U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Introduction to the DOE Hydrogen Program

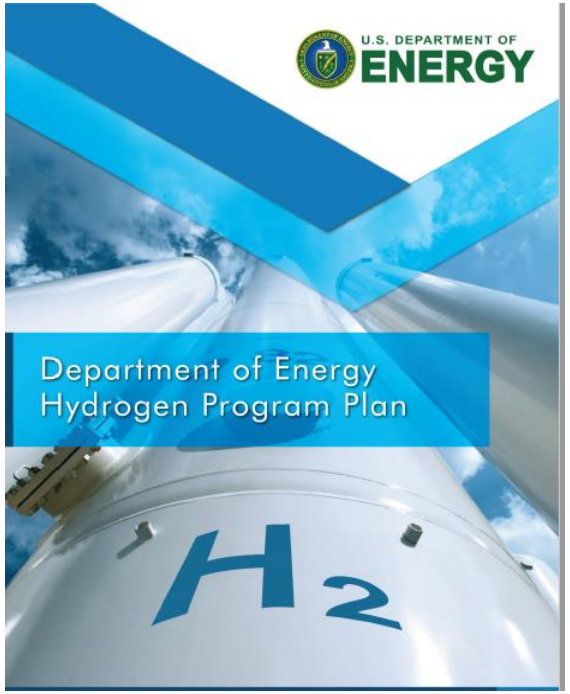
Dr. Ned Stetson (Program Manager),
Hydrogen and Fuel Cell Technologies Office

High-Temperature Electrolyzer Manufacturing Virtual Workshop, March 8-9, 2022

The U.S. DOE Hydrogen Program

Key DOE Hydrogen Authorizations in the Energy Policy Act (2005, 2020) and Infrastructure Investment and Jobs Act (2021)

Hydrogen is one part of a broad portfolio of activities



www.hydrogen.energy.gov

The DOE Hydrogen Program is an agency wide effort, encompassing efforts from across the DOE

EERE – Hydrogen and Fuel Cell Technologies Office –
H_2 Program Coordination Lead

Office of Energy Efficiency and Renewable Energy
Office of Fossil Energy and Carbon Management
Office of Nuclear Energy
Office of Electricity
Office of Science
Office of Clean Energy Demonstrations
Advanced Research Projects Agency – Energy
Office of Technology Transition
Loan Program Office

Priorities

1. **Low-cost, clean hydrogen**
2. **Low-cost, efficient, safe hydrogen delivery and storage**
3. **Enable end-use applications at scale for impact**

Workforce development, safety, codes, standards, and Environmental Justice priorities

Hydrogen Program Areas of Focus across Multiple Offices

NEAR-TERM → **LONGER-TERM**

Production
- Gasification of coal,* biomass, and waste with carbon capture, utilization and storage (*waste coal, other waste)
- Advanced fossil and biomass reforming/conversion/pyrolysis
- Advanced biological/microbial conversion
- Electrolysis (low-temperature, high-temperature)
- Advanced thermo/photoelectro-chemical H_2O splitting

Delivery
- Distribution from on-site production
- Tube trailers (gaseous H_2)
- Widespread pipeline transmission and distribution
- Cryogenic trucks (liquid H_2)
- Chemical H_2 carriers

Storage
- Pressurized tanks (gaseous H_2)
- Geologic H_2 storage (e.g., caverns, depleted oil/gas reservoirs)
- Cryogenic vessels (liquid H_2)
- Cryo-compressed
- Chemical H_2 carriers
- Materials-based H_2 storage

Conversion
- Turbine combustion
- Advanced combustion
- Fuel cell/combustion hybrids
- Fuel cells
- Next generation fuel cells
- Reversible fuel cells

Applications
- Fuel refining
- Blending in natural gas pipelines
- Space applications
- Distributed stationary power
- Utility systems
- Portable power
- Transportation
- Distributed CHP
- Integrated energy systems
- Industrial and chemical processes
- Defense, security, and logistics applications

President Biden and Energy Secretary Granholm at Climate Summit

"…I've asked the Secretary of Energy to speed the development of critical technologies to tackle the climate crisis. No single technology is the answer on its own because every sector requires innovation to meet this moment."

President Joseph R. Biden
April 23, 2021

Launch of Hydrogen Energy Earthshot
First of the Energy Earthshots
June 7, 2021
at DOE Hydrogen Program Annual Merit Review

Secretary Jennifer Granholm
June 7, 2021

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Hydrogen Energy Earthshot

“Hydrogen Shot”

“1 1 1”
$1 for 1 kg clean hydrogen in 1 decade

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

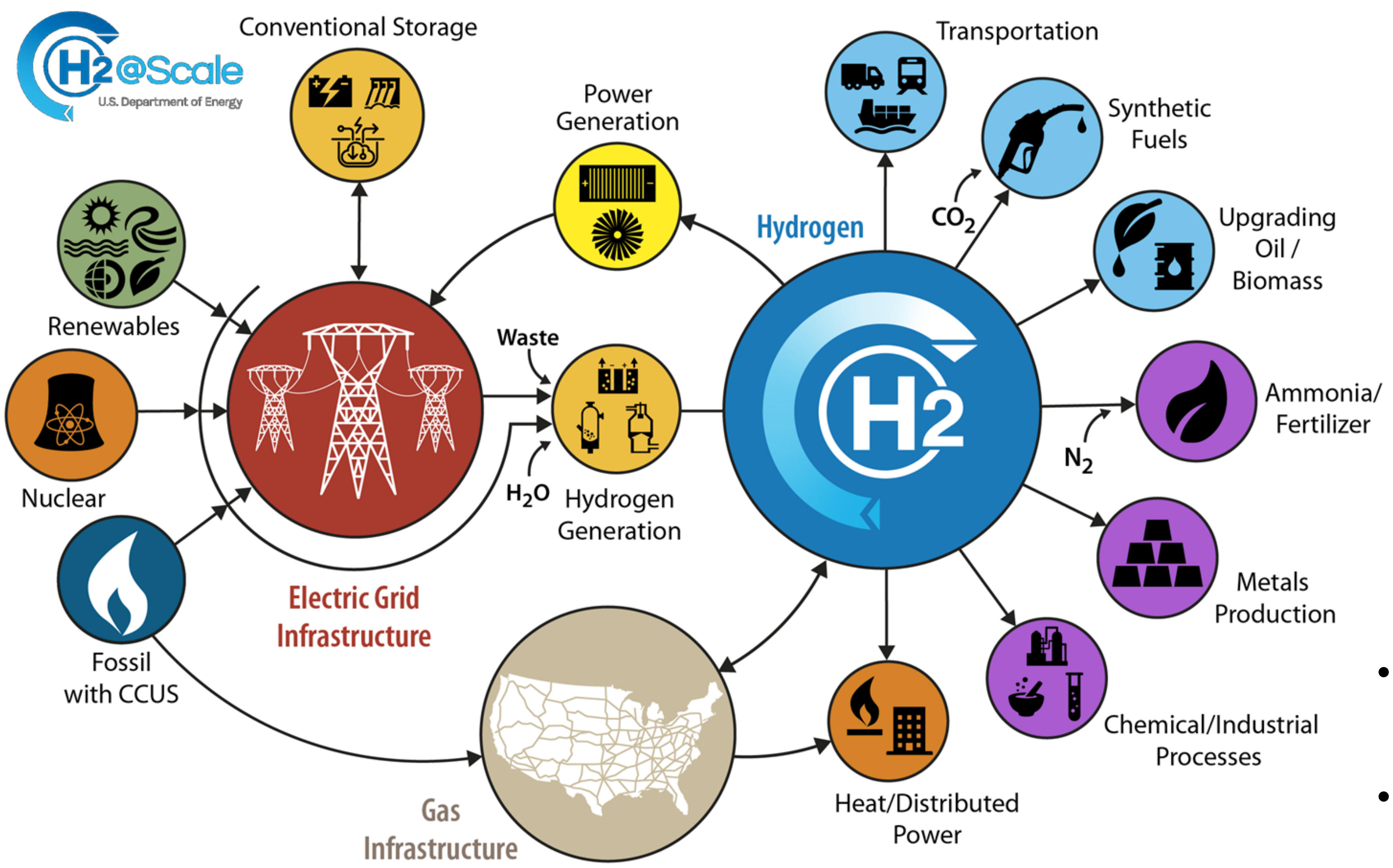
Bipartisan Infrastructure Law - Hydrogen Highlights

- **Covers $9.5B** for clean hydrogen:
  - $8B for at least four regional clean hydrogen hubs
  - $1B for electrolysis research, development, demonstration, commercialization, and deployment
  - $500M for clean hydrogen technology manufacturing and recycling R&D

President Biden Signs the Bipartisan Infrastructure Bill on November 15, 2021.
Photo Credit: Kenny Holston/Getty Images

- **Aligns with Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026**

- **Requires developing a National Hydrogen Strategy and Roadmap**



Key Opportunities

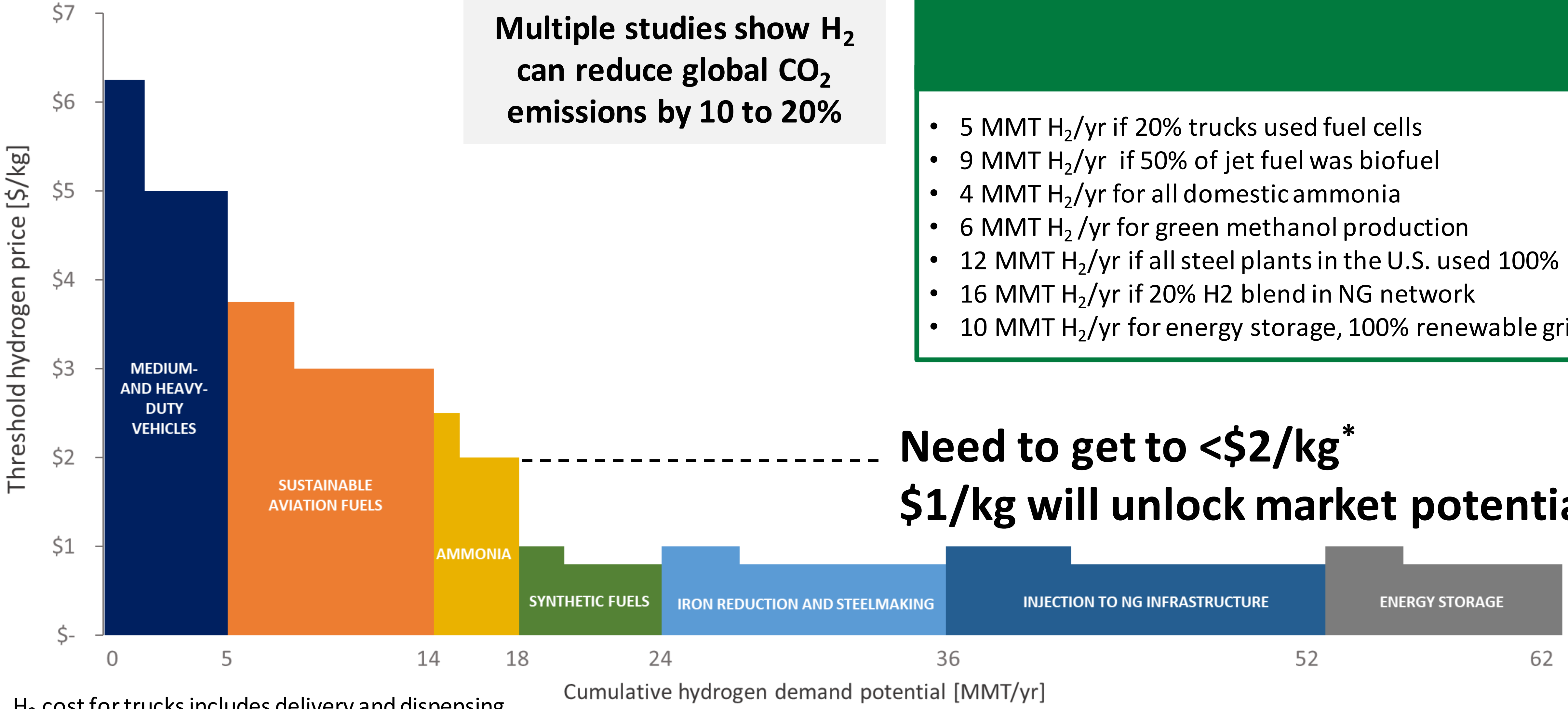
- **Industry and Chemicals**
  Steel, ammonia, cement, syn fuels (e.g., aviation), exports
- **Transportation**
  Trucks, marine, buses, etc.
- **Power and Energy Storage**
  Long duration storage, NG blending, turbines, fuel cells

U.S. Snapshot

- 10 MMT of H_2/yr produced today with scenarios for 2-5X growth.
- +10 MMT clean H_2 could require ~ double today's solar or wind deployment
- Potential for 700K jobs, $140B by 2030

Analysis Determines Market Potential Scenarios

Multiple studies show H_2 can reduce global CO_2 emissions by 10 to 20%



- 5 MMT H_2/yr if 20% trucks used fuel cells
- 9 MMT H_2/yr if 50% of jet fuel was biofuel
- 4 MMT H_2/yr for all domestic ammonia
- 6 MMT H_2 /yr for green methanol production
- 12 MMT H_2/yr if all steel plants in the U.S. used 100% H_2
- 16 MMT H_2/yr if 20% H2 blend in NG network
- 10 MMT H_2/yr for energy storage, 100% renewable grid

Need to get to <$2/kg*
$1/kg will unlock market potential

H_2 cost for trucks includes delivery and dispensing

* H_2 could compete at $1 to $2/kg higher cost with a carbon price

Results based on preliminary analysis

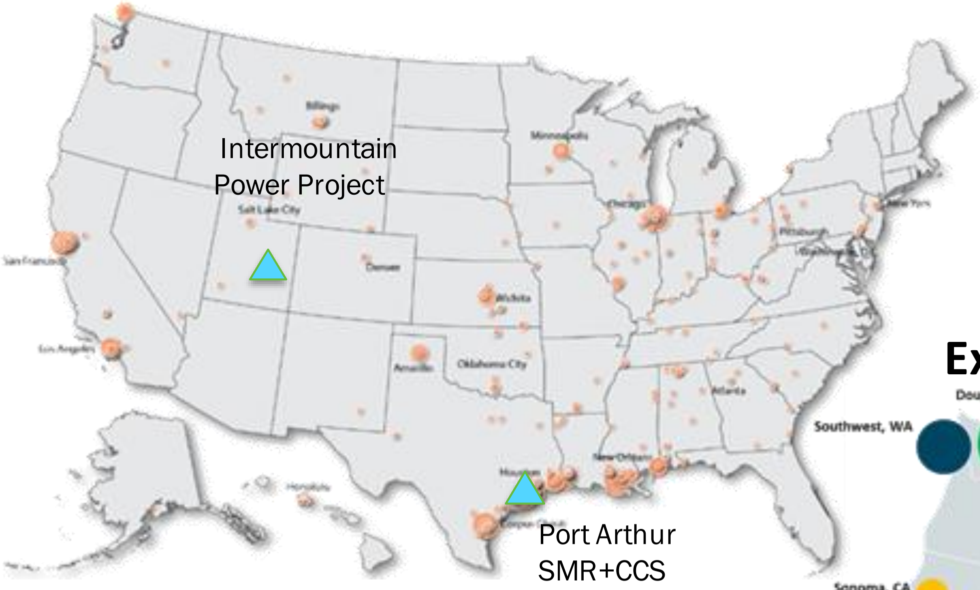
Snapshot of Hydrogen and Fuel Cells in the U.S.

Deployment Examples
June 2021 Snapshot

- **>500MW** Backup Power
- **>40,000** Forklifts
- **>172 MW** PEM* Electrolyzers
- **>60** Fuel Cell Buses
- **>45** H_2 Retail Stations
- **>12,000** Fuel Cell Cars

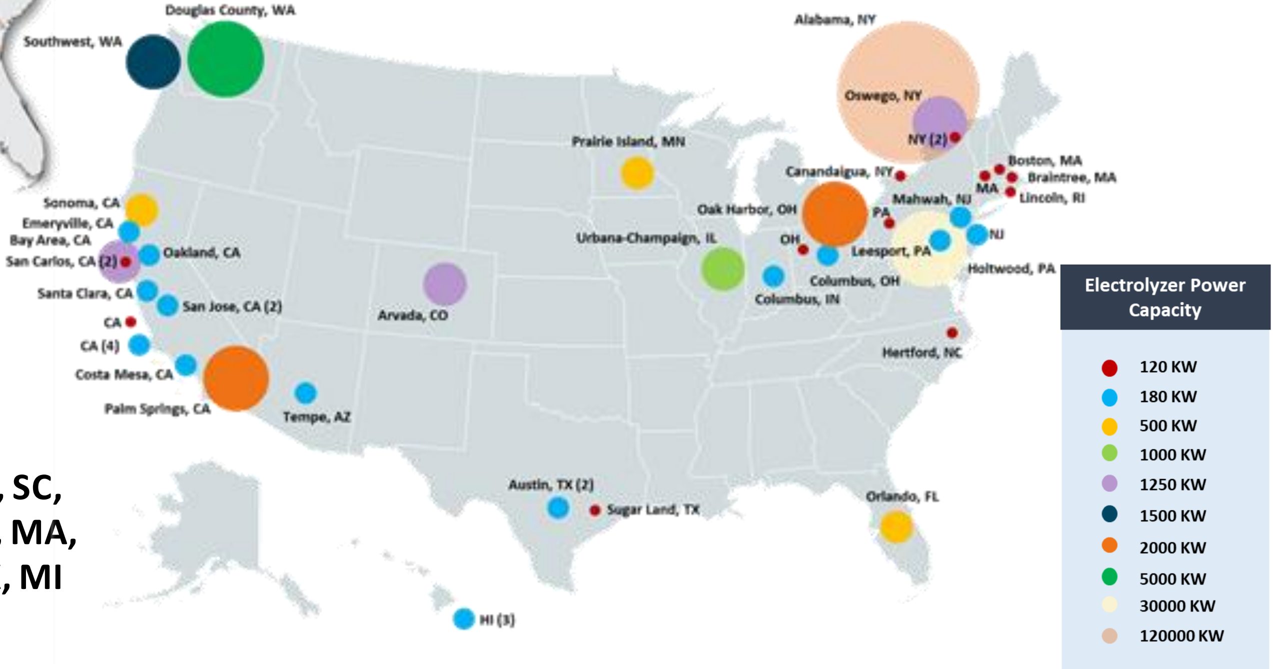
* Polymer electrolyte membrane

Examples of Hydrogen Production Locations



- 10 million metric tons (MMT) H_2/yr
- Over 1,600 miles of H_2 pipelines
- World's largest H_2 storage cavern

Examples of PEM Electrolyzer Installations



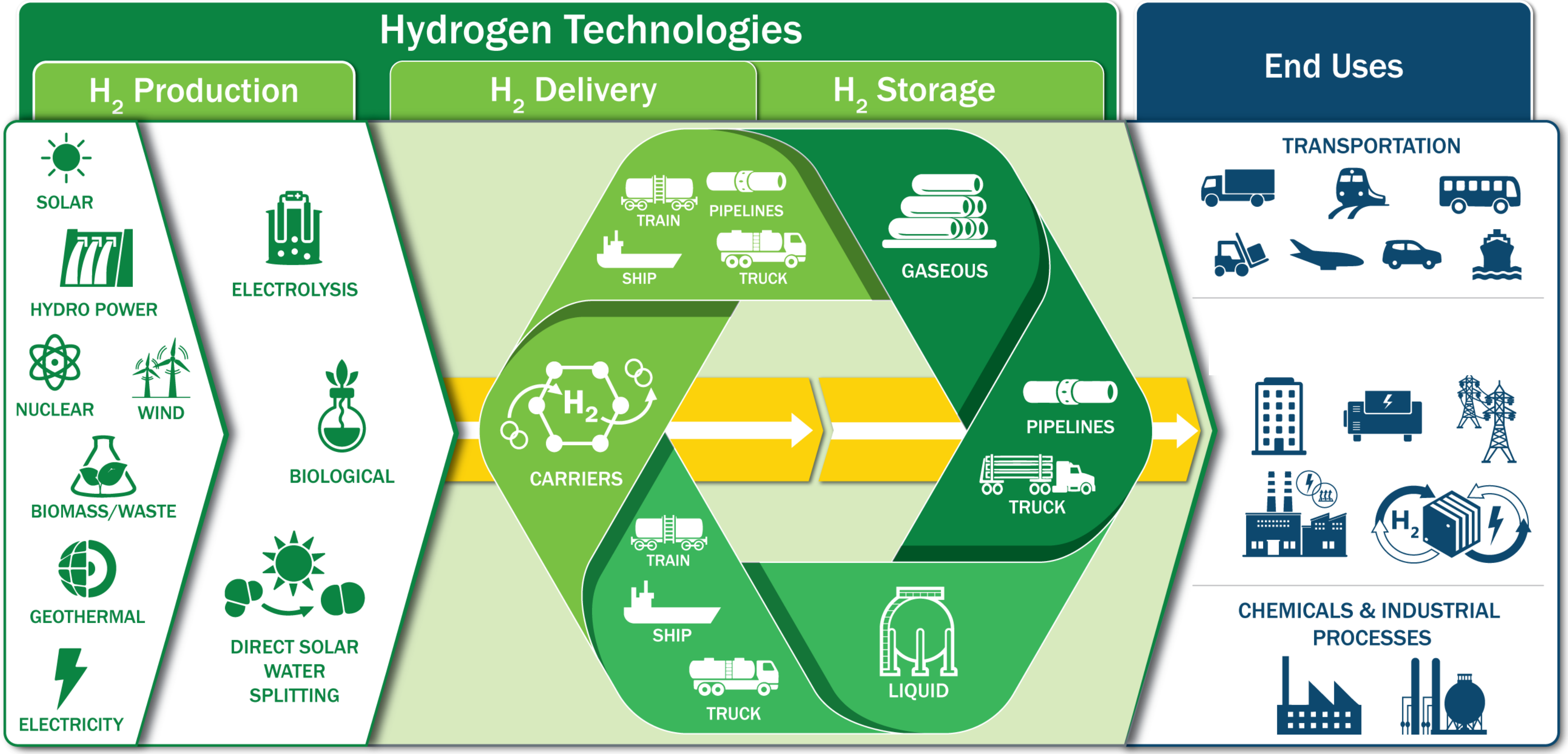
Current and under construction installations over 120 kW as of Jun. 2021

** Source: Arjona, et al, DOE HFTO Program Record, June 2021*

Examples of Hydrogen Station Plans

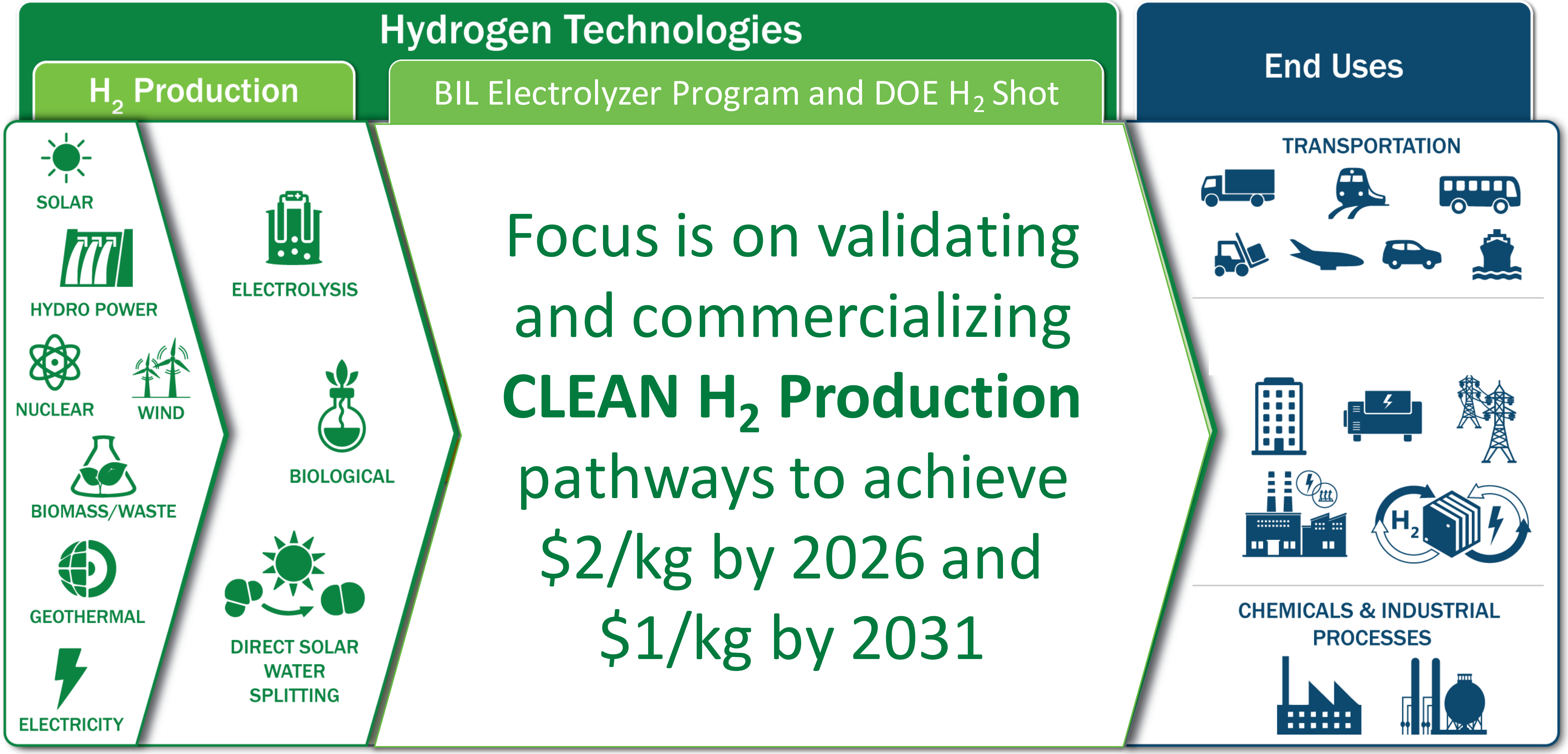
California	Northeast	AZ, HI, OH, SC, NJ, NY, CT, MA, CO, UT, TX, MI
200 Stations Planned California Fuel Cell Partnership Goal	12 – 20 Stations Planned	And more

Hydrogen Technologies RD&D Program



From producing hydrogen molecules through dispensing to end-use applications

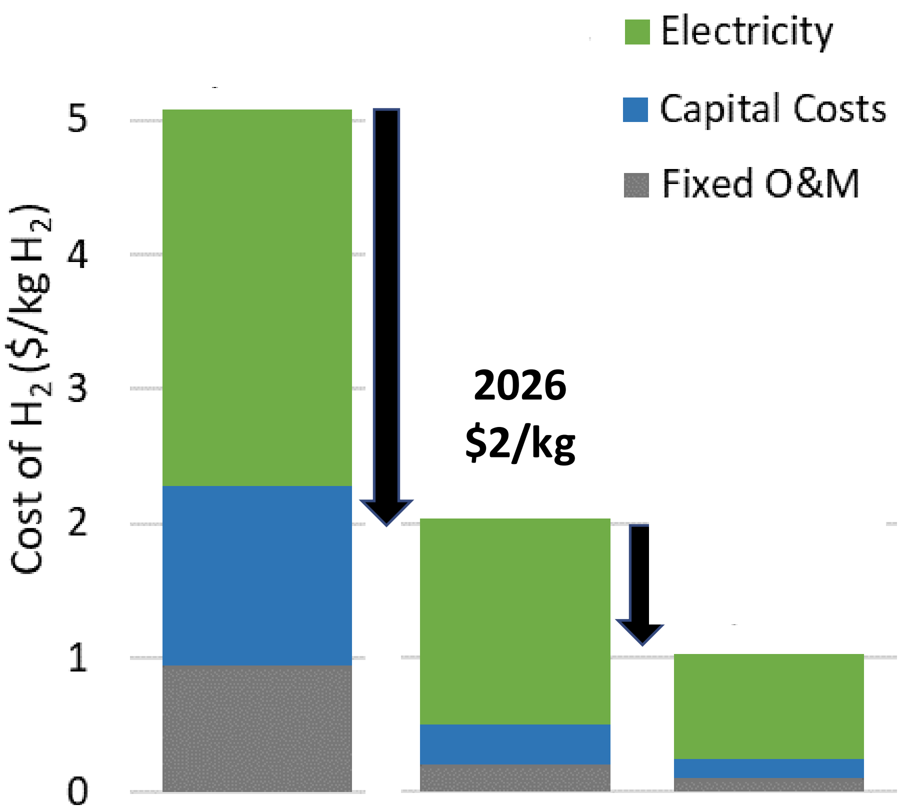
Hydrogen Technologies RD&D Program



Commercialization and deployment at a scale to address environmental and climate issues is needed

Pathways to Reduce the Cost of Electrolytic H_2

Cost Reduction of Clean Electrolytic H_2



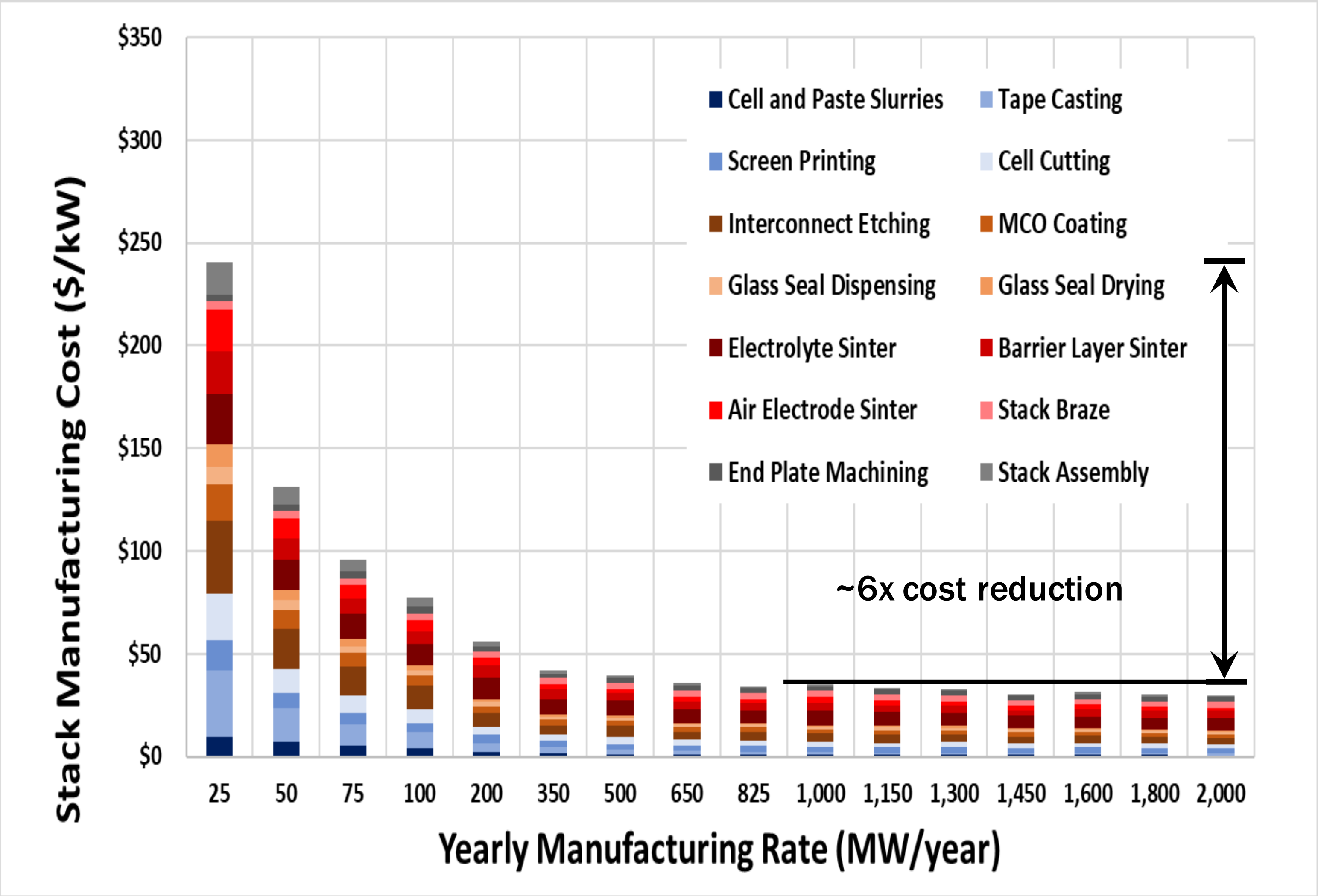
Key enablers for lower cost electrolytic H_2:

- Low-cost electricity, variable operation
- High electrical efficiency
- Low-cost capital expense
- Increased durability/lifetime
- Low-cost manufacturing processes
- Manufacturing at MW-scale
- Increased power density

Electrolyzer goals for 2025	Unit	PEM	SOEC
Higher electrical efficiency	% (LHV)	≥ 70	≥ 98
Lower stack costs	\$/kW	≤ 100	≤ 100
Increased durability	hours	80,000	60,000
Lower system CAPEX	\$/kW	≤ 250	≤ 300

https://www.hydrogen.energy.gov/pdfs/review21/plenary7_stetson_2021_o.pdf

Projected impact on manufacturing volume on cost



Projected stack manufacturing costs for H_2-electrode supported cells as a function of annual manufacturing rate – SA, Inc.

Analyses project a 4.5 – 6x reduction in SOEC stack manufacturing costs on increasing manufacturing rates from 25 MW to 1 GW per year

Strategic Analysis, Inc.

Workshop focus and objectives

- **To achieve the DOE H_2 Shot's and BIL Electrolysis Program's goals, low-cost commercial electrolyzer technologies will be essential**
  – What is the state-of-the-art for SOEC manufacturing
  – What is required to have low-cost, high-volume SOEC manufacturing processes
- **What is the role for the DOE in developing and supporting low-cost SOEC manufacturing to achieve high-volume, domestic manufacturing within the next 5 years**
  – What are the development needs for low-cost manufacturing processes
  – What should be the priority areas for DOE to focus on
- **What are other needs and considerations for DOE to address**
  – Technology R&D needs DOE should address to achieve low-cost SOECs
  – Other considerations DOE should address to achieve low-cost SOCEs

Meeting Objectives

Day 1 – Expert Presentations

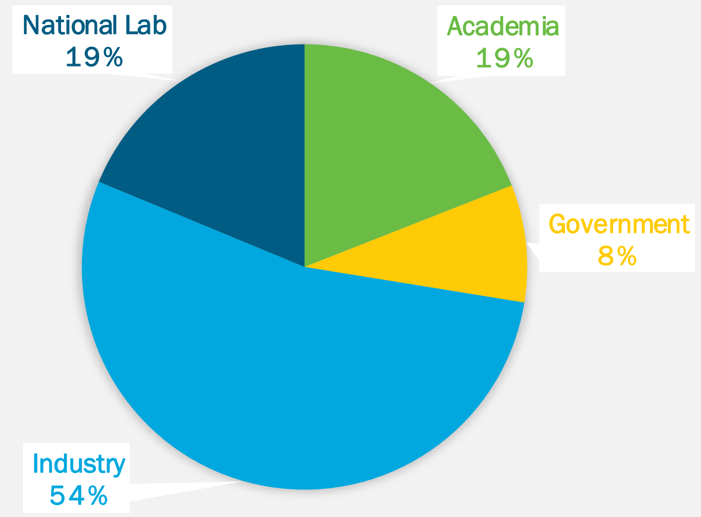
Hear from experts on the challenges & opportunities for high-volume stack, component, and system manufacturing

Day 2 – Parallel Discussions

Discuss and prioritize the most promising & impactful opportunities for high-volume manufacturing

Identify pathways to achieve $1/kg H_2

Diverse stakeholders from industry, government, academia & the labs



Please use the Zoom *Q&A* feature to record your comments & questions during the meeting

Thank You for Joining Us!

Special thanks to the Organizing Team…

HFTO	National Labs
Ned Stetson	Richard Boardman
Will Gibson	Jamie Holladay
Dave Peterson	Olga Marina
McKenzie Hubert	**The Building People**
Anne Marie Esposito	Stacey Young
Colin Gore	
Nikkia McDonald	
Cassie Osvatics	

And all Speakers, Panelists, Moderators, & Scribes!

Brian James	Edgar Lara Curzio
Paul Moses	Lorraine M. Seymour
Venkat Venkataraman	Long Q. Li
Tony Leo	Sarah Shulda
Scott Swartz	Jeremy Hartvigsen
Joe Hartvigsen	Christopher Coyle
John Pietras	Cameron Priest
Jens Suffner	Joel Berry
Greg Tao	Asha-Dee Celestine
Todd Striker	Fernando Dias
Harry Abernathy	Martha Welander
Peter Rupnowski	Joshua Tenney
Kerry Meinhardt	John T. Zaengle
Dong Ding	Joshua Gomez
Brandon Wood	Nathanael T. Royer

H2NEW Hydrogen from Next-generation Electrolyzers of Water
U.S. DEPARTMENT OF ENERGY

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Thank you for your participation

Ned T. Stetson, Ph.D.
Program Manager, Hydrogen Technologies
Hydrogen and Fuel Cell Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
ned.stetson@ee.doe.gov

www.energy.gov/fuelcells
www.hydrogen.energy.gov