U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

Fossil Energy and Carbon Management Hydrogen Program

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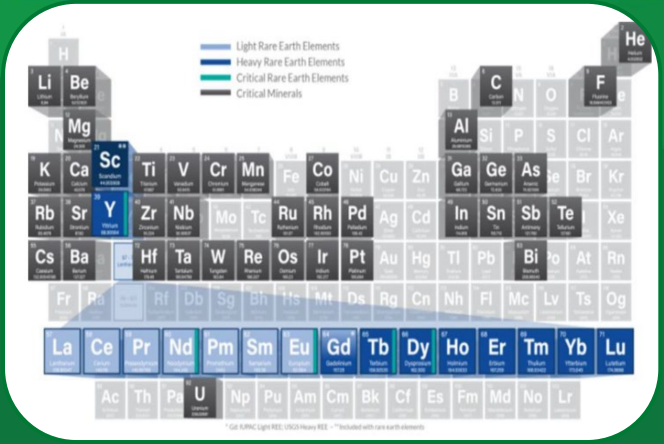
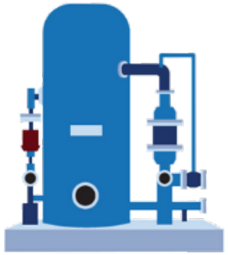
Division of Hydrogen with Carbon Management

April 5, 2023

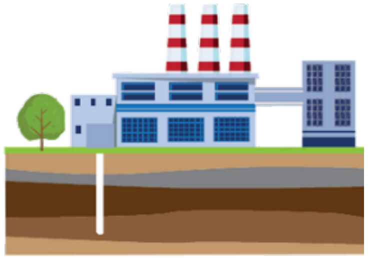


FECM Strategic Vision

Justice, Labor,
and Engagement



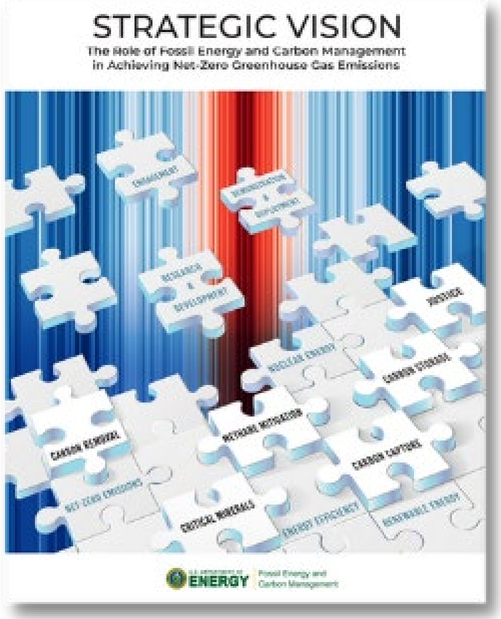
Technologies that
Lead to Sustainable
Energy Resources



Carbon Management
Approaches toward
Deep Decarbonization

FECM Role Achieving Net-Zero Greenhouse Gases

FECM's *Strategic Vision* will enable DOE to make strategic carbon management decisions to ensure that fossil fuel usage is put into proper context with climate change and is designed for a future that achieves and maintains net-zero greenhouse gas emissions.



Read FECM's Entire Strategic Vision
by Scanning the Code Above

Hydrogen Program in FECM

- Focus is on hydrogen production from fossil resources, waste (e.g., plastics), and available biomass, along with CCUS, to achieve net-zero carbon hydrogen as well as large-scale power generation using turbines and large-scale/geological H_2 storage.
- FECM works with EERE's Hydrogen and Fuel Cell Technologies Office and 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.

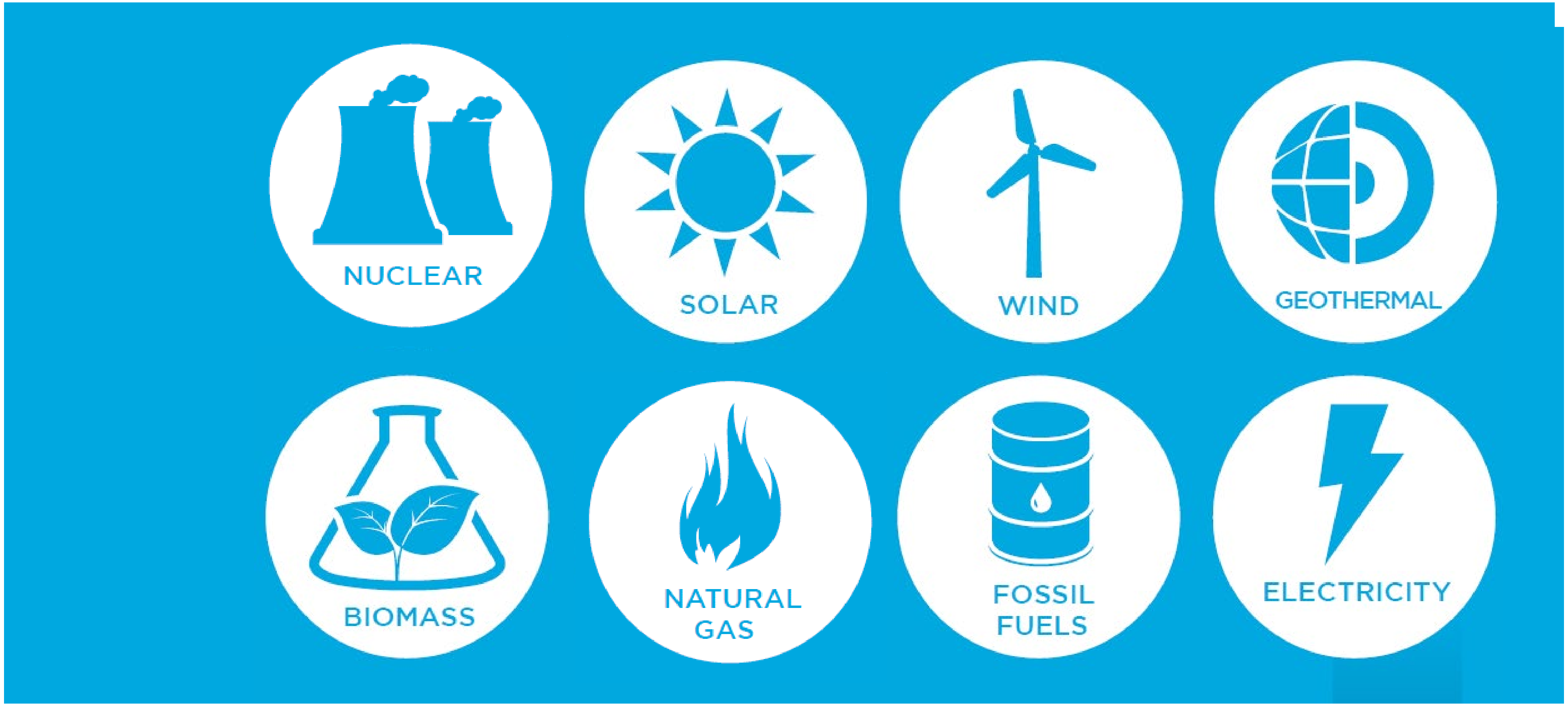
Natural Gas Decarbonization and H_2 Technologies

- 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.

Hydrogen Sources

Clean and domestic energy sources can be used to produce hydrogen

Most of today's hydrogen comes from natural gas



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

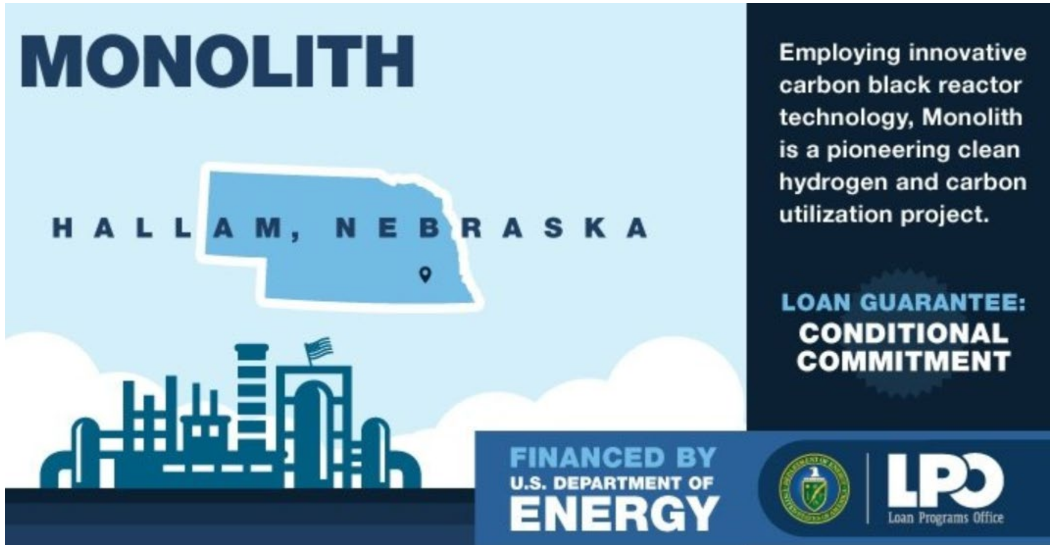
HARD-TO-DECARBONIZE SECTORS	TRANSPORTATION	ENERGY STORAGE	STATIONARY FUEL CELLS	PETROLEUM REFINING	CHEMICALS
Including steel, cement ammonia industries	For heavy-duty applications including trucks, trains and at ports	Good for long-term energy storage; improved electric grid efficiency	Electricity production 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

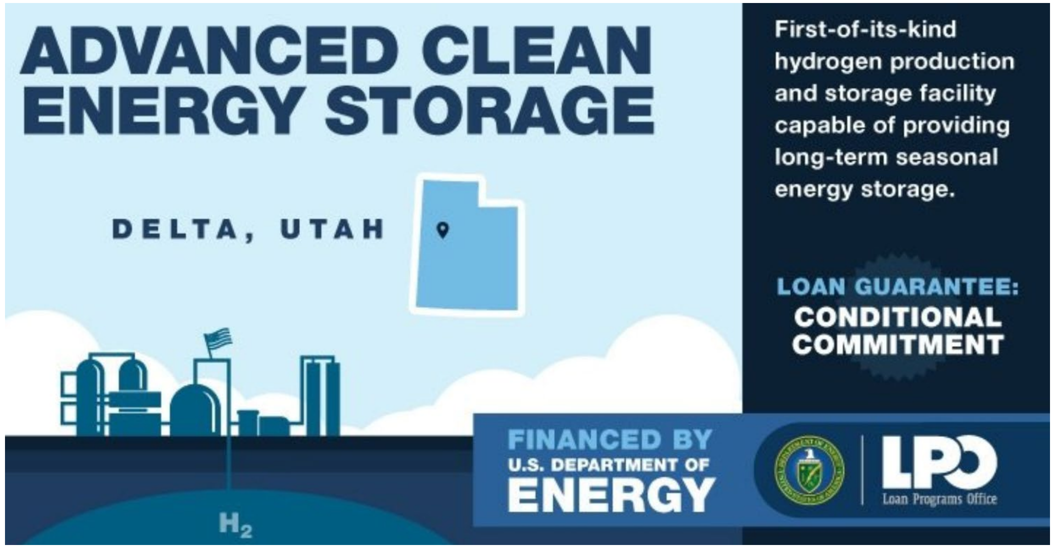
Financing to Enable Deployment at Scale

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

LPO announced loan guarantee conditional commitments for 2 clean hydrogen projects



$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

Important Hydrogen Provisions in Recent Legislation

Bipartisan Infrastructure Law

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

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

Inflation Reduction Act

➢ **Includes production tax credit for clean Hydrogen**

FEED Studies for CCS Systems at New or Existing Hydrogen Plants (SMR and ATR)

CCS System for SMR and ATR Plants

100,000+ tonne/yr. net CO_2 from new or existing Hydrogen Plants (SMR and ATR) and 90% Carbon Capture Efficiency

FOA #2400

Problem Statement

Complete an initial engineering design for an advanced CO_2 capture system for commercial application at new or existing Hydrogen Plants (SMR or ATR) with the following specifications:

- 90%+ Carbon Capture Efficiency, 95+% CO_2 Purity,
- 100,000+ t/year CO_2 captured
- 99.97+% H_2 Purity
- Advanced Pre- and Post- Carbon Capture Technology at TRL 6+
- Identification of possible CO_2 storage or utilization options.

Success Criteria: By 2023, projects will develop an initial engineering study for an advanced CCS at a new or existing Hydrogen Plant facility. These designs should provide the basis for the subsequent deployment of CCUS projects that are targeting the 45Q tax credits and will be early adopters of the technology.

Leveraging Advanced CCS for H_2 Generation

Pre-Commercial.. H_2 Generation (TRL 6+)

Advanced CCS Systems for SMR

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

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 MLP Operations, LLC

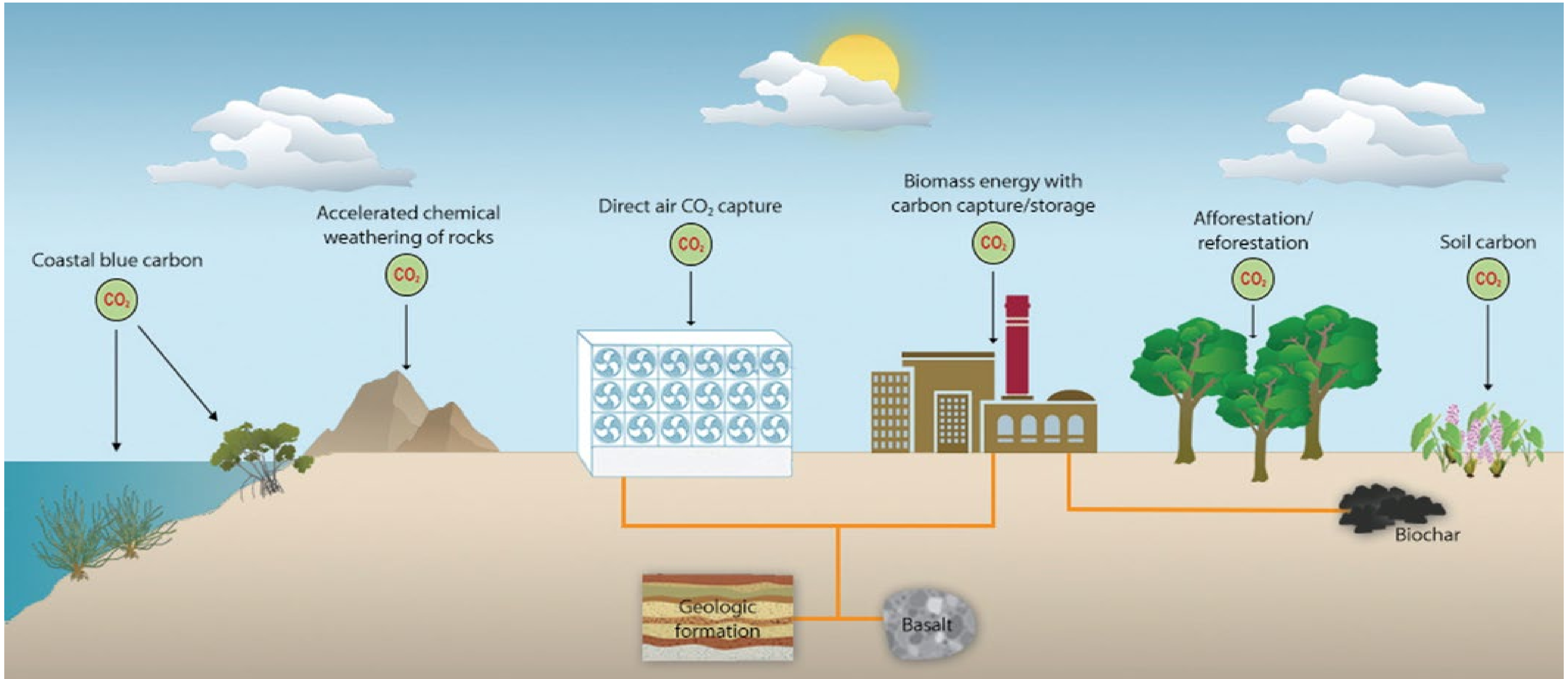
CO2 Capture Unit at Tallgrass MLP Operations LLC's Planned Blue Bison ATR Plant Douglas, WY

- 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

CDR Areas of Interest in FECM

- Biomass with Carbon Removal and Storage
- Direct Air Capture (DAC)
- Direct Ocean Capture (DOC)
- Accelerated Weathering and Mineralization

- Rigorous LCA and TEA (net-removed costs)
- Low-carbon energy, land, water resources required
- Leveraging transport and storage infrastructure
- Justice and work force considerations



Reference: NASEM, 2019

DOE’s Carbon Matchmaker

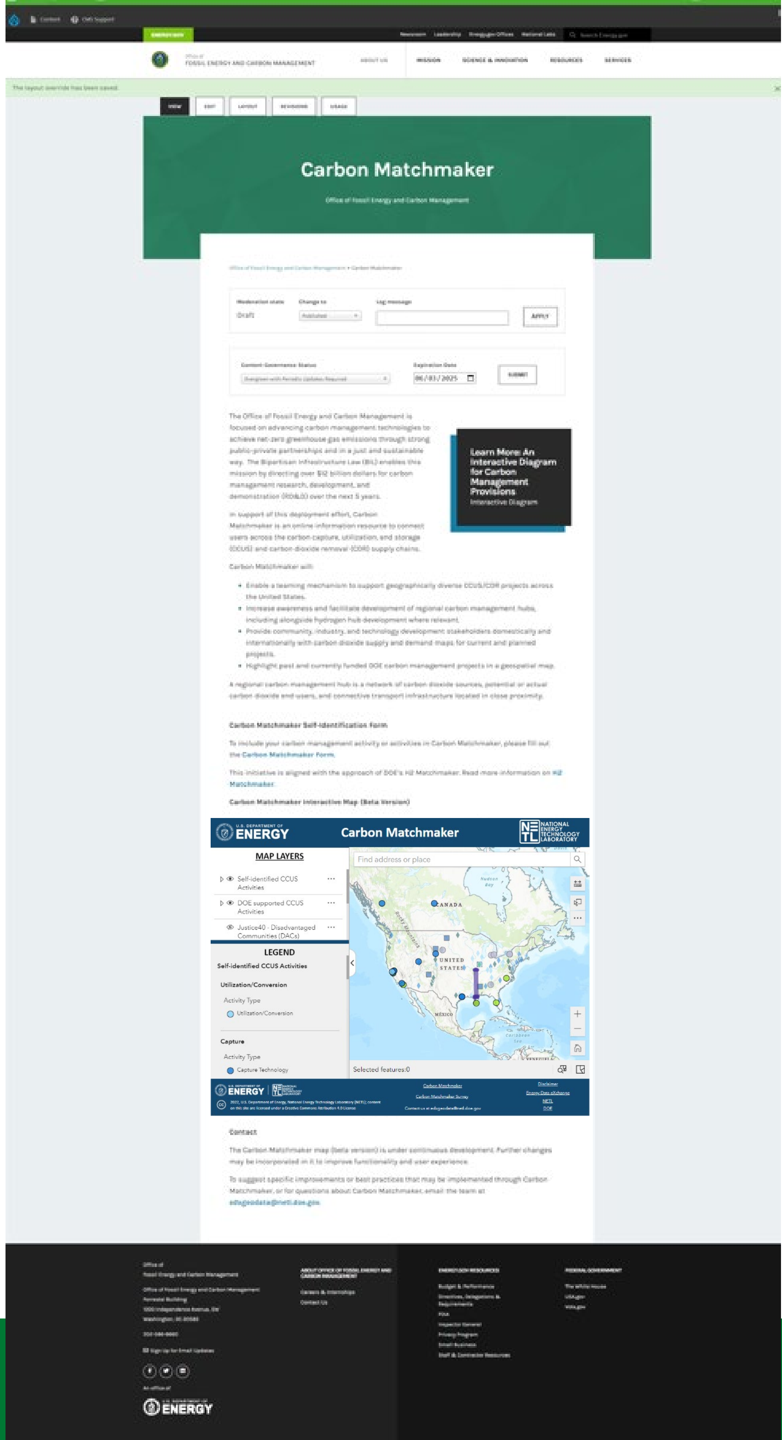
A partnering and teaming tool for DOE carbon management funding opportunities, mirroring DOE’s H2 Matchmaker.

Carbon Matchmaker is an online information resource to connect users across the carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) supply chains.

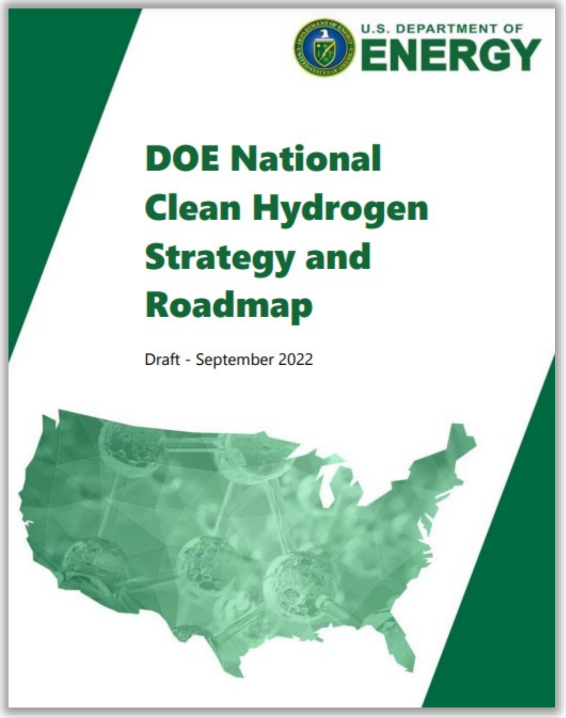
Carbon Matchmaker will:

- Enable a teaming mechanism to support geographically diverse CCUS/CDR projects across the United States.
- Increase awareness and facilitate development of regional carbon management hubs, including alongside hydrogen hub development where relevant.
- Provide community, industry, and technology development stakeholders domestically and internationally with carbon dioxide supply and demand maps for current and planned projects.
- Highlight past and currently funded DOE carbon management projects in a geospatial map.

https://www.energy.gov/fecm/carbon-matchmaker



DOE's National Clean Hydrogen Strategy and Roadmap



Roadmap and Action Plan to Address Barriers

	2022-2025		2026-2029		2030-2035
Clean Hydrogen Production	Catalyze RD&D in electrolysis, thermal conversion, & new pathways to meet Hydrogen Shot	Demonstrate replicable, scalable production from renewables, nuclear, & fossil and waste with CCS	Deploy gigawatt-scale electrolyzers and develop domestic supply chains	Scale up electrolyzer manufacturing and recycling/reuse capacity	Achieve 5 MMT production capacity and $1/kg target
Delivery and Storage Infrastructure	Identify and prioritize barriers to infrastructure roll out	Initiate supporting infrastructure for regional hubs	Demonstrate advanced and efficient infrastructure components	Develop sustainable regional clean hydrogen networks	Deliver hydrogen at scale
End Uses and Market Adoption	Engage regulators to lay groundwork for strategic adoption across sectors	Initiate transition for hard to decarbonize industries	Deploy at least four regional clean hydrogen hubs	Deploy technologies that lower pollution and provide resiliency	Scale up hydrogen hubs and prepare export opportunities
Enablers	Engage stakeholders; address safety codes and standards; develop critical supply chains	Use and expand workforce, talent pools, and apprenticeship programs	Ensure 40% of benefits accrue to disadvantaged communities in hub regions	Demonstrate business cases and attract private capital	Achieve Justice 40, create good-paying jobs, and ensure public health & safety

Includes quantitative, industry-driven targets to enable market competitiveness:
Examples include: $1/kg H_2 production, $2/kg delivery, $8/kWh storage, $80/kW fuel cell, etc.

https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

Energy Justice, Stakeholder Engagement, DEI, Place-Based Engagement Strategies

Strategy: Identify and enable concrete benefits & workforce development with emphasis on EJ, DEI, labor unions, tribal communities, DACs, and those jobs impacted by the energy transition

Challenge: Need to address constructive feedback from stakeholders (non-renewable H_2, siting, NOx, jobs, etc.)

Future Engagement Strategy

- Small, focused meetings, with CBOs, EJ groups, labor unions, tribal groups
- Large, open, public webinars
- Educational materials for dissemination on lessons learned and best practices
- Identify and enable near-, mid- & long-term jobs, registered apprenticeships
- Implement new ideas: e.g., "Dig once"

CENTER FOR Hydrogen SAFETY 水素安全センター
Connecting a Global Community

Center for H_2 Safety (>60 partners) for training

- **H2 Matchmaker** for identification
- **H2EDGE** – EPRI FOA project on workforce development
- **Sustainability Tool**
- **Fellowships** (H-Shot, Rose, IPHE fellows)
- **IPHE Early Career Network** (global)
- **HBCU/MSI FOA**
- **H2 Twin Cities** (global)
- **FOA criteria**, policy factors, teaming lists

Use DOE IGEA Regions

H2 Lab & HBCU/MSI to Jobs Pipeline

Expand current Lab program

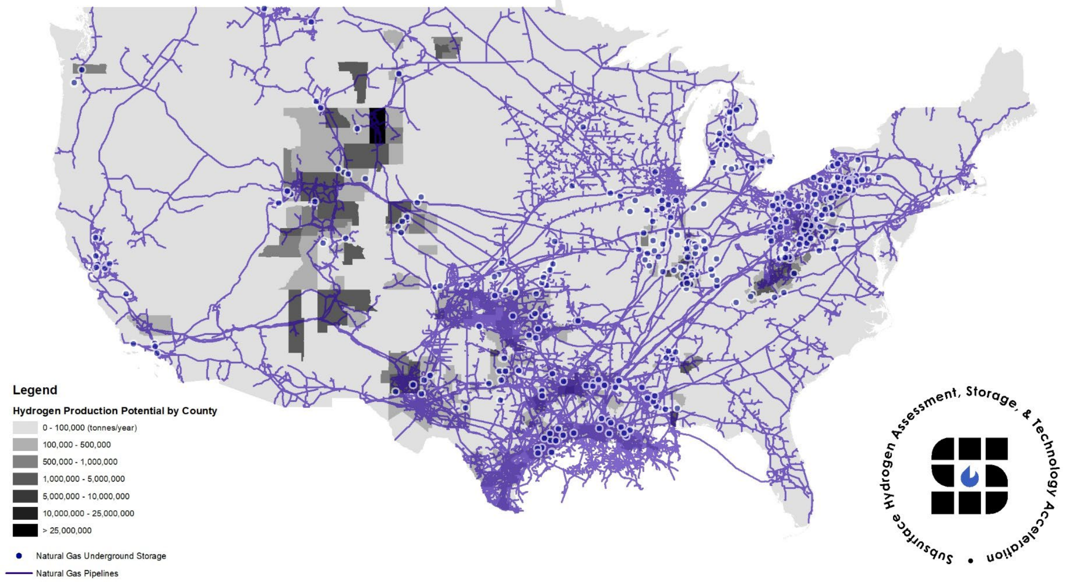
- LANL hosted approximately 100 students
- ~ 40 involved in LANL Fuel Cell research

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.

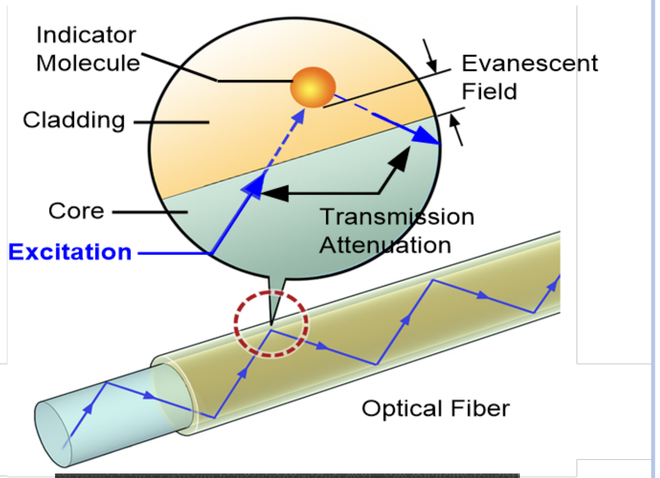
U.S. Natural Gas Pipeline Network
~3 million miles of mainline and other pipelines that link production areas, storage facilities, and consumers.

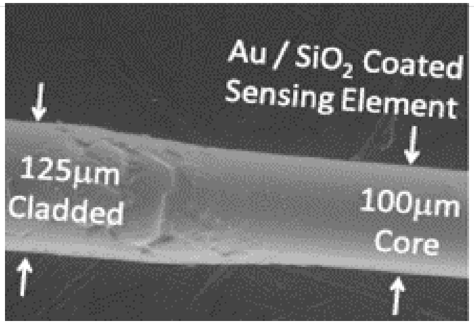
Dedicated Hydrogen Pipeline System
~1,600 miles, owned by merchant hydrogen producers.



Subsurface Hydrogen Assessment, Storage, & Technology Acceleration

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

Natural Gas Pipeline Infrastructure and Hydrogen

Goals & Objectives

- Validate the utilization potential of existing natural gas infrastructure as a potential means to expedite increased transport of hydrogen, ammonia, and carbon dioxide.
    - Efficient and flexible transport requires pipelines capable of handling both single components and blended mixtures, as well as intermittent and alternating gas chemistries.
- Determine material compatibility of natural gas pipeline materials with hydrogen, carbon dioxide, and ammonia for current pipeline routes to guide decisions on introducing non-traditional gases in these pipes.
- Address design challenges of hydrogen transport and compression, including:
    - Materials and coatings; light gas compression; sealing; safety; and control of hydrogen content variability.
- Investigate regional uncertainties regarding pipeline materials, methods of construction, their location of use, and other relevant characteristics.
    - Identify, preclude, or limit the introduction of hydrogen and other gases into established natural gas pipelines.

Greater Predictability and Management of Pure Hydrogen vs. Hyblends

- Hydrogen is ~9 times lighter than natural gas
- Different viscosity
- Higher speed of sound
- Carries less energy per unit volume
- Carries more energy per unit mass
- Higher heat capacity
- Higher flame temperature
- Wider flammability range
- Lower autoignition temperature
- Lower ignition energy

Subsurface Hydrogen Storage

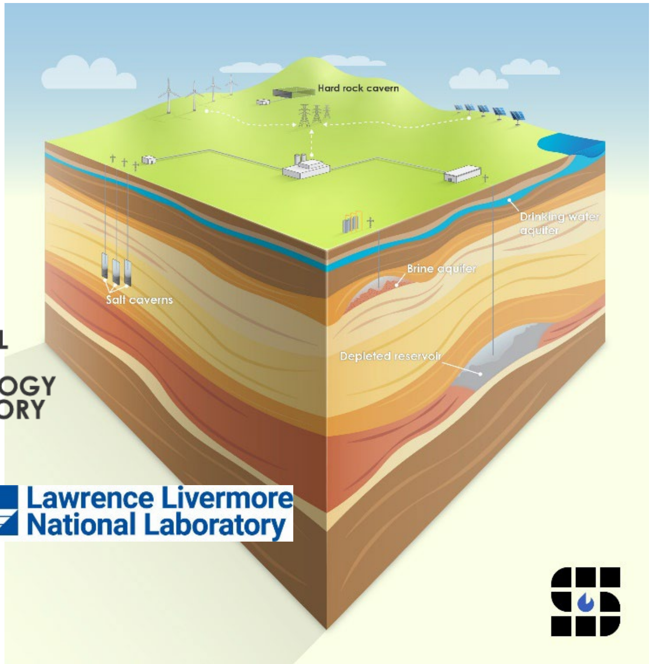
SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

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

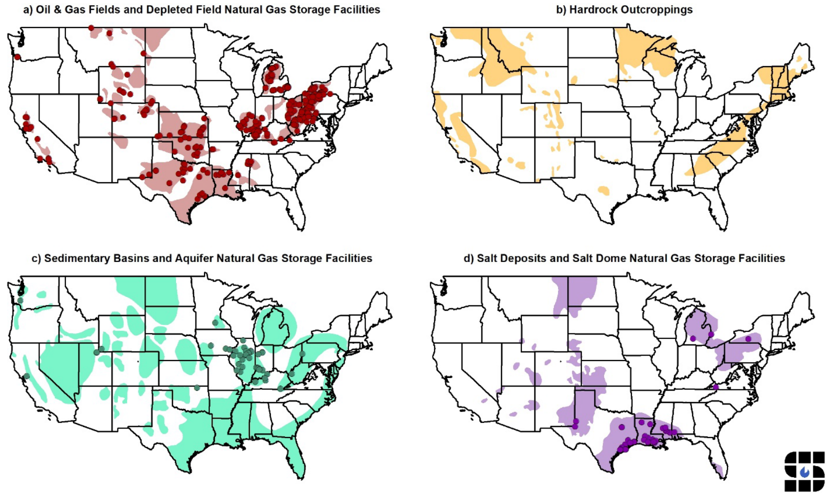
- Multi-lab team will identify and address key technological hurdles and develop tools and technologies to enable broad public acceptance for subsurface storage of hydrogen blended with natural gas or pure hydrogen storage.
- Subsurface geologic characterization efforts to demonstrate storage permanence 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.



NATIONAL ENERGY TECHNOLOGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

Lawrence Livermore National Laboratory



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Thank You!

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