U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# U.S. DOE Hydrogen and Fuel Cell Remarks

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**U.S. Department of Energy**

Fuel Cell Expo

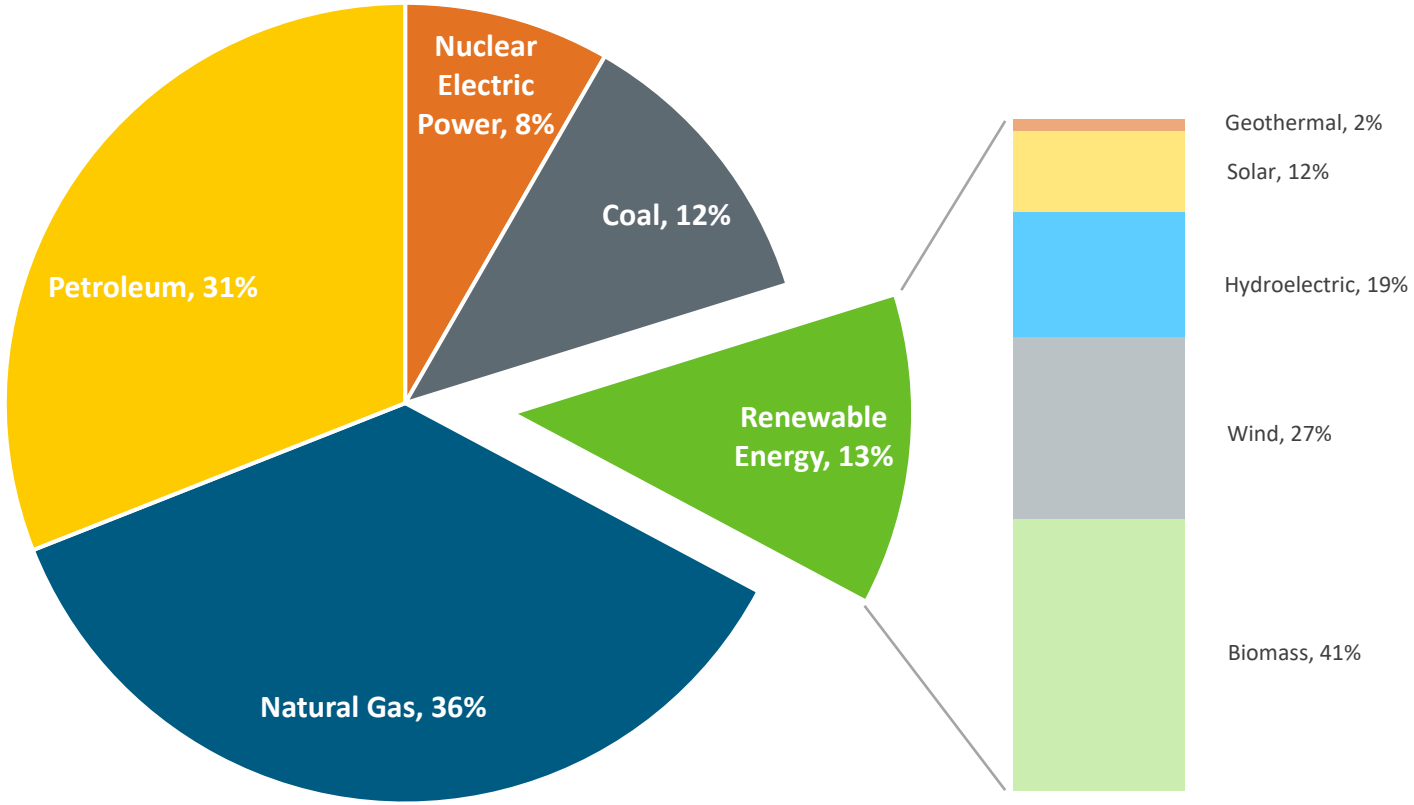
March 16, 2023

# *Introduction – Energy, Market, and Policy Context*

# U.S. Energy Landscape and Key Goals

## U.S. primary energy consumption by energy source, 2021

Total = 97.8 quadrillion British thermal units (Btu)




**Note**: Sum of components may not equal 100% because of independent rounding
**Source**: Data collected from U.S. Energy Information Administration, April 2022, *Monthly Energy Review,* preliminary data

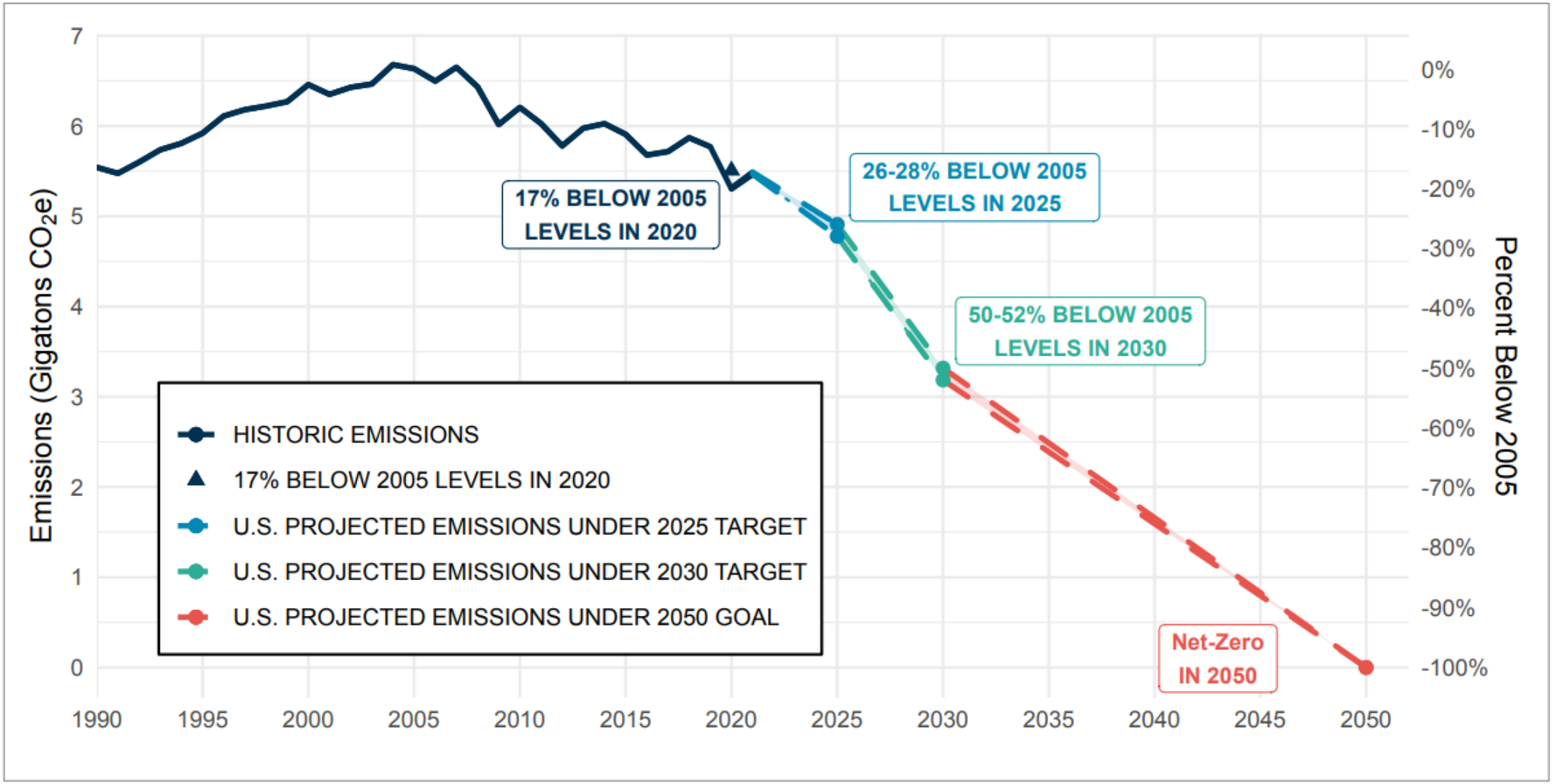
## Administration Goals include:

- Net-zero emissions economy by 2050 and 50–52% reduction by 2030
- 100% carbon-pollution-free electric sector by 2035

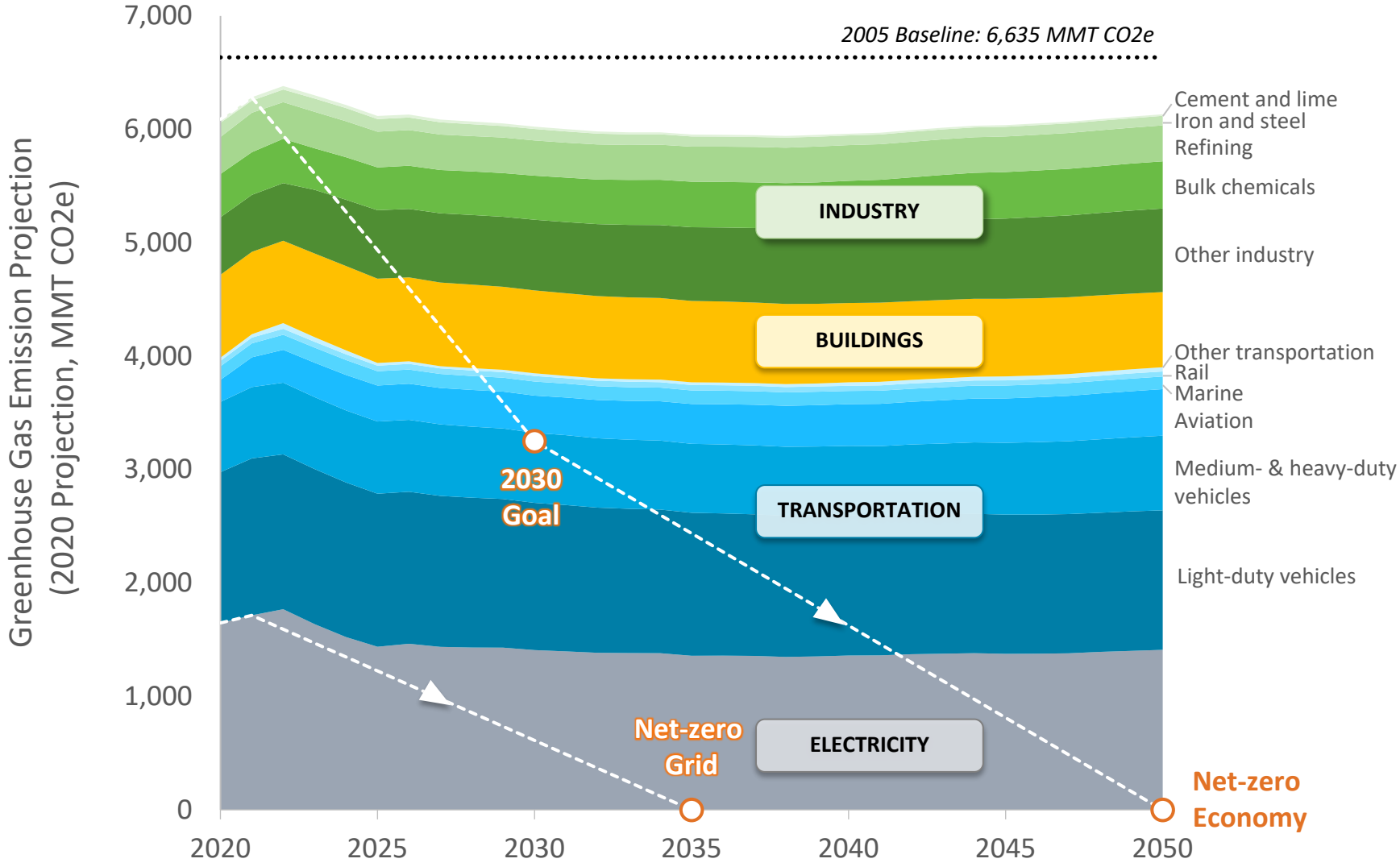
**Priorities: Ensure benefits to all Americans, focus on jobs, Justice40: 40% of benefits in disadvantaged communities**

EJ: Environmental Justice

# U.S. Carbon Dioxide Emissions and Goals



# Carbon Dioxide Emissions by Sector




**Source**: Annual Energy Outlook 2021, DOE National Clean Hydrogen Strategy and Roadmap

# U.S. DOE Hydrogen Program

## Hydrogen is a key element of a portfolio of solutions to decarbonize the economy.

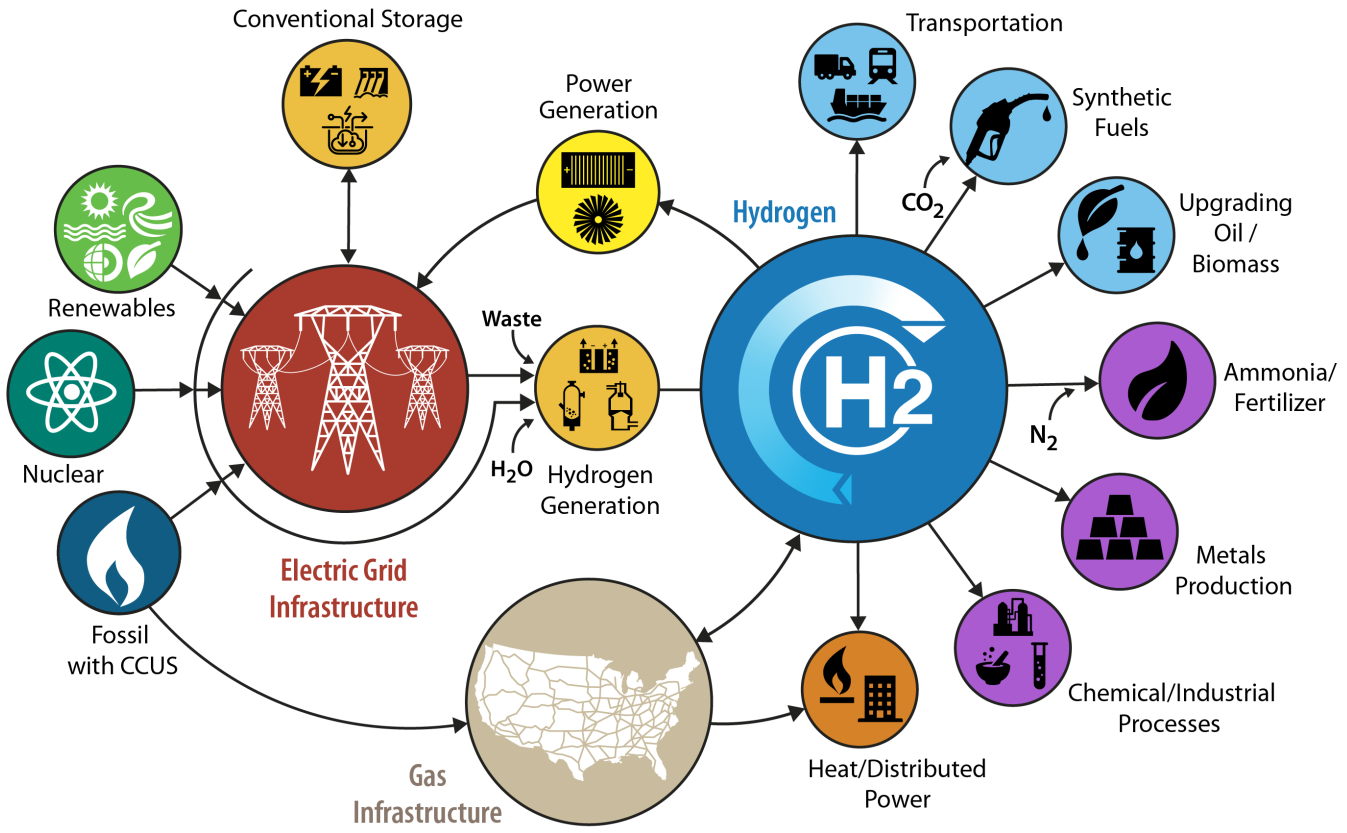
### Hydrogen Program

**Coordinated across DOE** on **research, development, demonstration, and deployment (RDD&D)** to address:

- **The entire $H_2$ value chain** from production through end use
- **$H_2$ production from <u>all</u> resources** (renewables, nuclear, and fossil + CCS)

**www.hydrogen.energy.gov**

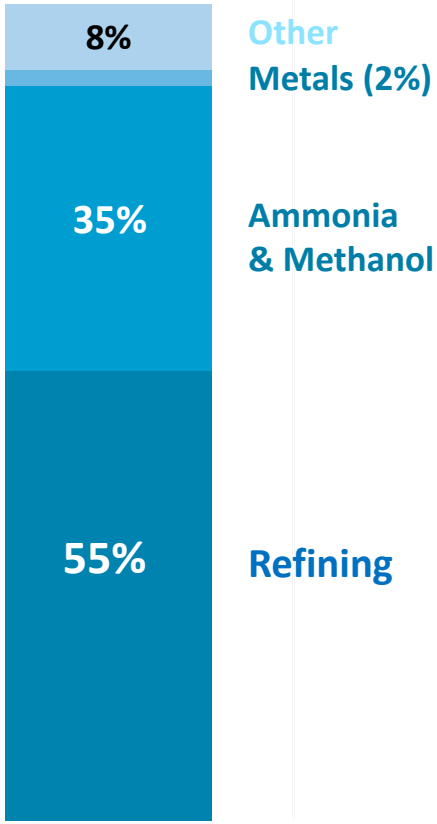
**H2@Scale provides vision to guide how hydrogen can enable clean-energy pathways across applications and sectors**



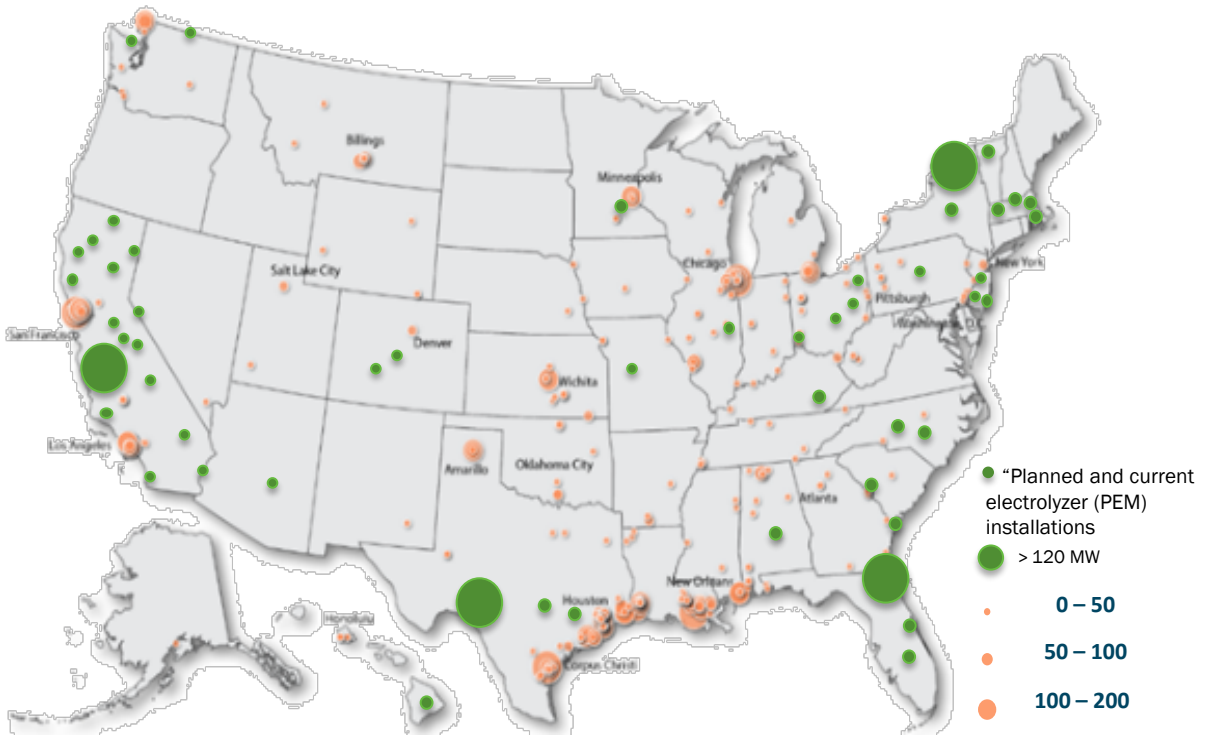
# Snapshot of Hydrogen and Fuel Cells in the U.S.

- 10 million metric tons produced annually
- More than 1,600 miles of $H_2$ pipeline
- World's largest $H_2$ storage cavern

## Use of Hydrogen in the U.S. Today

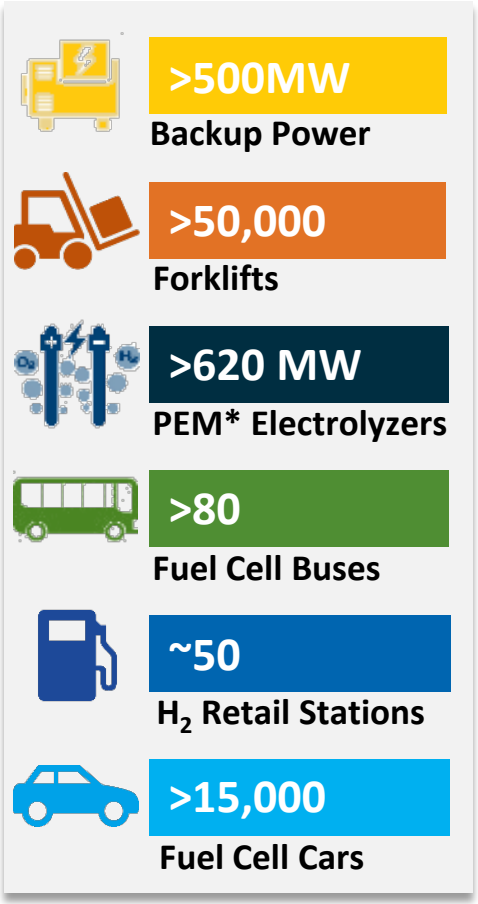



## Examples of Hydrogen Production Locations




>620 MW of PEM* electrolysis in the U.S.
>3X increase since 2021

## Examples of Deployments




*Proton exchange membrane

# Recent Legislation Highlights

## Bipartisan Infrastructure Law

- **Includes $9.5B for clean hydrogen**:
  - $1B for electrolysis
  - $0.5B for manufacturing and recycling
  - $8B for at least four regional clean hydrogen hubs
- **Requires** developing a **National Clean Hydrogen Strategy and Roadmap**

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

## Inflation Reduction Act

- **Includes significant tax credits** (e.g., up to $3/kg for production of clean hydrogen)

# Inflation Reduction Act (IRA) – Examples of $H_2$ and Fuel Cell Incentives

## Clean Hydrogen Production Tax Credit (45V) up to $3/kg

| Carbon Intensity (kg $CO_2$ per kg $H_2$) | Max Tax Credit ($/kg $H_2$)* |
|---|---|
| 4–2.5 | $0.60 |
| 2.5–1.5 | $0.75 |
| 1.5–0.45 | $1.00 |
| 0.45–0 | $3.00 |

## Qualified Commercial Clean Vehicles Credit (45W)

Creates a **new 30% credit** for commercial fuel cell electric vehicles through 2032, capped at **$40,000**:

- Class 1–3 vehicles: **$7,500 tax credit** for purchase of qualified clean vehicles
- Class 4 and above: **$40,000 tax credit**

## Alternative Fuel Refueling Property Credit (30C)

**Tax credit up to 30%** of the cost of alternative fuel refueling property up to **$100,000**

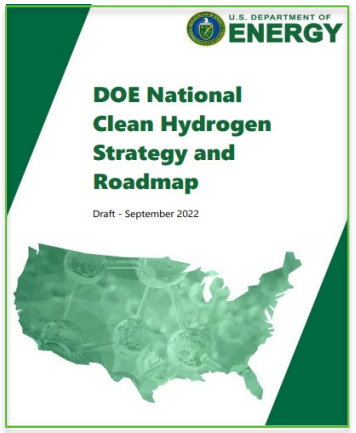
View more at: www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects

* Well to gate, using GREET

# Recent DOE Announcements and BIL Deliverables

## DOE National Clean Hydrogen Strategy and Roadmap

**Draft Document Released**




**Feedback closed 12/1/22**

## H2 Hubs Funding Opportunity Announcement (FOA)

**FOA Released**

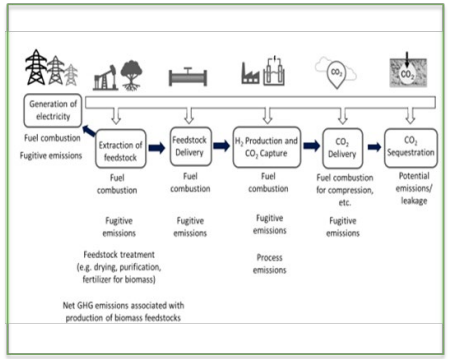
**6 to 10 H2 Hubs for a combined total of $6B to $7B**

**Concept papers due 11/7/22**
**Full applications due 4/7/23**

**Submit any questions:**
h2hubs@hq.doe.gov

## Clean Hydrogen Production Standard (CHPS)

**Draft Guidance Document Released for Initial Standard**



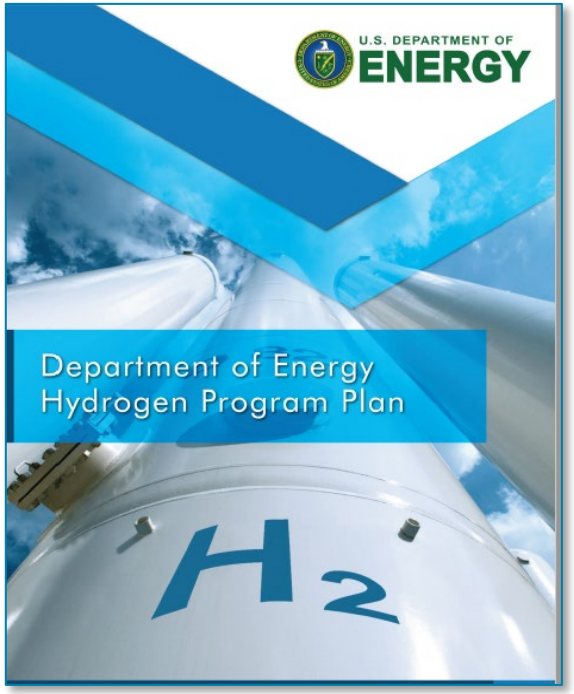

**Notice of Intent:** On December 16, 2022, DOE announced its intent to issue **$750 million** in funding from President Biden's Bipartisan Infrastructure Law to dramatically reduce the cost of clean-hydrogen technologies.

**Stay Tuned: DOE Life Cycle Emissions Analysis and GREET tool webinars and outreach planned**
**www.hydrogen.energy.gov**

# *Strategy & Goals*

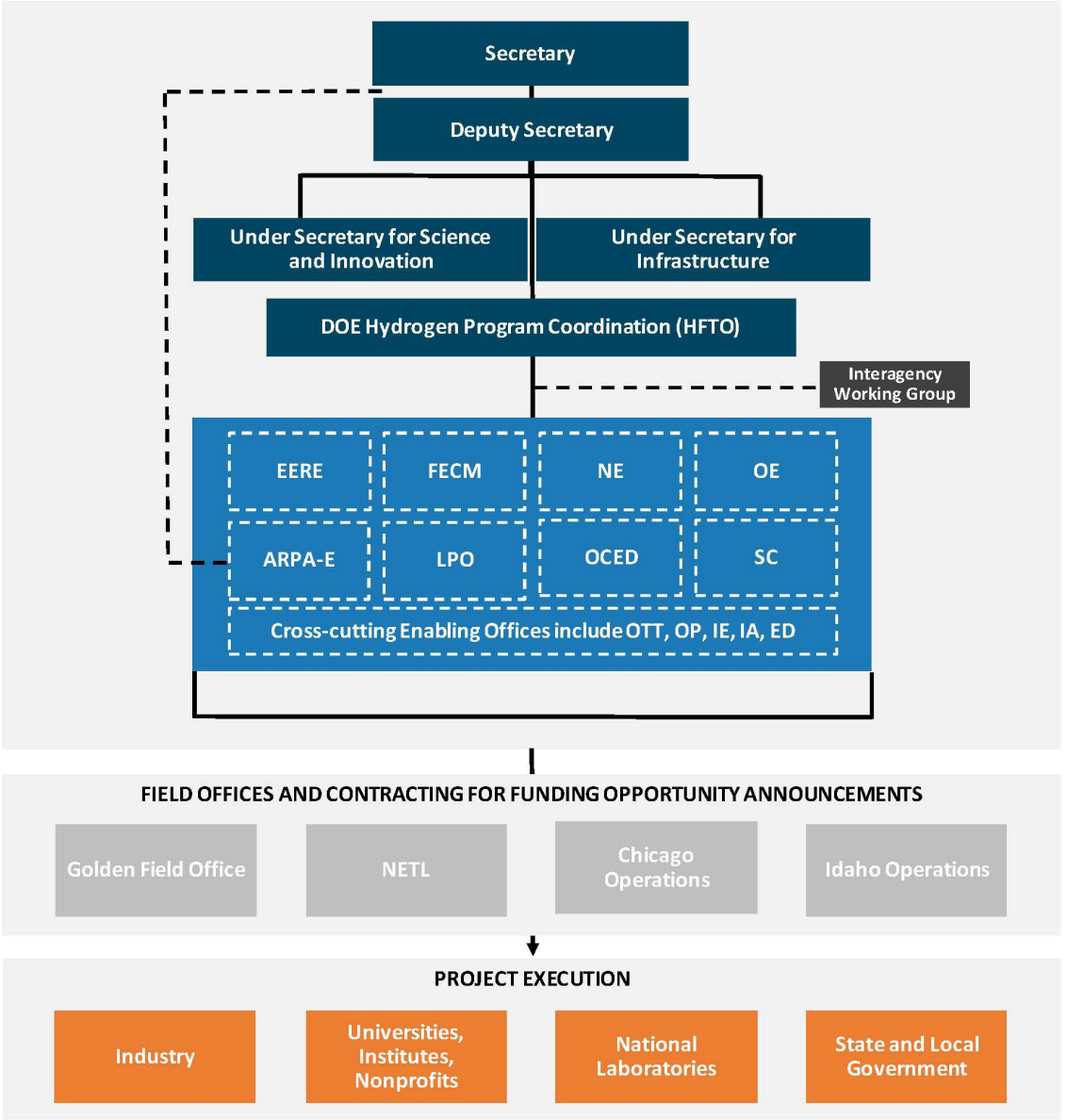
# U.S. DOE Hydrogen Program

**Hydrogen is part of a broad portfolio of activities. The Program includes multiple offices and addresses the entire RDD&D value chain from production through end use.**

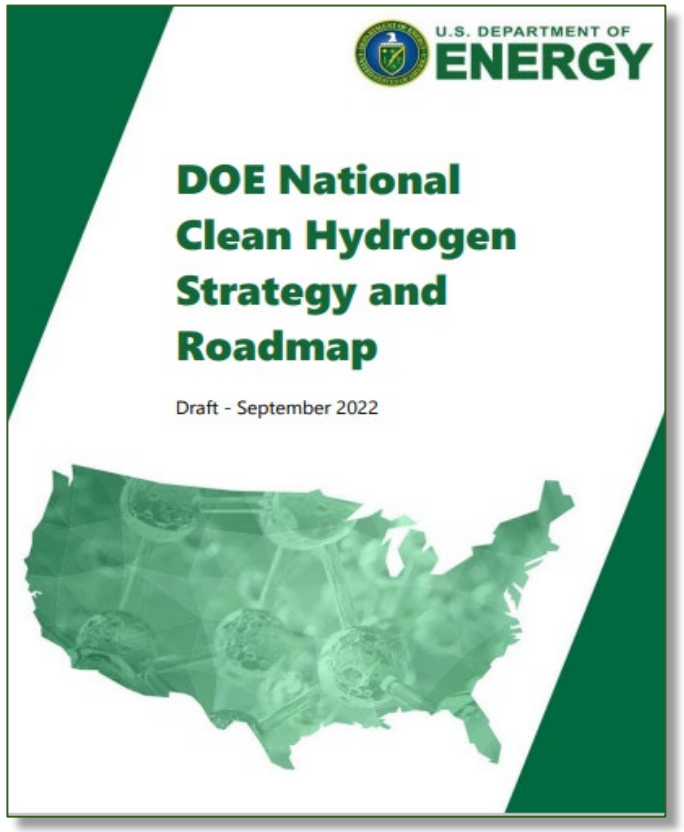



**www.hydrogen.energy.gov**

Includes multiple offices across DOE, led by DOE's Hydrogen and Fuel Cell Technologies Office



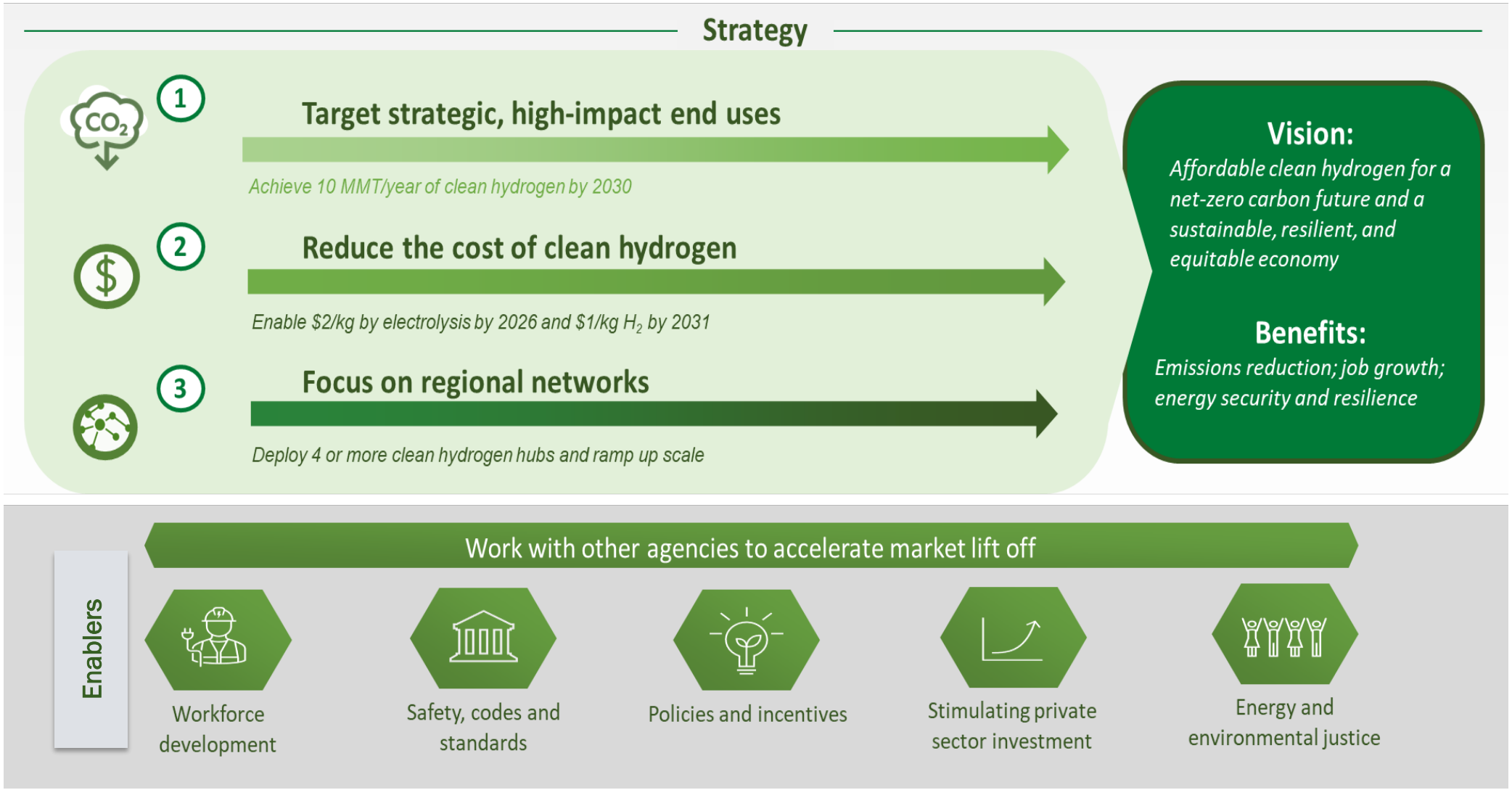
# Draft *DOE National Clean Hydrogen Strategy and Roadmap*



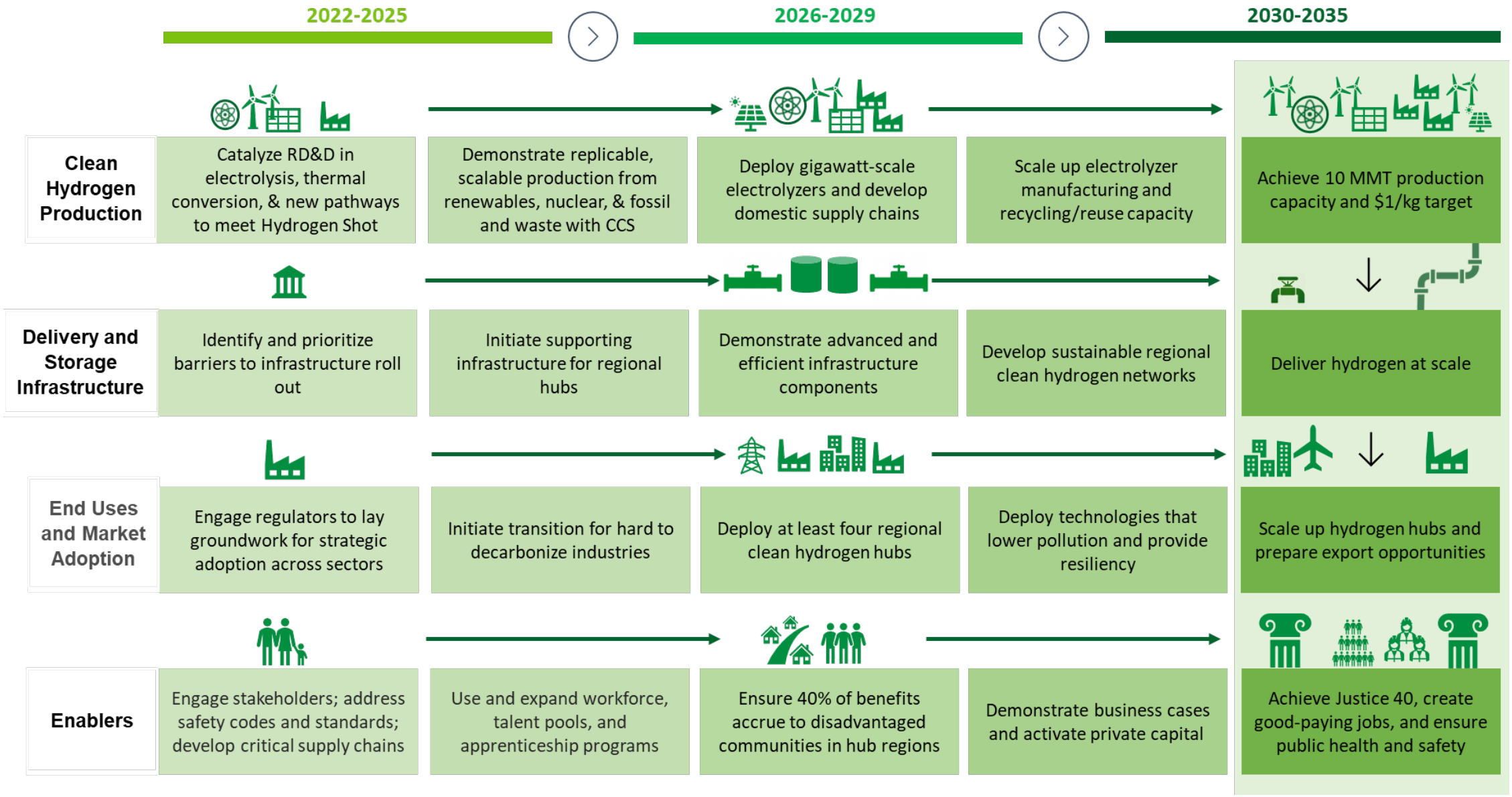

- Provides a snapshot of hydrogen production, transport, storage, and use in the United States today
- Explores the potential for clean hydrogen to contribute to national goals across multiple sectors
- **Identifies opportunities for domestic production of clean hydrogen:**
  - **10 million metric tons per year by 2030**
  - **20 MMT by 2040**
  - **50 MMT by 2050**
- The *Strategy and Roadmap will be finalized in early 2023* and updated per Bipartisan Infrastructure Law at least every 3 years.

**https://www.hydrogen.energy.gov/clean-hydrogen-strategy-roadmap.html**

# Draft *DOE National Clean Hydrogen Strategy and Roadmap*

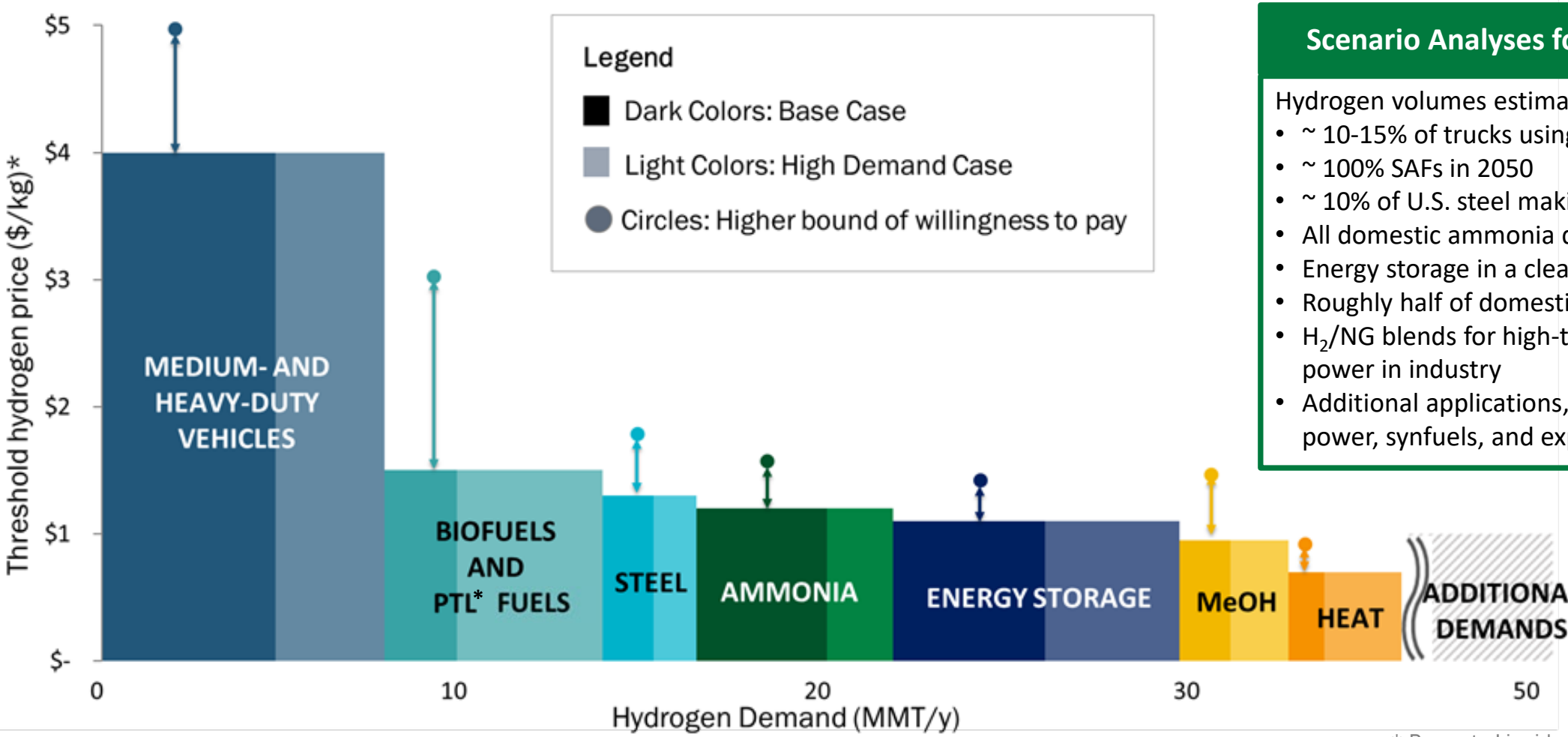


# Actions from Draft DOE National Strategy and Roadmap



# Strategy 1: Target High-Impact Uses of Hydrogen

## Clean Hydrogen Demand and Costs for Market Penetration




**Scenario Analyses for $H_2$ Demand****

Hydrogen volumes estimated for:

- ~ 10-15% of trucks using fuel cells
- ~ 100% SAFs in 2050
- ~ 10% of U.S. steel making
- All domestic ammonia demand
- Energy storage in a clean grid
- Roughly half of domestic methanol
- $H_2$/NG blends for high-temp heat and power in industry
- Additional applications, include stationary power, synfuels, and export potential

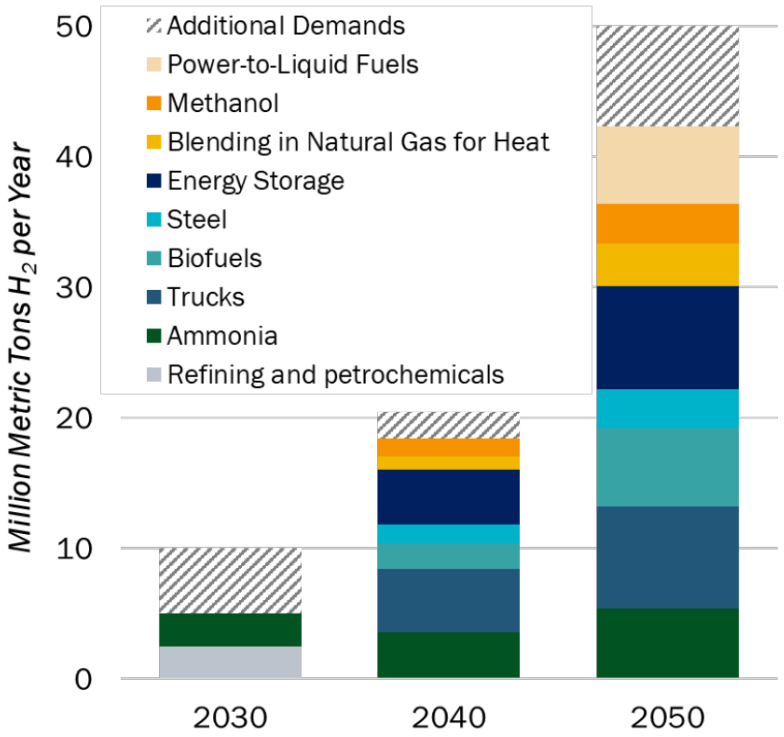
Costs include production, delivery, dispensing to the point of use (e.g., high-pressure fueling for vehicle applications)

* Power to Liquid

** Volumes dependent on multiple variables

# Strategy 1: Target High-Impact Uses of Hydrogen

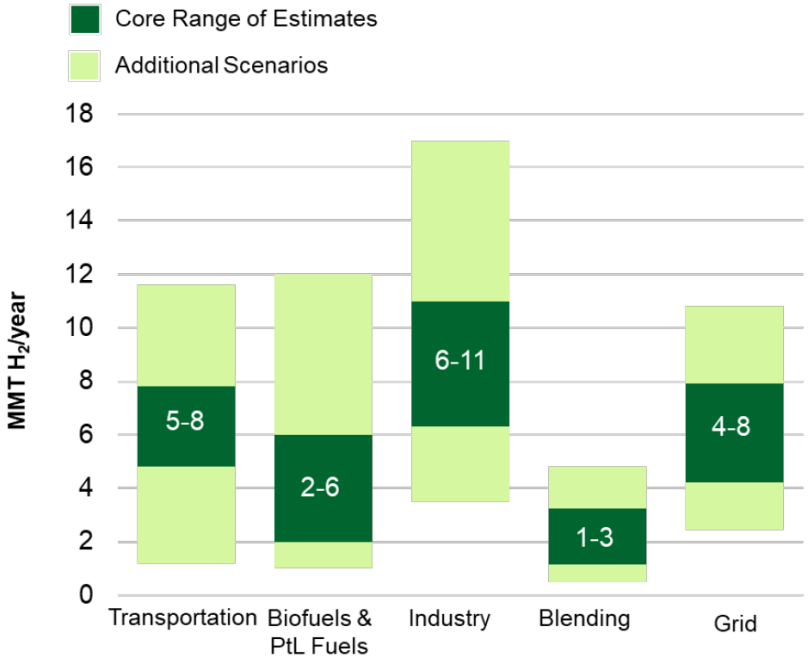
## Opportunities for Clean Hydrogen Across Applications




### Clean Hydrogen Use Scenarios

- Catalyze clean $H_2$ use in existing industries (ammonia, refineries), initiate new use (e.g., sustainable aviation fuels (SAFs), steel, potential exports)
- Scale up for heavy-duty transport, industry, and energy storage
- Market expansion across sectors for strategic, high-impact uses

## Range of Potential Demand for Clean Hydrogen by 2050



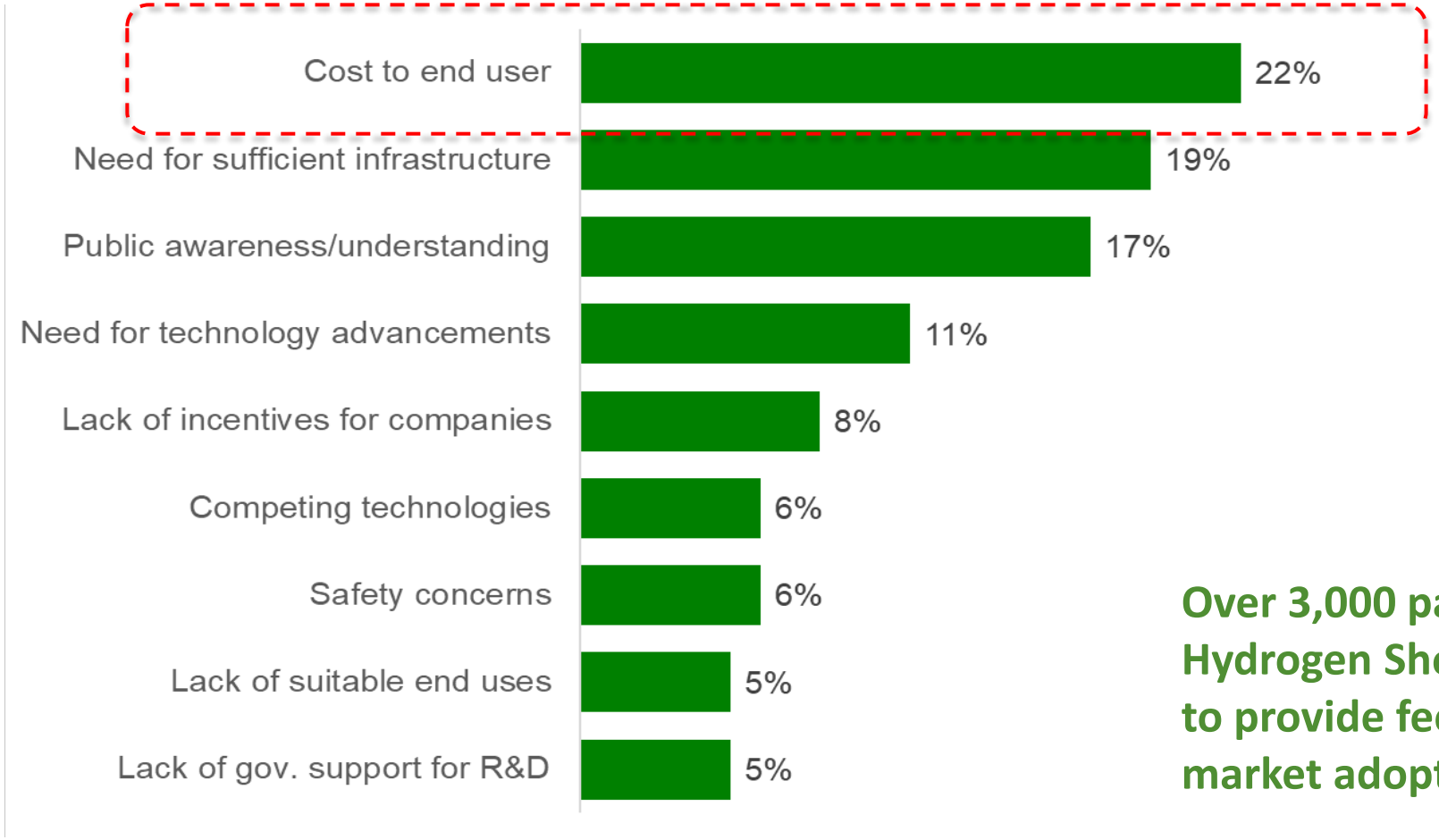

- **Core range: ~ 18–36 MMT $H_2$**
- **Higher range: ~ 36–56 MMT $H_2$**

**U.S. Opportunity:**
**10MMT/yr by 2030, 20 MMT/yr by 2040, 50 MMT/yr by 2050**


Refs: 1. NREL MDHD analysis using TEMPO model; 2. Analysis of biofuel pathways from NREL; 3. Synfuels analysis based off H2@Scale ; 4. Steel and ammonia demand estimates based off DOE Industrial Decarbonization Roadmap and H2@Scale. Methanol demands based off IRENA and IEA estimates; 5. Preliminary Analysis, NREL 100% Clean Grid Study; 6. DOE Solar Futures Study; 7. Princeton Net Zero America Study

# Strategy 2: Focus on Cost-Reduction

## Stakeholder Reported Barriers to Hydrogen Market Adoption




**Over 3,000 participants at DOE Hydrogen Shot Summit were requested to provide feedback on key barriers to market adoption of hydrogen**

Source: Hydrogen Shot Summit, Sept 2021

https://www.energy.gov/eere/fuelcells/hydrogen-shot-summit


# Hydrogen Energy Earthshot

## “Hydrogen Shot”

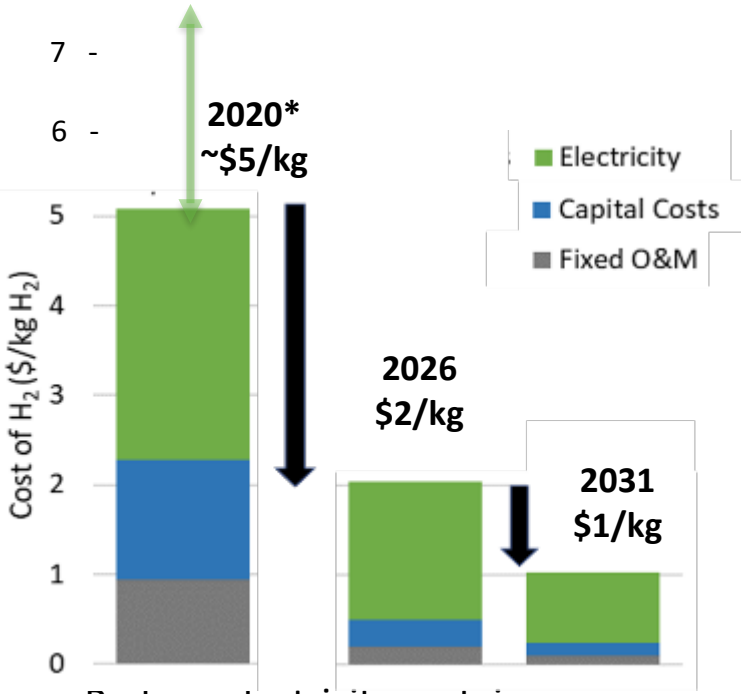
## “1 1 1”
## $1 for 1 kg clean hydrogen in 1 decade

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

# How to reduce cost? Examples across multiple pathways

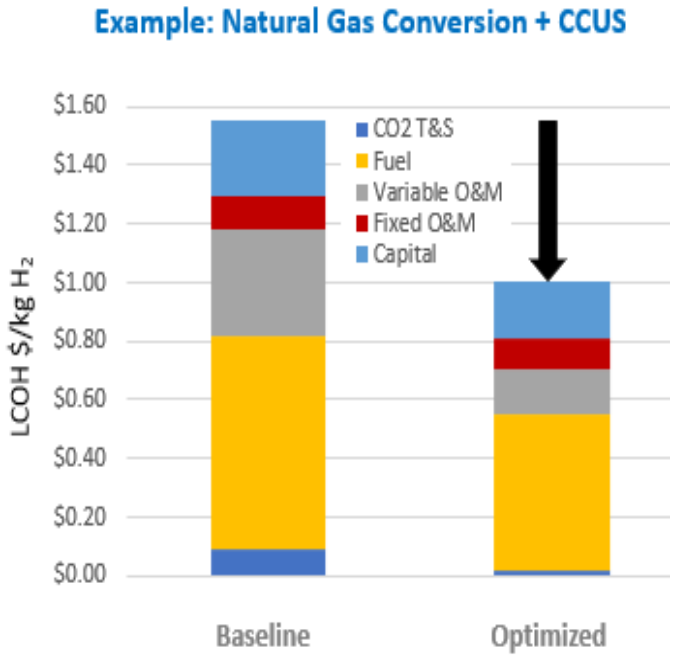
## Strategies and scenarios being developed to reduce cost and emissions across pathways

### $H_2$ from Electrolysis



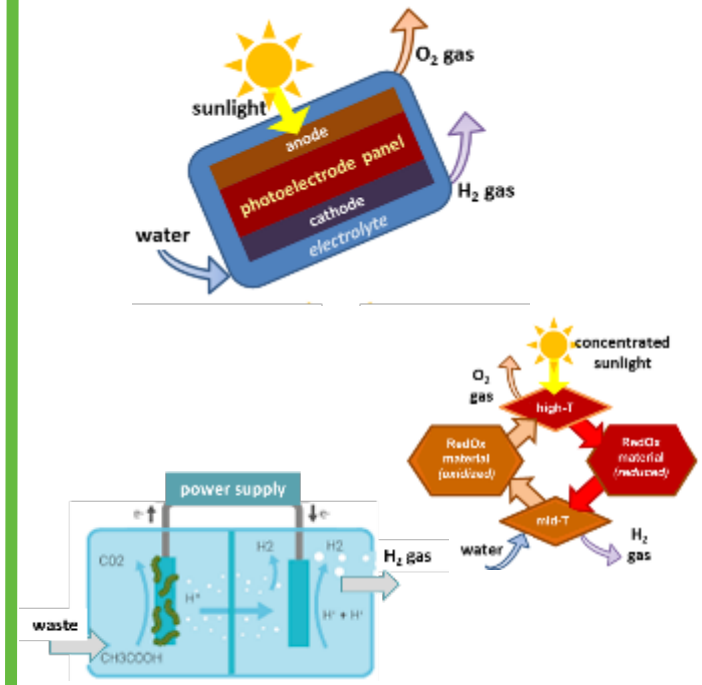

- Reduce electricity cost, improve efficiency and utilization
- Reduce capital cost >80%, operating & maintenance cost >90%

### Thermal Conversion




- Reforming; pyrolysis; air separation; catalysts; carbon capture and storage (CCS); upstream emissions

### Advanced Pathways

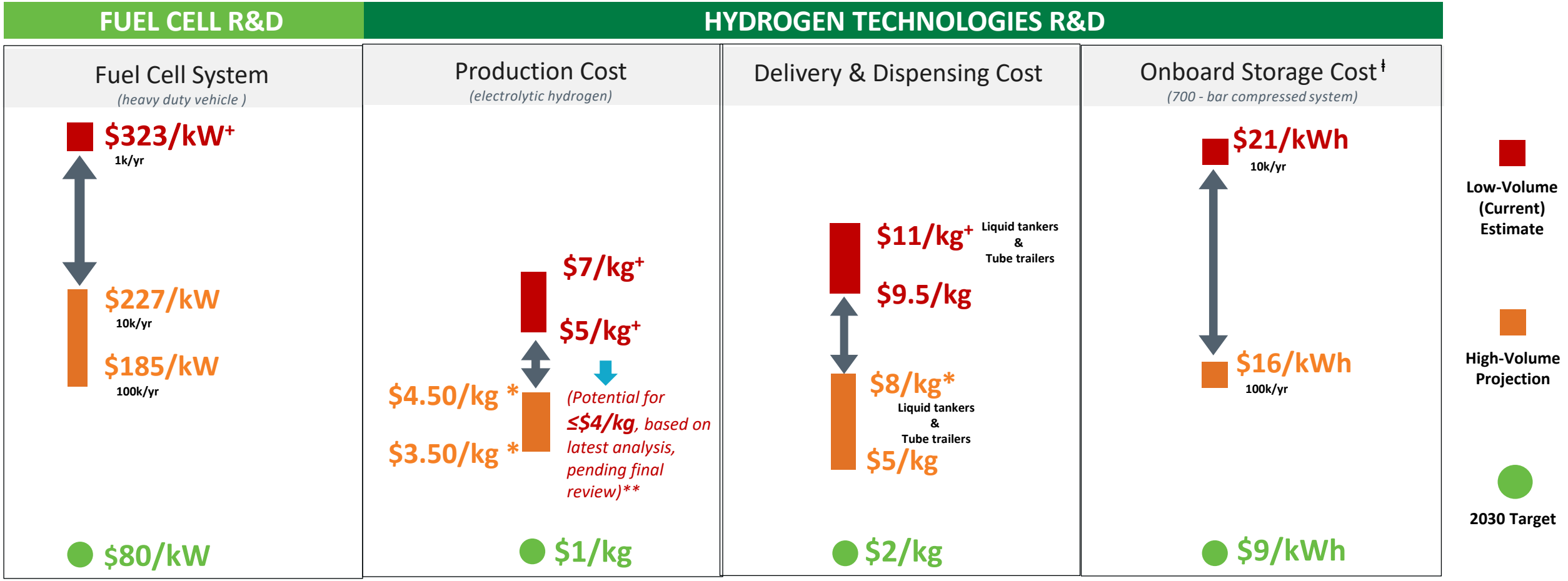



- Photoelectrochemical (PEC), thermochemical, biological, etc.

*2020 Baseline: PEM (Polymer Electrolyte Membrane) low volume capital cost ~$1,500/kW, electricity at $50/MWh. Pathways to targets include capital cost <$300/kW by 2025, < $150/kW by 2030 (at scale). Assumes $50/MWh in 2020, $30/MWh in 2025, $20/MWh in 2030

# Technology Targets Guide RD&D Activities

**Key Goals: Reduce the cost of fuel cells and hydrogen production, delivery, storage, and meet performance and durability requirements – guided by applications specific targets**




†Based on 275 kW Heavy Duty Fuel Cell System Cost Analysis (2021), adjusted to reflect cost of system that meets 25,000 hours durability

‡5 to 7 cents/kWh, 90% capacity factor at $1500/kW
*5 to 7 cents/kWh, 90% capacity factor at $460/kW
** See Hydrogen Technologies Plenary presentation for more information about pending Program Record

†For range: Delivery and dispensing at today's (2020) stations with capacity ~450 kg/day
*For range: Delivery and dispensing at today's (2020) stations with capacity 450-1,000 kg/day at high volume manufacturing

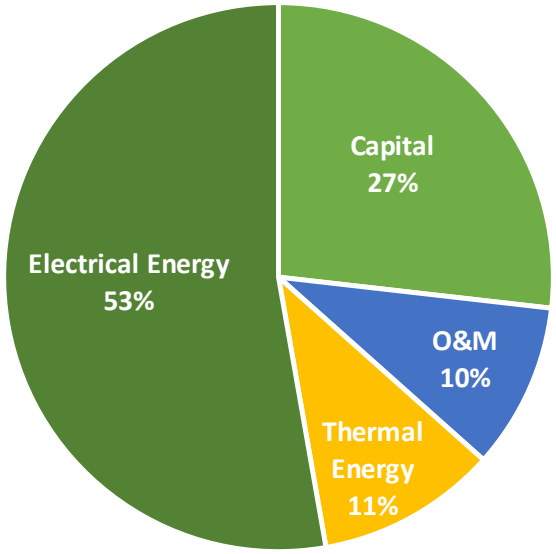
‡Storage costs based on 2019 storage cost record

All costs based on $2016

Note: Graph is not at scale. For illustrative purposes only

# Examples of Cost Drivers and Focus Areas for Hydrogen Technologies

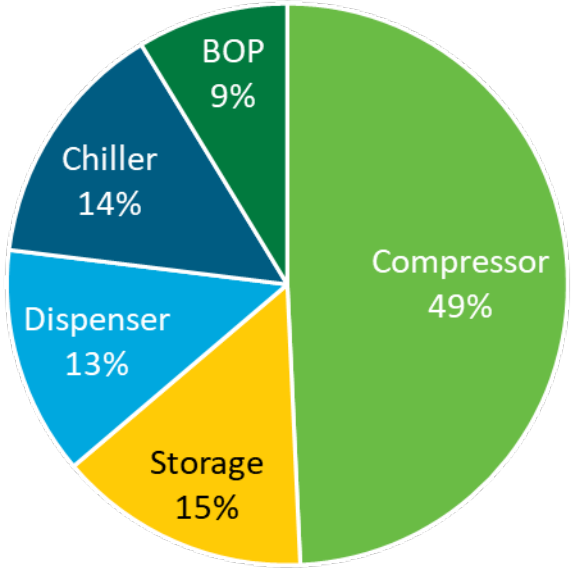
**Hydrogen Production Cost**
(High Temperature Electrolysis)



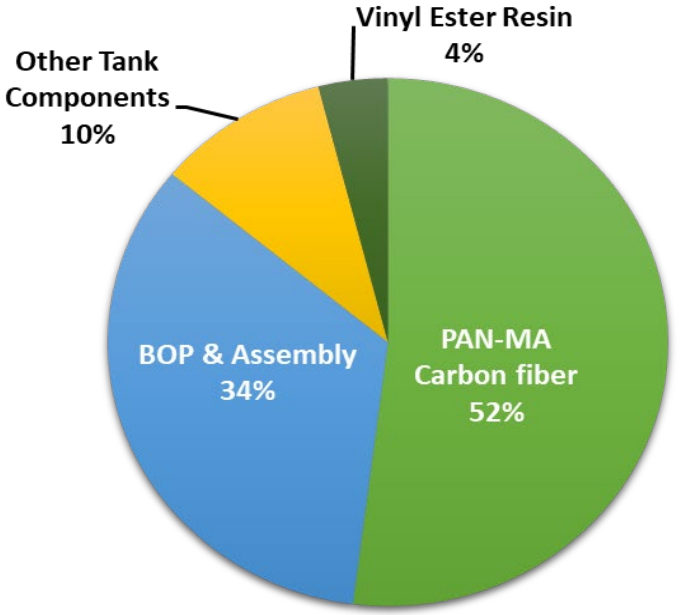

$H_2$ Production (Electrolysis) Cost Drivers:
**Electrical energy and capital costs**

$H_2$ Infrastructure Cost Drivers:
**Compressors, Chiller, Dispenser and Storage**

**Hydrogen Fueling Station Levelized Cost**
(700 Bar, 800 kg/day Station)



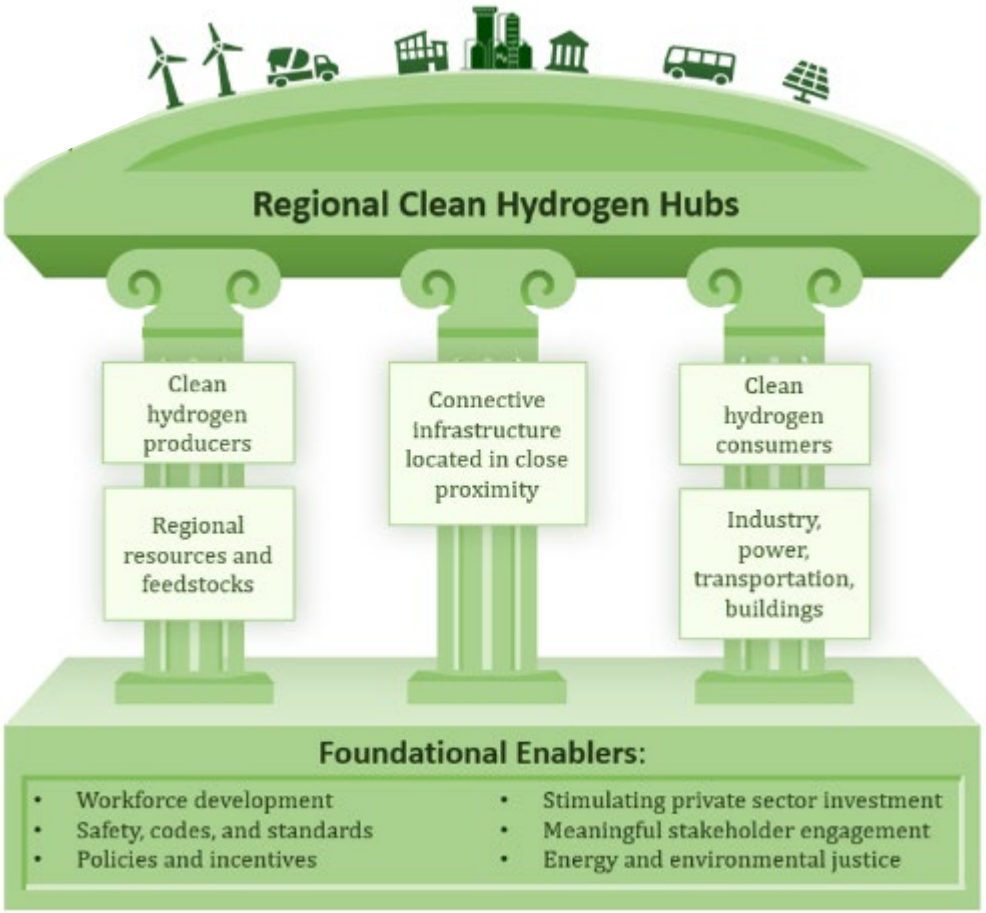

**Hydrogen Storage Cost**
(700 bar Type IV, 5.6 kg Hydrogen Storage System)



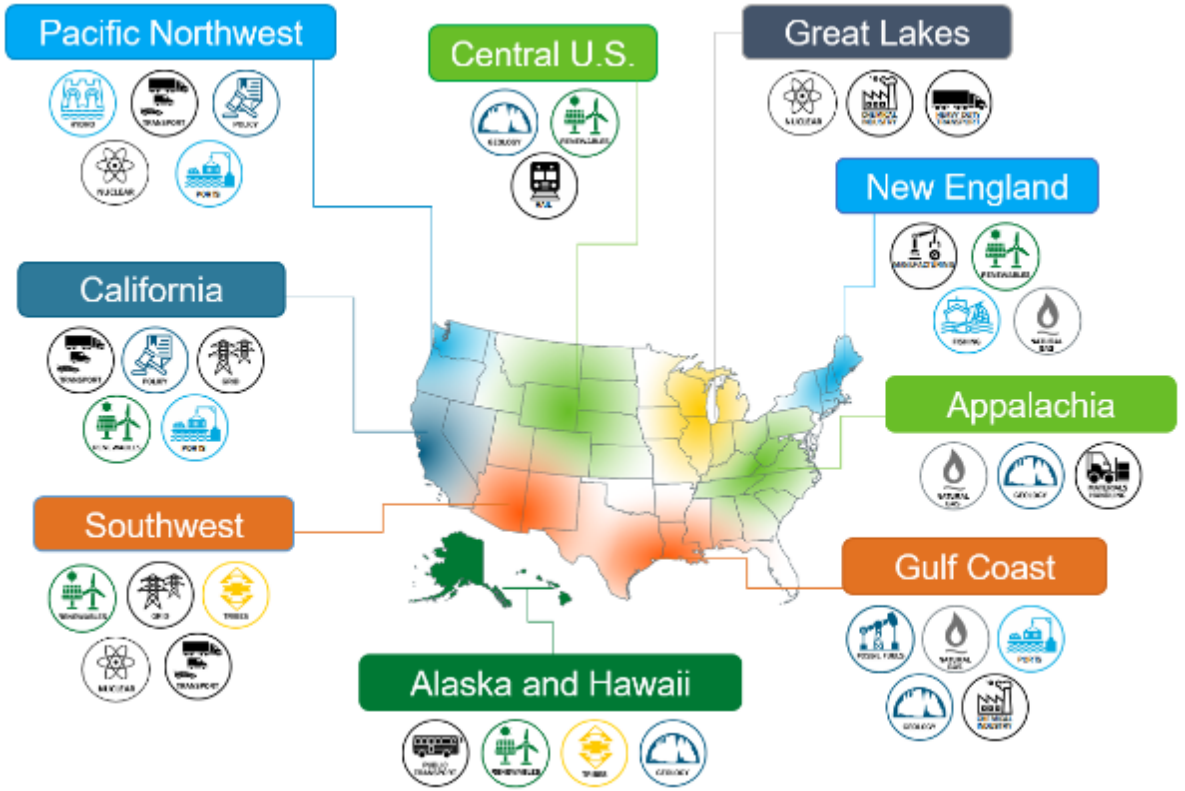

$H_2$ Onboard Storage Cost Drivers:
**Carbon Fiber Precursors and Processing**

# Strategy 3: Focus on Regional Networks

## Build Regional Networks through "Clean Hydrogen Hubs"




### Examples of Stakeholder and RFI Input



# Example: Industrial Clusters to Enable Large-Scale Offtakers

**Priority deployments for hydrogen in industry include sectors where other decarbonization pathways are challenging, such as high-temperature heat generation, steelmaking, and ammonia production.**

National Distribution of **Industrial Sites**, **$CO_2$ Output**, and **$CO_2$ Sink Demand**


Mapping industrial sites to $CO_2$ sources and demands can help identify **industrial clusters for potential decarbonization hubs**

Adapted from Carbon Capture and Utilization in the Industrial Sector | Environmental Science & Technology (acs.org)

# *Ongoing Work and Accomplishments to Address Key Priorities*

# Program Enabled Accomplishments

## Innovation


**1,256 Patents**

in hydrogen and fuel cell technologies through HFTO funding from Labs, Industry and Academia

**35% from National Labs**

## Technology-to-Market

**30 Technologies Commercialized**

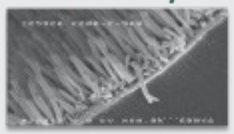
By private industry

**65 With Potential to Enter Market**

in the next 3-5 years

***Examples of Technologies Enabled***

Fuel Cell Catalysts



Catalyst and Supports for PEM Fuel Cells
3M

Hydrogen Tube Trailers

Hydrogen Tube Trailers
Hexagon Lincoln

Forklifts

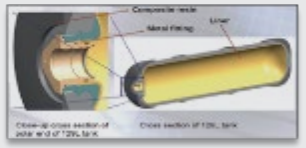
Class-1, -2, and -3 Forklifts
Plug Power (GenDrive FCs)

Electrolyzers

Electrolyzer System
Proton Series

PEM Electrolyzer System
Giner

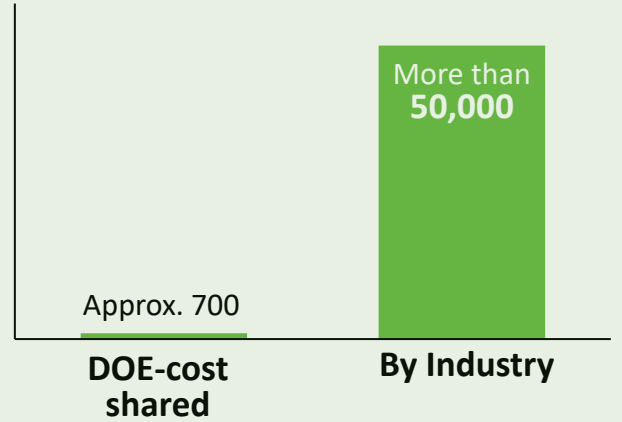
Hydrogen Tanks



Optimized 129L Tank
Quantum Technologies

## Market Uptake

**Hydrogen fuel cell forklifts in the U.S.**




**American-made small-scale hydrogen refueler**

- Exported to Japan
- Uses electrolysis

# DOE Hydrogen Activities across RDD&D – Examples

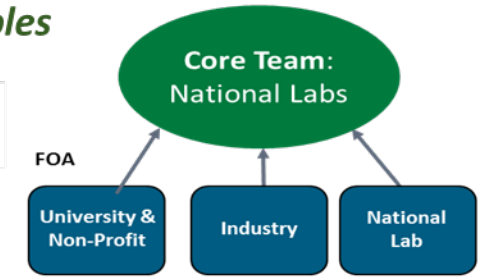
## Research and Development

Basic and applied research through individual projects and consortia

***Consortia Examples***

HydroGEN Advanced Water Splitting Materials

H2NEW U.S. DEPARTMENT OF ENERGY




H-Mat Hydrogen Materials Compatibility Consortium

ElectroCat Electrocatalysis Consortium

HyMARC Hydrogen Materials Advanced Research Consortium

FCTO U.S. DEPARTMENT OF ENERGY

MILLION MILE FUEL CELL TRUCK

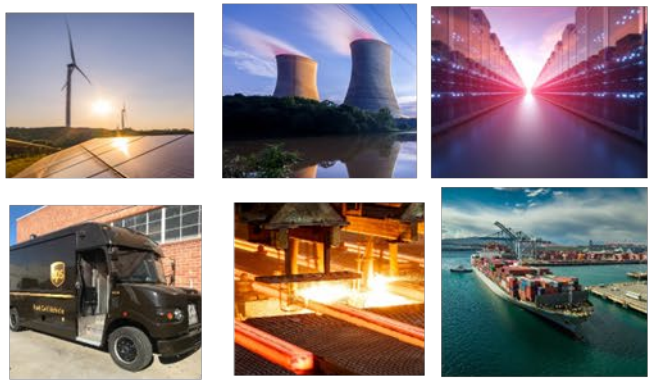
SHASTA Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

***Basic science user facilities, theory, modeling***

## Technology Integration, Validation, Demos

1st of a kind demonstrations and systems integration to de-risk deployments

***Examples:***



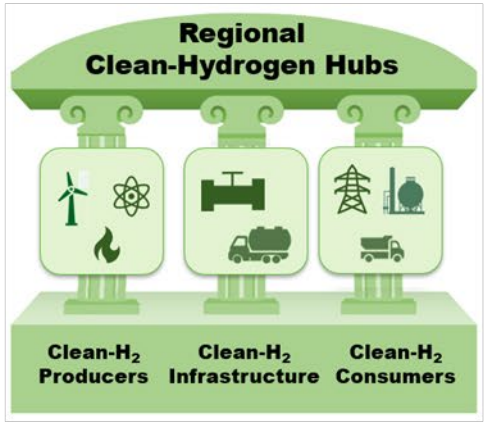
***Renewables and nuclear to $H_2$, 15 delivery trucks in disadvantaged area, 3 Super Truck projects, data center, fueling for passenger ferry, energy storage, $H_2$ for steel***

## Deployment and Financing

H2 Hubs, loan guarantee program, workforce development

***Example:***

**$8 billion for at least 4 hubs:** Renewables, fossil w/CCS, nuclear; multiple end-uses




***2 new loan guarantee projects ($1.5B total) on pyrolysis and large-scale electrolysis, $H_2$ energy storage and power generation***

## Enabling Activities

- Analysis and tools
- Safety, codes & standards
- Manufacturing
- Workforce development

H2EDGE Hydrogen Education for a Decarbonized Global Economy

CENTER FOR Hydrogen SAFETY Connecting a Global Community

HyBlend U.S. DEPARTMENT OF ENERGY

H2 Matchmaker

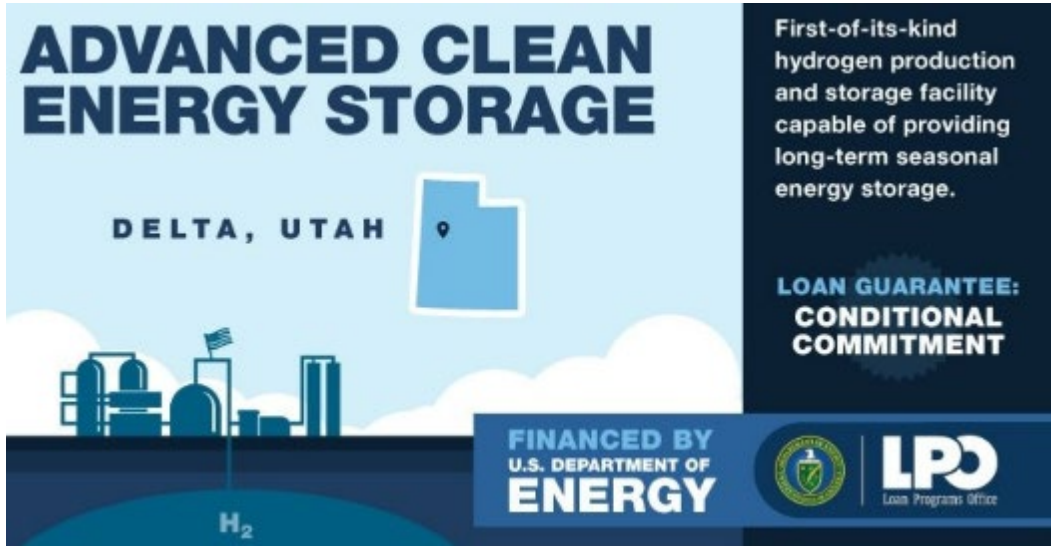
# Financing to Enable Deployment at Scale

## Loan Programs Office (LPO) has $40 Billion in Available Debt Capital

**LPO announces loan guarantees for two clean hydrogen projects**

(one guarantee pending, as "conditional commitment")


**$1.04B** for the first-ever commercial-scale project to deploy methane pyrolysis technology. Will enable 1,000 construction jobs and 75 operations jobs. (Conditional commitment for loan guarantee announced December 2021)




**$504.4M** for large-scale hydrogen energy storage, 220 MW electrolysis and turbine. Will enable up to 400 construction jobs and 25 operations jobs. (Loan guarantee closed in June 2022)


Collaboration
Diversity, Equity, Inclusion

**The redwoods are the tallest trees on earth—growing tall and enduring long dry spells—on harsh terrain and despite shallow roots.**

**They are able to do this through the collective strength of their roots which are an interwoven system, where each tree supports—and is supported by—the trees around it.**

# Examples Promoting DEIA, bridging academia, labs and industry

## Tommy Rockward, Scientist, Los Alamos National Lab (LANL) Advancing Diversity, Equity, Inclusion, & Accessibility (DEIA)

**Lead for Minority Serving Institution Partnership Program (MSIPP) at LANL.**
Has mentored over 100 minority students, enabling fuel cell jobs

INCREASE YOUR H2IQ hydrogen.energy.gov

*Featured with others in February's spotlight in celebration of Black History Month! And view Oct 6, 2022, webinar for more.*

## Funding for MSIs and Historically Black Colleges and Universities (HBCUs) to join HFTO consortia

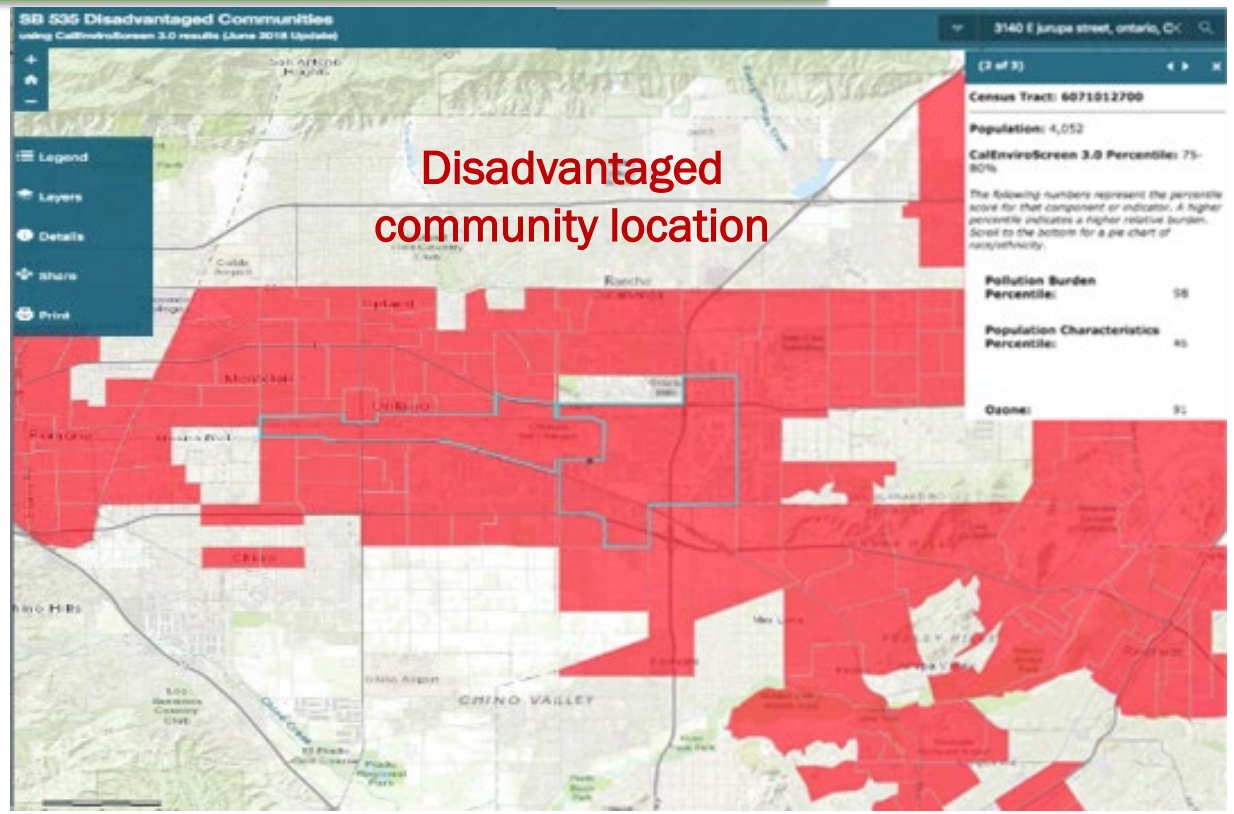
DOE Announces $1.5 Million to Train the Next-Generation Hydrogen Workforce | Department of Energy

## LANL and Pajarito Powder Establish Collaboration with Minority Serving Institutions (MSIs)


**Pajarito Powder and LANL host Industry day**

# Example of DOE-funded Project in Disadvantaged Community

## EERE HFTO project with CTE for UPS Fuel Cell Delivery Vans in Ontario, CA




**Key Accomplishments and Status:**

- 15 trucks built with validation testing complete on 10.
- Third party inspection soon to be completed on remaining trucks
- Operations have begun in disadvantaged community out of UPS Service center in CA. Vehicle deployment is beginning soon.

**Goal: Demonstrate 15 fuel cell trucks (up to 125-mile range)**

Project impact per year: Savings of

- 285 metric tons of $CO_2e$
- 280,000 grams of criteria pollutants
- 56,000 gallons of diesel

# H2 Twin Cities 2022 Winners Announced!


- **Announced at COP27 on Nov 16** by US DOE Sec. Granholm in collaboration **with UK, Japan and CEM H2I**

- H2 Twin Cities 2023: To be **launched early 2023** and to focus on **Mentor-Mentee partnerships**

Learn more about the winners: www.energy.gov/eere/h2twincities/h2-twin-cities-2022-winners

# Call to Action: Join the Center for Hydrogen Safety!

IPHE

AIChE
The Global Home of Chemical Engineers

Hydrogen Council

Pacific Northwest NATIONAL LABORATORY

hySafe
INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

**www.aiche.org/CHS**

**Over 90 members from industry, government, and academia—and growing!**


**New Hydrogen Safety Credential!**

Composed of 7 fundamental hydrogen safety e-courses, including:

- Properties & Hazards
- Safety Planning
- System Operation
- Inspection & Maintenance

# Examples of International Collaboration

**Collaborating through multiple global and bilateral partnerships—key priority is creating coordinated framework to leverage activities, identify gaps, and avoid duplication to accelerate progress**

CEM Global Ports Coalition with EC
Numerous Bilaterals on Hydrogen
Hydrogen Council, IRENA, and more

**The International Partnership for Hydrogen and Fuel Cells in the Economy**

Enabling the global adoption of hydrogen and fuel cells in the economy

**$H_2$ Production Analysis (H2PA)**
**To facilitate international trade**
**Common analytical framework for GHG emissions footprint**

**Regulations, Codes, Standards, Safety and Education & Outreach Working Groups**

www.iphe.net

**Breakthrough Agenda in collaboration with other partnerships is mapping activities across global $H_2$ initiatives to identify gaps, focus areas, and prioritized workstreams**

# IPHE Early Career Network

Calling all hydrogen-enthusiast **STUDENTS** (undergraduate & graduate), **POST-DOCS**, and **EARLY CAREER PROFESSIONALS** worldwide!

Connect with peers, mentors, scientific researchers, industry professionals, and policymakers!

Networking ● Career Development ● Webinars
Research ● Policy ● Leadership ● Science

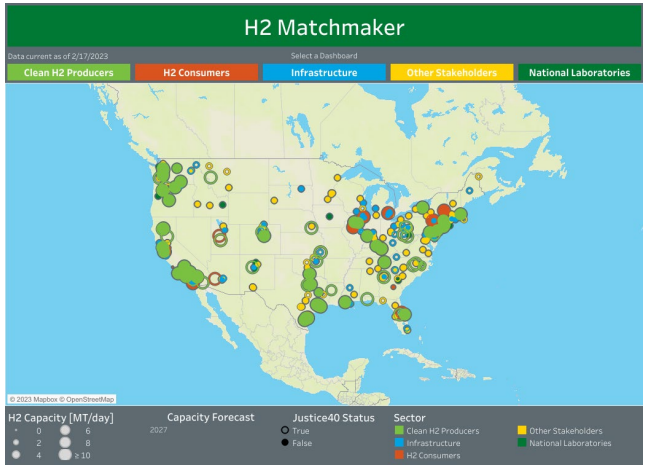

230+ members from 37 countries

**www.iphe.net/early-career-chapter**

2022-2023 Leadership Team

# Resources and Opportunities for Engagement

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

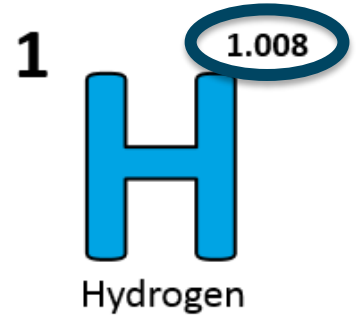



## Save the date!

**2023 DOE Annual Merit Review and Peer Evaluation Meeting**
**June 5-8, 2023**

## Hydrogen and Fuel Cells Day
## October 8

- Held on hydrogen's very own atomic weight-day





**Join Monthly**
**H2IQ Hour Webinars**

**Download**
**H2IQ For Free**

**Visit H2tools.Org For Hydrogen Safety And Lessons Learned**

https://h2tools.org/

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

**www.aiche.org/CHS**

## Sign up to receive hydrogen and fuel cell updates

www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

**Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov**

# Thank you

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