U.S. DEPARTMENT OF ENERGY

U.S. DOE Hydrogen Program

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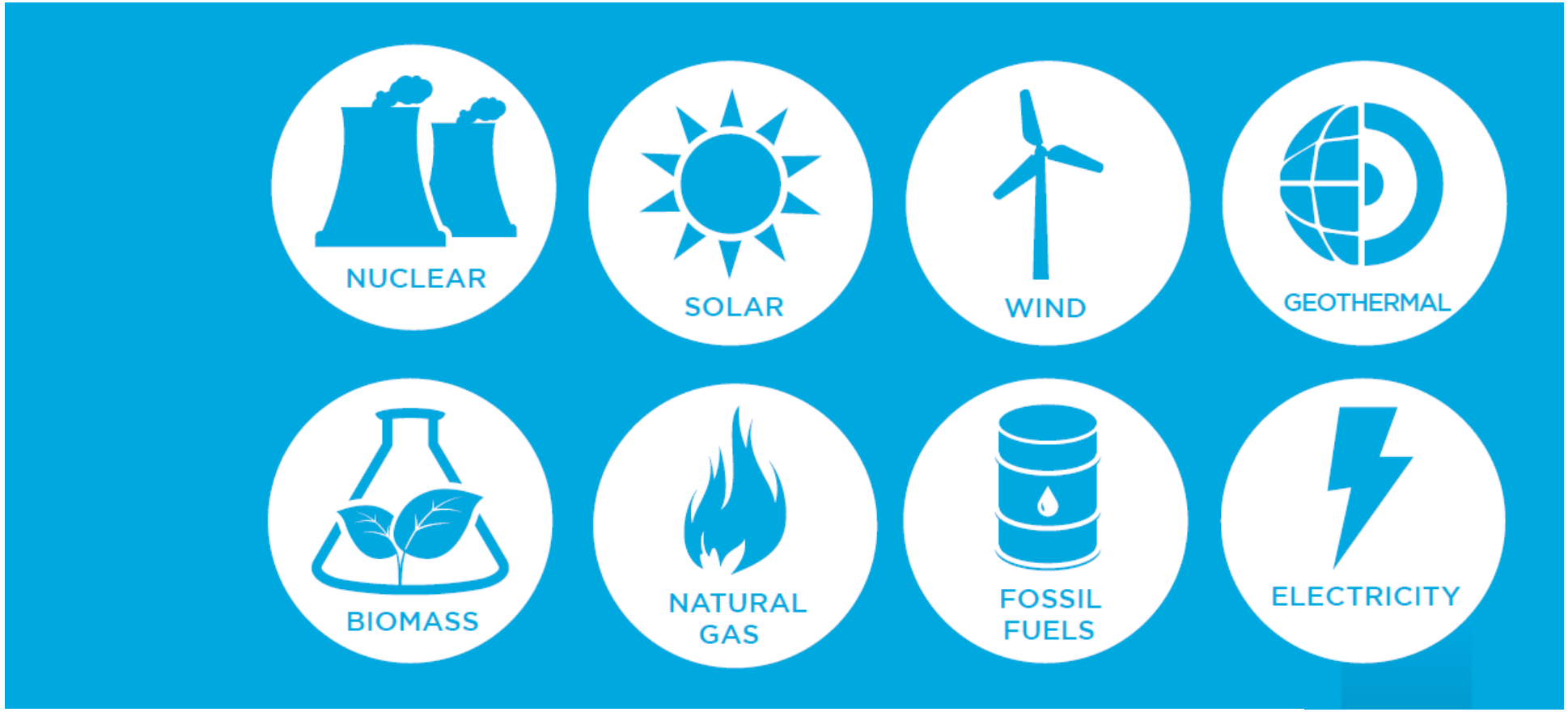
Norway Bilateral Discussions, Washington DC
November 1, 2023

Hydrogen Sources

Clean and domestic energy sources can be used to produce hydrogen

Over 95% of today's hydrogen comes from natural gas without CCS



10 million metric tons of hydrogen

produced annually in the United States, mostly for oil refining and fertilizer production

Learn more at: http://www.energy.gov/eere/fuelcells/hydrogen-resources

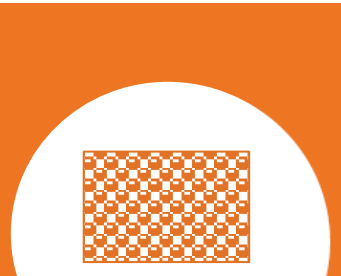
Hydrogen Uses

Multiple industries

Multiple applications

Including steel, cement ammonia industries

For heavy-duty applications including trucks, trains and at ports



Good for long-term energy storage; improved electric grid efficiency

Electricity production for cell phone towers, data centers, hospitals and supermarkets

Largest use of hydrogen produced today

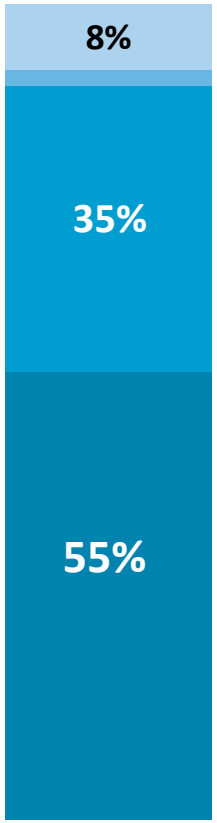
Second largest use of hydrogen produced today

Learn more at: https://energy.gov/eere/fuelcells/fuel-cell-technologies-educational-publications

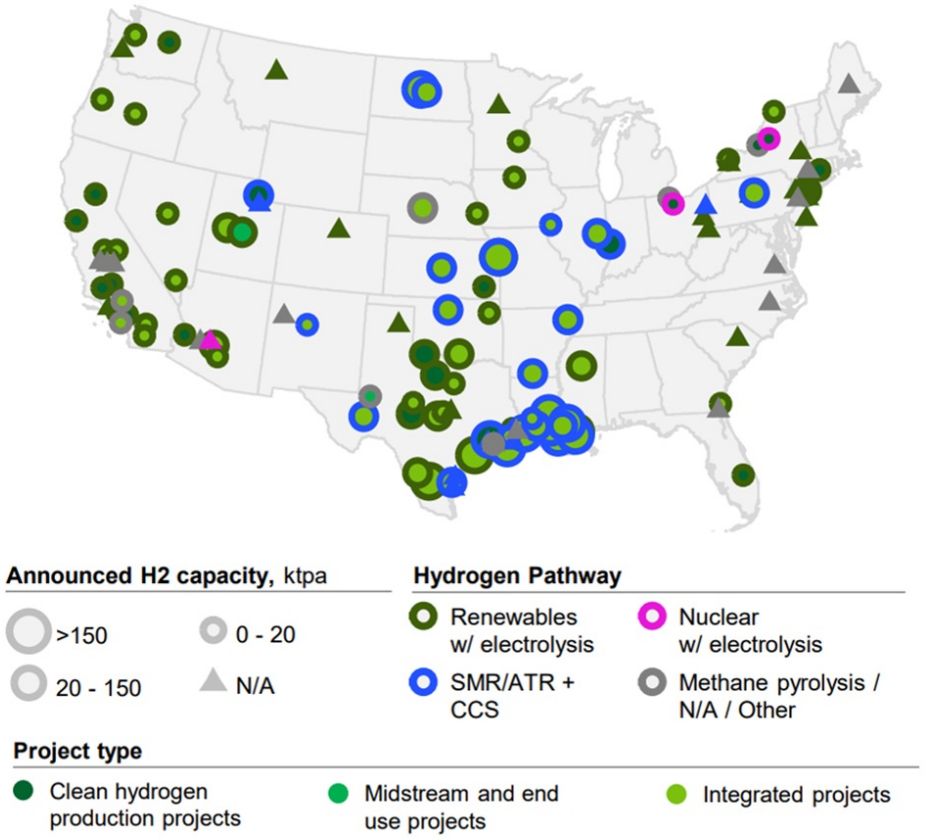
Snapshot of Hydrogen and Fuel Cells in the U.S.

- 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

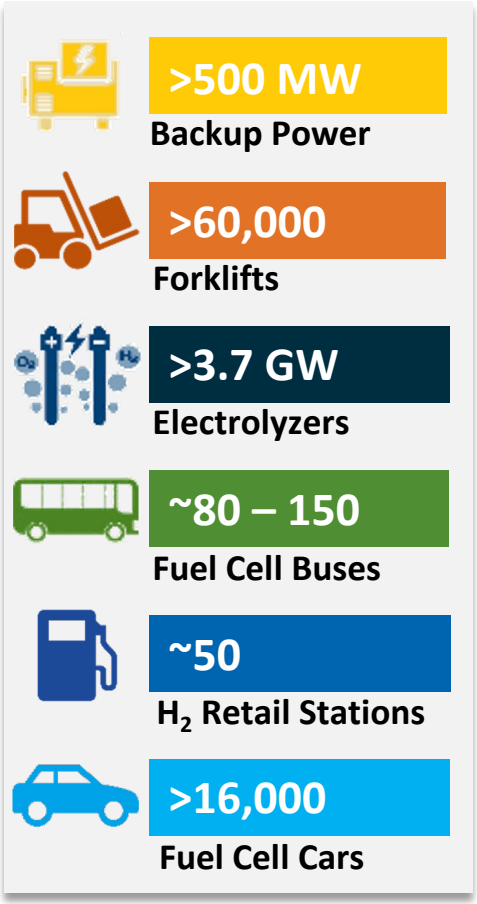


Current publicly announced clean hydrogen production projects*



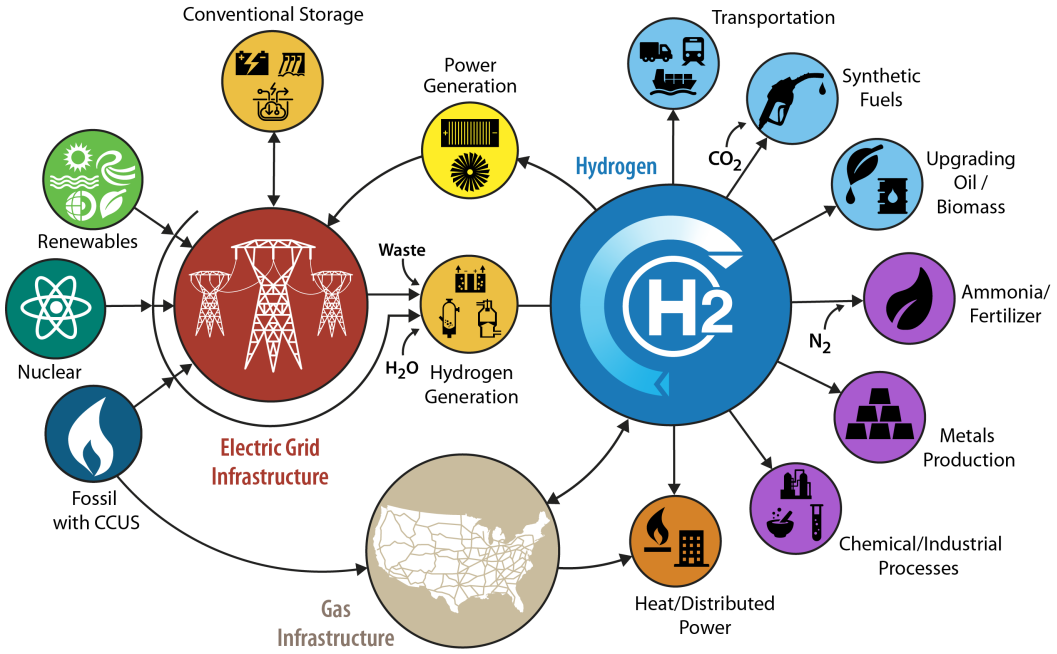
*as of EOY 2022, DOE Commercial Liftoff Report

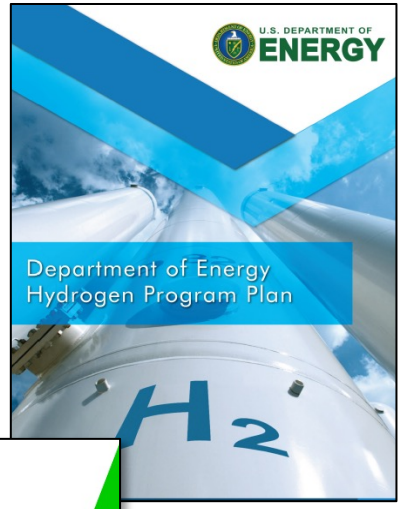
Examples of Deployments

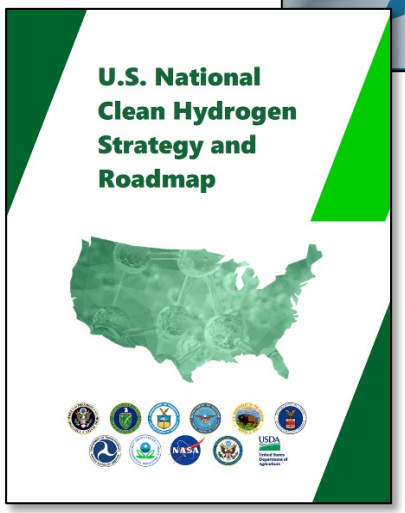


U.S. DOE Hydrogen Program

Hydrogen is one part of a broad portfolio of activities Includes multiple offices and the entire RDD&D value chain from production through end use







www.hydrogen.energy.gov

Coordinated across Offices by DOE Hydrogen and Fuel Cell Technologies Office (HFTO)

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

Legislation Highlights: 2021 - 2022

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 & Enhancement of CO_2 storage tax credit)

U.S. National Clean Hydrogen Strategy and Roadmap

Strategy

1. **Target strategic, high-impact end uses**
   Achieve 10 MMT/year of clean hydrogen by 2030
2. **Reduce the cost of clean hydrogen**
   Enable $2/kg by electrolysis by 2026 and $1/kg H_2 by 2031
3. **Focus on regional networks**
   Deploy regional clean hydrogen hubs and ramp up scale

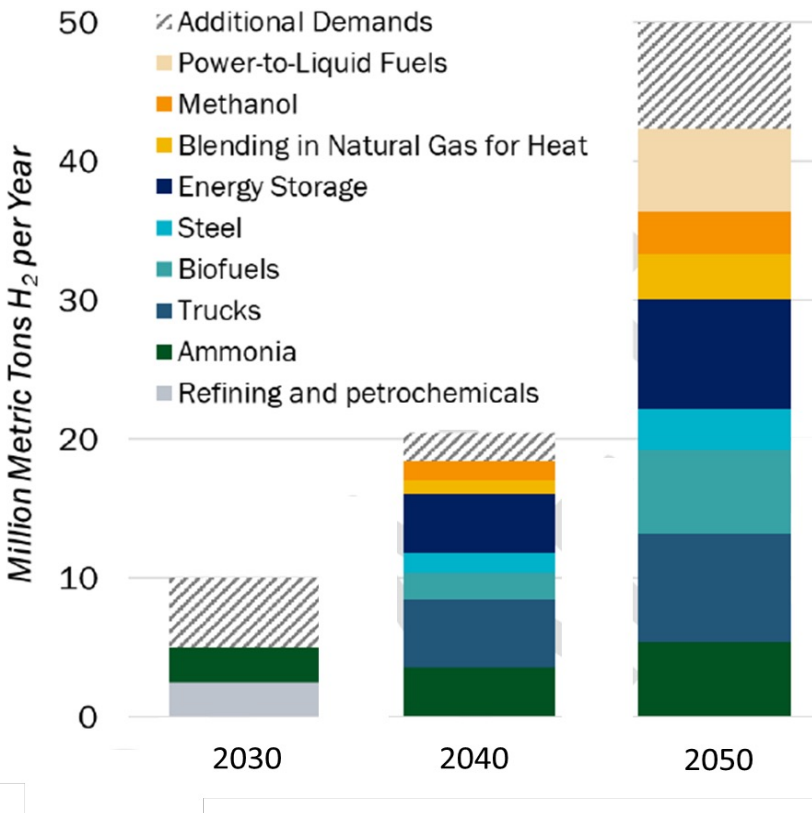
Vision:
Affordable clean hydrogen for a net-zero carbon future and a sustainable, resilient, and equitable economy

Benefits:
Emissions reduction; job growth; energy security and resilience

Enablers

Work with other agencies to accelerate market lift off

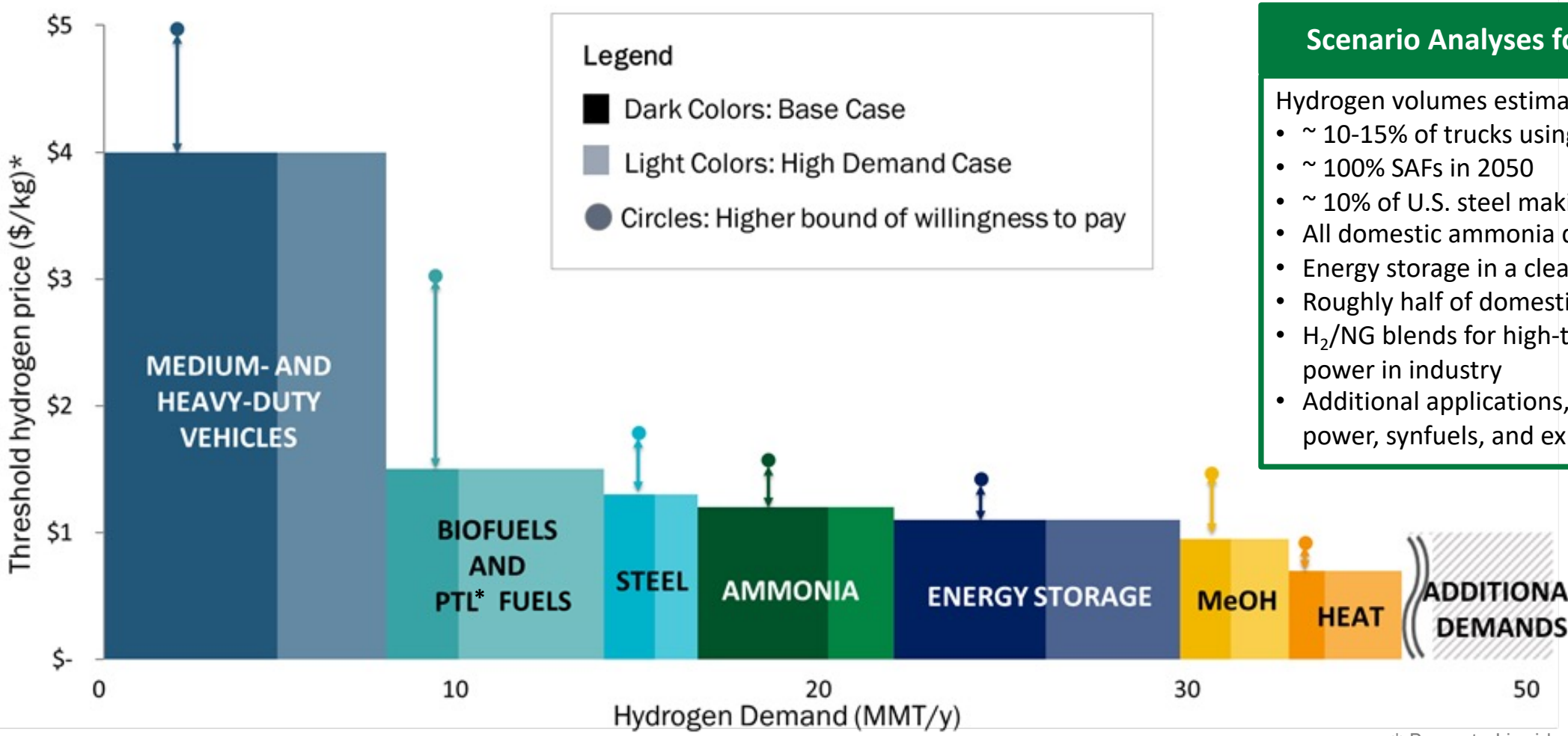
- Good Jobs and Workforce Development
- Safety, codes and standards
- Policies and incentives
- Stimulating private sector investment
- Energy and environmental justice



Opportunity: 10MMT/yr by 2030 → 20 MMT/yr by 2040 → 50 MMT/yr by 2050

Targeting 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

Reducing Cost:

Hydrogen Energy Earthshot

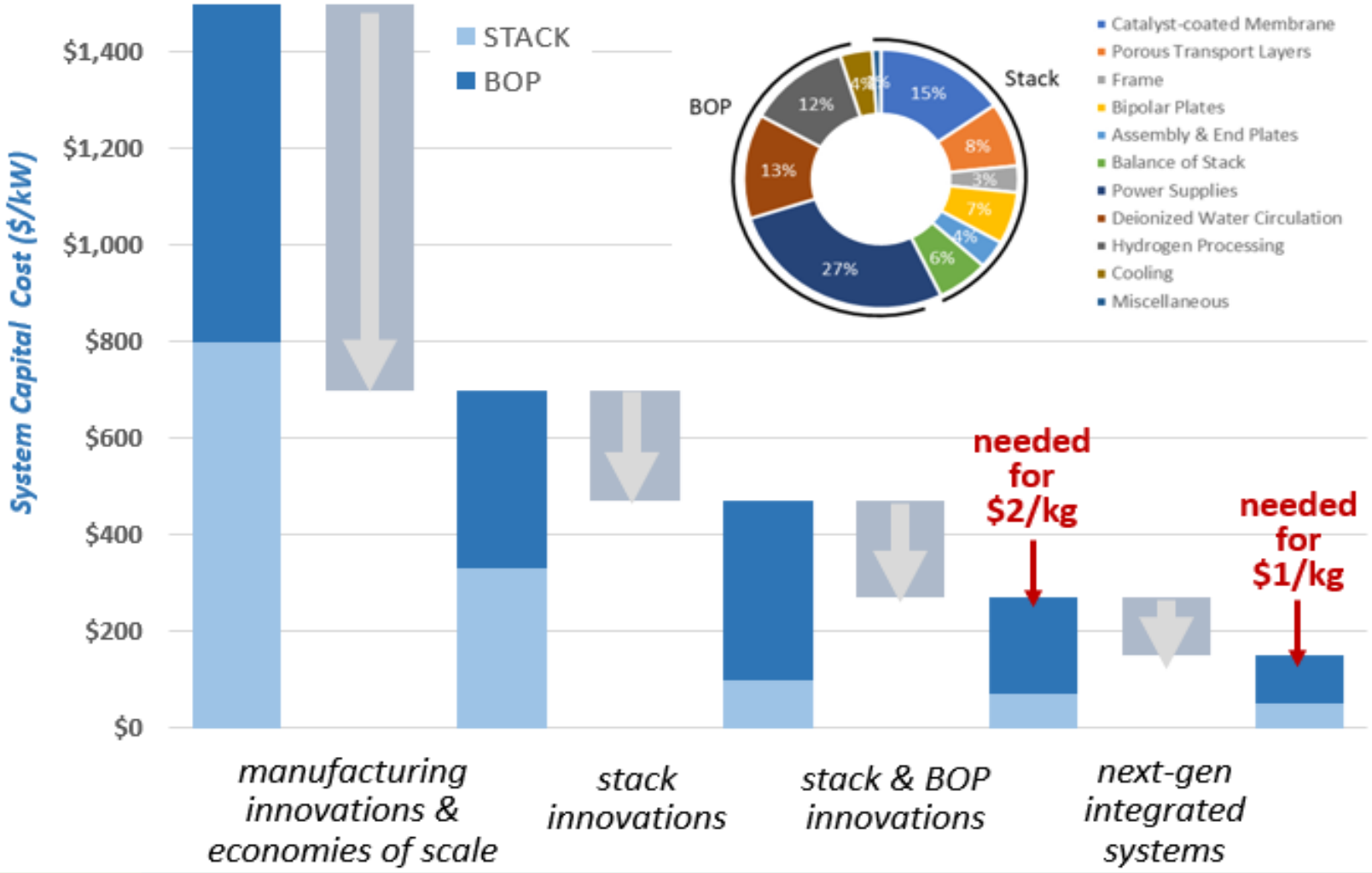
“Hydrogen Shot”

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

Strategy also includes delivery and storage infrastructure cost reduction

Addressing Electrolyzer Capital Cost Reduction

Analysis shows pathways to cost targets require both scale and RD&D



Specific PEM Case Study

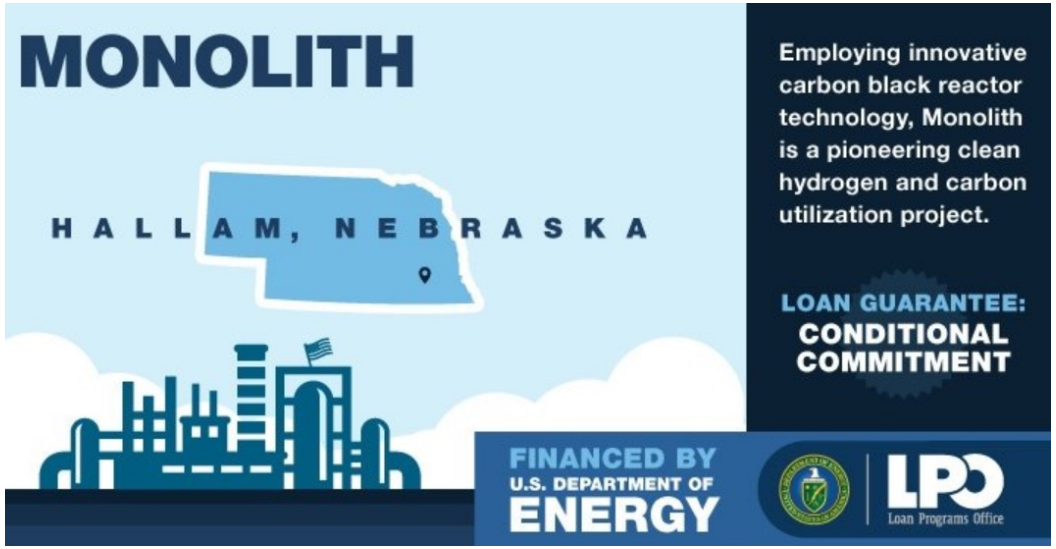
Seven Regional Clean Hydrogen Hubs Selected

Bipartisan Infrastructure Law Clean H_2 Hubs Leveraging:

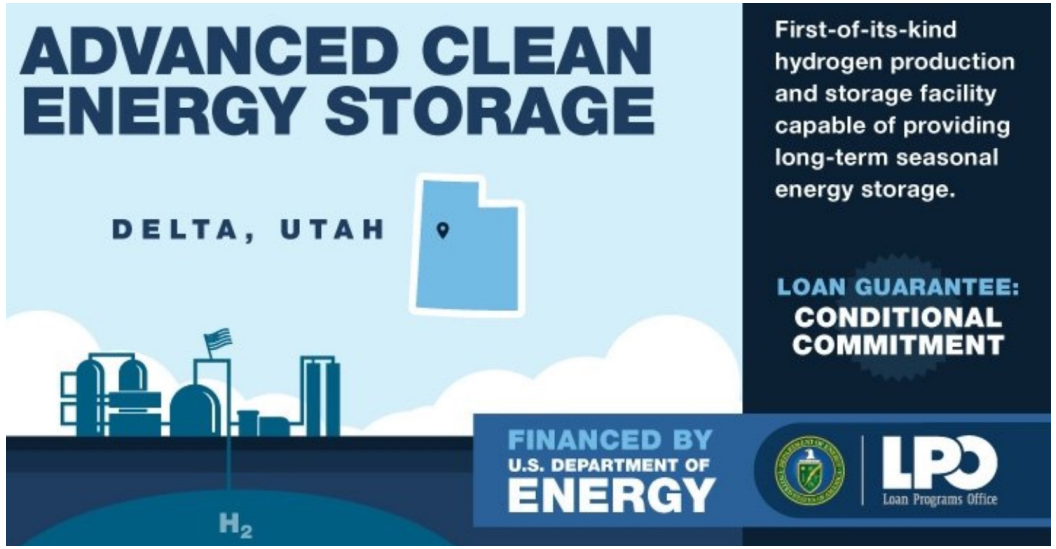
- Natural gas resources with carbon management;
- Renewable and nuclear power generation coupled with electrolysis
- Other regional resources supporting H_2 production, distribution, and end use

Financing to Enable Deployment at Scale

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



$1.04B for the first-ever commercial-scale project to deploy methane pyrolysis technology. Will enable 1,000 construction jobs and 75 operations jobs. (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. (April 2022)

LPO@hq.doe.gov

DOE Hydrogen Program Activities across RDD&D – Examples

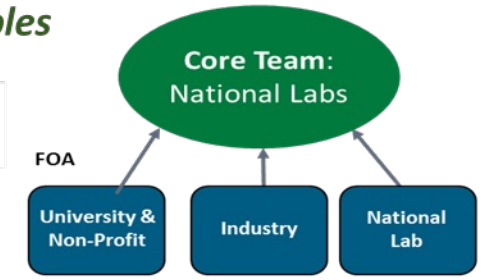
Research and Development

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

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

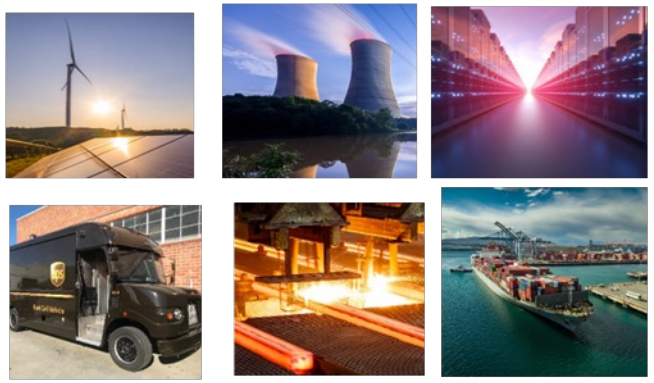
SHASTA Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

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

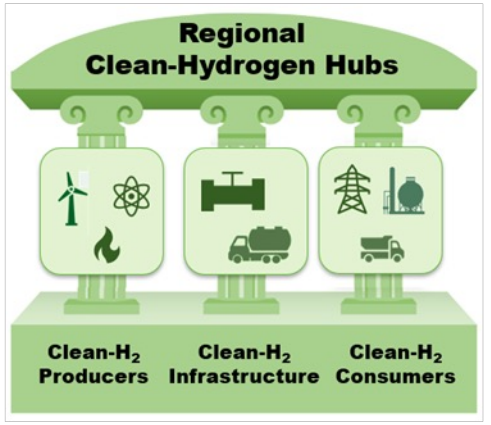
Deployment and Financing

H2 Hubs, loan guarantee program, workforce development

Example:

$7 billon for 7 hubs:

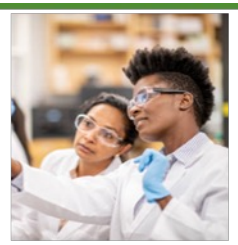
Renewables, fossil w/CCS, nuclear; multiple end-uses



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

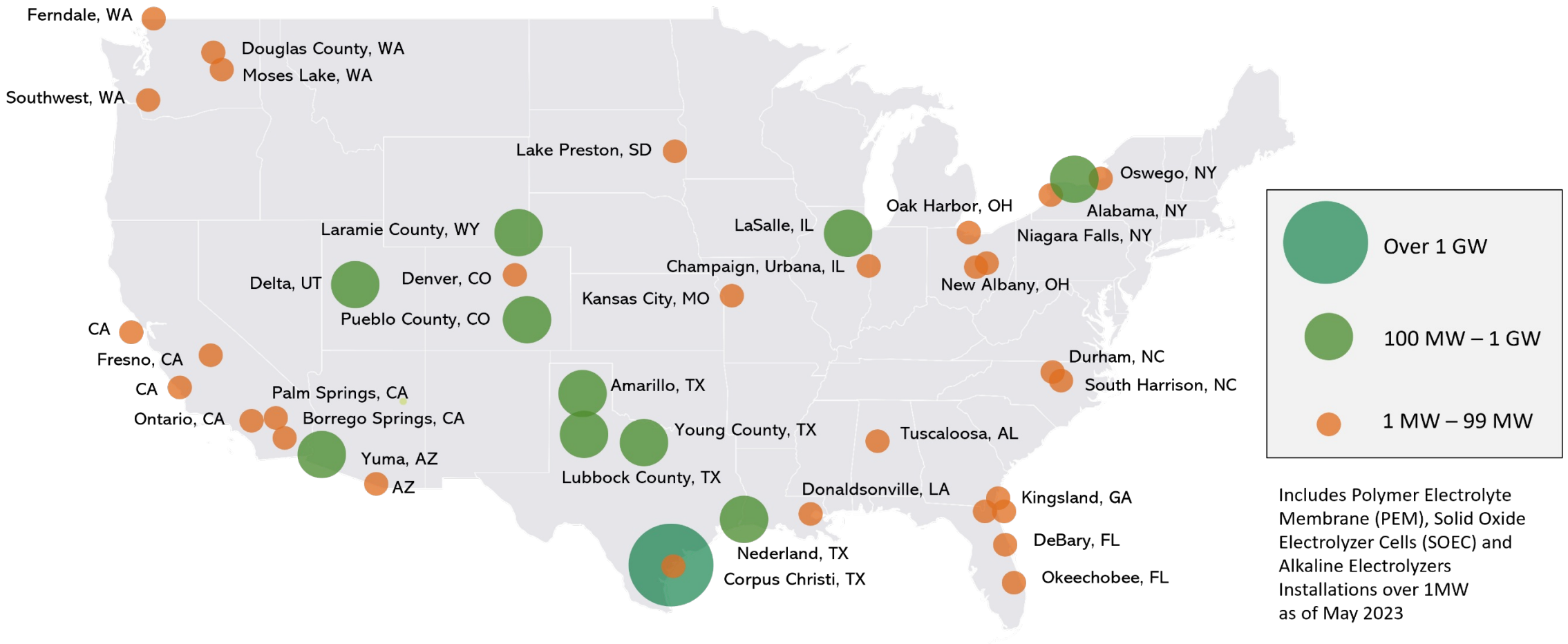
HyBlend U.S. DEPARTMENT OF ENERGY

H2 Matchmaker

HFTO-Led Clean Electrolysis Program: RD&D Accelerating Adoption

Total 3.7 GW in Planned & Installed Electrolyzer Capacity *(5-fold increase since 2022)*

Focus on Integration with Renewable or Nuclear Power Sources



Includes Polymer Electrolyte Membrane (PEM), Solid Oxide Electrolyzer Cells (SOEC) and Alkaline Electrolyzers Installations over 1MW as of May 2023

Source: Arjona, DOE Program Record #23003, June 2023

Hydrogen Program in FECM – Annual Appropriations

- Focus is on hydrogen production from fossil resources, waste (e.g., plastics), and available biomass, along with CCUS, to achieve net-zero carbon hydrogen, power generation/energy storage using reversible solid oxide cells and/or turbines, hydrogen transport, and large-scale/geological H_2 storage.
- FECM's Methane Mitigation division works to reduce methane flaring/venting/leakage, reducing the CI of hydrogen produced from natural gas.
- FECM works with EERE's Hydrogen and Fuel Cell Technologies Office and the Nuclear Energy office

Hydrogen with Carbon Management

- Program elements include Advanced Gasification, Advanced Turbines, and reversible Solid Oxide Fuel Cells
- The program will not fund R&D specific to traditional fossil power generation, focusing instead on hydrogen-related turbines, fuel cells, CCUS-relevant technologies, and gasification.

Natural Gas Decarbonization and H_2 Technologies

- The Natural Gas Technologies Program is comprised of four subprograms, including the newly-proposed Natural Gas Decarbonization and Hydrogen subprogram.
- Focus areas for the new subprogram include advancing technologies for the carbon-neutral production, transportation, and geologic storage of hydrogen sourced from natural gas.

Pre-Commercial – H_2 FEEDs

Steam Methane Reforming

Linde-BASF technology using OASE® blue solvent

Advanced CCS Systems for SMR

THE LINDE GROUP

Svante VeloxoTherm™ solid adsorbent at Linde SMR H_2 plant

- ~1,100,000 tonnes/year net CO_2 capture
- 90% Capture Efficiency
- Production of "blue" H_2 with 99.97% purity

PHILLIPS 66

Gen 1 CCS technology at Phillips 66 refinery in Rodeo, California

- Separate & store ~190,000 tons/year net CO_2 from hydrogen production unit with >90% carbon capture efficiency

Advanced CCUS +for ATR

TALLGRASS ENERGY

CO_2 Capture Unit at Tallgrass MLP Operations LLC's Planned Blue Bison ATR Plant

- Separate and store 1.66 million tonnes/year of 95% pure CO_2 with >97% carbon capture efficiency
- System combining carbon capture, H_2 production (220 MMSCFD at 99.97% purity), and H_2 combustion in auxiliary burners

8 RIVERS

CCS system at the Painter Gas Complex, WY

- **100 million SCF per day of 99.97%-pure hydrogen**
- **Capture 90–99% of CO2 emissions.**
- **Three design cases implementing the subsystems and equipment of the 8RH2 ATR technology and a CO2 separation unit, are being evaluated.**

FEED Studies on Existing Energy Assets

Electric Power Research Institute, Inc. (Palo Alto, CA)

Gasification of Coal and Biomass: The Route to Net-Negative-Carbon Power and Hydrogen

Integrated design study on an oxygen-blown gasification system coupled with water-gas shift, pre-combustion CO_2 capture, and pressure-swing adsorption working off a waste coal/biomass mix to yield high-purity hydrogen and a fuel off-gas that can generate power.

- Nebraska Public Power District Sheldon Station coal fired plant
- CO_2 Storage: enhanced oil recovery and saline sequestration
- Co-feed corn stover, possibly other biomass and waste plastics

Wabash Valley Resources, LLC (West Terre Haute, IN)

Wabash Hydrogen Negative Emissions Technology

Complete system integrated design study for redeveloping the existing Wabash Valley Resources coal gasification site in West Terre Haute, Indiana, into a 21st century power plant for flexible fuel gasification-based carbon-negative power and carbon-free hydrogen co-production.

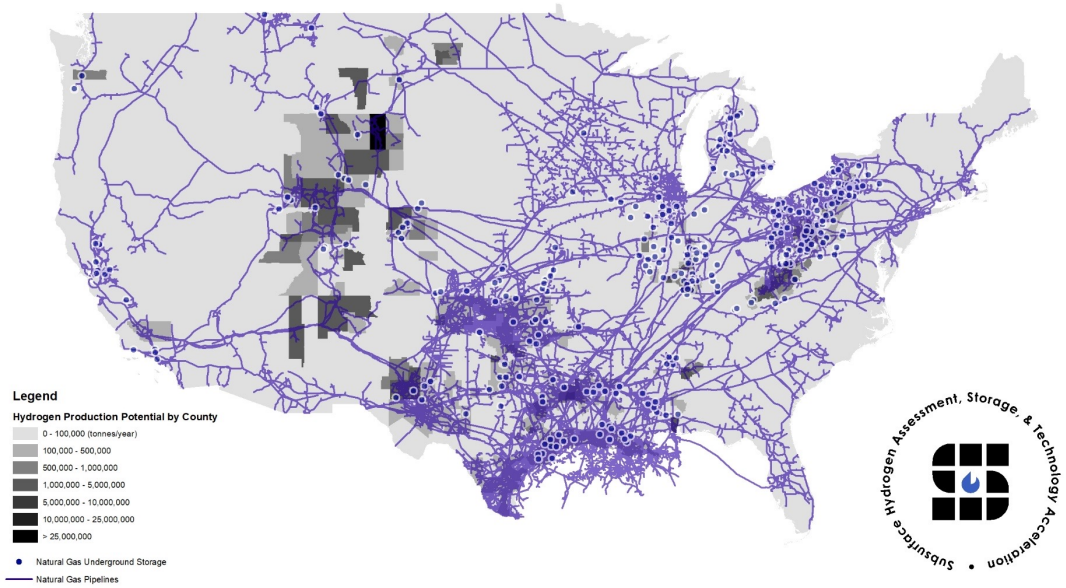
- Facility: Wabash Gasification Facility
- CO_2 Storage: Saline sequestration
- Co-feed woody biomass and/or agricultural residue and waste plastics

Hydrogen Pipeline Transportation

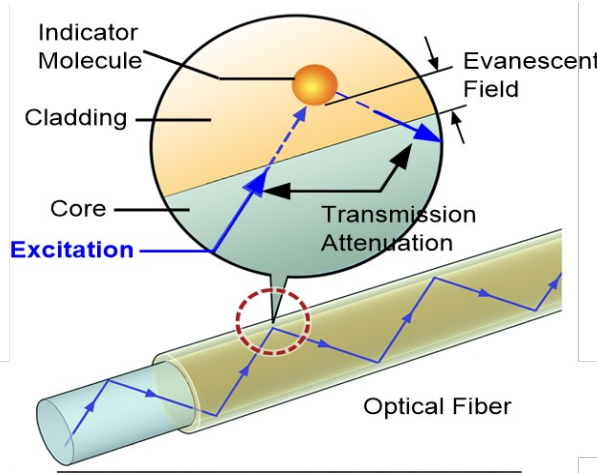
- Characterization of long-term hydrogen impact on piping and pipeline materials and gas blending.
- Life-cycle analysis of emissions from transportation infrastructure.
- Develop advanced sensors, coatings, and materials for hydrogen transportation within blended or dedicated infrastructure.

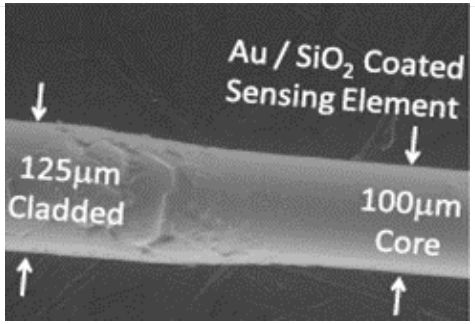
U.S. Natural Gas Pipeline Network
~3 million miles of mainline and other pipelines that link production areas, storage facilities, and consumers.

Dedicated Hydrogen Pipeline System
~1,600 miles, owned by merchant hydrogen producers.



Distributed Fiber Optics Sensors for real-time pipeline monitoring and hydrogen leak detection

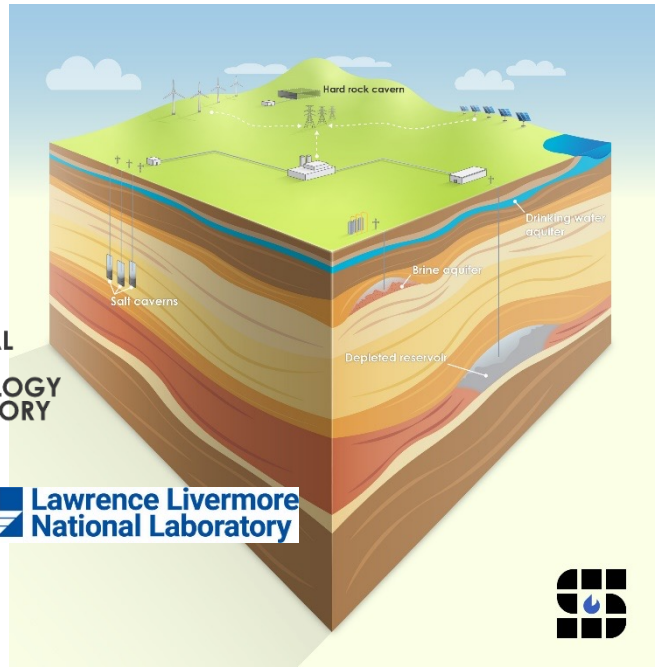




https://publications.anl.gov/anlpubs/2008/02/61034.pdf
https://www.energy.gov/eere/fuelcells/hydrogen-pipelines

Subsurface Hydrogen Storage

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration



NATIONAL ENERGY TECHNOLOGY LABORATORY

Lawrence Livermore National Laboratory

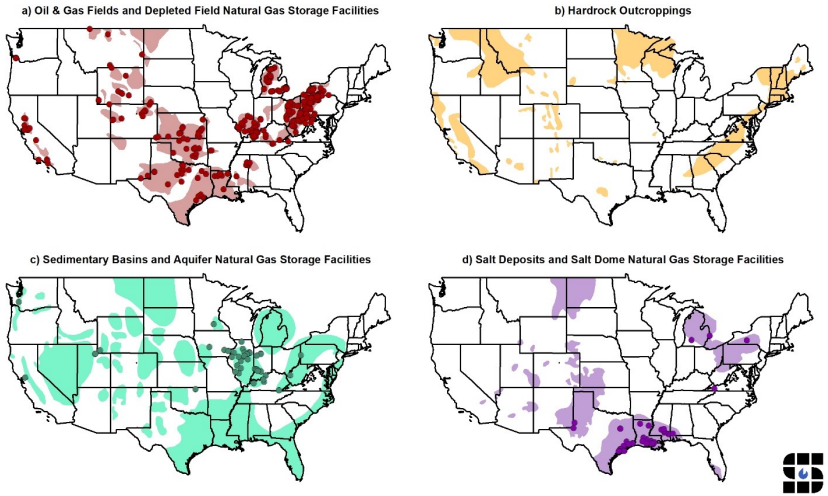
Pacific Northwest NATIONAL LABORATORY

Current Status

- Subsurface hydrogen storage is domestically limited to salt cavern storage facilities.
- Expanding the footprint for subsurface storage to different geologies and geographies is crucial to enabling widespread hydrogen utilization through bulk storage.

Goals & Objectives

- Multi-lab team will identify and address key technological hurdles and develop tools and technologies to enable broad public acceptance for subsurface storage of hydrogen blended with natural gas or pure hydrogen storage.
- Subsurface geologic characterization efforts to demonstrate storage permanence and adequate demonstration of minimal risk to sensitive receptors, including drinking water resources.
  - Determine geophysical and geochemical interactions between pure hydrogen and blended gas storage and effects on structural integrity and microbial communities.
- Subsurface characterization and validation with respect to potential leakage; long-term effects on reservoir rock; biogeochemical characteristics,; well casing, cement, and transportation infrastructure; and assess overall hydrogen recoverability.
  - Determine viability, safety, and reliability of pure hydrogen or blended gas storage by conducting field demonstrations.



Equity and Environmental Justice Perspectives

I. Listening, Engaging & Increasing Transparency

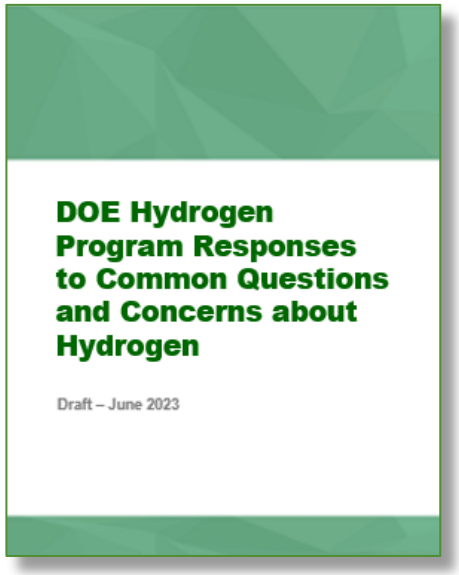
II. Prioritizing Safety and Positive Impacts

III. Lowering Barriers

IV. Diversifying the Clean Hydrogen Workforce

V. Building Capacity & Skills

VI. Environmental Justice in Permitting and Siting



Stay tuned for more information on Community Benefits Plans, Mapping Tools, and upcoming activities

Examples of International Collaborations

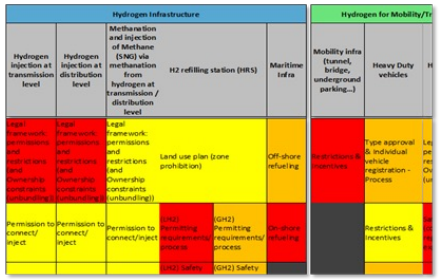
Collaborating through multiple partnerships – prioritization of gaps and key activities underway

CEM Global Ports Coalition with EC
Numerous Bilaterals on Hydrogen
Hydrogen Council, IRENA, G7, UNIDO, 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

Common analytical framework for GHG emissions footprint and facilitating international trade

Regulations, codes, standards, harmonization gap analysis



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

H2 Twin Cities - A Clean Energy Ministerial (CEM) Hydrogen Initiative

What is H2 Twin Cities?

A CEM H2I effort to connect communities around the world to:

- **Share ideas**
- **Mentor and Learn from each other**
- **Build community of best practices**
- **Strengthen commitment to environmental justice and diversity equity and inclusion**

2023 H2 Twin Cities Round Updates

- Focus on **mentor-mentee partnerships**
- **Review** for 2023 round **submissions underway**
- **2023 winning teams announcement expected in late 2023/early 2024**

Background

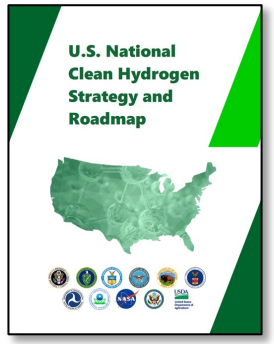
- **H2 Twin Cities kicked off in Nov 2021** at COP26
- **Two teams selected in 2022** covering mentor-mentee and sibling cities partnerships, include participation from **US, Japan and UK**

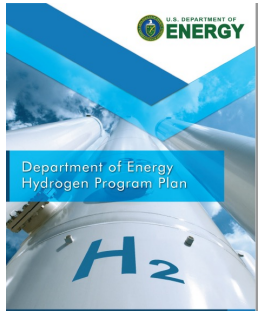
- **2023 H2 Twin Cities round underway**, potentially more teams to be announced in 2024
- **Winning teams receive nominal funding of up to $100K** (or in-kind contribution) subject to each country's ministry.

Share and learn more: www.energy.gov/eere/twincities
Questions? Contact: h2twincities@nrel.gov

Resources and Opportunities for Engagement

Key Publications





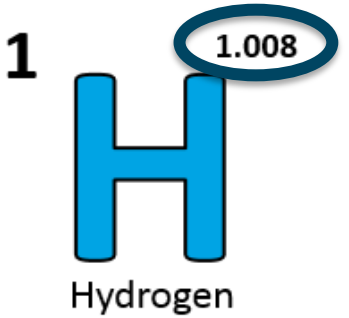
www.hydrogen.energy.gov

Save the date!

2024 DOE Annual Merit Review May 6-9, 2024

Hydrogen and Fuel Cells Day October 8

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



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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

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Thank You!

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