U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Fuel Cell Technologies Overview

Dr. Dimitrios Papageorgopoulos, HFTO – Fuel Cell Technologies Program Manager

2023 Annual Merit Review and Peer Evaluation Meeting

June 6, 2023 – Arlington, VA

The Hydrogen and Fuel Cell Technologies Office (HFTO)

Mission

Support research, development and demonstration (RD&D) of hydrogen and fuel cell technologies to advance:

- Clean Energy and Emissions Reduction Across Sectors
- Job Creation and a Sustainable and Equitable Energy Future

Office Sub-Programs

Hydrogen Technologies	Fuel Cell Technologies	Systems Development & Integration
Hydrogen Production Hydrogen Infrastructure	Materials & Components Systems	Transportation Industrial and Chemical Applications Grid Energy Storage and Power Generation

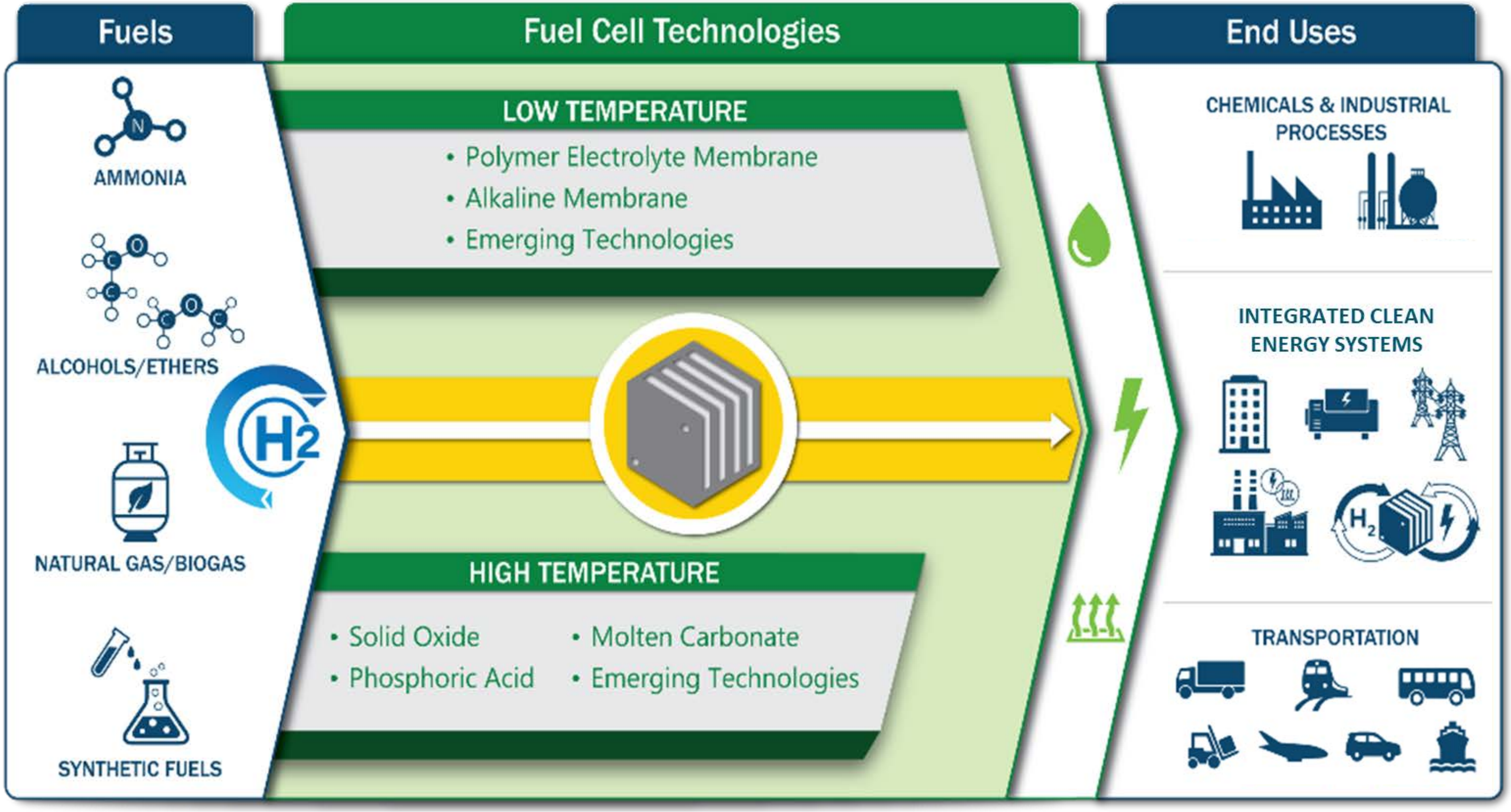
Data, Modeling, Analysis, Safety, Codes and Standards

Enabling

Energy Earthshots U.S. Department of Energy | Hydrogen

H2@Scale U.S. Department of Energy

Fuel Cell Technologies



Fuel cells use a wide range of fuels and feedstocks; deliver power for applications across multiple sectors; provide long-duration energy storage for the grid in reversible systems.

Innovative RD&D Focused on End-Use Requirements




***Goal:* Fuel cells that are competitive with incumbent and emerging technologies across applications**





Efforts support clean H_2 end-use and broader market adoption objectives as outlined in the National Clean Hydrogen Strategy and Roadmap

National Clean Hydrogen Strategy and Roadmap (energy.gov)

RD&D Strategies Address Fuel Cell Challenges

Fuel cell challenges

- Durability
- Efficiency
- Cost
- Power Density
- Supply Chain

Are strategically addressed through...

Materials and Components

- High activity, durable catalysts and electrodes
- Innovative membranes and ionomers
- Durable, high performance MEAs
- Advanced bipolar plates and coatings

Systems and Manufacturing

- System design and operating conditions
- Standardized stacks and modular systems
- Improved manufacturing and supply chain
- Advanced BOP components and subsystems
- Advanced recycling of systems and stacks

Analysis and Modeling

Emphasis on Heavy-Duty (HD) Applications

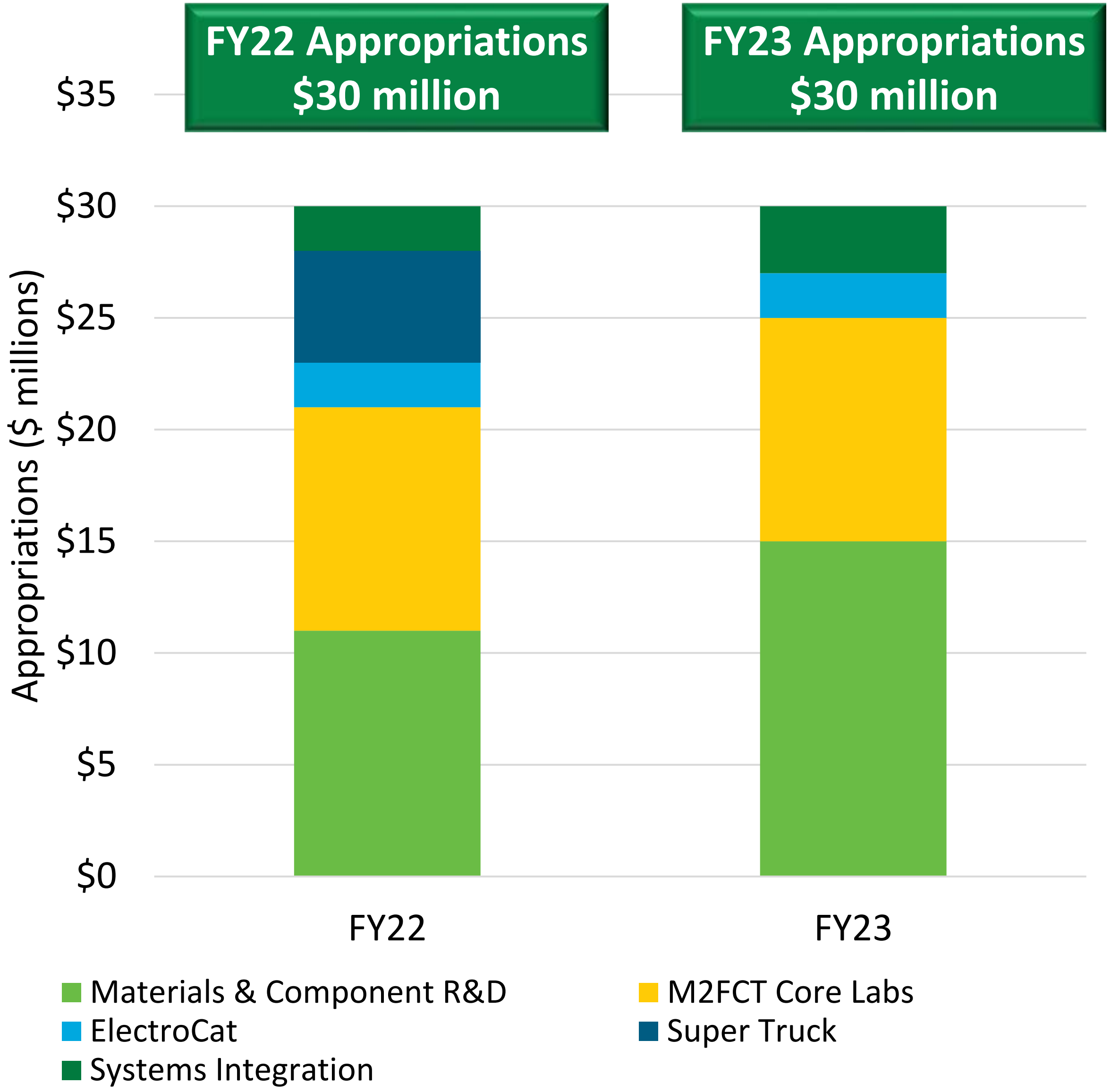
- Direct-H_2 Polymer Electrolyte Membrane Fuel Cells (PEMFCs)
- Transferable benefits for medium-duty and stationary applications
- Long-term approaches considered

Supported by Market-Driven Targets

2030 targets for long-haul truck fuel cell systems:

- $80/kW cost
- 25,000-hour durability

Fuel Cell Technologies Funding



Program Direction

Fuel cell materials, components and integration with a focus on low cost, enhanced durability and efficiency, for HD applications

- Low-PGM catalysts and MEAs
- Membranes, ionomers
- PGM-free catalysts and electrodes
- Bipolar plates, gas diffusion layers
- Stacks and system BOP
- System analysis
- Advanced manufacturing, supply chain development, and recycling

FY24 Request
$25 M

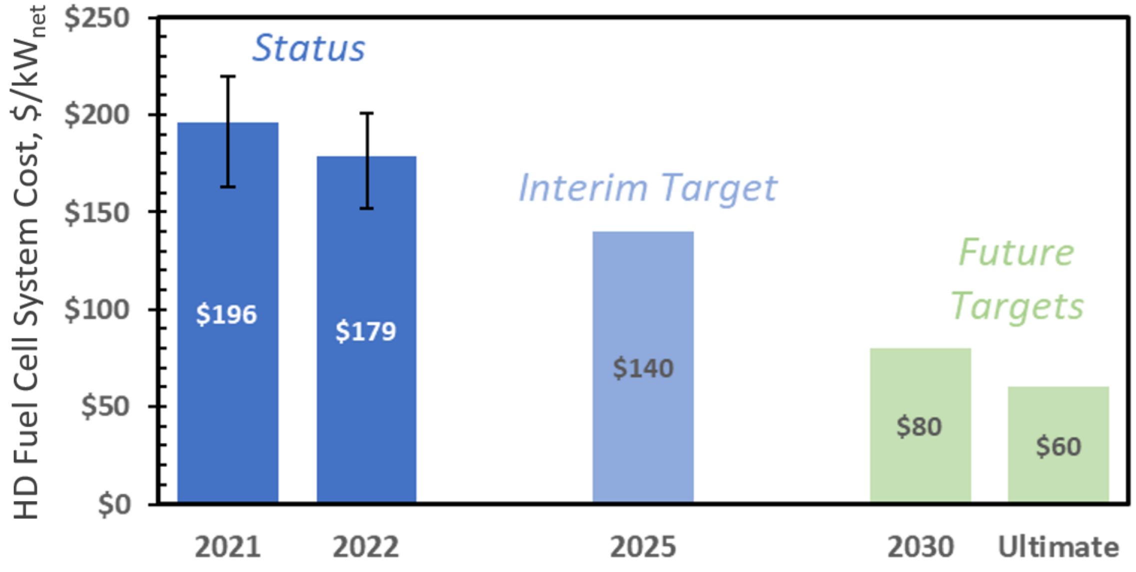
IIJA Clean H_2 Manufacturing & Recycling Provisions
$100 M/year over 5 years

RD&D Portfolio Guided by Analysis

HD Vehicle (HDV) Fuel Cell Durability-Adjusted Costs (for 25,000-hour lifetimes)

Modeled cost of a 275-kW_{net} PEMFC system

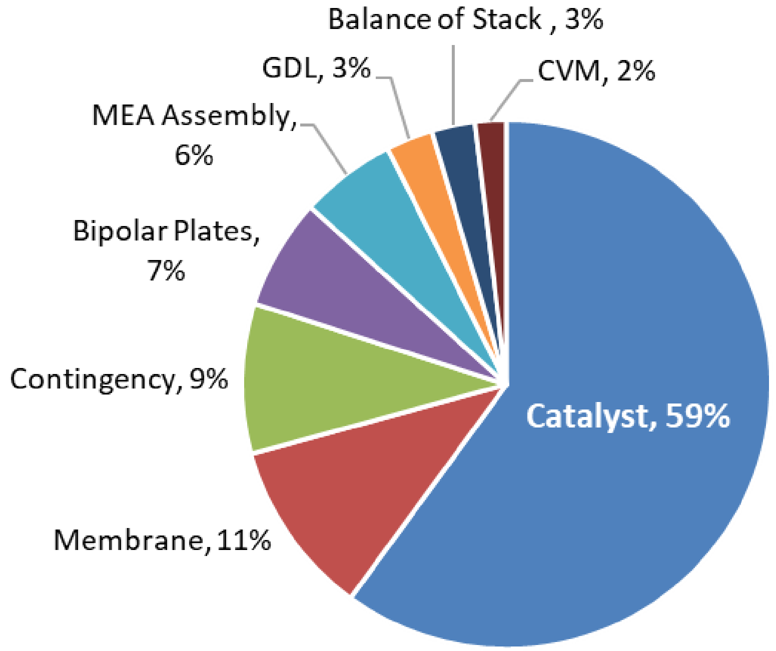
- **$302/$kW_{net}$** at 1,000 systems/year
- **$179/$kW_{net}$** at 50,000 systems/year
- **$170/$kW_{net}$** at 100,000 systems/year



Cost status (2021, 2022) and interim target (2025) for a manufacturing volume of 50,000 systems/year. Future (2030, ultimate) targets at 100,000 systems/year

Stack cost breakdown

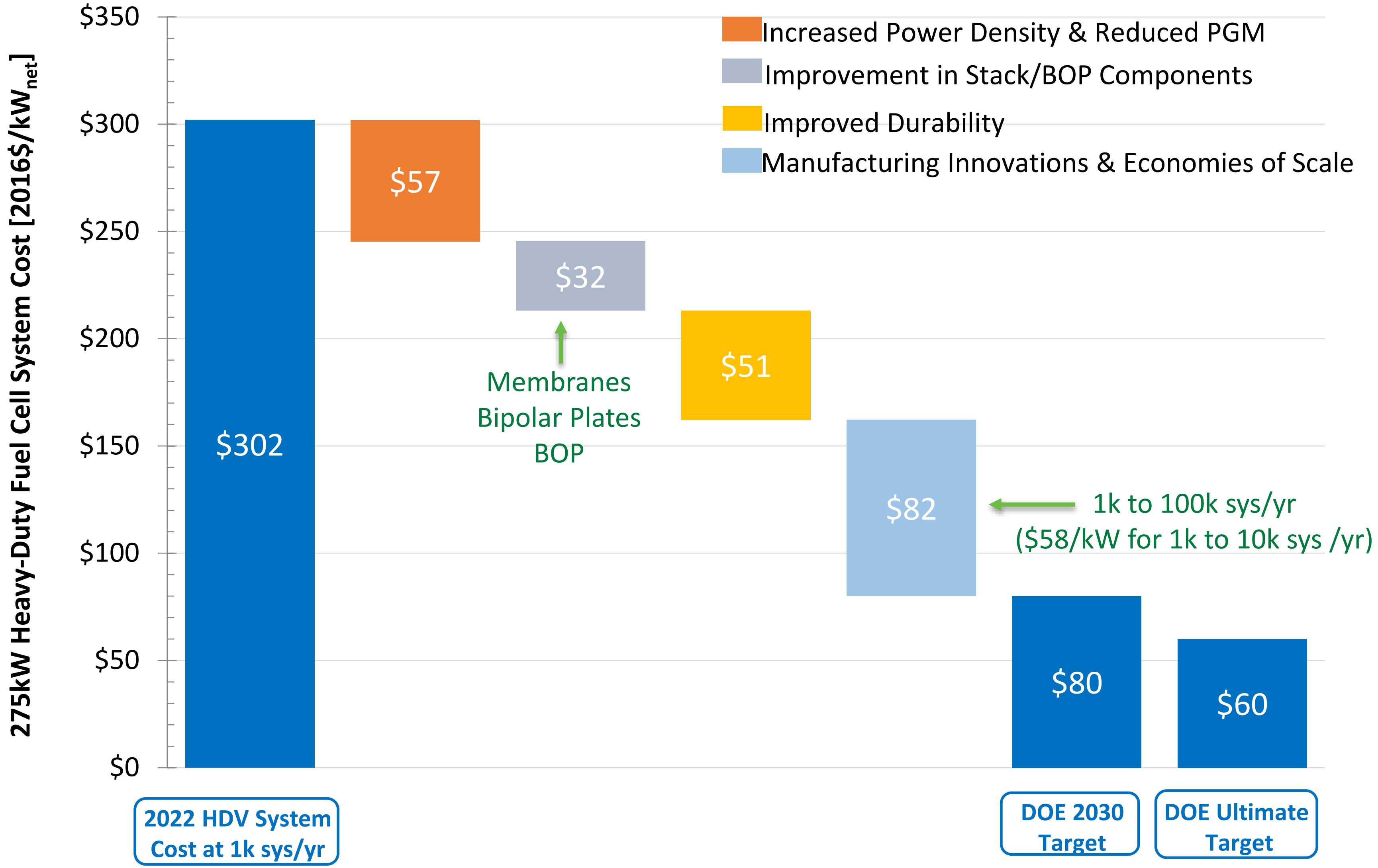
($112/$kW_{net}$ at 50,000 systems/year)



- Stack cost dominates system cost
- Catalyst cost is projected to be the largest single component of stack cost

https://www.hydrogen.energy.gov/pdfs/23002-hd-fuel-cell-system-cost-2022.pdf

Focusing on Key Areas to Meet Cost Target



Pathway towards cost target requires both technology improvements and manufacturing innovations

Highlights

Million Mile Fuel Cell Truck Consortium (M2FCT)

MILLION MILE FUEL CELL TRUCK
U.S. DEPARTMENT OF ENERGY

MISSION

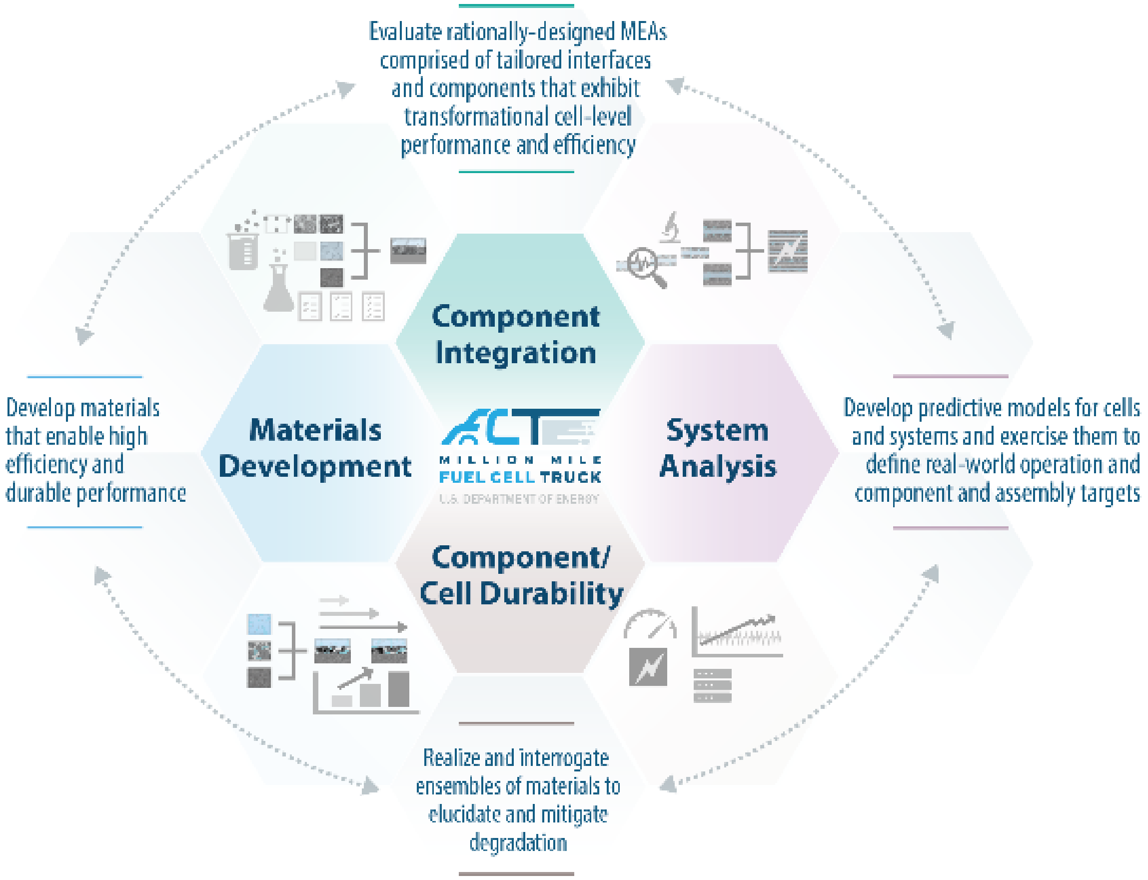
Advance efficiency and durability, and lower cost, of PEMFCs for HDV applications

APPROACH

Pursue a “team-of-teams” approach with teams in analysis, durability, integration, and materials development

OBJECTIVE

Achieve MEA target:
2.5 kW/g_{PGM} power (1.07 A/cm^2 current density) at 0.7 V after 25,000 hour-equivalent AST



MEAs
gm, Carnegie Mellon University, NIKOLA

Membranes
Lubrizol, 3M, NIKOLA

Stacks
Cummins, plug

Bipolar Plates
Raytheon Technologies, NEOGRAF SOLUTIONS, TreadStone Technologies, Inc., gm, plug

Air Management
CATERPILLAR, EATON, R&D Dynamics Corporation, MAHLE Driven by performance

Main Laboratories
Los Alamos National Laboratory, Oak Ridge National Laboratory, Argonne National Laboratory, Berkeley Lab, NREL National Renewable Energy Laboratory

Affiliate Laboratories
Pacific Northwest National Laboratory, NIST National Institute of Standards and Technology, Brookhaven National Laboratory

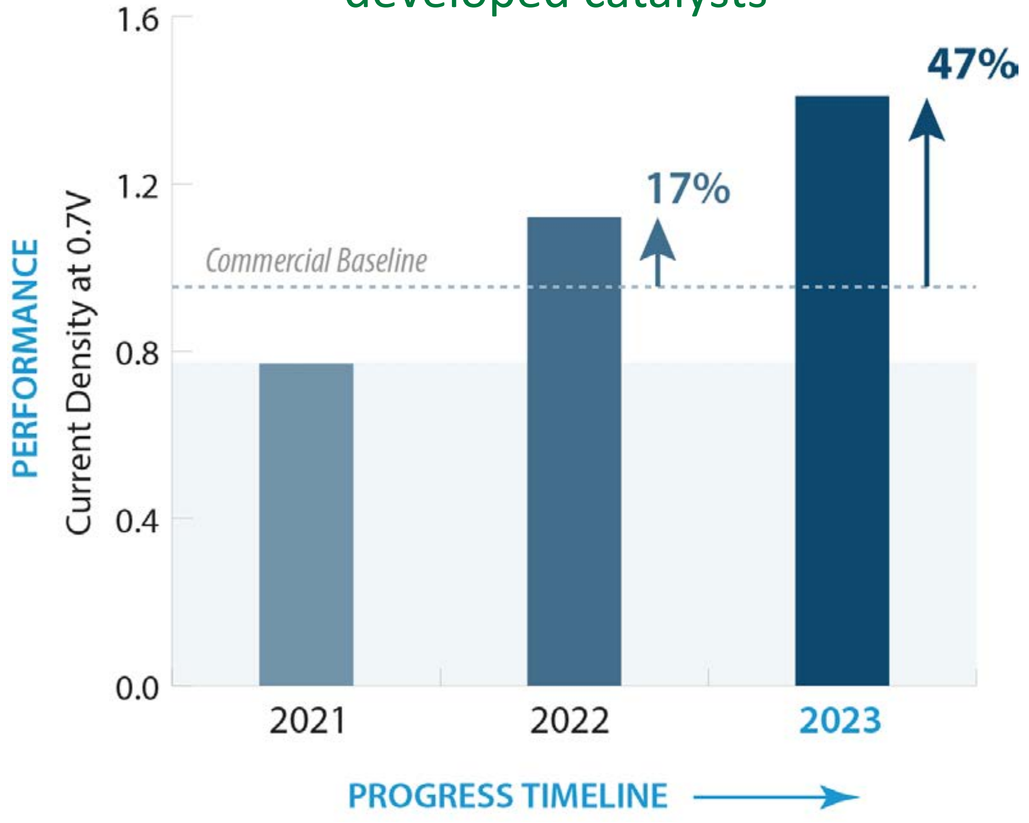
Catalyst Development Progress

Innovations in intermetallic catalysts and supports lead to improved MEAs

- 2023 best-of-class catalyst: Intermetallic PtCo on ZIF carbon
- End of Test (EOT) after 90,000 AST cycles
- Need to further evaluate with M2FCT developed AST corresponding to heavy-duty drive cycle operation of 25,000 hours

Improved MEA performance by >45% compared to commercial baseline*

EOT MEA performance with M2FCT developed catalysts

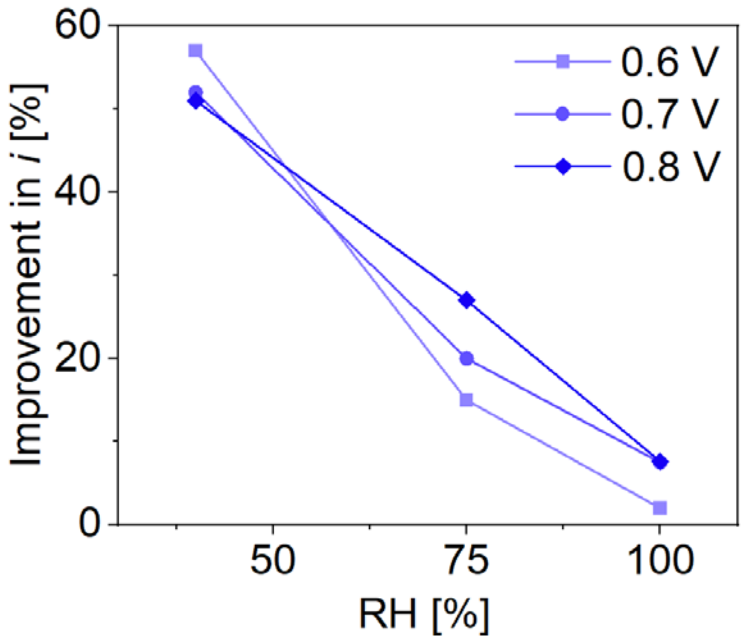


Commercial baseline: Umicore Elyst Pt50 0550 Pt/HSC

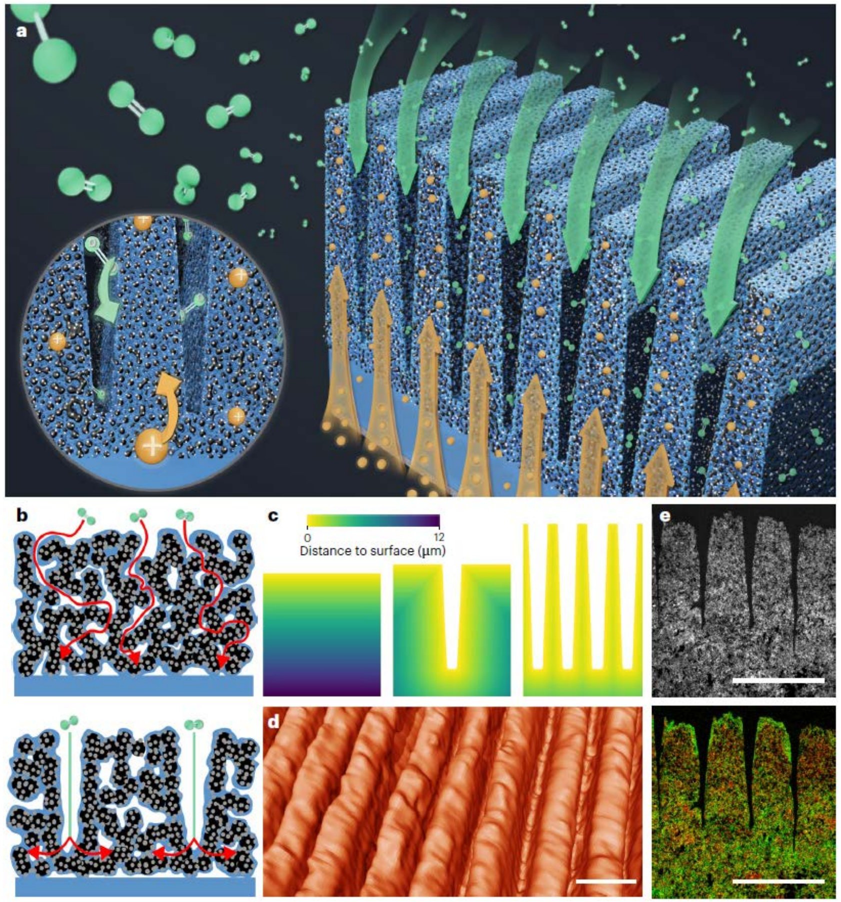
Conditions: 0.7V, 250 kPa, 85% RH, H_2/15% O_2. Total loading: 0.3 mg_{PGM}/cm^2

Advanced Electrodes for High-Power-Density Fuel Cells

Grooved electrode design enables up to **50% higher power density** than flat electrodes with the same materials, especially under the dry conditions needed for HDVs



Electrode structure can be equally important as electrode materials



Grooved electrodes separate O_2 and H^+ transport into discrete channels for higher performance

Lee et al., Nature Energy, 2023.

MEA Accelerated Stress Test (AST) for HDVs

MILLION MILE FUEL CELL TRUCK
U.S. DEPARTMENT OF ENERGY

Draft AST incorporating catalyst, support and membrane degradation published*

Heavy Duty MEA Protocol and Metrics

Cycle	Square wave between 0.675 V (30s) and 0.925 V (30s); Single-cell 50 cm^2 [a]	
Number	500 hours or 30,000 cycles	
Cycle time	1 minute	
Temperature	90°C	
Relative Humidity	Anode/Cathode: 50%/50%	
Fuel/Oxidant	Hydrogen/Air (H$_2$ at 1000 sccm and Air at 2500 sccm for a 50 cm^2 cell	
Pressure	250 kPa	
Metric	**Frequency**	**Target**
Catalytic Mass Activity[b]	At BOT[c], after 100h, 200h, 300h, 400h, and 500h	TBD
ECSA/Cyclic Voltammetry[d]	At BOT, after 100h, 200h, 300h, 400h, and 500h	TBD
Hydrogen Crossover[e]	At BOT, after 100h, 200h, 300h, 400h, and 500h	TBD
Polarization curve[f]	At BOT, after 100h, 200h, 300h, 400h, and 500h	TBD

- H_2/Air testing at 90 °C using temperature as key accelerating factor
- Inlet RH (50%) optimized to accelerate both catalyst and membrane degradation
- Need to define EOT targets and correspondence to heavy-duty drive cycle operation of 25,000 hours

***https://millionmilefuelcelltruck.org/astwg**

New M2FCT Industry and University Partner Projects Selected

FOA Topic M2FCT - High-Performing, Durable, Low-PGM Catalysts and Membrane Electrode Assemblies for Medium- and Heavy-Duty Applications

General Motors LLC *Dr. Nagappan Ramaswamy*

Design of Catalyst Nanostructures and Interfaces for Enhanced Durability in Low PGM HD Fuel Cell MEA

SUNY University at Buffalo *Dr. Gang Wu*

Designing Highly Curable Ternary PtCoM Intermetallic Catalysts on Advanced Support for Heavy-Duty MEAs

University of California Irvine *Prof. Vojislav Stamenkovic*

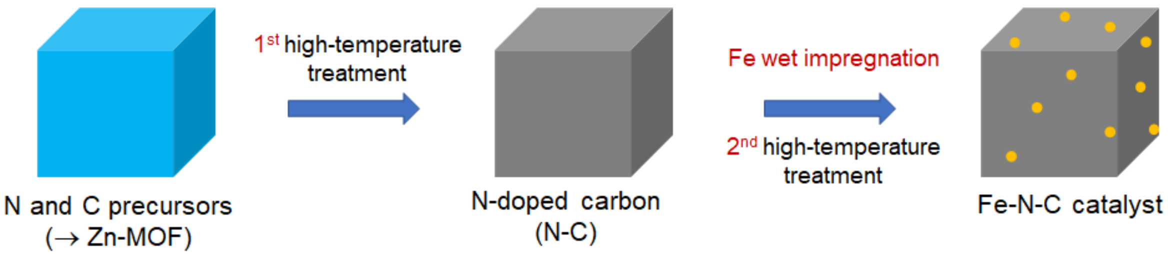
Advanced Low-PGM Cathode Catalysts with Self-Healing Properties for High Performing and Durable MEAs

https://www.energy.gov/eere/fuelcells/selections-funding-opportunity-support-hydrogen-shot-and-university-research

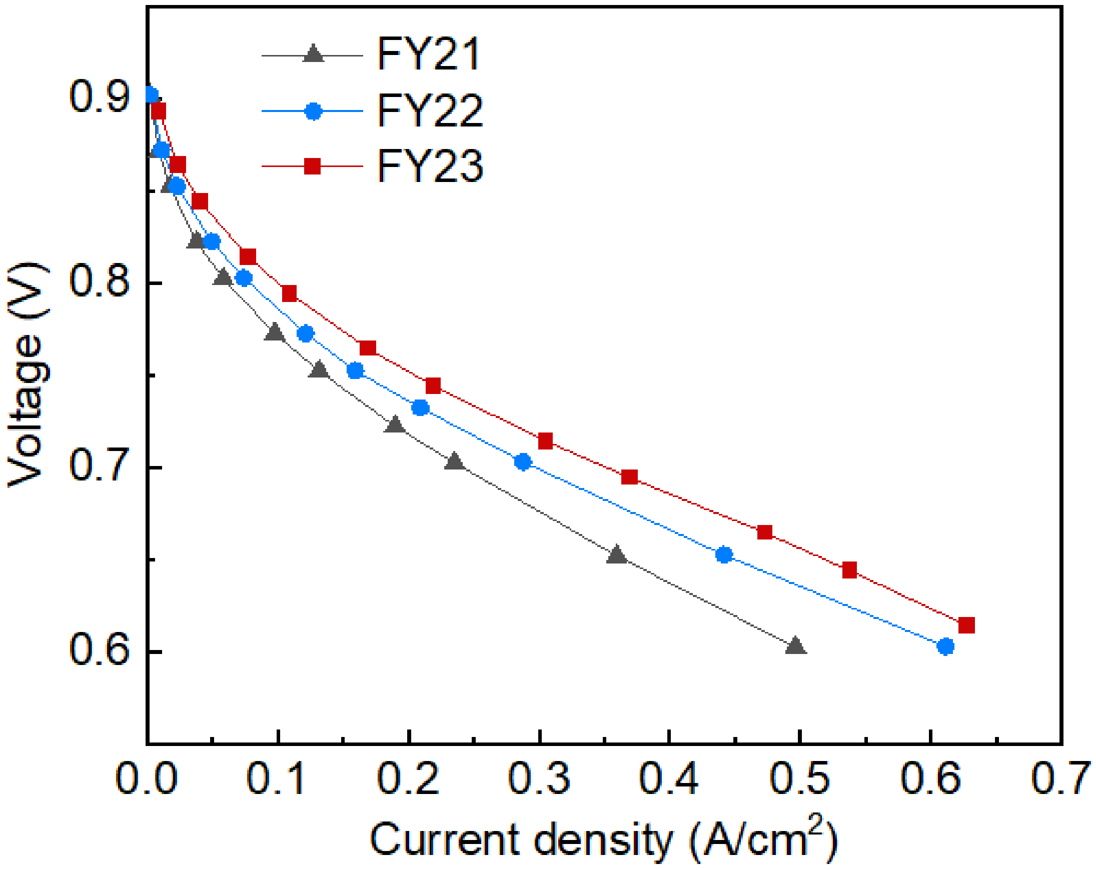
PGM-Free Catalyst Performance Enhancement

ElectroCat
Electrocatalysis Consortium

Two-step, two heat-treatment synthesis of an Fe-N-C catalyst:



Voltage (V)	Current density (mA cm^{-2})		
	FY21	FY22	FY23
0.80	61	79	97
0.675	302	377	435



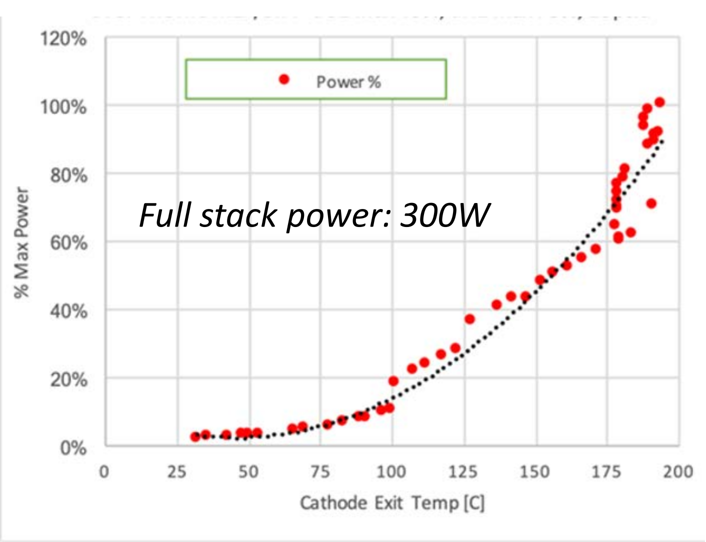
Fe-N-C catalyst developed via a two-step, two heat-treatment approach showing ~60% (at 0.80 V) and ~45% (at 0.675 V) performance improvement over FY21 baseline

L'Innovator™ Transitions National Lab Fuel Cell Technologies to the Private Sector

Advent Technologies partnered with LANL, BNL and NREL to develop a minimum viable product from LANL ion pair HT-PEM and BNL catalyst technology

Advancing Innovative Technology

Starting up from ambient: A **world's first** for HT-PEM



YS Kim (LANL) named Recipient of Battelle's Inventor of the Year Award (2022)

Facilitating Commercial Success

L'Innovator™ helped Advent secure ~**$160M of investment** which enabled a new manufacturing and R&D facility in Boston, MA

Massachusetts Governor Maura Healy tours Advent's new facility

ADVENT

Promoting DEIA: Bridging Academia, Labs and Industry

Workforce Development for Minority Serving Institution (MSI) Scholars

The Partnership:

- Builds relationships between HFTO, LANL, industry and MSIs
- Provides opportunities to MSIs & scholars to participate in and perform cutting-edge fuel cell research
- Encourages MSI scholars to pursue advanced degrees and enter the H_2 and fuel cell workforce

Over 100 minority students have participated in the partnership

Activities students have been a part of:

MSI students attending consortia meetings

Visit to GM facilities

University recruiting & engagement leads to more students

MOUs established with notable industry partners, including:

plug™

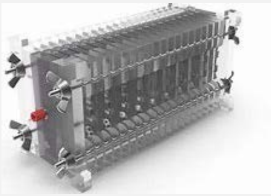
gm

PAJARITO POWDER FUEL CELL CATALYSTS

Chemours™

Sec. 40314 (EPACT Sec 815)
Clean Hydrogen Manufacturing & Recycling

Sec. 40314, EPACT Sec. 815 and Related IIJA Provisions



"Clean H_2 Electrolysis Program": BIL Includes RDD&D across multiple electrolysis technologies, compression, storage, drying, integrated systems, etc. - directly supports Hydrogen Shot

Sec. 40314 (EPACT Sec 816): Clean Hydrogen Electrolysis Program; **$1 Billion over 5 years. Goal $2/kg by 2026**

"Clean Hydrogen Manufacturing and Recycling"

Raw Materials → **Processed Materials** → **Subcomponents** → **End Product**

Focus on manufacturing and end of life/recycling RD&D

Sec. 40314 (EPACT Sec 815): Clean Hydrogen Manufacturing & Recycling **$0.5 Billion over 5 years**

Regional Clean H_2 Hubs: At least 4 Hubs, geographic diversity, includes renewables, fossil + CCS, nuclear, for clean hydrogen production, multiple end use applications.

Sec. 40314 (EPACT Sec 813): Regional Clean Hydrogen Hubs; **$8 Billion over 5 years**

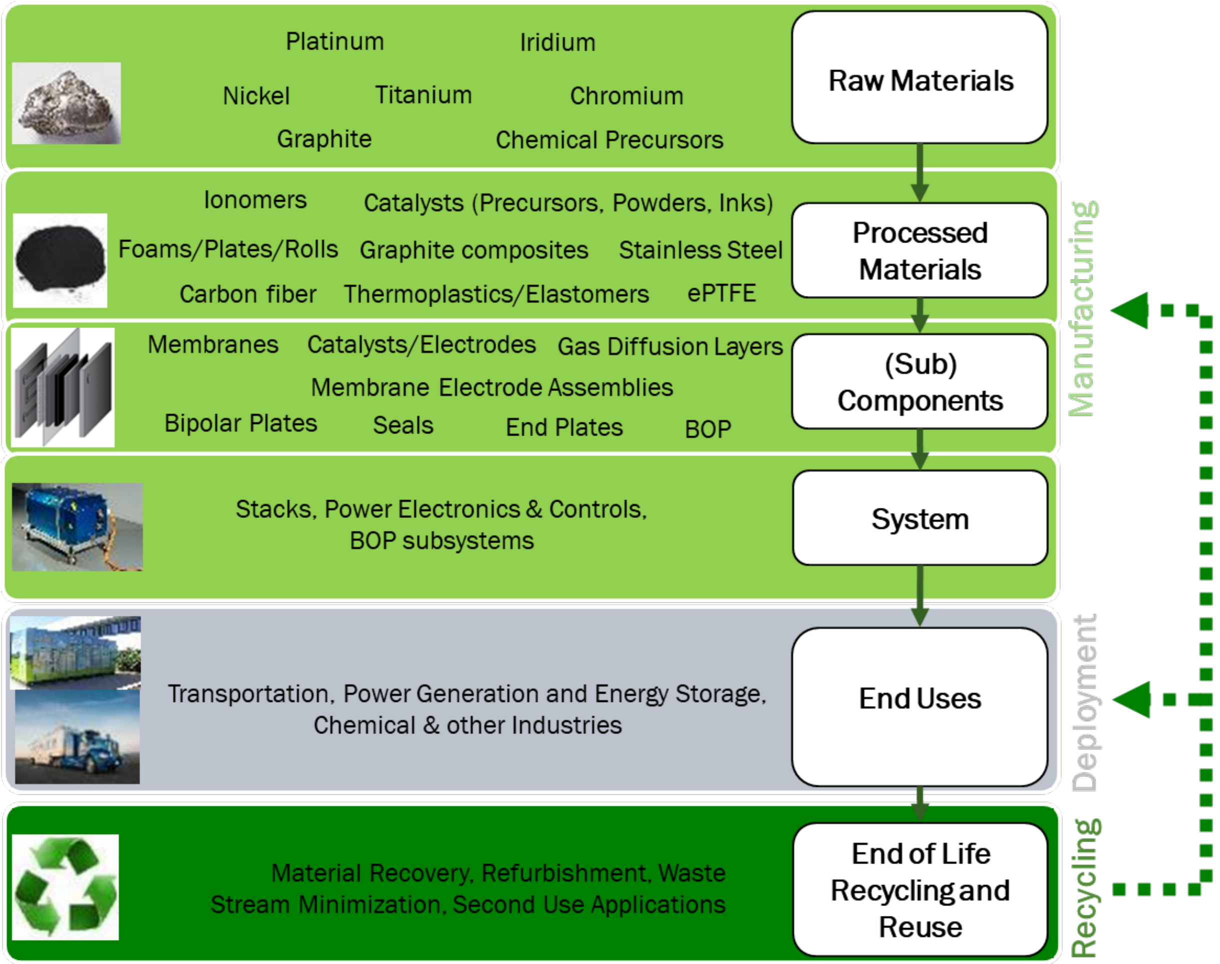
National Hydrogen Strategy and Roadmap: Includes working with EPA to develop an initial clean hydrogen production standard per Sec. 822 $\leq$ 2 kg CO_2e/kg H_2

Sec. 40314 (EPACT Sec 814: Strategy & Roadmap and **Sec. 40315 (EPACT Sec 822)**: Clean Hydrogen Production Qualifications)

Clean H_2 Manufacturing, Supply Chain Development, and Recycling

Growth required across domestic clean H_2 supply chains

Example: PEM fuel cell & electrolyzer supply chain

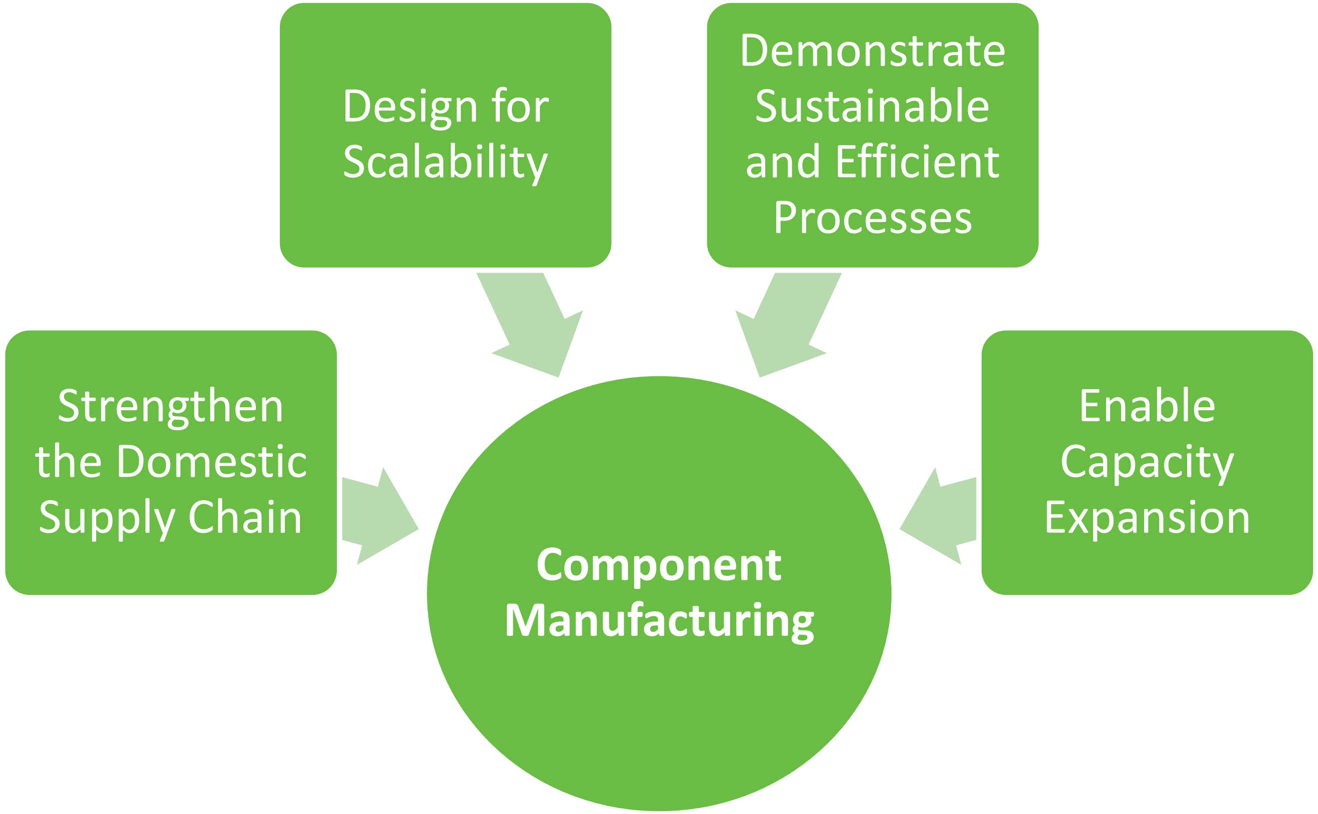


Addressing opportunities to:

- Bridge the gap between technology development and deployment
- Enable manufacturing scale-up to achieve economies of scale benefits
- Facilitate the reuse and recycling of materials and components

Efforts will support national decarbonization goals by helping remove barriers to the widespread at-scale deployment of clean H_2 technologies

Advanced Manufacturing of Fuel Cell Assemblies and Stacks



Analysis of manufacturing (and recycling) processes to identify the economics, life cycle, environment and social impacts of H_2 technologies

Established a near-term target (2027) for HD fuel cell manufacturing capacity:

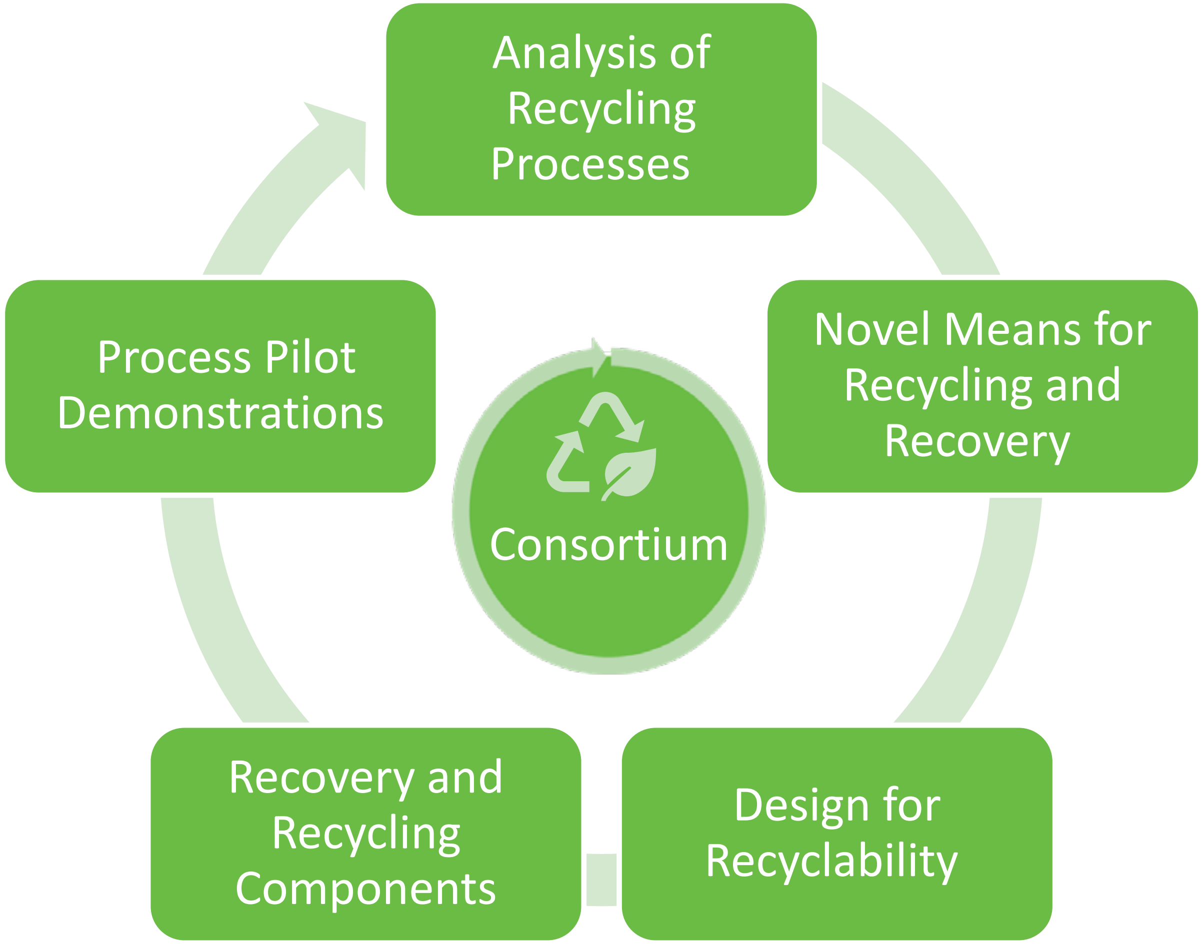
20,000 HD fuel cell stacks per year
in a single production line, while still aiming towards the 2030 DOE targets for cost, durability, and efficiency

Component	Rate
Stack	6 stacks/hour
MEA	2,400 MEAs/hour
BPP	2,400 BPPs/hour
GDL	650,000 m^2/year
Membrane	370,000 m^2/year
Catalyst	1,300 kg PGM/year

These are estimated component manufacturing rates commensurate with the stack manufacturing capacity target.

Clean H_2 Technologies Recycling

Goal: Create innovative and practical approaches to enable the recovery, recycling and reuse of clean H_2 technologies



Strategy:

- Establish a **Recovery and Recycling Consortium** comprising diverse stakeholders to address end-of-life and critical supply chain challenges for **fuel cell and electrolyzer** systems.

Priorities for PEM technologies include:

- PGM reclamation RD&D (Pt and Ir)
- Ionomer/membrane recycling from MEAs
- Development and use of analysis tools
- Efficient and automated disassembly
- Reuse of recovered materials and components
- Designing for recyclability

Hydrogen Eligible for $4 billion in Manufacturing Tax Credits

What is 48C?

- Competitively-awarded Investment Tax Credit (ITC) established in 2009 with $2.3B
- Expanded by IRA with $10B available
- Projects receive up to 30% investment tax credit
- DOE will accept a first round of applications in 2023 to allocate up to $4B
- Approximately 40% of credits ($1.6B) will be allocated to projects in coal communities

- Clean Energy Manufacturing and Recycling
- Critical Materials Process, Refining, and Recycling
- Industrial GHG Emissions Reductions

Timeline & Review

Notice Released: May 31

Informational Webinar: June 27

Concept Papers Due: July 31

Full Applications Due: Fall 2023

Collaborations, Milestones, Team

Collaboration Network

Fostering technical excellence, economic growth and environmental justice

Industry Engagement

- US DRIVE and 21st Century Truck Partnerships: Fuel Cell Joint Tech Team
- M2FCT
- ElectroCat
- Workshops/RFIs
- FCHEA

DOE H_2 Joint Strategy Team *(Conversion Working Group)*

EERE/VTO: SuperTruck	ARPA-E: Advanced Fuel Cell Concepts	FECM: SOFCs/RFCs	BES: Fundamental R&D

DOE Cross-Cutting Initiatives

Critical Minerals	SBIR/STTR	Energy Storage Grand Challenge
HPC	EMN	Space-related
IIJA Provisions		

Cross-Agency Collaborations

- DOC/NIST Fuel Cell Neutron Imaging
- DOT/FTA (Fuel Cell Buses)
- DOC (Supply Chain)

International Collaborations

IEA Technology Collaboration Programme on Advanced Fuel Cells	M2FCT AST Working Group	ElectroCat Benchmarking	Mission Innovation PFAS

Highlights and Milestones

FY2022	FY2023	FY2024
Improved MEA performance at a PGM loading of 0.3 mg_{PGM}/cm^2 by over 15% compared to commercial baseline	*Improved MEA performance at a PGM loading of 0.3 mg_{PGM}/cm^2 by over 45% compared to commercial baseline*	*Improve MEA performance at a PGM loading of 0.3 mg_{PGM}/cm^2*
Improved PGM-free cathode H_2-air initial fuel cell performance by 25% compared to FY21 baseline	*Improved PGM-free cathode H_2-air initial fuel cell performance by ~60% compared to FY21 baseline*	*Improve PGM-free cathode H_2-air initial fuel cell performance*
Solicited M2FCT FOA projects	*Solicited and selected M2FCT FOA projects*	*Solicit and select M2FCT FOA projects*
Met durability adjusted HDV cost of $179/kW at 50,000 systems/year	*Meet durability adjusted HDV cost of $170/kW at 50,000 systems/year*	*Meet durability adjusted HDV cost of $155/kW at 50,000 systems/year*
Initiated Sec. 815 efforts on Clean H_2 Manufacturing and Recycling	*Solicit and review Sec. 815 Manufacturing projects and Recovery & Recycling consortium*	*Initiate Sec. 815 Manufacturing projects and launch Recovery & Recycling consortium*

The Team

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Scan for Open Positions

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Open position
Technology Manager

Open position
Technical Project Officer

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Thank You

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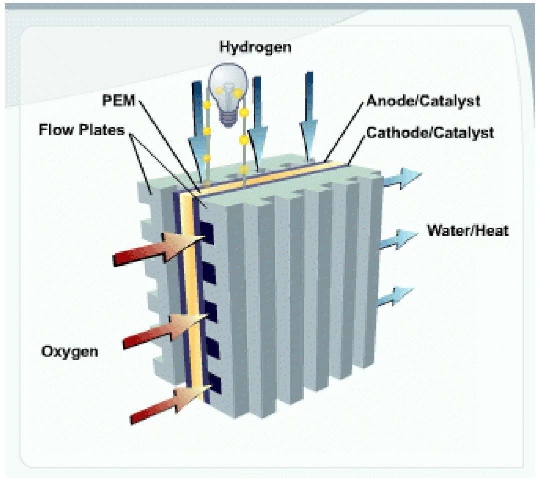
hydrogenandfuelcells.energy.gov

Agenda – Fuel Cell Technologies

	Tuesday, June 6, 2023	Wednesday, June 7, 2023	Thursday, June 8, 2023
	Fuel Cell Technologies		
8:00 AM	Continental Breakfast		
9:00 AM	FC000 Fuel Cell Technologies Subprogram Overview Dimitrios Papageorgopoulos, HFTO	FC337 Cummins PEM Fuel Cell System for Heavy Duty Applications Jean St-Pierre, Cummins Inc.	FC354 L'Innovator Program Emory De Castro, Advent Technologies
9:30 AM	FC160 ElectroCat 2.0 (Electrocatalysis Consortium) Deborah Myers, ANL & Piotr Zelenay, LANL	FC338 Domestically Manufactured Fuel Cells for Heavy-Duty Applications Karen Swider Lyons, Plug Power	FC333 Advanced Membranes for Heavy Duty Fuel Cell Trucks Andrew Baker, Nikola Motor Company
10:00 AM		FC167 FY22 SBIR IIC: Multi-Functional Catalyst Support Minette Ocampo, pH Matter, LLC	FC336 A Systematic Approach to Developing Durable, Conductive Membranes for Operation at 120C Tom Zawodzinski, University of Tennessee - Knoxville
10:30 AM	Break		
11:00 AM	FC339 M2FCT: Million Mile Fuel Cell Truck Consortium Rod Borup, LANL & Adam Weber, LBNL	FC344 Low-Cost Corrosion-Resistant Coated Aluminum Bipolar Plates by Elevated Temperature Formation and Diffusion Bonding Tianli Zhu, Raytheon Technologies Research Center	FC330 High Efficiency Reversible Solid Oxide System Hossein Ghezel-Ayagh, FuelCell Energy, Inc.
11:30 AM		FC345 Development and Manufacturing for Precious Metal Free Metal Bipolar Plate Coatings for PEM Fuel Cells CH Wang, Treadstone Technologies, Inc.	FC331 A Novel Stack Approach to Enable High Round Trip Efficiencies in Unitized PEM Regenerative Fuel Cells Katherine Ayers, Nel Hydrogen
12:00 PM		FC346 Fully Unitized Fuel Cell Manufactured by a Continuous Process Jon Owejan, Plug Power	FC317 Stationary Direct Methanol Fuel Cells Using Pure Methanol Xianglin Li, University of Kansas
12:30 PM	Lunch		
1:45 PM	FC353 Fuel Cell Cost and Performance Analysis Brian James, Strategic Analysis, Inc.	FC347 Development of Low Cost, Thin Flexible Graphite Bipolar Plates for Heavy Duty Fuel Cell Applications David Chadderdon, NeoGraf Solutions, LLC	
2:15 PM	FC323 Durable Fuel Cell MEA through Immobilization of Catalyst Particle and Membrane Chemical Stabilizer Nagappan Ramaswamy, GM	FC348 Fuel Cell Bipolar Plate Technology Development for Heavy Duty Applications Siguang Xu, GM	
2:45 PM	FC326 Durable MEAs for Heavy-Duty Fuel Cell Electric Trucks John Slack, Nikola Motor Company	FC349 Foil Bearing Supported Compressor-Expander Giri Agrawal, R&D Dynamics Corporation	
3:15 PM	Break		
3:45 PM	FC327 Durable High Power Density Fuel Cell Cathodes for Heavy-Duty Vehicles Shawn Litster, Carnegie Mellon University	FC350 High Efficiency and Transient Air Systems for Affordable Load-Following Heavy-Duty Truck Fuel Cells Doug Hughes, Eaton Corporation	
4:15 PM	FC356 FY22 SBIR II: Durable High Efficiency Membrane and Electrode Assemblies for Heavy Duty Fuel Cell Vehicles Gang Wu, University of Buffalo	FC351 Durable and Efficient Centrifugal Compressor-Based Filtered Air Management System and Optimized BOP Mike Bunce, Mahle Powertrain, LLC	
4:45 PM	FC355 LANL Minority Serving Institution Program Tommy Rockward, LANL	FC352 Leveraging ICE Air System Technology for Fuel Cell System Cost Reduction Paul Wang, Caterpillar, Inc.	



Wednesday, June 7 Poster Presentations 5:30–7:00 p.m.		
Fuel Cell Technologies		
FC335	Additive Functionalized Polymers for Extended Heavy Duty Polymer Electrolyte Membrane Lifetimes	Tom Corrigan, The Lubrizol Corporation
FC341	Advanced AEMFCs through Material Innovation	Yu Seung Kim, LANL
FC342	Advanced Ionomers & MEAs for Alkaline Membrane Fuel Cells (AMFCs)	Bryan Pivovar, NREL
FC343*	FY20 SBIR II: Improved Ionomers and Membranes for Fuel Cells	Chris Topping, Tetramer Technologies, LLC
FC361*	FY22 SBIR I: Durable Bulk Metallic Glass Catalysts for Medium and Heavy-Duty PEM Fuel Cells	Evgenia Pekarskaya, Supercool Metals LLC
FC362	FY22 STTR I: Mobile Fuel Cell Generator	Paul Scott, RockeTruck, Inc.
FC363	Advanced FC Vehicle DC-DC Converter Development	Vivek Sujan, ORNL

Session Logistics

General Information

- This meeting is a review, not a conference
  - **Questions will be taken first from reviewers**, and then from other audience members as time allows
  - Remote reviewers are reminded to enter their questions in CHAT
  - Remote general attendees can enter questions or comments into Q&A
- The schedule will be strictly followed so that reviewers can move between sessions
- Presentations are 20 minutes followed by 10 minutes Q&A

Thank You, Reviewers!

Your input on our Program and subprograms helps guide our decisions.

Thank you for your thoughtful, objective, and timely feedback!

Save the date!

2024 DOE Hydrogen Program AMR

May 6-9, 2024

Visit H2tools.Org For Hydrogen Safety And Lessons Learned

https://h2tools.org/

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

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