U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Fuel Cell Technologies Overview

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

2024 Annual Merit Review and Peer Evaluation Meeting

May 7, 2024 – Arlington, VA

The Hydrogen and Fuel Cell Technologies Office (HFTO)

Mission

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

HFTO Subprograms

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

Systems Analysis | **Safety, Codes & Standards**

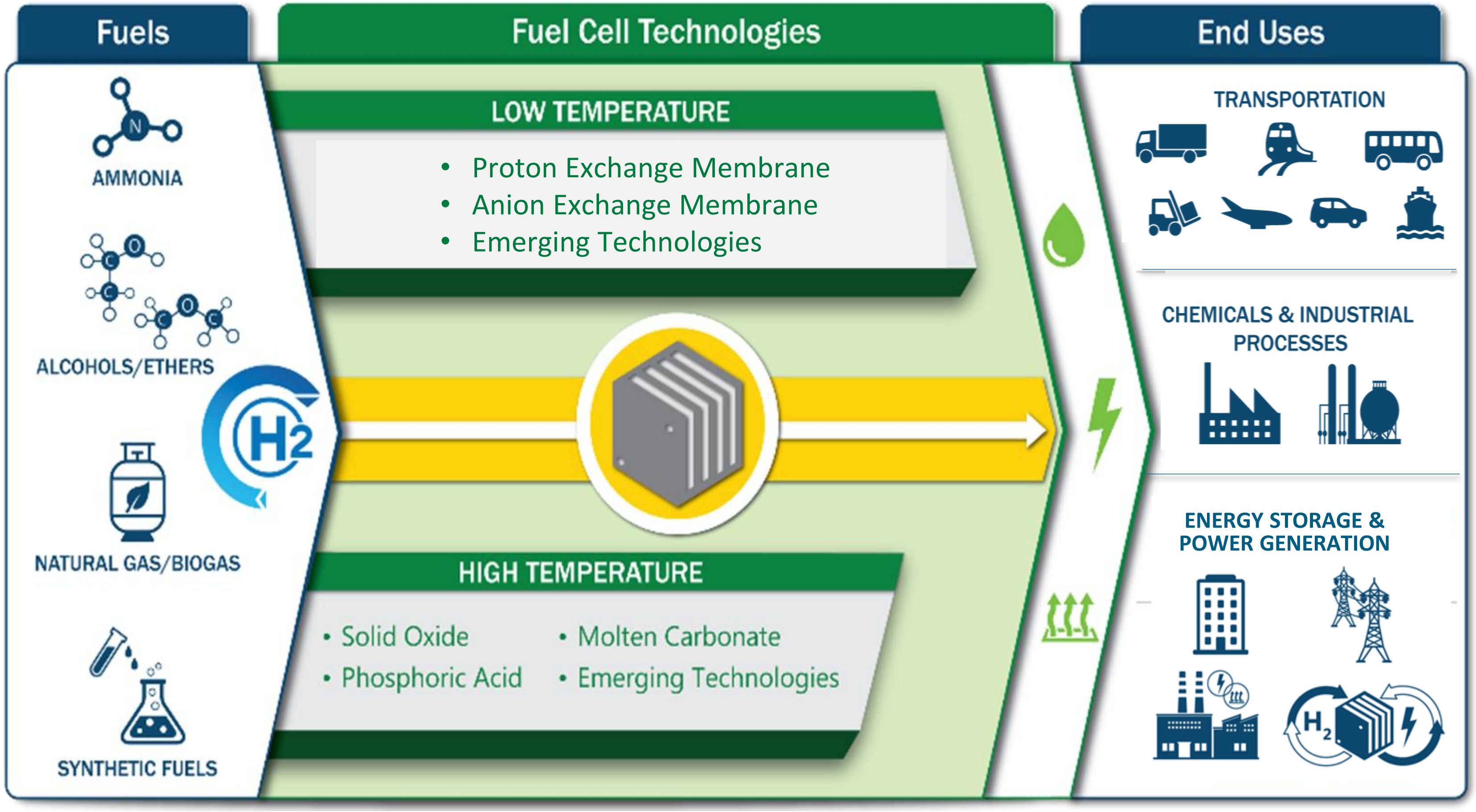
Crosscutting / Enabling: manufacturing, supply chain, workforce, regional clean H_2 networks

Enabling

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

H2@Scale U.S. Department of Energy

Fuel Cell Technologies



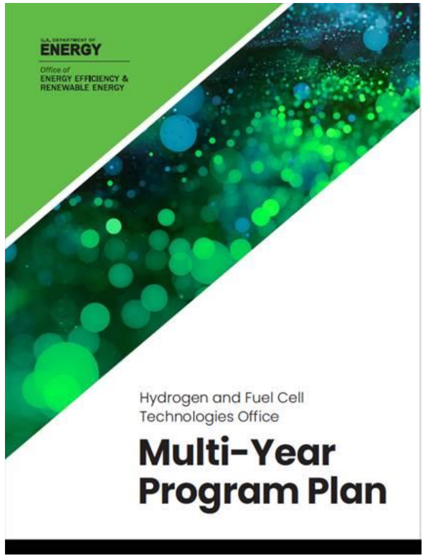
Goal
Fuel cells that are competitive with incumbent and emerging technologies across applications

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

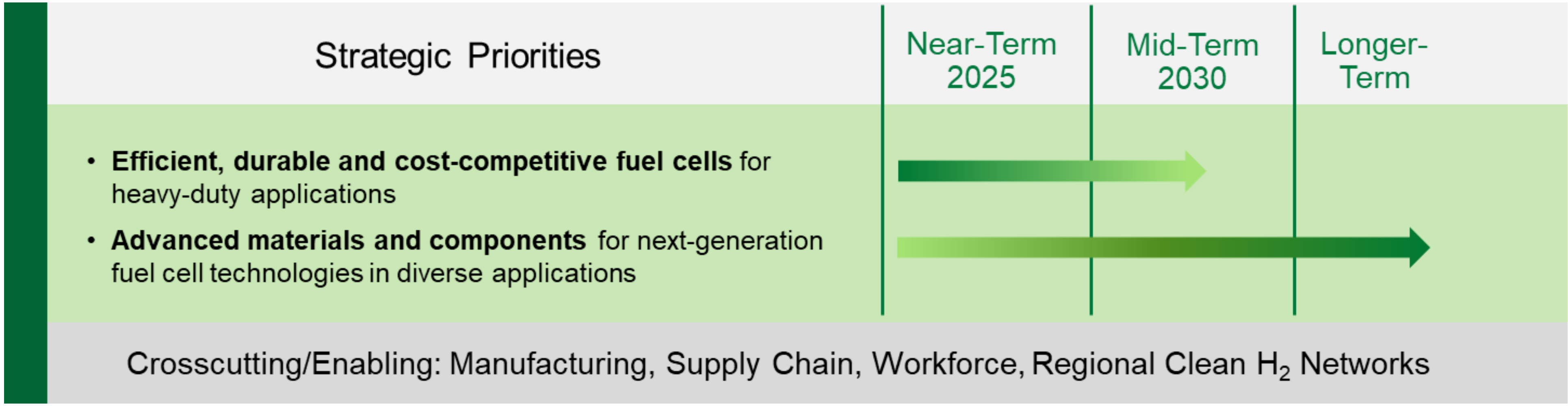
Fuel cells use a wide range of fuels and feedstocks; deliver power for applications across multiple sectors; provide long-duration energy storage for the grid in reversible systems.

DOE National Clean Hydrogen Strategy and Roadmap (energy.gov)

Updated Multi-Year Program Plan (MYPP)



The MYPP defines barriers, develops market-driven targets, and lays out plans with key RD&D priorities and milestones for meeting those targets



Includes baselines and targets that are periodically assessed and adjusted as needed based on updated information, analysis, and stakeholder feedback

End Use	2023 Status	2030 Target	Ultimate Target
Heavy-Duty Transportation	•Cost \$170/kW •Durability >10,000 h •Peak efficiency 64% •PGM loading >0.4 mg/cm^2	•Cost \$80/kW •Durability 25,000 h •Peak efficiency 68% •PGM loading ≤0.3 mg/cm^2	•Cost \$60/kW •Durability 30,000 h •Peak efficiency 72% •PGM loading ≤0.25 mg/cm^2

www.energy.gov/eere/fuelcells/mypp

RD&D Strategy

Fuel cell challenges

- Durability
- Efficiency
- Materials & Component Cost
- Power Density
- Supply Chain

Are strategically addressed through….

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

Systems & Manufacturing
- System design & operating conditions
- Standardized stacks and modular systems
- Improved manufacturing & supply chain
- Advanced BOP components & subsystems
- Recycling of components, stacks, & systems

Supporting analysis & modeling

… and supported by market-driven targets

2030 Example Targets

Fuel Cells for Long-Haul Trucks
- $80/kW system cost
- 25,000-hour durability

Fuel Cells for Stationary Power
- $1.000/kW system cost
- 80,000-hour durability

Fuel Cell Manufacturing Capacity
- 20,000 stacks/yr*
- 2,400 MEAs/hr

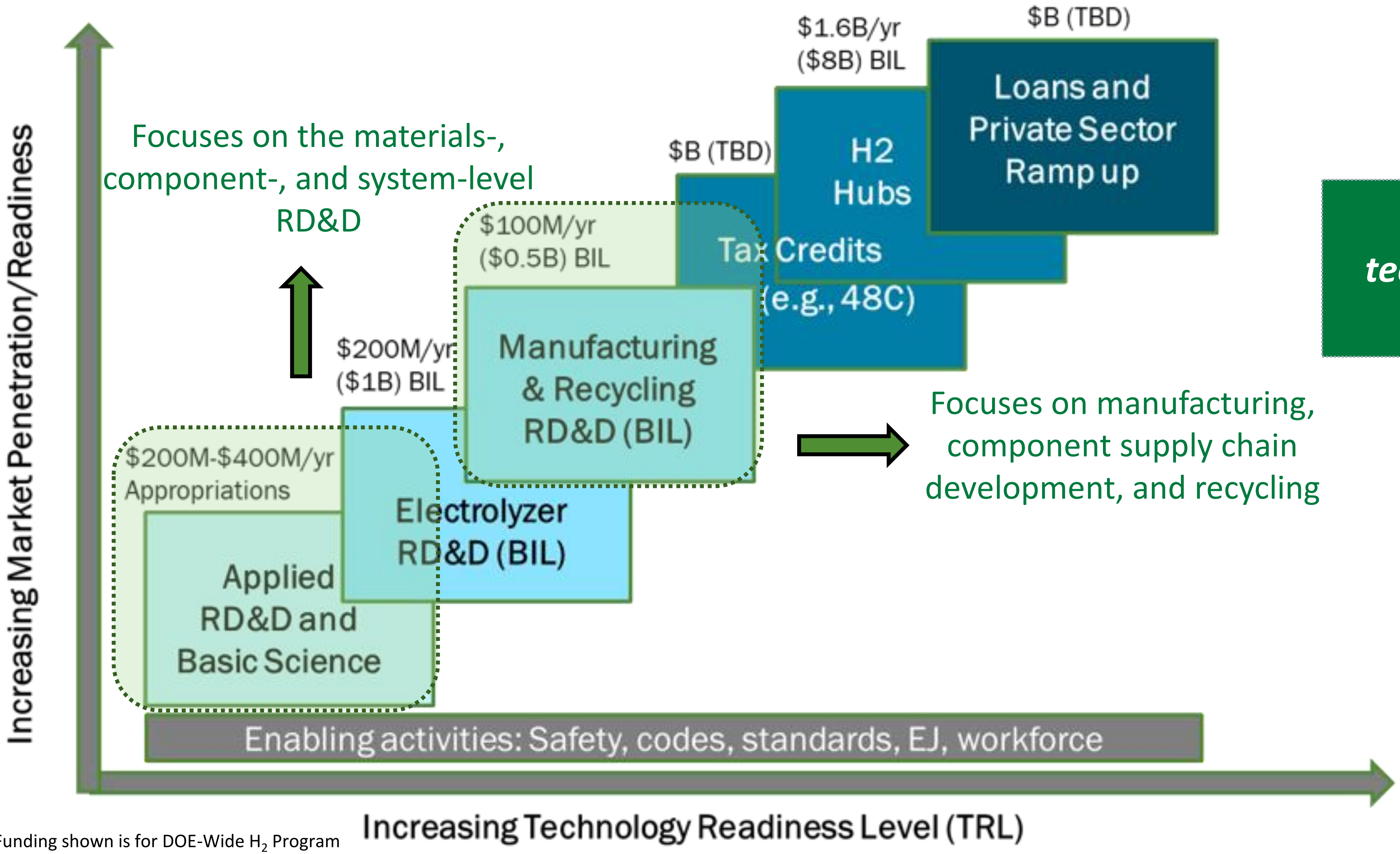
Reversible Fuel Cells for Energy Storage
- $1.800/kW system cost
- 40,000-hour durability

Emphasis: H_2 PEMFCs for heavy-duty applications

www.energy.gov/eere/fuelcells/mypp

* In a single manufacturing system

Hydrogen Program RDD&D Portfolio across TRLs



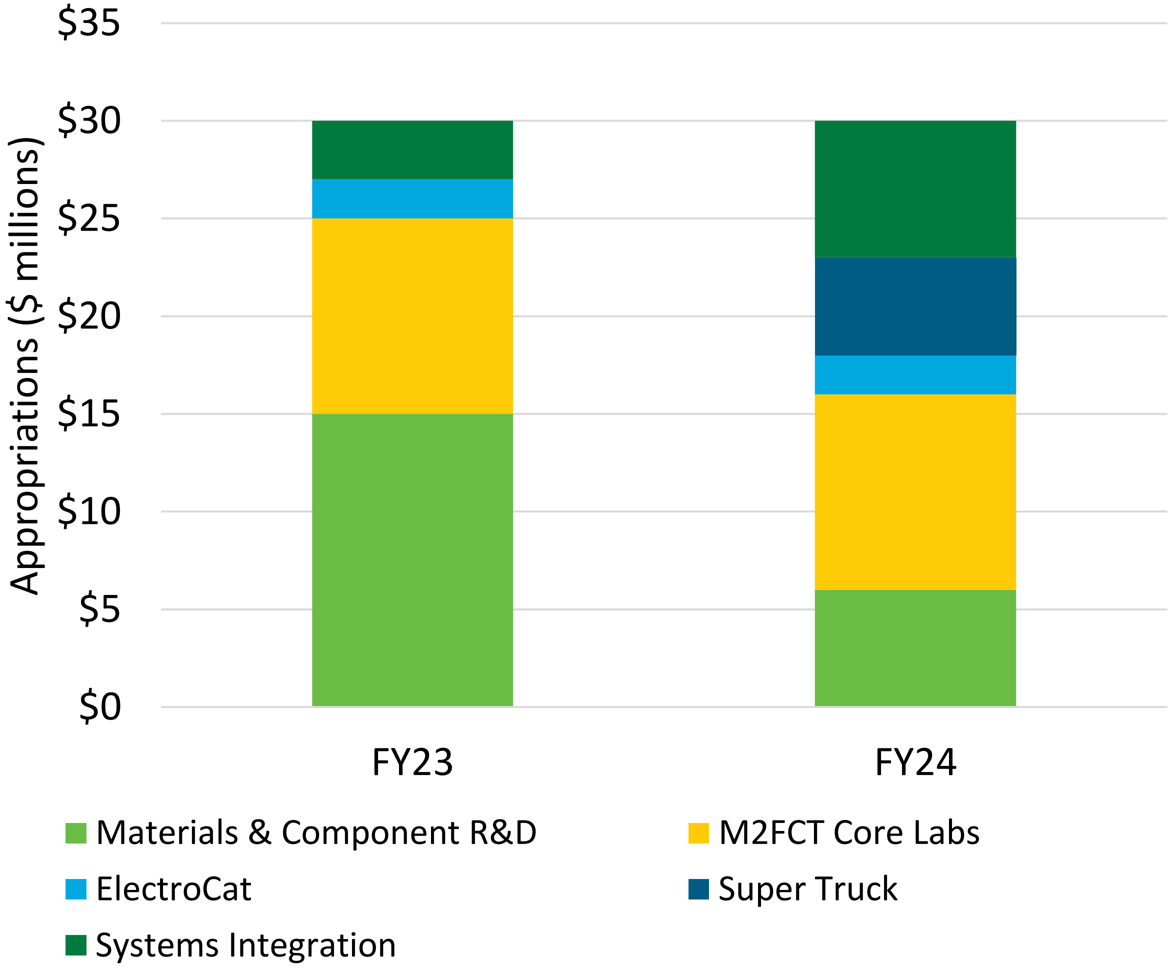
Advancing fuel cell technologies across the value chain

Funding shown is for DOE-Wide H_2 Program

Fuel Cell Technologies Funding

FY23 Appropriations
$30 million

FY24 Appropriations
$30 million



Program Direction

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

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

FY25 Request
$25 M

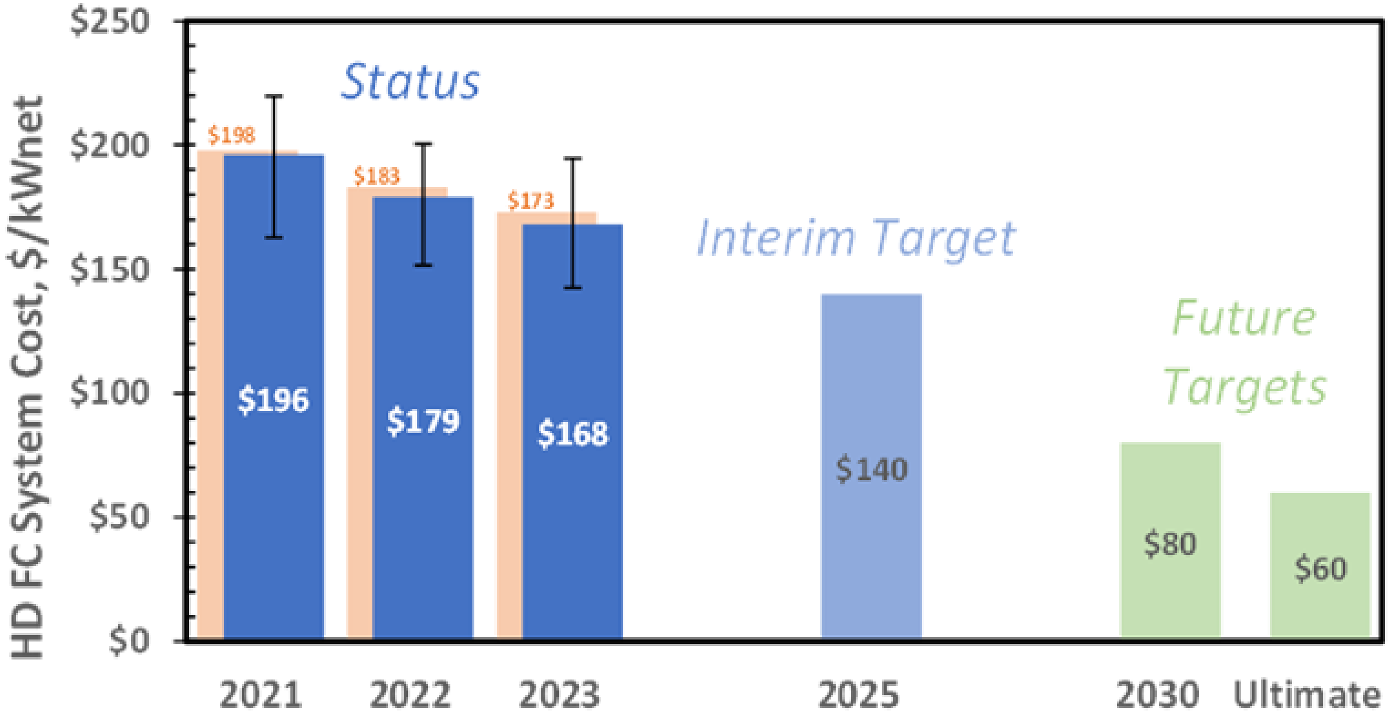
IIJA Clean H_2 Manufacturing & Recycling Provisions
$100 M/year over 5 years

Analysis Guides RD&D

Heavy Duty Truck Fuel Cell Durability-Adjusted Costs (for 25,000-hour lifetimes)

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

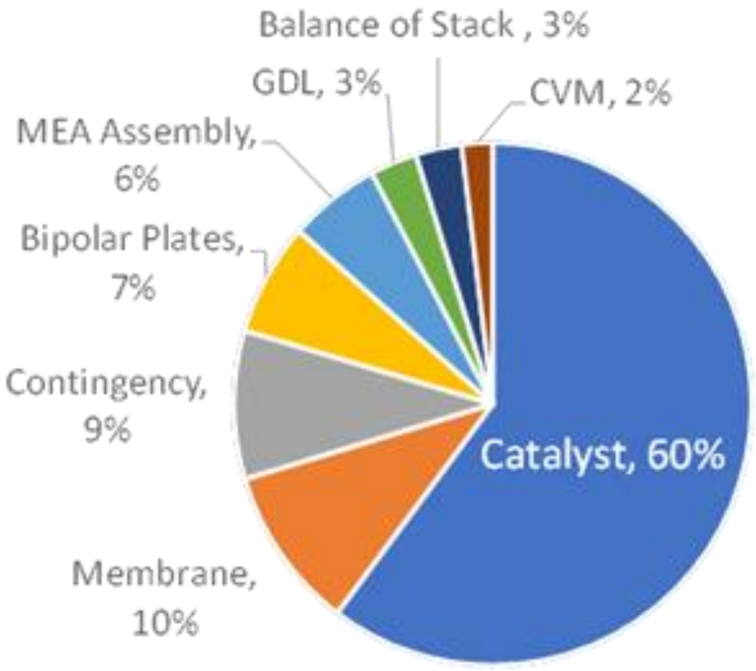
- **~$170/$kW_{net}$** at 50,000 systems/yr
- **~$160/$kW_{net}$** at 100,000 systems/yr



Cost status (2021, 2022, 2023) in 2016$ (blue bars) and 2020$ (orange bars) compared to the interim target (2025) for a manufacturing volume of 50,000 systems/yr. 2030 and ultimate targets are at 100,000 systems/yr.

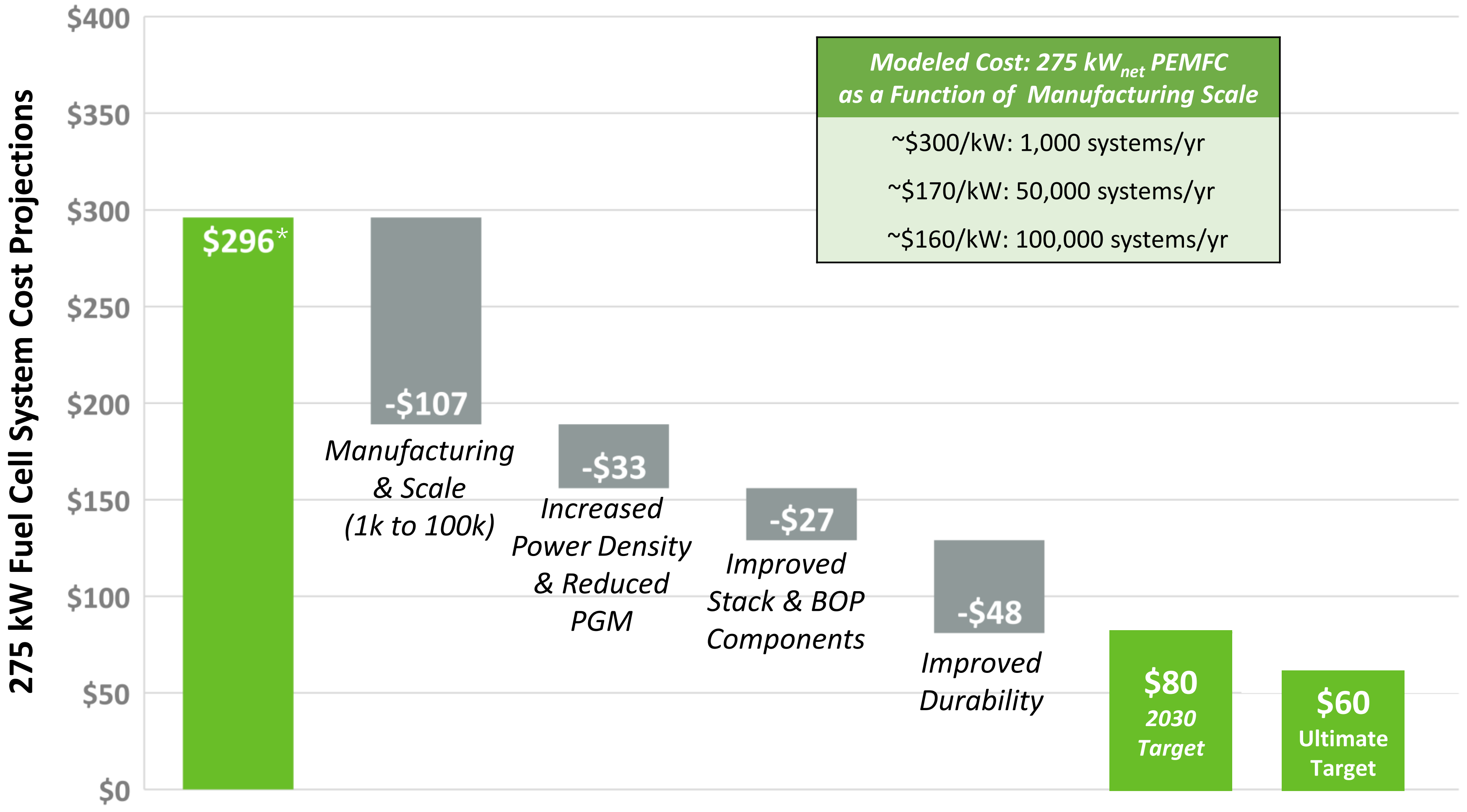
Stack cost breakdown

($105/$kW_{net}$ at 50,000 systems/yr)



Catalyst cost projected to be largest single component of stack cost to meet durability requirements

Emphasis on Key Areas Drives Cost Reduction

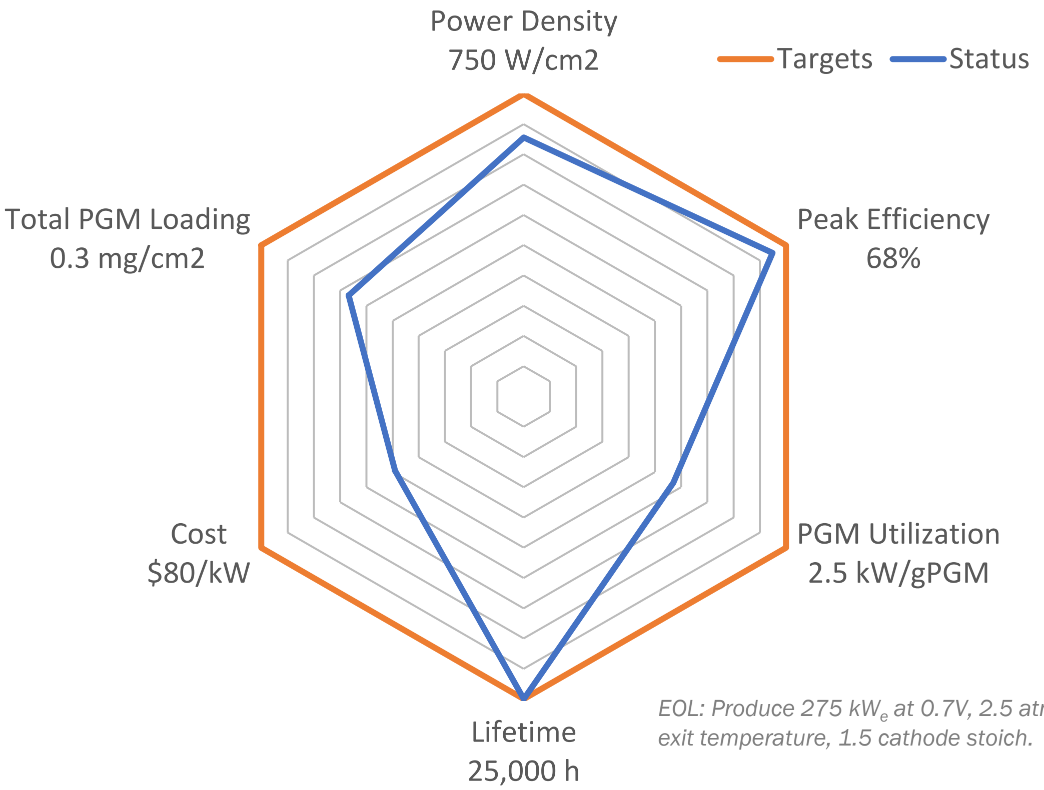


** For 1,000 systems/yr in 2020$*

Pathway towards cost target requires both technology improvements and manufacturing innovations

Analysis Assumptions Focus on Required Durability

25,000-hour lifetime is a primary requirement



EOL: Produce 275 kW_e at 0.7V, 2.5 atm, 90°C coolant exit temperature, 1.5 cathode stoich.

Analysis notes

- Stack oversized by 67% and overloaded with PGM for 25,000-hour electrode lifetime
- Analysis addresses heat rejection requirements
- Active and stable catalysts are needed to meet 750 mW/cm^2 power density at EOL with 0.3 mg/cm^2 total PGM loading

Targets need to be met concurrently to achieve fuel cell competitiveness for heavy-duty applications

Fuel Cell RD&D Highlights

Million Mile Fuel Cell Truck Consortium (M2FCT)

MISSION

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

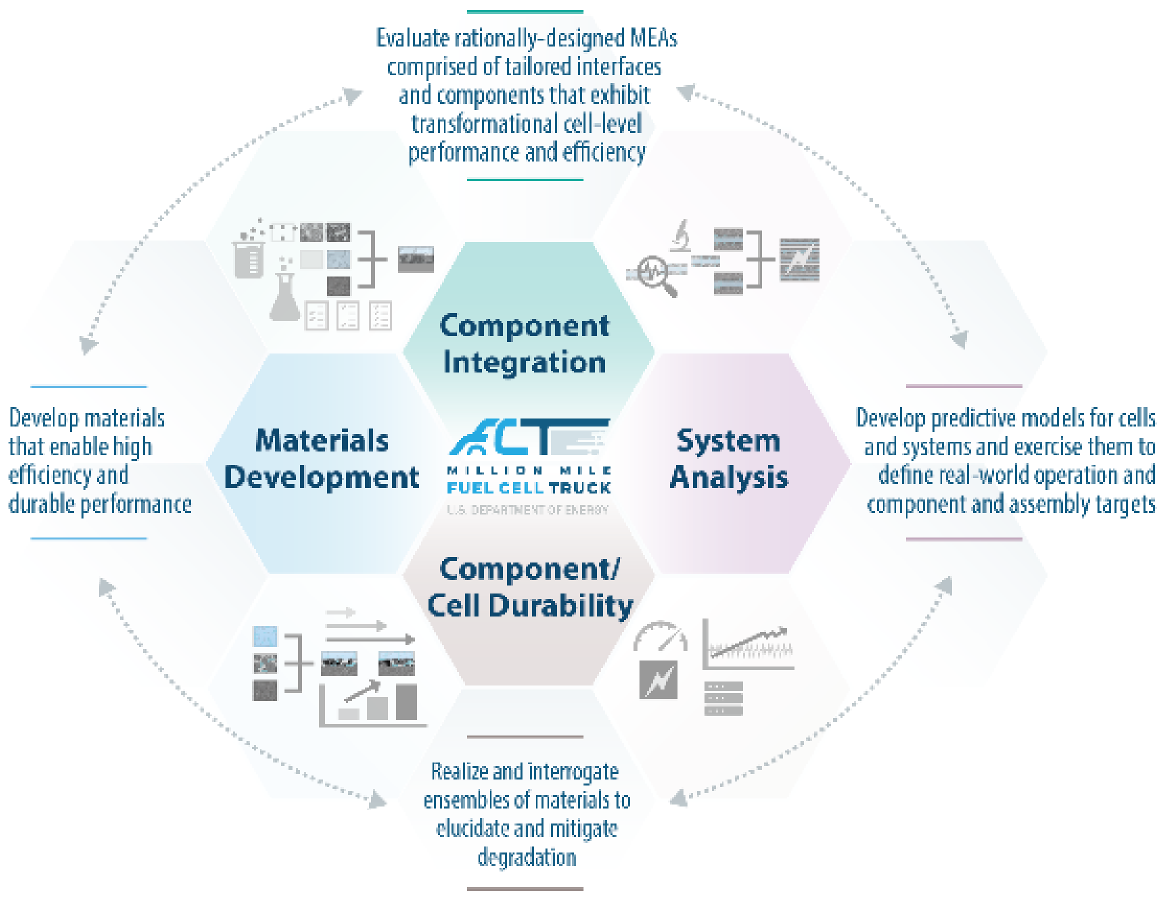
APPROACH

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

https://millionmilefuelcelltruck.org



Catalysts

Membranes

MEAs

Bipolar Plates

Stacks

Air Management

Analysis

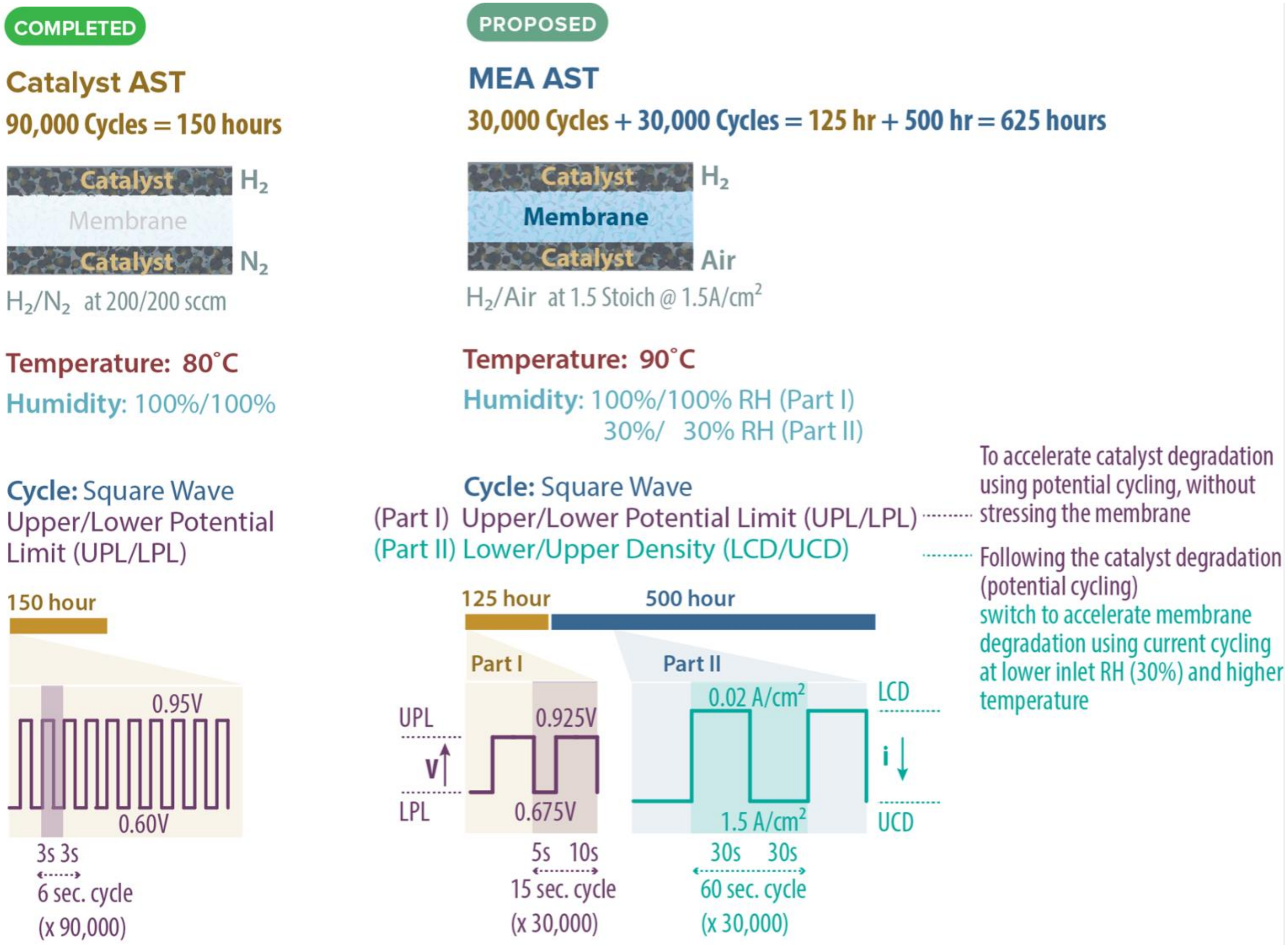
Main Laboratories

Affiliate Laboratories

Accelerated Stress Test (AST) Development

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

Developing 25000-hour equivalent ASTs for HD fuel cells



ASTs developed with stakeholder input and shared through the International Durability Working Group (iDWG)

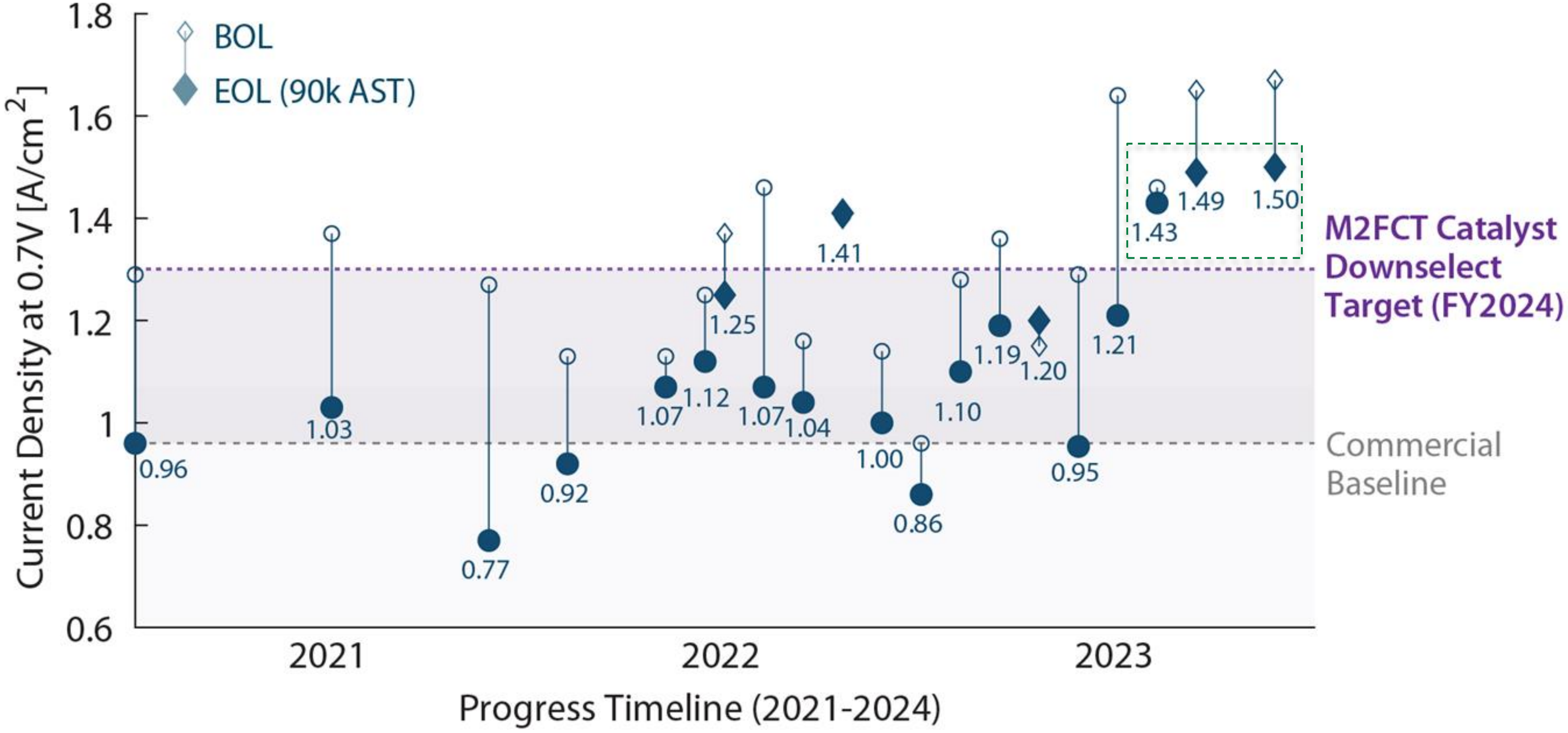
Finalized ASTs to be published on www.m2fct.org

Contact: M2FCTSC@lbl.gov

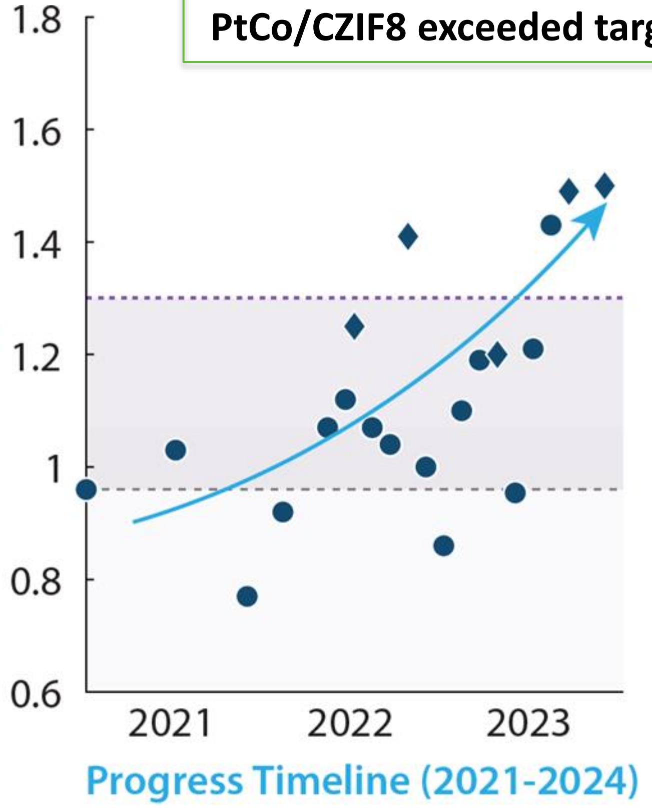
Catalyst Development Progress

Catalyst AST implemented for material down selection

Current Density before and after catalyst AST at a total PGM loading of 0.3 mg_{PGM}/cm^2



Pt/CZIF8* and GEN2-L10-PtCo/CZIF8 exceeded target



Circles: Conventional electrode design; Diamonds: Array electrode design.

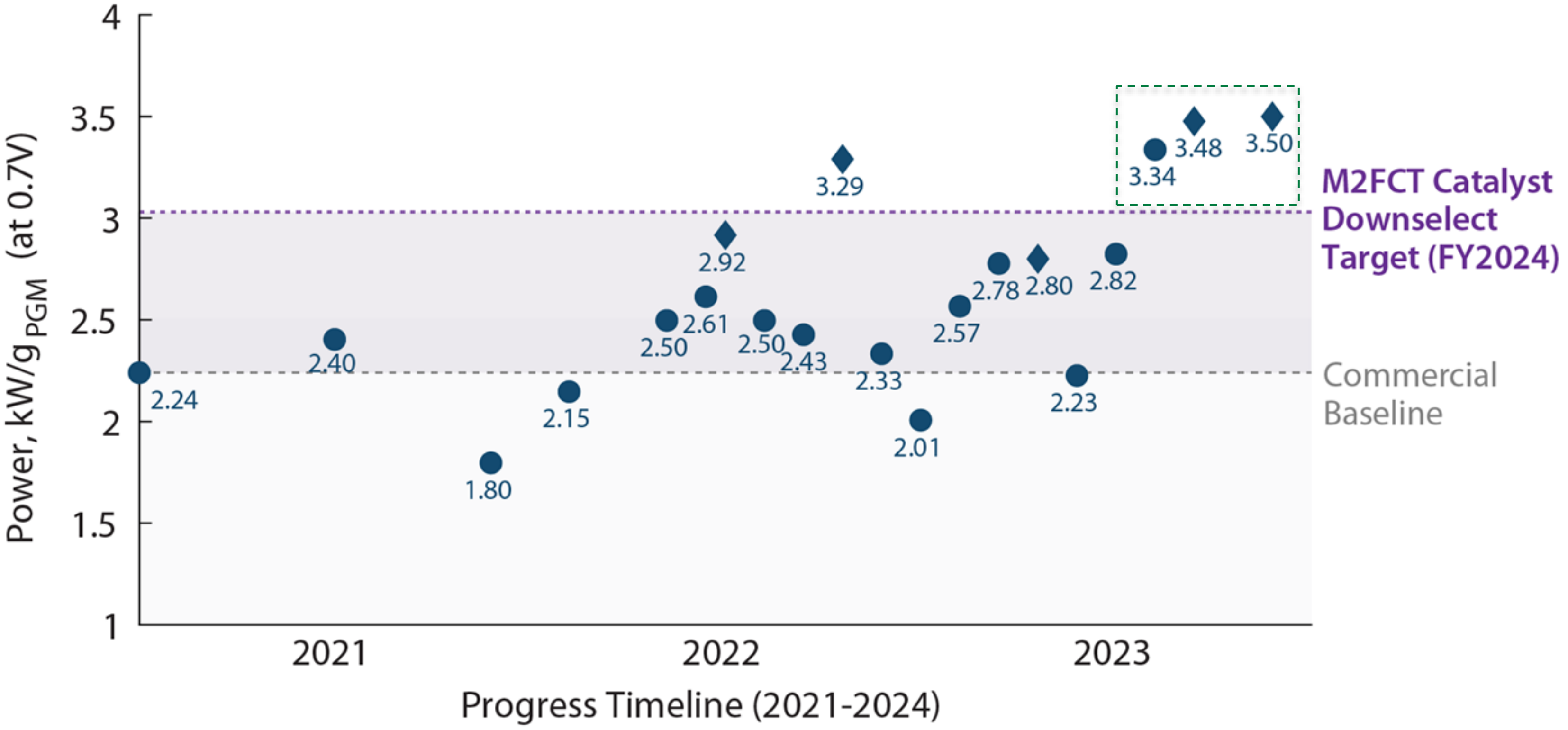
Commercial baseline: Umicore Elyst Pt50 0550 Pt/HSC

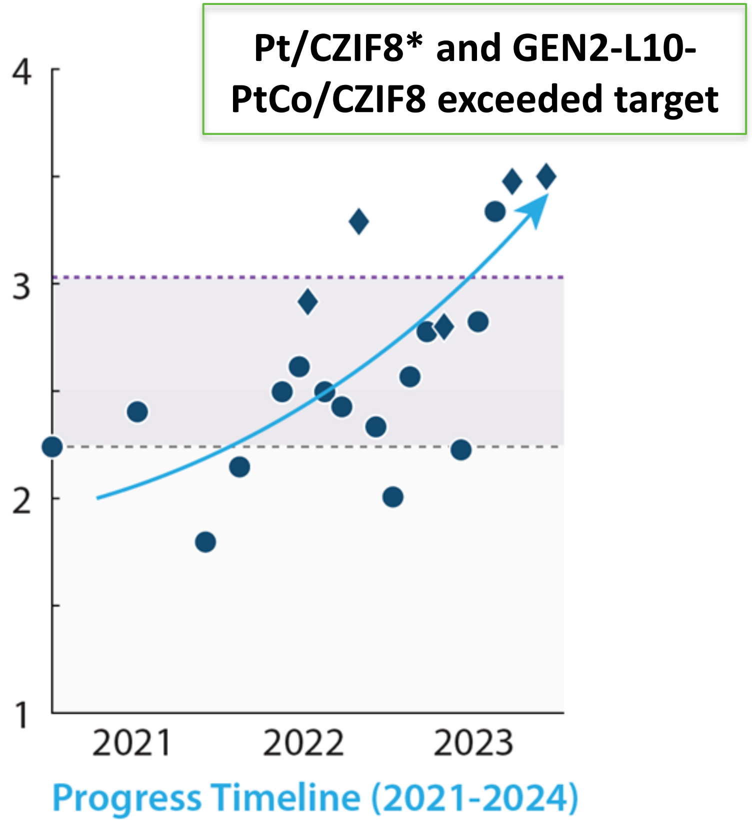
Conditions: 0.7V, 250 kPa, 85% RH, H_2/15% O_2.

**Performance also demonstrated with Pt/CZIF8 scaled to >10g batch*

Catalyst Development Progress

Power Density before and after catalyst AST at a total PGM loading of 0.3 mg_{PGM}/cm^2





Circles: Conventional electrode design; Diamonds: Array electrode design.

Commercial baseline: Umicore Elyst Pt50 0550 Pt/HSC

Conditions: 0.7V, 250 kPa, 85% RH, H_2/15% O_2.

**Performance also demonstrated with Pt/CZIF8 scaled to >10g batch*

Improved catalyst performance by over 55% in an MEA compared to commercial baseline

New M2FCT Industry and University Partner Projects Selected

High Performing and Durable Membrane Electrode Assemblies for Medium- and Heavy-Duty Applications

General Motors LLC *Dr. Anu Kongkanand*
Selective Transport Layers for PEM Fuel Cell and Electrolyzer MEAs

RTX *Dr. Robert Darling*
High Performance Hydrocarbon Membrane Electrode Assembly

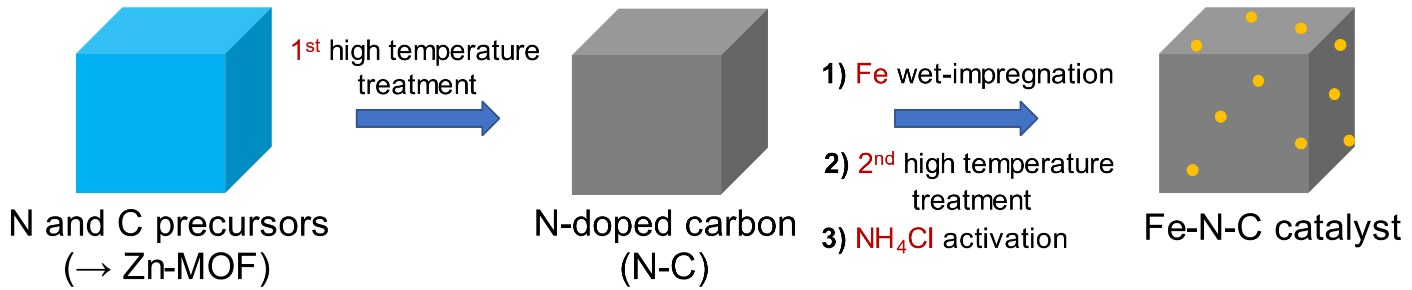
University of Hawaii at Manoa *Dr. Yunfeng Zhai*
High Performing and Durable MEAs with Novel Electrode Structures and Hydrocarbon Proton Exchange Membranes

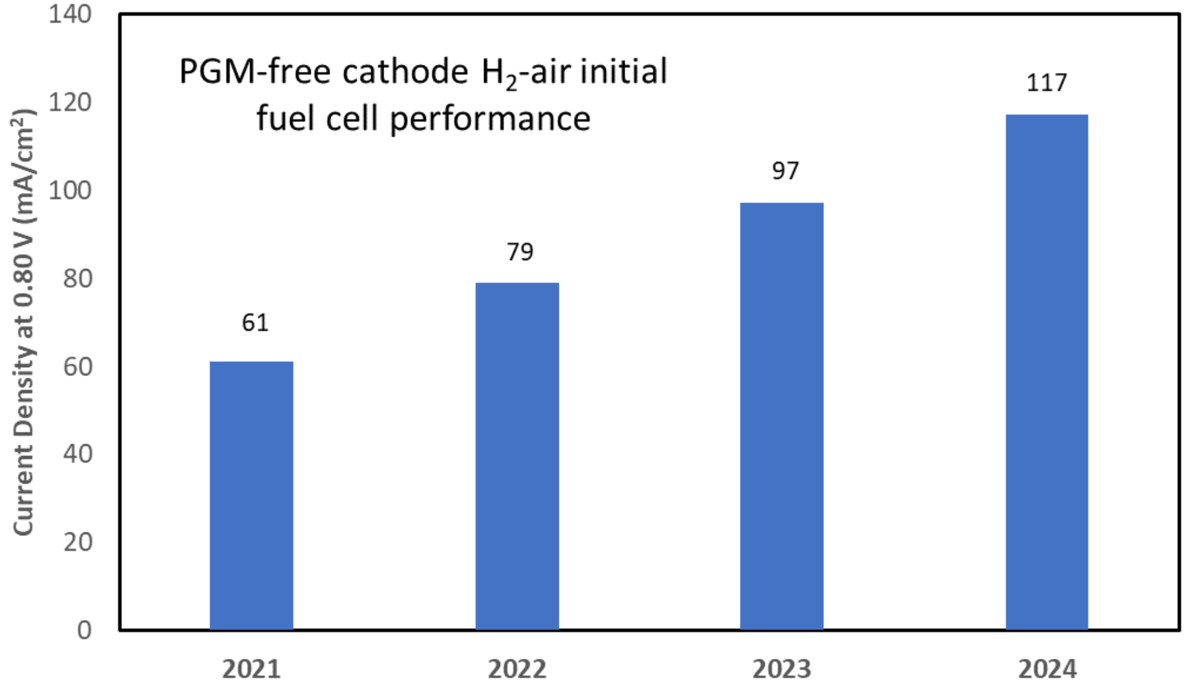
https://www.energy.gov/eere/fuelcells/selections-hydrogen-and-fuel-cell-technologies-office-funding-opportunity

PGM-Free Catalyst Performance Enhancement

ElectroCat
Electrocatalysis Consortium

Two-step, ammonia chloride activation synthesis of Fe-N-C catalyst:





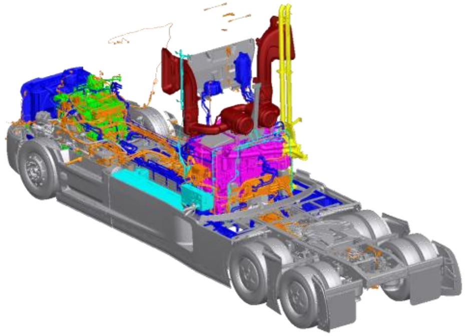
- Synthesis process development has led to more active PGM-free ORR catalysts
- Future work to focus on enhancing durability while retaining demonstrated activity

Improved PGM-free cathode H_2-air initial fuel cell performance by >90% compared to 2021 baseline

Hydrogen Fuel Cell Heavy Duty Truck Projects – SuperTruck 3

DAIMLER

Walmart
SCHNEIDER
Linde
MAHLE
MICHELIN



Argonne
NREL
Oak Ridge National Laboratory
Auburn University
Oregon State University

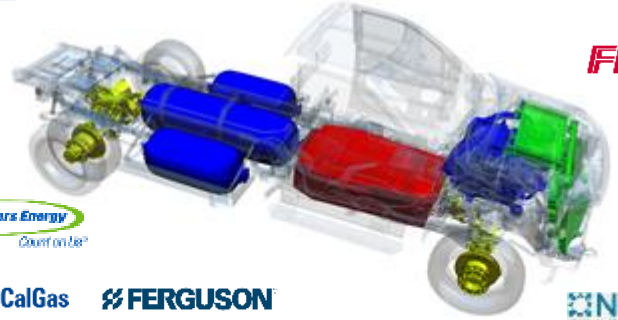
Goals:

- Demonstrate 2 total (Class 8) HD long-haul fuel cell electric trucks (B-sample & final truck demo)
- 6.0 mi/kg H_2 fuel economy
- 600-mile range (onboard LH_2 storage)
- 65,000 pounds GVW
- 25k hour lifetime

Key Accomplishments:

- Commissioned fuel cell system
- 1st complete B-sample prototype truck expected in 2024
- sLH_2 fueling protocol developed

Ford Motor Company



FEV
Consumers Energy
SoCalGas
FERGUSON
NREL

Goals:

- Demonstrate 5 total (Class 4-6) MD vocational trucks
- 300+kW_{net} vehicle power, H_2 PEMFC + Li-Ion battery
- 300-mile range (700 bar H_2 storage)
- 10K/20K pounds payload/tow capacity
- Meet or exceed 7.3L gas performance feel

Key Accomplishments:

- Commissioned fuel cell system
- 1st complete vehicle build expected in May 2024
- Over 20 patents filed

gm general motors

Southern Company
nel
Argonne

Goals:

- Demonstrate 8 total (Class 4-6) MD trucks
  - 4 fuel cell & 4 battery electric trucks
- Fuel Cell System Goals:
  - 65% peak efficiency
  - <$80/kW system cost (100K units/yr)
  - 20K-30K hour lifetime
- Demonstrate microgrid with electrolyzer & fuel cell (H_2 fueling & fast charging)

Key Accomplishments:

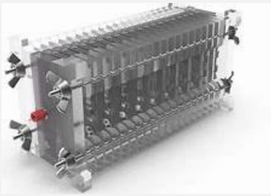
- Commissioned fuel cell system
- Early demo fleet build expected in 2024
- Path to >62% peak efficiency & >50% efficiency at full power

Images above are not final product and are subject to change

Co-funded with Systems Development & Integration (SDI); projects presented in SDI session

Manufacturing & Recycling Highlights

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.

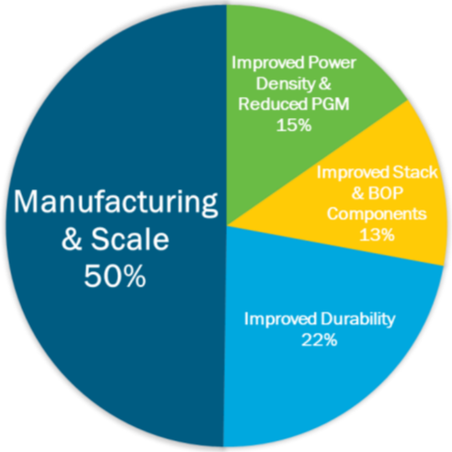
Sec. 40314 (EPACT Sec 813): Regional Clean Hydrogen Hubs; **$8 Billion over 5 years**

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)

Manufacturing Advancements to Enable Economies of Scale

Cost Reduction Opportunities
(From ~$300/kW @ 1k to $80/kW @100k systems/yr)



~1000 systems/year

Low volume:
- Manual assembly, stacking, inspection
- Minimal automation.

10,000 systems/year*

Near-term Capacity Increase:
- **Continuous processes**
- **Automated stacking, material handling**
- **In-line inspection**
- **Introduction of AI**
- **Streamlined acceptance testing.**

* Two HD stacks per system correspond to 20,000 stacks/yr

100,000 systems/year

Long-term Capacity Increase:
- Further increased throughput and manufacturing advancements
- Improved automation and integrated material handling
- Fully integrated IoT, metrology and AI
- Multiple manufacturing systems.

Needed production volumes will require manufacturing capabilities not seen in the field to date

Targets for HD Fuel Cell Components and Stack Production

Targets support near-term manufacturing capacity increase

Established 2030 target to enable market lift-off

HD fuel cell manufacturing capacity:

20,000 HD fuel cell stacks per year

in a single manufacturing system, while still aiming towards the 2030 DOE targets for cost, durability, and efficiency

Two HD stacks per system would correspond to 10,000 systems/yr

Estimated component manufacturing rates commensurate with 20,000 stacks/yr

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

Scaled-up fuel cell manufacturing will also require a reliable supply of materials and components

BIL FOA Selections

Clean Hydrogen Manufacturing and Recycling

$540M Total

$282M DOE Share

$357M Total $150M — **Fuel Cell MEA and Stack Manufacturing and Automation**

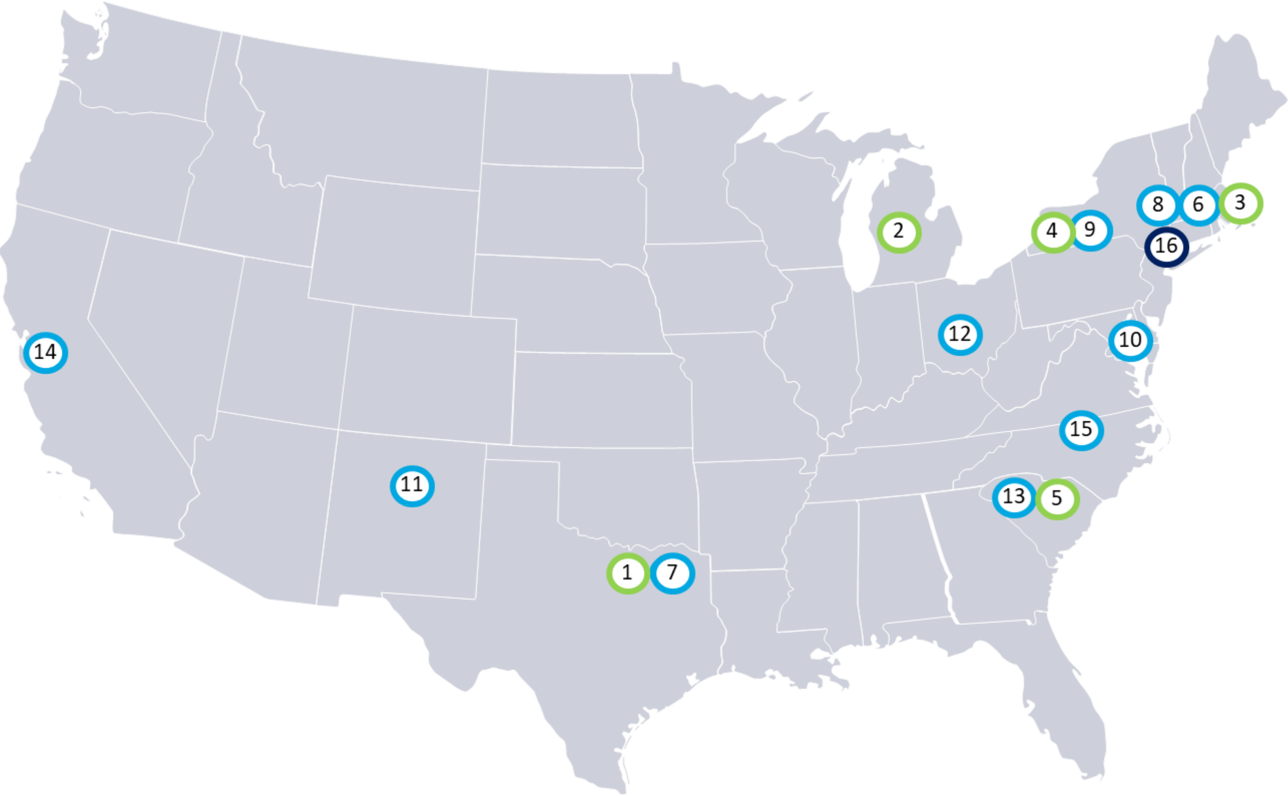
1. Ballard Power Systems
2. General Motors
3. Nuvera Fuel Cells
4. Plug Power
5. Robert Bosch

$119M Total $82M — **Fuel Cell Supply Chain Development***

6. AvCarb Material Solutions
7. Ballard Power Systems
8. Cabot Corporation
9. Ionomr Innovations
10. Materic
11. Pajarito Power
12. pH Matter
13. Robert Bosch
14. Robert Bosch
15. Saueressig

$64M Total $50M — **Recovery & Recycling Consortium**

16. American Institute of Chemical Engineers



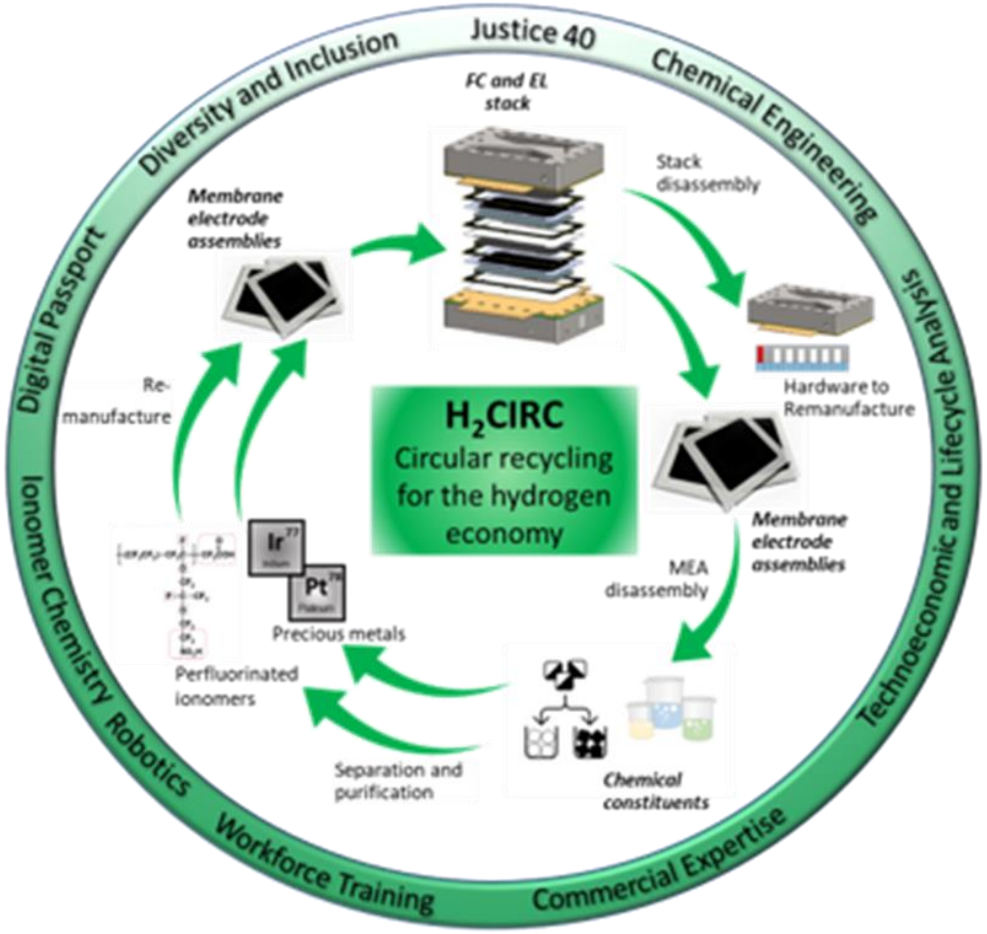
GDLs, Catalysts, Bipolar Plates, Non-PFSA Membranes

Enabling fuel cell manufacturing of 14 GW/yr

https://www.energy.gov/articles/biden-harris-administration-announces-750-million-accelerate-clean-hydrogen-technologies

Circular Recycling for the Hydrogen Economy Consortium (H_2CIRC)

Developing a robust domestic recovery and recycling capability for electrolyzers and fuel cells



Goal: Demonstrate pilot-scale validation activities over the entire recycling process along with analysis, digital passport, and community benefits/energy equity.

Impact: Established approach for recycling electrolyzers and fuel cells, long-term supply chain security, and environmental sustainability.

Emphasis

- Automated Stack Disassembly
- MEA Disassembly and Recycle*
- Analysis
- Digital Material Passport
- Community Benefits

* Includes PGM reclamation and ionomer recycling

Partners

AIChE (PI)	Delaware State U.
Chemours	U. of Delaware
Plug Power	Worchester Poly
Cummins	University of Houston
Heraeus	ORNL
Johnson Matthey	NREL
Nel Hydrogen	LBNL
General Motors	Strategic Analysis Inc.

Sustainable processes to recover and reuse >70% of ionomer and ≥95% of PGMs

Roll-to-Roll (R2R) Consortium

ROLL TO ROLL CONSORTIUM
U.S. DEPARTMENT OF ENERGY
Hydrogen and Fuel Cell Technologies Office

Advancing efficient, high-throughput, and high-quality manufacturing processes

National Lab Team

Argonne National Laboratory
NREL Transforming ENERGY
Berkeley Lab Bringing Science Solutions to the World
Oak Ridge National Laboratory
Sandia National Laboratories

Industry Advisory Board

Association for Roll-to-Roll Converters
gm
pH Matter llc
Chemours
IONOMR Innovations
Pajarito Powder
De Nora
nel
plug

Task Areas

- Materials Scale-Up Science
- MEA Fabrication
- Quality Control
- Process Modeling and AI/ML
- Characterization for Manufacturing Environment
- Technoeconomic Analysis

Request for CRADA Proposals

- Collaborative projects with Industry and Labs
- Concept Papers Due **June 3**

http://www.nrel.gov/hydrogen/r2r-crada-call.html

Tribal College Engagement with Hydrogen Technologies

Pilot project to strengthen national lab and tribal collaboration on clean H_2 manufacturing RD&D

NAVAJO TECHNICAL UNIVERSITY

Turtle Mountain Community College

Los Alamos NATIONAL LABORATORY

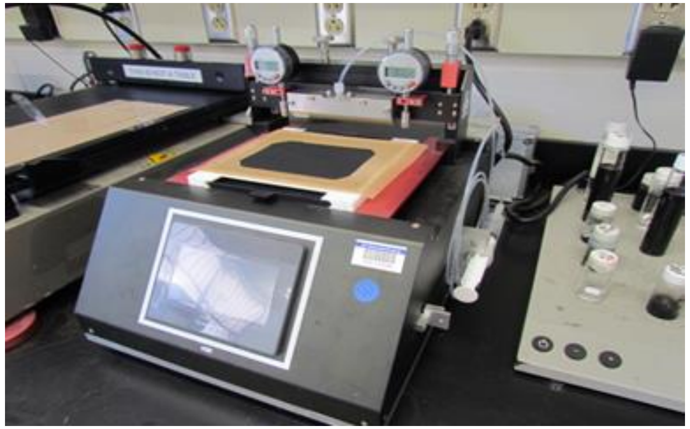
Collaboration with Navajo Technical University supports clean hydrogen careers

Internships offer opportunities in hydrogen and fuel cell research

https://discover.lanl.gov/news/1130-ntu-collaboration/

Native American Scholars make meaningful contributions to the team

Using AM for Complex Manufacturing Challenges



Modification to Slot Die Coater Electrode Manufacturing Overcomes Challenge

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

Cross-DOE Collaborations
(Including H_2 Joint Strategy Team Conversion Working Group)

EERE/VTO: SuperTruck	ARPA-E: Advanced Fuel Cell Concepts	FECM: SOFCs/RFCs
AMMTO: Manufacturing & Recycling	MESC: Supply Chain	BES: Fundamental R&D

DOE Cross-Cutting Initiatives

Critical Materials Collaborative	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)
- Hydrogen Interagency Taskforce (H_2 Supply Chain)

International Collaborations

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

Highlights and Milestones

FY2023	FY2024	FY2025
Improved catalyst performance in an MEA by over 45% compared to commercial baseline	*Improved catalyst performance in an MEA by over 55% compared to commercial baseline*	*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*
Improved PGM-free cathode H_2-air initial fuel cell performance by ~60% compared to 2021 baseline	*Improved PGM-free cathode H_2-air initial fuel cell performance by >90% compared to 2021 baseline*	*Improve PGM-free cathode H_2-air fuel cell performance*
Solicited and selected M2FCT FOA projects	*Solicited M2FCT Lab Call projects*	*Solicit and select M2FCT FOA projects*
Met 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*	*Meet durability adjusted HDV cost of $140/kW at 50,000 systems/year*
Solicited Sec. 815 Manufacturing and Recycling projects	*Selected Sec. 815 Manufacturing projects and Recovery & Recycling consortium*	*Initiate Sec. 815 Manufacturing projects and launch Recovery & Recycling consortium*

The Team

Dimitrios Papageorgopoulos

Fuel Cell Technologies Program Manager

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Scan for Open Positions

Technology Managers

Donna Ho
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Greg Kleen
Gregory.Kleen@ee.doe.gov

Will Gibbons
Willam.Gibbons@ee.doe.gov

Eric White
Eric.White@ee.doe.gov

Shaylynn Crum-Dacon
shaylynn.crum-dacon@ee.doe.gov

Open position
Technology Manager

Open position
Technical Project Officer

Fellows and Contractors

John Kopasz
Technical Advisor from ANL
Kopasz@anl.gov

Mike Ulsh
On Detail from NREL
Michael.Ulsh@ee.doe.gov

Open position
Fuel Cell Technologies Fellow

Open position
Manufacturing & Recycling Fellow

Ty Genard
Contractor
Ty.Genard@ee.doe.gov

Joe Troy
Contractor
Joseph.Troy@ee.doe.gov

Join Our Clean Energy Workforce Today

Stop by the table outside Independence Ballroom at lunch today to learn more!

EERE is driving the clean energy revolution by funding the innovation that's building the technologies that will forever change the way energy is generated and consumed. So now is a great time to become a **Clean Energy Champion** by joining EERE today!

Together we strive to:

- **Build the clean energy economy in a way that benefits all Americans.**
- **Create good paying jobs for the American people.**
- **Overcome the technological, economic, and institutional barriers to the development of hydrogen and fuel cells.**
- **Make renewable energy cost-competitive with traditional sources of energy.**
- **Increase access to domestic, clean transportation fuels.**
- **Reduce the carbon footprint of buildings.**
- **And so much more.**

EERE is committed to building a clean energy workforce with skilled professionals from diverse backgrounds. If interested in learning more about **becoming a Clean Energy Champion & joining the Clean Energy Revolution, stop by our booth to speak with our EERE Talent Acquisition representatives today!**

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Thank You

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