U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Welcome and an Introduction to the DOE Hydrogen Program

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

Liquid Hydrogen Virtual Workshop, February 22-23, 2022

Workshop Agenda

Day 1 - Liquefaction: Current Status and RD&D Needs

11:00 am Opening remarks
- DOE Hydrogen Program Perspectives (Ned Stetson, U.S. Department of Energy)
- NASA Perspectives (Michael Meyer, National Aeronautics and Space Administration)

11:20 am Current State-of-the-Art of Hydrogen Liquefaction (Oriane Farges, Air Liquide)

11:40 am Experiences and Lessons Learned with Liquid Hydrogen (Raja Amirthalingam, Plug Power)

12:00 pm Innovative Approaches to Improve Scalability and Efficiency
- Amgad Elgowainy (Argonne National Laboratory)
- Jacob Leachman (Washington State University)

12:40 pm *Break*

1:00 pm Liquid Hydrogen in Emerging Large-Scale Markets (Jotsu Liao, Shell International, Inc.)

1:20 pm Panel Discussion and Q&A with Speakers

1:40 pm Breakout Sessions
- Hydrogen Liquefaction
- Liquid Hydrogen Delivery and Distribution
- Emerging Applications of Liquid Hydrogen

2:20 pm *Break*

2:35 pm Breakout Session Report Out

2:55 pm Day 1 Closing Remarks

Day 2: Liquid Hydrogen Storage and Handling Infrastructure: Current Status and RD&D Needs

11:00 am Introduction to Day 2

11:05 am Current Status of Technologies Used for Bulk Storage of Liquid Hydrogen
- John Jacobson (CB&I Storage Solutions)
- Reid Larson (Chart Industries)

11:45 am Potential Benefits and Challenges to Liquid Hydrogen for MD/HD vehicles
- Rajesh Ahluwalia (Argonne National Laboratory)
- Gladys Anyenya (Wabtec Corporation)

12:25 pm Current Practices to Transfer and Deliver Liquid Hydrogen
- Ravi Subramanian (Air Products)
- Angela Krenn (NASA-Kennedy Space Center)

1:05 pm *Break*

1:25 pm Safety Requirements for Liquid Hydrogen Handling and Refueling (Aaron Harris, Hydrogen Safety Panel)

1:45 pm Materials Performance at Cryogenic Temperatures (Joseph Ronevich, Sandia National Laboratories)

2:05 pm Breakout Sessions
- Liquid Hydrogen Handling
- Liquid Hydrogen Storage

2:45 pm *Break*

3:05 pm Breakout Session Report Out

3:25 pm Workshop Concluding Remarks

Workshop Objectives

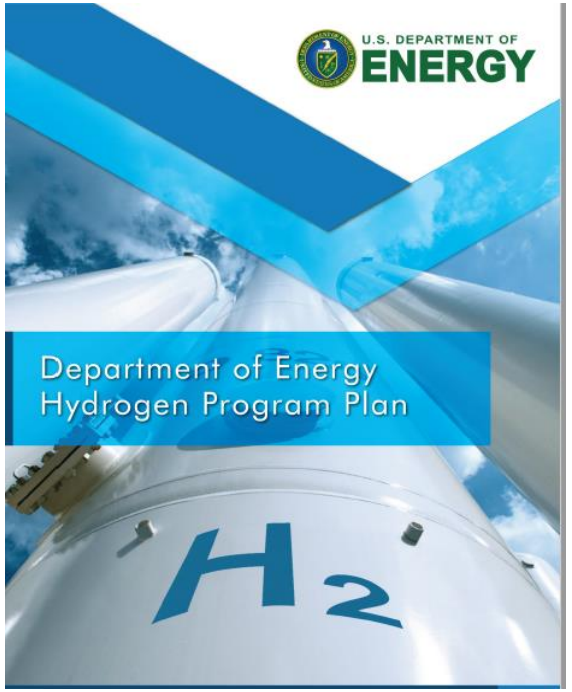
- With the increasing role of hydrogen to meet decarbonization goals across many sectors of the economy, liquid hydrogen technologies is expected to play a critical role. To meet the goals, however, reduced cost, higher performance and greater efficiencies must be achieved.

- Workshop Objectives
  - Review current state-of-the-art of liquid hydrogen technologies
  - Identify R&D needs, specifically for:
    - Reduced costs
    - Higher efficiencies
    - Increased scalability
  - Identify ways to improve safety, especially if used in consumer applications
  - Address other considerations

The U.S. DOE Hydrogen Program

Key DOE Hydrogen Authorizations in 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

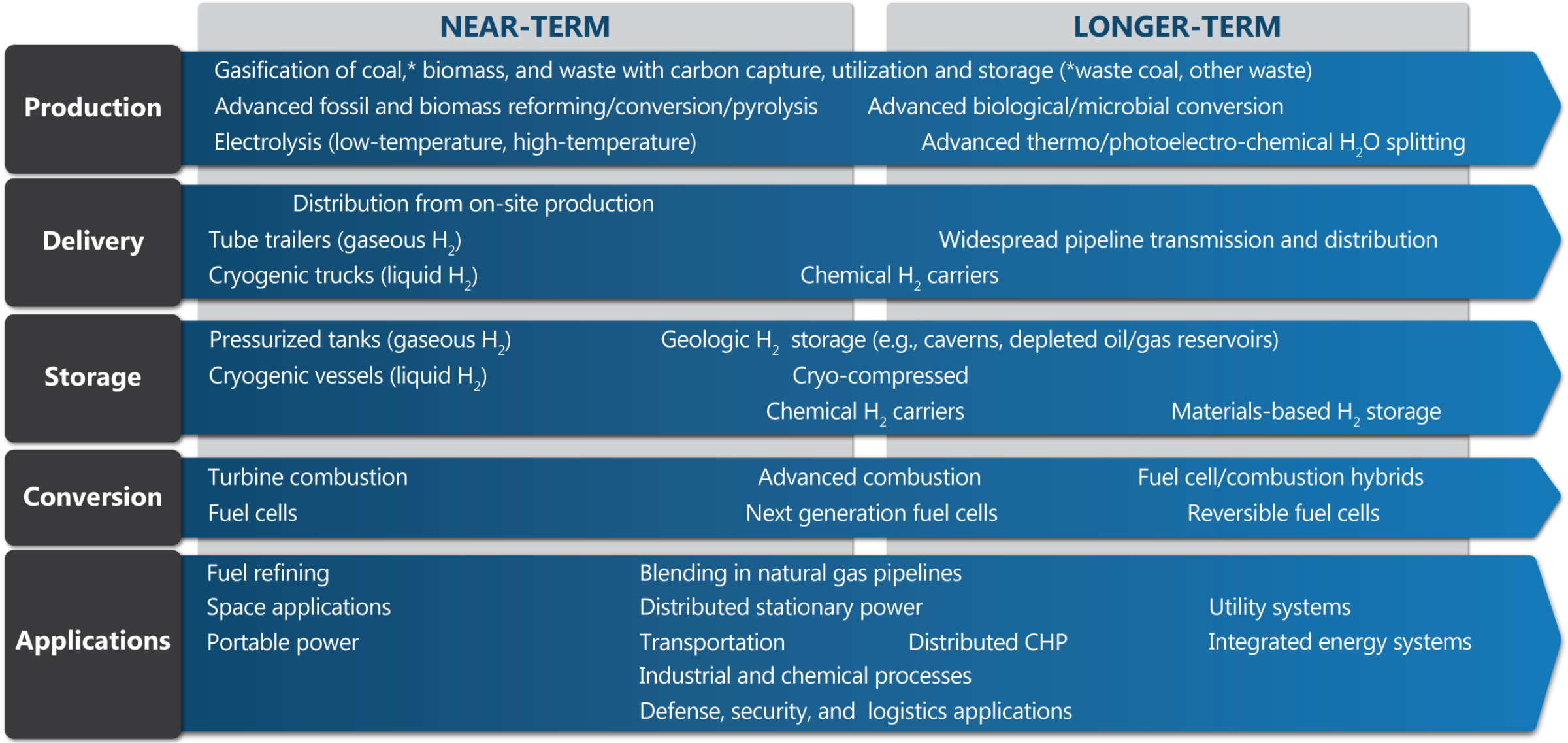
Office of Energy Efficiency and Renewable Energy
Office of Fossil Energy and Carbon Management
Office of Nuclear Energy
Office of Electricity
Office of Science
Office of Clean Energy Demonstrations
Advanced Research Projects Agency – Energy
Office of Technology Transition
Loan Program Office

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



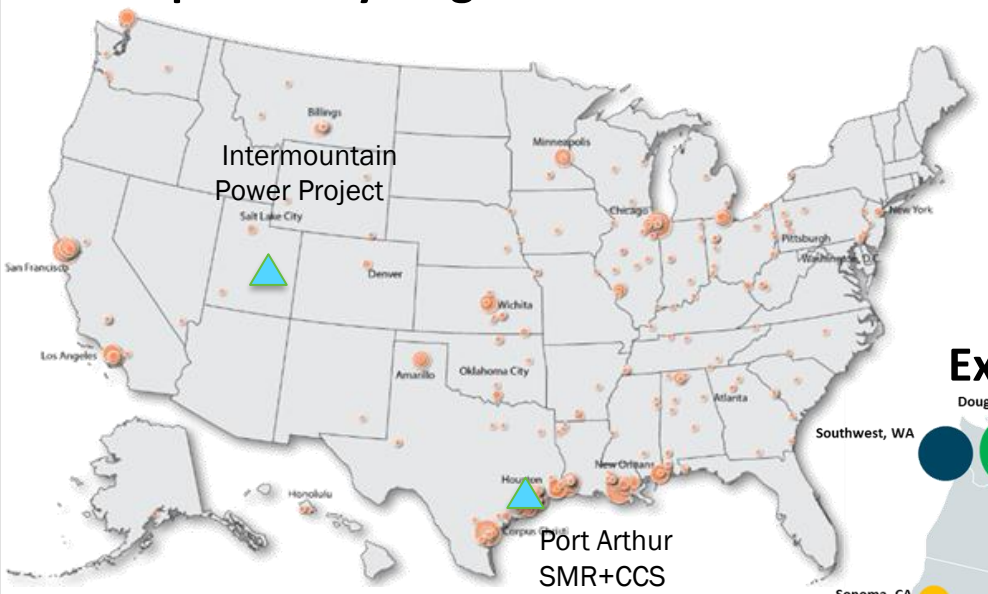
Snapshot of Hydrogen and Fuel Cells in the U.S.

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

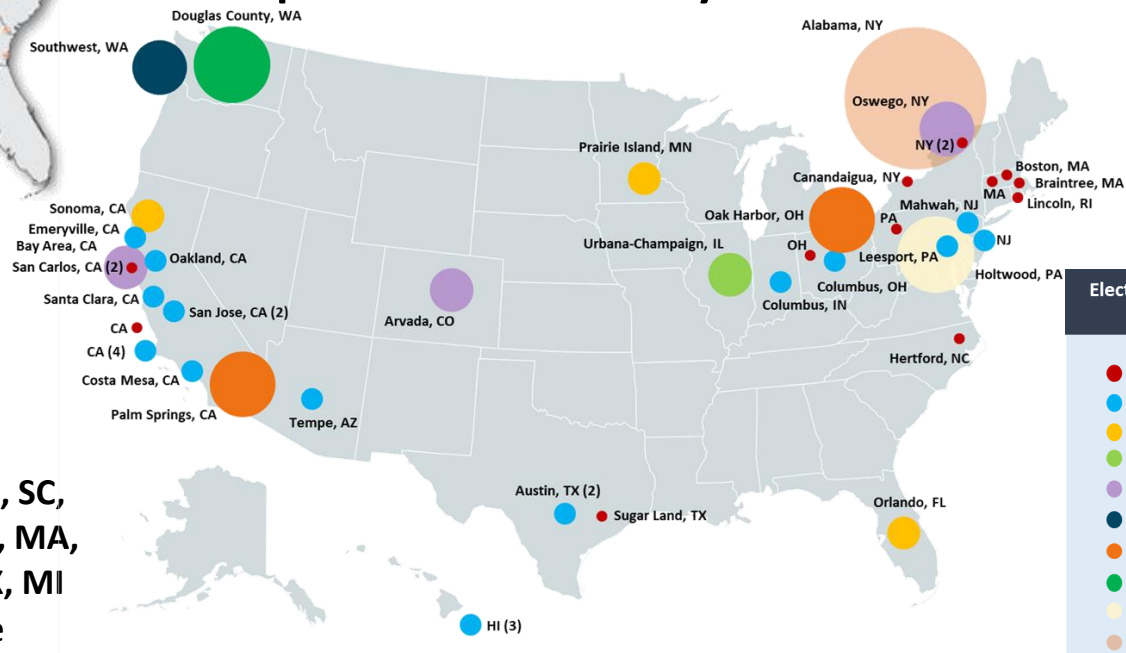
* Polymer electrolyte membrane

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



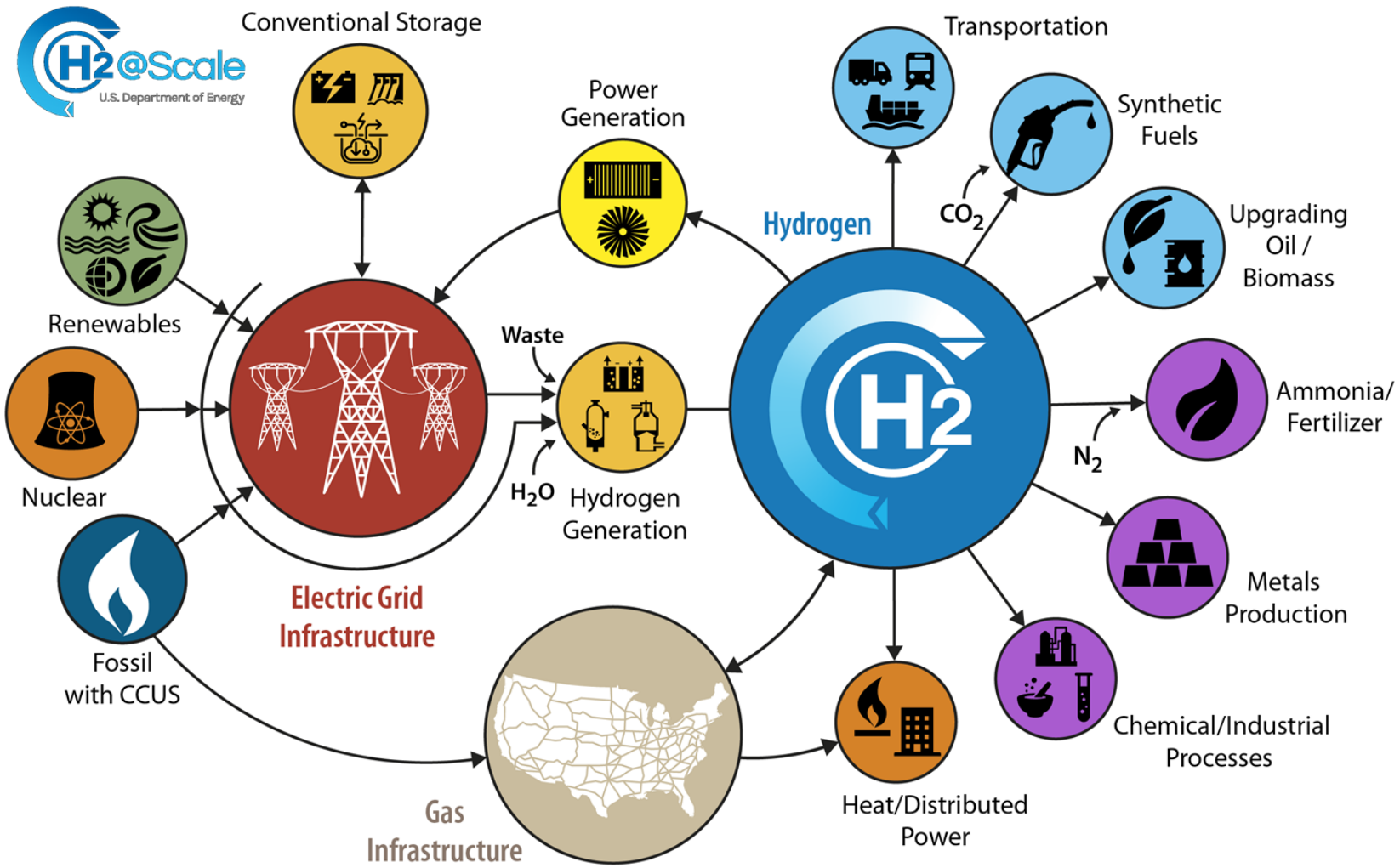
Current and under construction installations over 120 kW as of Jun. 2021
** Source: Arjona, et al, DOE HFTO Program Record, June 2021*

Examples of Hydrogen Station Plans

California
200 Stations Planned
California Fuel Cell Partnership Goal

Northeast
12 – 20 Stations Planned

AZ, HI, OH, SC, NJ, NY, CT, MA, CO, UT, TX, MI
And more



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 H_2 would require ~2x today's solar or wind deployment
- Potential for 700K jobs, $140B by 2030

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

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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

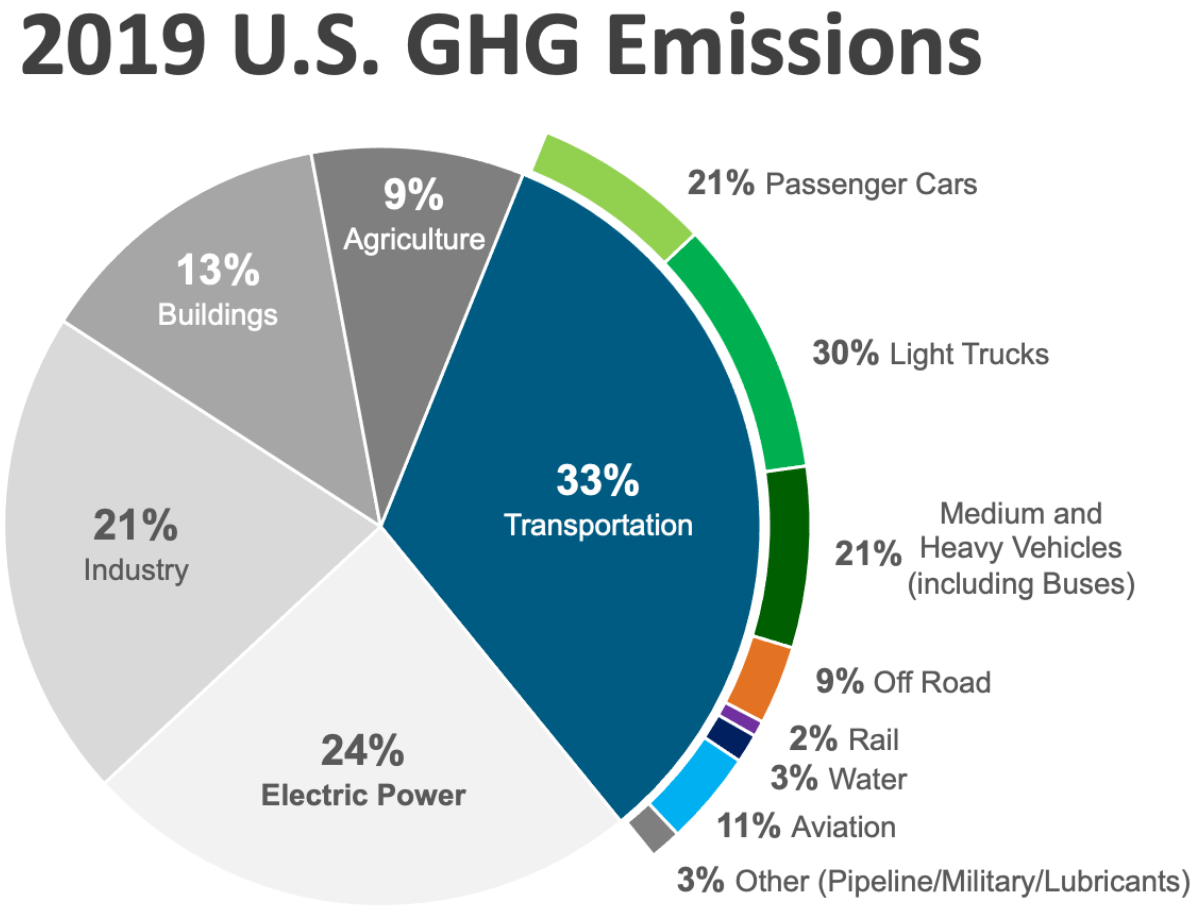
Bipartisan Infrastructure Law - Hydrogen Highlights

- **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**

U.S. GHG Emissions by Sector



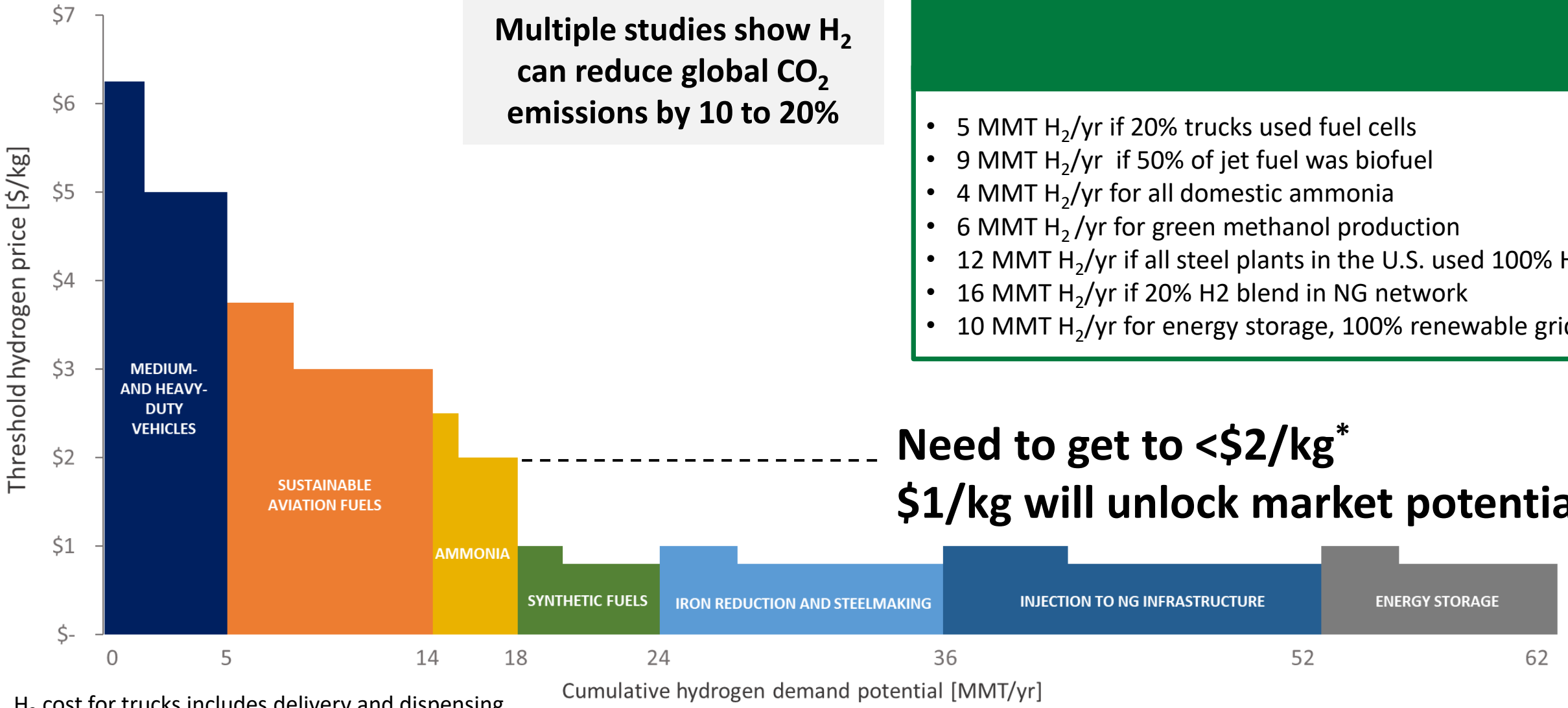
Aviation and water include emissions from international bunker fuels. Fractions may not add up to 100% due to rounding.

- **Transportation is the largest source of GHG emissions**
  - 50% of **energy expenditures and local pollution issues**
  - Significant implications for global competitiveness, trade, and domestic jobs
- **Industry and Electric Power generation account for another ~45% of GHG emissions**

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



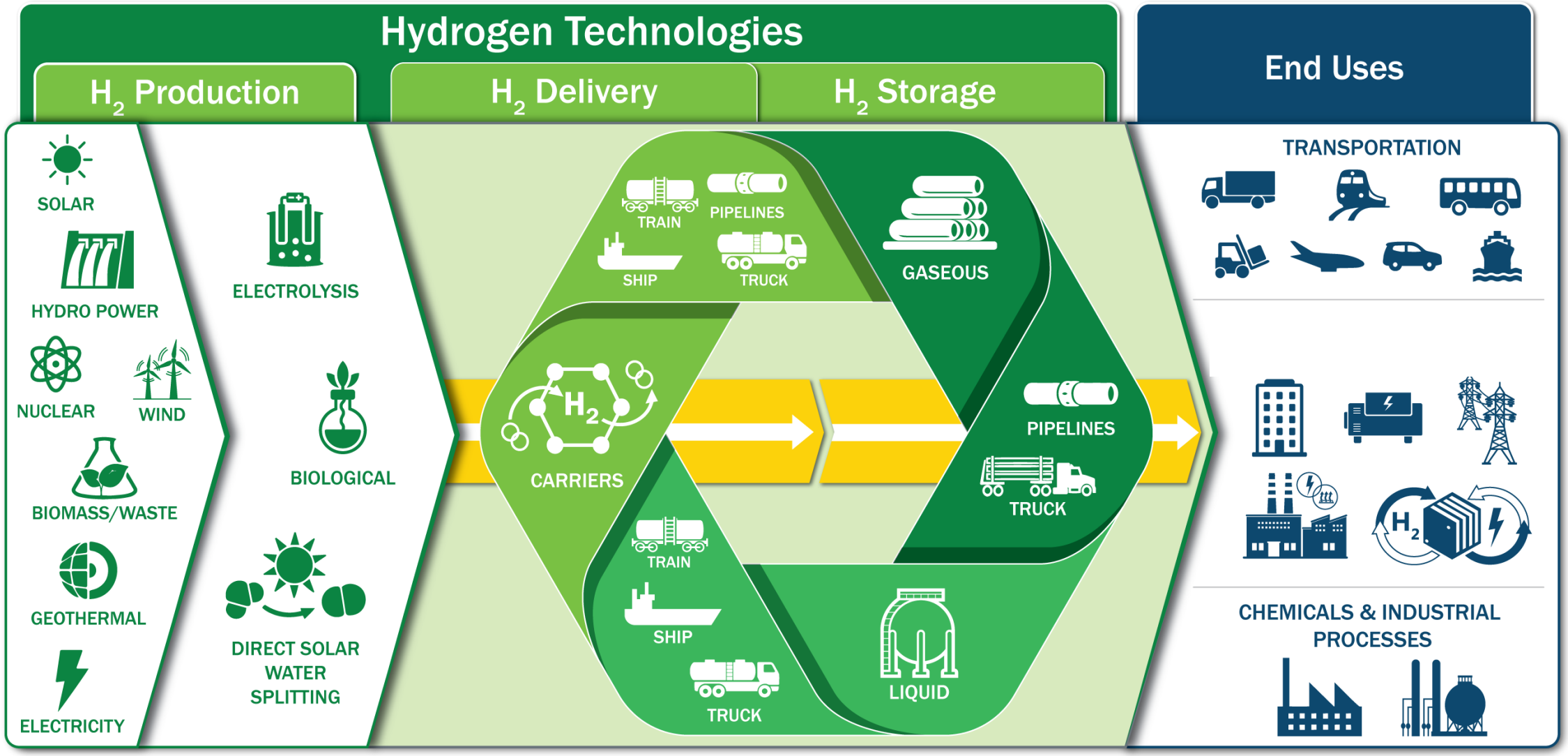
**Need to get to <$2/kg*
$1/kg will unlock market potential**

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

Hydrogen Technologies RD&D Program



From producing hydrogen molecules through dispensing to end-use applications

Topic Areas and Key Concerns

- **Hydrogen liquefaction**
  - Efficiency of liquefaction processes
  - Scalability of liquefaction processes
- **Large-scale markets and applications for liquid hydrogen**
  - Options for liquid hydrogen delivery, storage and distribution
- **Liquid hydrogen storage and handling infrastructure**
  - Limitations and potential advancements for storage
  - Development needs for dispensing liquid hydrogen as a transportation fuel
  - Minimization of losses – from storage and during transfers
  - Required safety considerations for handling and materials selection

Thank you for your participation

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www.energy.gov/fuelcells
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