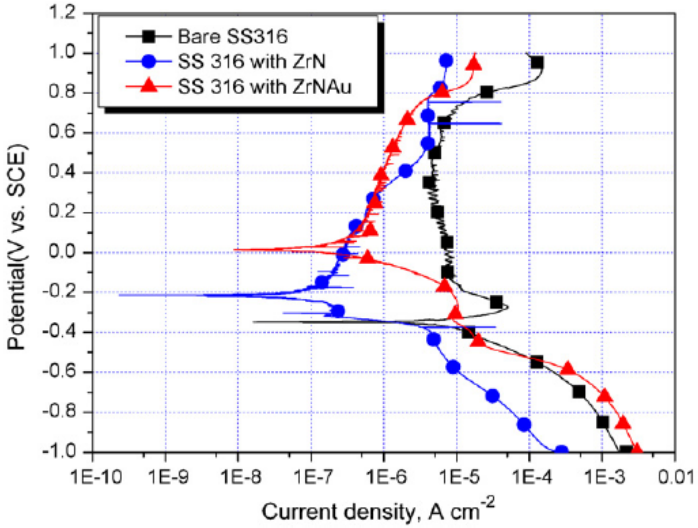


Fig. 10. Comparison of the corrosion resistance for ZrN and ZrNAu-coated SS 316 samples.

Yoon, et al J. Power Sources 179, 265, 2008

pH 2 H_2SO_4 @ 80C, 1mV/s scan rate, SCE (RHE -0.42 V)
E_{corr} ~ 0.1 V vs. RHE

Confirmed method values and analysis to literature