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

FECM's Hydrogen Activities

May 7th, 2024

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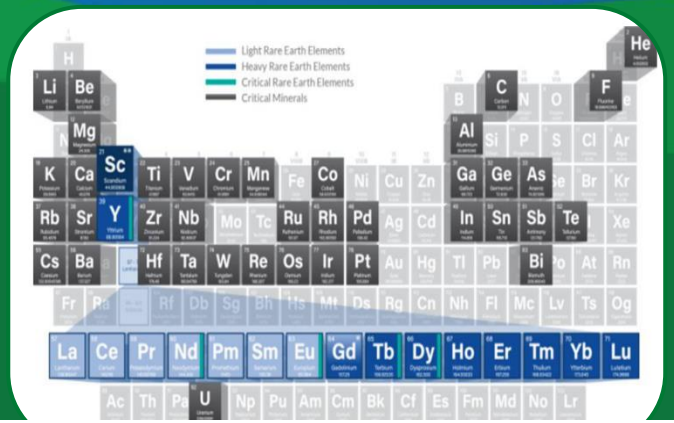


FECM's Focus

- Mitigation of environmental impacts from resource recovery and use
- Management of carbon dioxide emissions, including legacy emissions

FECM RDD&D Priorities

Advance Carbon Dioxide Removal & Low Carbon Supply Chains for Industry

Demonstrate and Deploy Point Source Carbon Capture

Accelerate Carbon-Neutral Hydrogen (H_2)

Reduce Methane Emissions

Low-Carbon Industrial Supply Chains

Advance Critical Minerals, Rare Earth Elements (REE), and Mine Remediation

Increase Efficient Use of Big Data and Artificial Intelligence

Address the Energy Water Nexus

Invest in Thoughtful Transition Strategies

FECM Hydrogen Equities

- **Production**
  - Gasification
  - CCS
  - SOECs
  - Reforming
  - Pyrolysis
- **Pipeline Transport**
- **Underground Storage**
- **Use**
  - Turbines
  - Solid Oxide Fuel Cells

Advanced Gasification Program

Gasification Process Improvements

- Modular design integration capability for cost reduction
- Process intensification
- Microwave-assisted gasification
- Reduce pre-treatment costs

Air Separation Technology

Reduce oxygen production costs (membranes, novel cryogenics, advanced sorbents, etc.)

Achieving Negative CO_2 Emissions

Reduce CO_2 emissions using biomass, wastes & CCS

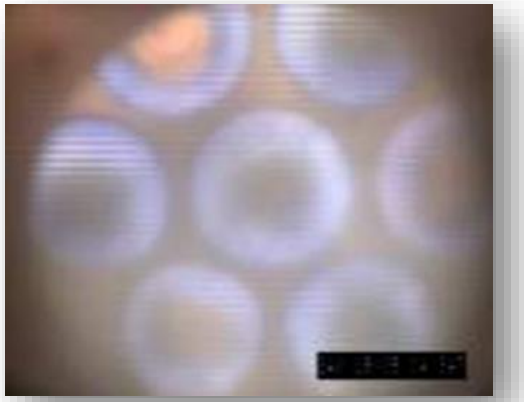
Advanced Turbines Program

Advanced Combustion Turbines

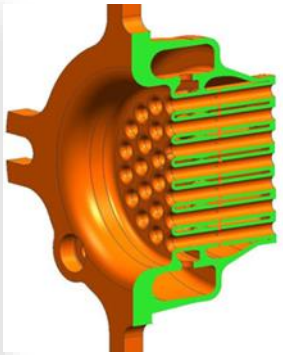
- Syngas, natural gas, **H_2, NH_3 Fuels**
- Achieve low NOx emissions & high efficiencies

OVERALL GOAL:

Large frame, industrial and aeroderivative turbines able to fire 100% H_2 by 2030



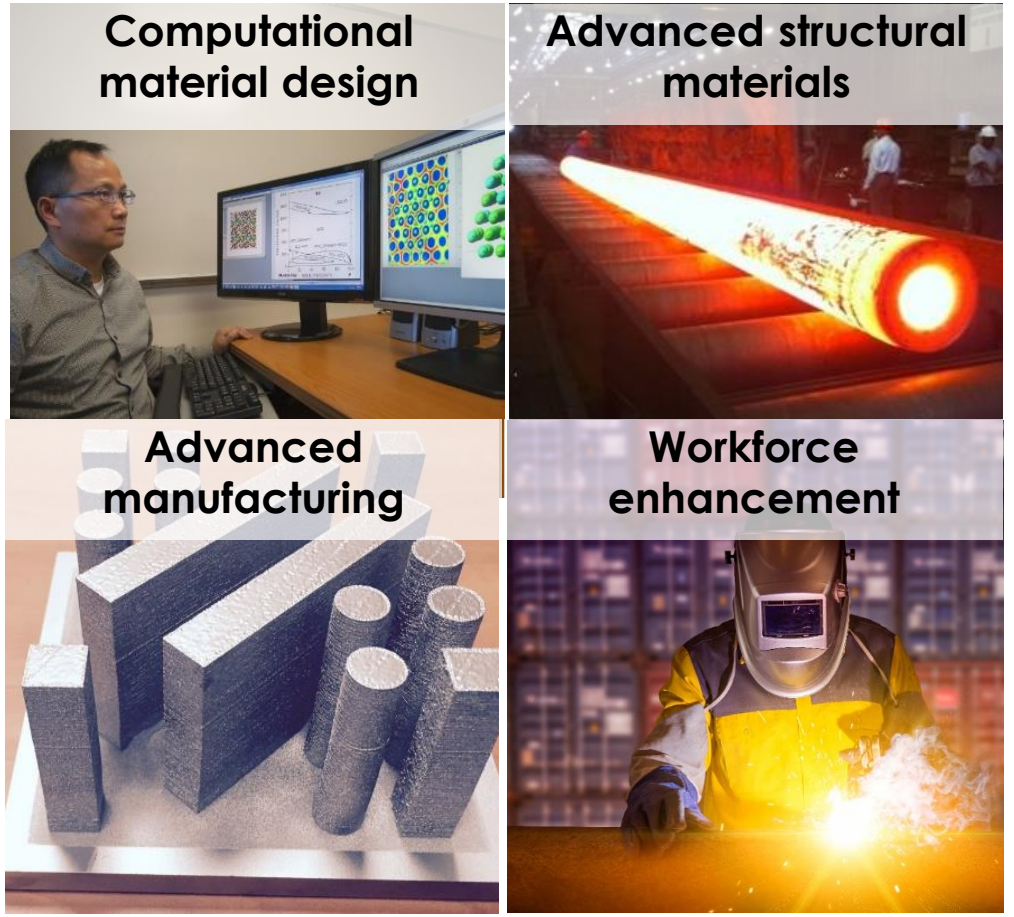
High-Hydrogen



Advanced Energy Materials Program

Goals:

- Evaluate impacts of hydrogen on materials using modeling tools.
- Develop Ceramic Matrix Composite (CMC) materials for greater turbine efficiency and H_2 firing.
- Improve the cost, reliability and performance of materials operating in harsh environments.

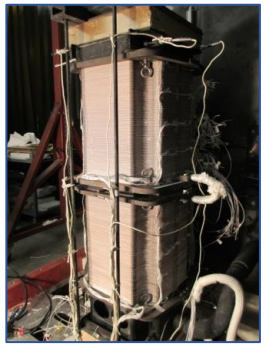


SOFC/SOEC Program

Enable:

- Highest efficiency and lowest cost electric power generation from hydrogen
- Dynamic operation of SOFCs/SOECs
- Flexible, modular, hybrid SOFC/SOEC system design

Cell and Stack Performance Improvements

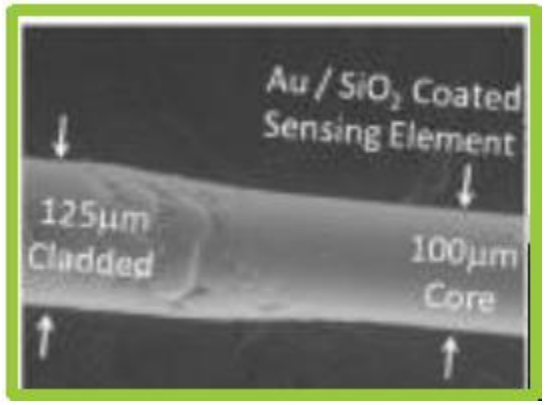


Proof-of-Concept Systems

(courtesy LG Fuel Cell Systems)

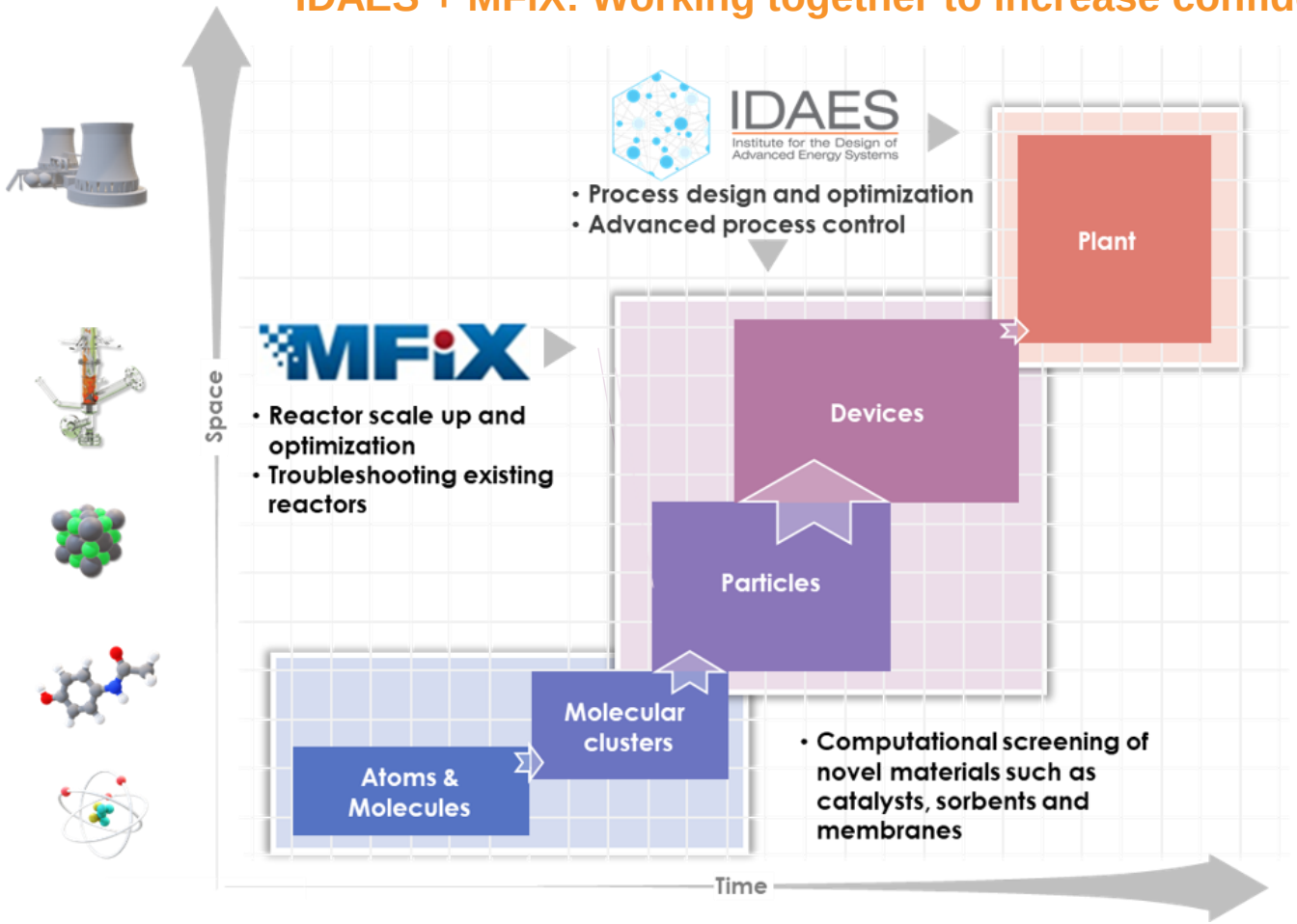
Sensors, Controls and Novel Concepts Program

- Advanced sensors for new hydrogen technologies
- Control and optimization strategies for new hybrid systems
- Novel sensing concepts



Simulation Based Computational Tools

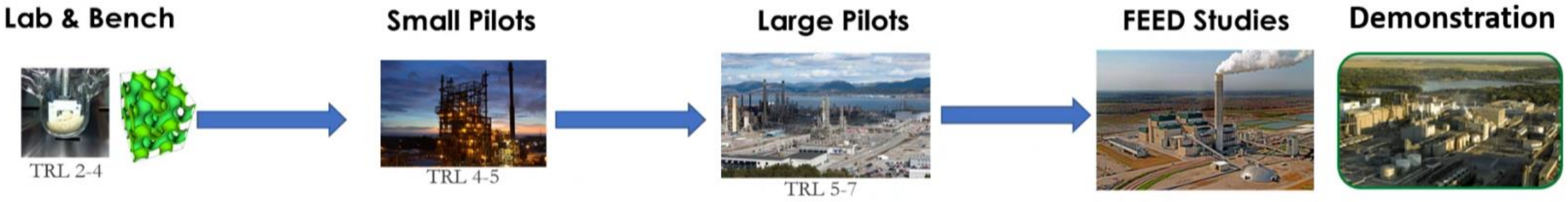
IDAES + MFiX: Working together to increase confidence systems modeling realism and fidelity



Computational Tools Working Together

- **IDAES** is a process systems engineering framework for the design and optimization of innovative steady state and dynamic processes
- **MFiX** is a suite of multiphase flow simulation software for designing and troubleshooting devices such as gasifiers and combustors

Carbon Capture Program



What we've learned in 20+ years:

- "First generation" (e.g. liquid solvent) systems work:
  - At commercial scale at some power plants and industrial facilities
  - With high efficiency (90+%) at moderate cost
  - With manageable non-CO2 pollution

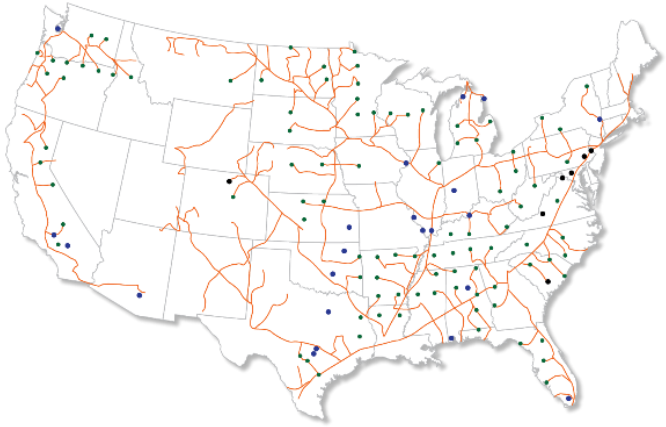
What we're learning now:

- Which "next generation" systems have the greatest potential
- How to increase capture efficiencies (>95%)
- How to enable low carbon supply chains (i.e., cement, steel, hydrogen, etc.)
- Co-Benefits Analysis..How to further reduce other pollutants
- How to accelerate deployment

Carbon Transport and Storage RD&D

CO_2 Transport

- FEED studies & pilots for large-scale transport networks
- Extensive inter-agency coordination
- Sensors for corrosion and metallurgy



Storage

- Site geological characterization
- Well integrity and mitigation
- Monitoring, verification, and accounting
- Storage complex efficiency and security

EarthShot Initiatives – Hydrogen & Others

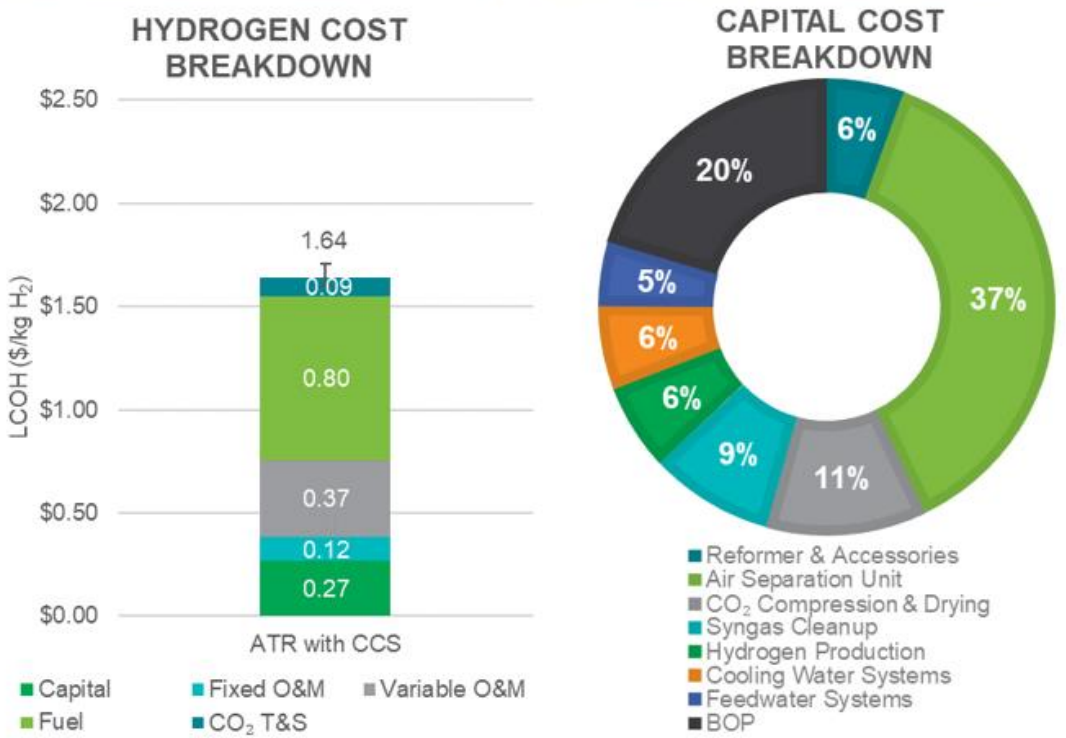
Gasification Analyses to Obtain the Shots:

- Conduct cost and performance models for gasification systems fed with biomass, MSW and waste plastics.
- Assess the potential of gasification technologies to achieve cost, performance, or operability improvements.
- Down select gasification systems for pilot-scale testing.

Hydrogen Shot | Clean Fuels and Products Shot | Carbon Negative Shot

Analyses on Hydrogen Production Routes

Breakdown of ATR with CCS baseline LCOH by cost component (left) and capital costs (right)



[Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies (doe.gov)]

[Strategies for Achieving the DOE Hydrogen Shot Goal: Thermal Conversion Approaches (Technical Report) | OSTI.GOV]

How FECM Efforts Fit In With Other DOE Offices

EERE

Feedstocks:
- Renewables and Water

Technologies:
- Electrolysis – Low- and High-Temperature
- Advanced Water Splitting – Solar/High-Temp Thermochemical, Photoelectrochemical
- Biological Approaches

FECM

Feedstocks:
- Fossil Fuels – Natural Gas and Solid Wastes

Technologies:
- Gasification, Reforming, Pyrolysis
- Carbon Capture & Storage
- Advanced Approaches – Co-firing and Modular Systems
- SOFCs/SOECs/rSOFCs

Nuclear Energy

Feedstocks:
- Nuclear Fuels and Water

Technologies:
- Electrolysis Systems for Nuclear
- Advanced Nuclear Reactors
- Systems Integration and Controls – LWRs and Advanced Reactors

Areas of Collaboration

Reversible Fuel Cells, Biomass, Municipal Solid Waste, Plastics, Polygeneration, High-Temperature Electrolysis, Systems Integration

Funding Opportunities

- None currently open/existing 😟 but soon to come! 😃
- Check here periodically: https://www.energy.gov/fecm/solicitations-and-business-opportunities

<u>Past FOAs, for reference</u>:

- FOA 2400: Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions → $100M+ awarded, 50 awards made, closed November 2023
- FOA 3016: University Turbine Systems Research, closed December 2023

To Find Funding Opportunities, Visit:

- Fedconnect.com
- Grants.gov
- SAM.gov

Filter/Search for DOE to find open solicitations!

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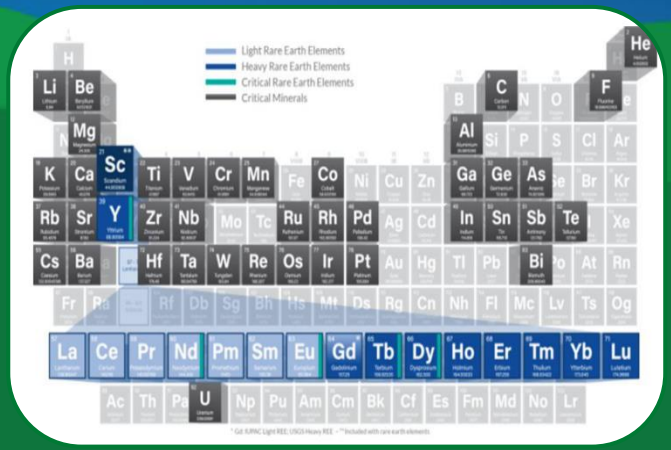
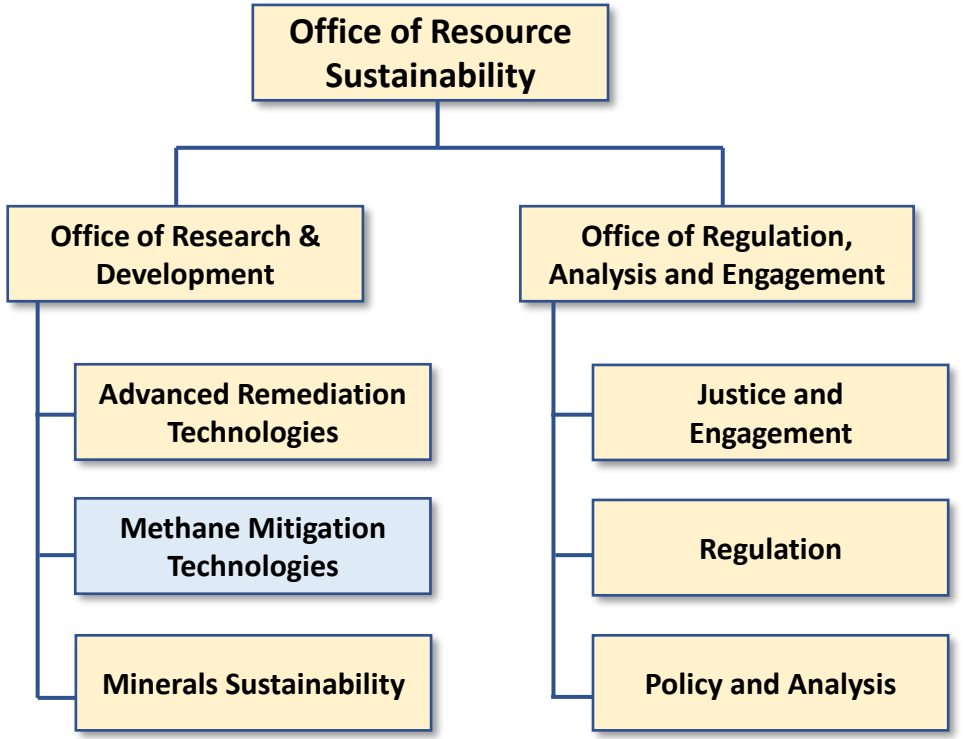
Fossil Energy and Carbon Management

Natural Gas Decarbonization and Hydrogen Technologies (NG-DHT) Program Overview



Office of Resource Sustainability

- Design and administer activities associated with technologies and approaches that will reduce the environmental impacts of our historical and continued dependence on coal, oil, and natural gas:
  - Reduce
  - environmental impacts and emissions associated with fossil energy development, use, transportation, and storage - produced water, abandoned mine remediation, methane mitigation, etc.
  - Improve the economics and reduce environmental impacts of critical minerals extraction, processing, use, and disposal.
  - Regulate the import and export of natural gas.
  - Conduct analysis of oil and natural gas markets
  - Assess policy and regulatory frameworks for potential exports of hydrogen and ammonia (hydrogen carrier), and oversight of carbon offset efforts.
- Accomplish these goals through policy, research, innovation, outreach, and stewardship.



Resource Technologies and Sustainability	FY2023 Enacted ($K)	FY2024 Enacted ($K)
Advanced Redimiation Technologies	$ 55,000	$ 53,000
Methane Mitigation Technologies	$ 60,000	$ 55,000
Natural Gas Decarbonization and Hydrogen Technologies	$ 26,000	$ 23,000
Mineral Sustainability	$ 54,000	$ 70,000
Resource Sustainability - Analysis and Engagement	$ -	$ -
	$ 195,000	$ 201,000

Division of Methane Mitigation Technologies

Methane Emissions Mitigation

Advanced materials, data management tools, inspection and repair technologies, and dynamic compressor R&D for eliminating fugitive methane emissions across the natural gas value chain

Methane Emissions Quantification

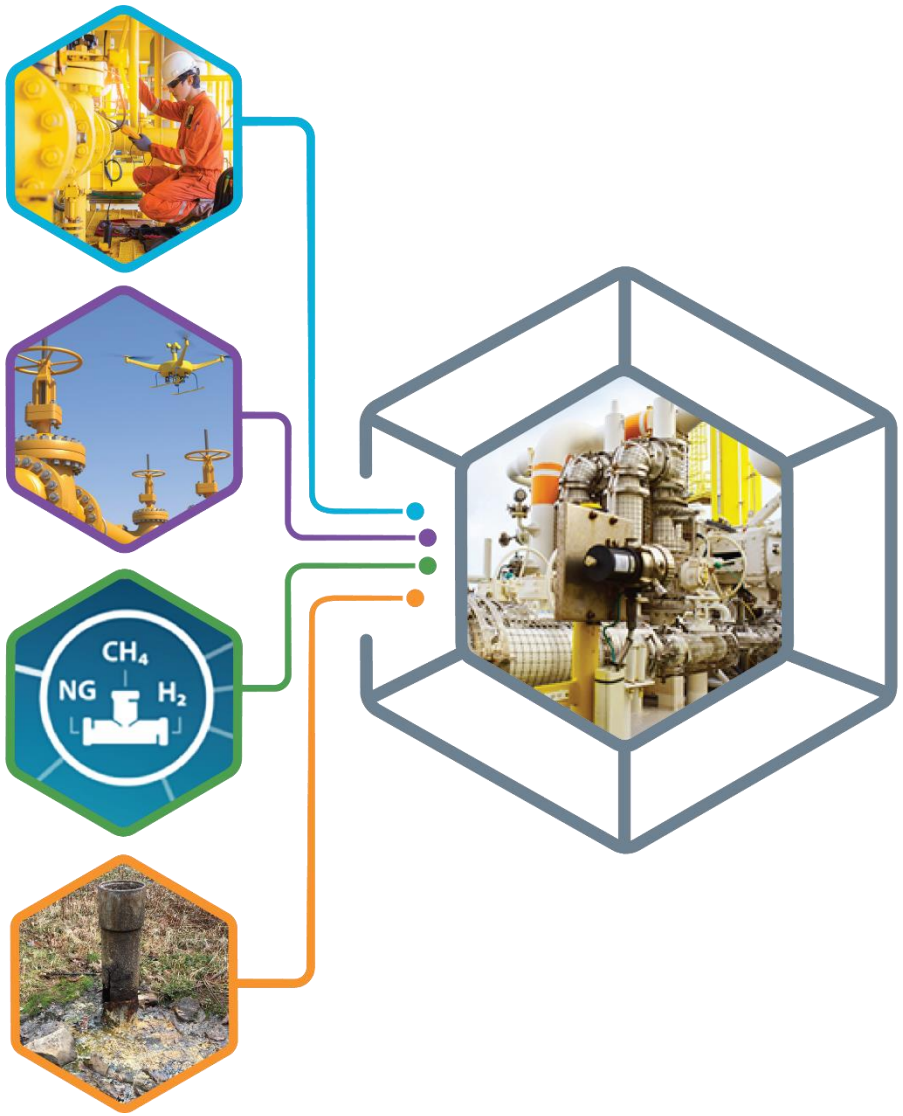
Direct and remote measurement sensor technologies and collection of data, research, and analytics that quantify methane emissions from point sources along the upstream and midstream portion of the natural gas value chain

Natural Gas Decarbonization and Hydrogen Technologies

Technologies for clean hydrogen production, safe and efficient distribution, and geologic storage technologies supported by analytical tools and models

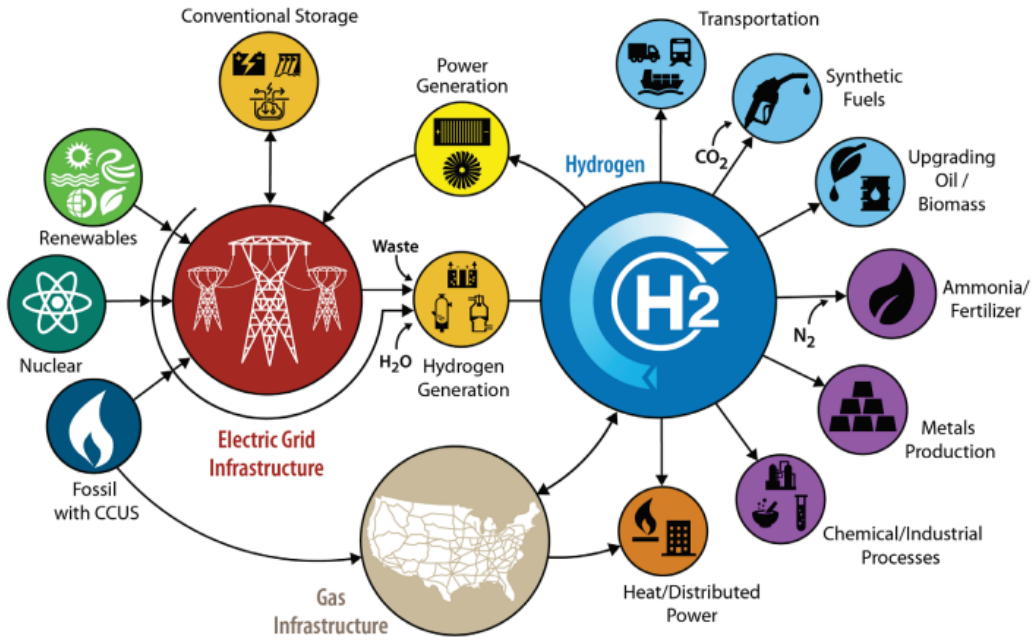
Undocumented Orphaned Wells Research

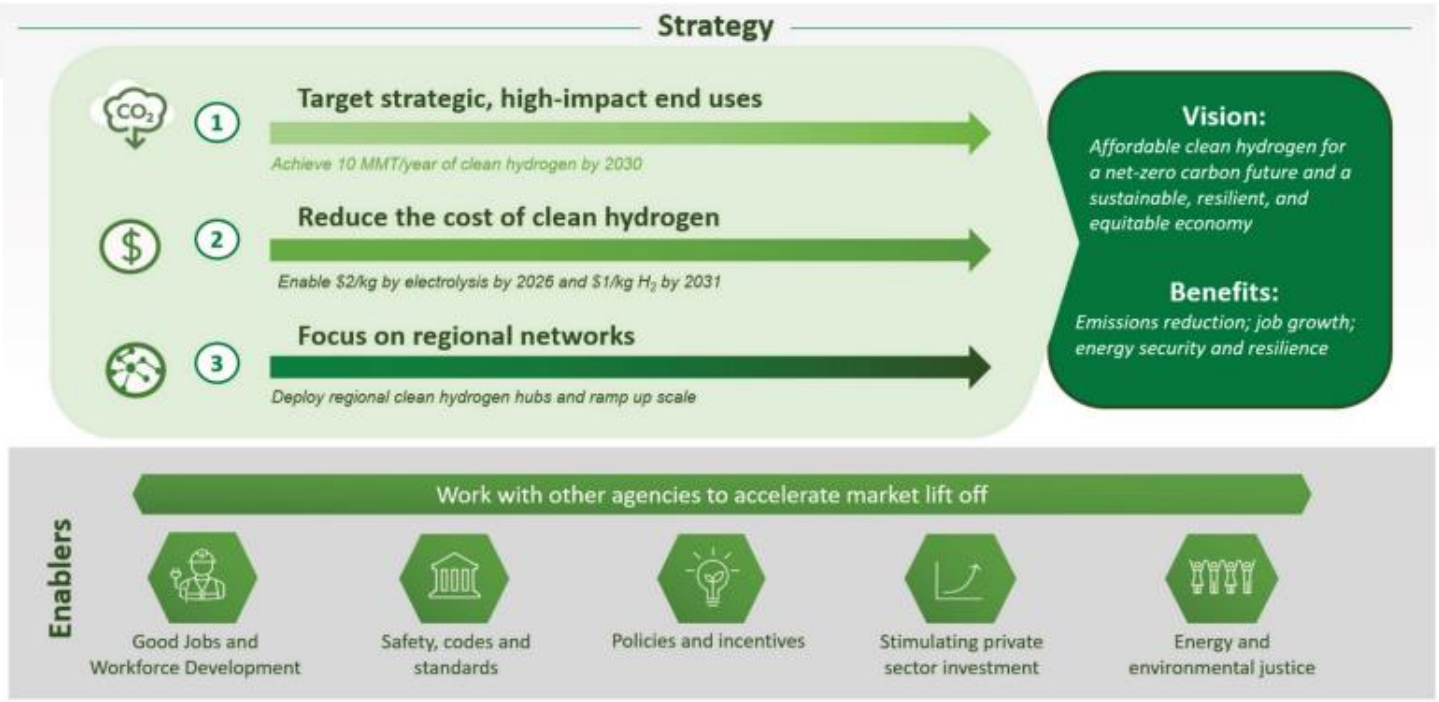
Developing tools, technologies, and processes to efficiently identify and characterize undocumented orphaned wells in order to prioritize them for plugging and abandonment.



Natural Gas Decarbonization and Hydrogen Technologies

Source: H2@Scale





Source: U.S. Clean Hydrogen Strategy and Roadmap

Hydrogen Shot™

Accelerate innovation and spur demand of clean hydrogen by reducing the cost by 80%, to $1 per 1 kilogram of clean hydrogen within 1 decade.

Long Duration Storage Shot™

Achieve affordable grid storage for clean power—anytime, anywhere—by reducing the cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within the decade.

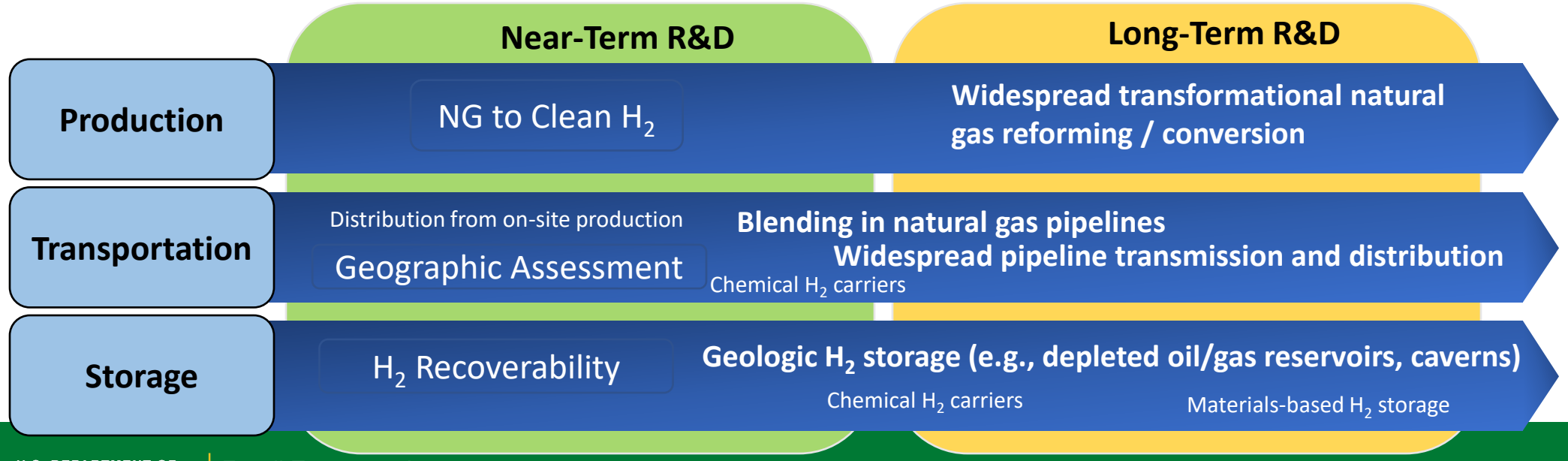
Clean Fuels & Products Shot™

Decarbonize the fuel and chemical industry through alternative sources of carbon to advance cost-effective technologies.

Source: Energy Earthshots Initiatives

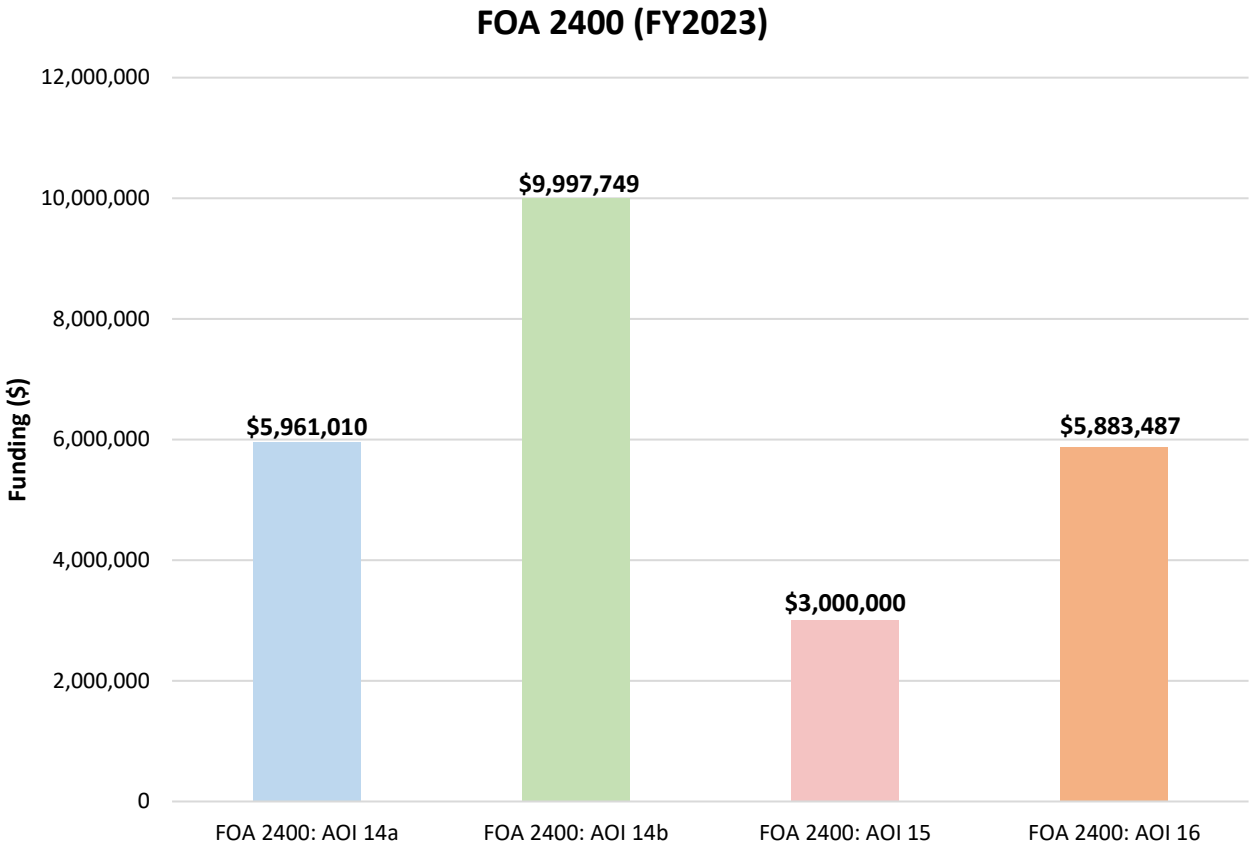
Natural Gas Decarbonization and Hydrogen Technologies

- The **Natural Gas Decarbonization and Hydrogen Technologies** (**NG-DHT**) Program was formally initiated in 2022 Omnibus.
- The NG-DHT Program coordinates with other DOE offices to support the transition towards a clean hydrogen-enabled economy through the decarbonization of natural gas conversion, transportation, and storage.
  - Supports transformational concepts for clean hydrogen production from domestic natural gas resources, with emphasis on decarbonization opportunities and value tradeoffs within energy markets.
  - Works to ensure the suitability of existing natural gas pipelines and infrastructure for hydrogen distribution, while emphasizing technology opportunities to detect and mitigate emissions.
  - Identifies underground storage infrastructure to handle high-volume fractions of hydrogen, while seeking demonstration opportunities for novel bulk storage mechanisms.



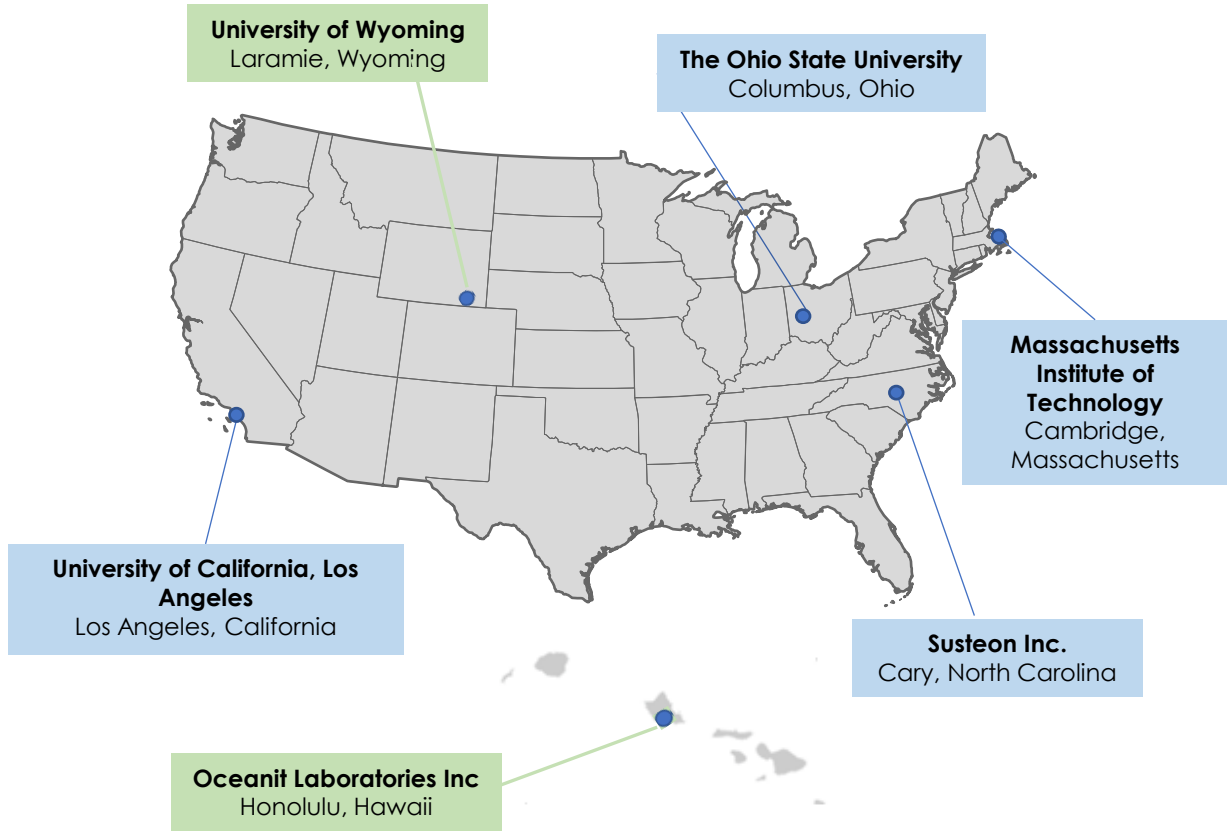
FOA2400 - Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions

FOA 2400 Clean Hydrogen Production, Storage, Transport and Utilization to Enable a Net-Zero Carbon Economy	Area of Interest 14a: Methane Pyrolysis/Decomposition, In situ Conversion, or Cyclical Chemical Looping Reforming
	Area of Interest 14b: Hydrogen Production from Produced Water
	Area of Interest 15: Technologies for Enabling the Safe and Efficient Transportation of Hydrogen Within the U.S. Natural Gas Pipeline System
	Area of Interest 16: Fundamental Research to Enable High Volume, Long-term Subsurface Hydrogen Storage



Hydrogen Production Projects

Performer	Project Title	DOE Share	Non-DOE Share	Total Cost
Ohio State University	Bench-scale Testing and Development of Fixed Bed Chemical Looping Reactor for Hydrogen Generation from Natural Gas with CO2 Capture	$1,499,238	$375,000	$1,874,238
Massachusetts Institute of Technology	Lower Cost, CO2 Free, H2 Production via CH4 Pyrolysis in Molten Tin	$1,500,000	$ 375,048	$1,875,048
Susteon Inc.	Thermo-Catalytic Co-Production of Hydrogen and High-Value Carbon Products from Natural Gas using Structured Materials	$1,500,000	$ 375,000	$ 1,875,000
University of California, Los Angeles	Direct Solar Self-Catalyzing Pyrolysis of Natural Gas to Hydrogen and High-Quality Graphite	$1,461,772	$ 377,848	$1,839,620
University of Wyoming	Integration of Produced Water Thermal Desalination and Steam Methane Reforming for Efficient Hydrogen Production	$4,997,749	$4,999,387	$ 9,997,136
Oceanit Laboratories Inc	HALO: Hydrogen-Recovery Using an AI-Arc-Plasma Learning Operational System for Produced Water	$ 5,000,000	$5,000,000	$10,000,000
		$15,958,759	**$11,502,283**	**$27,461,042**



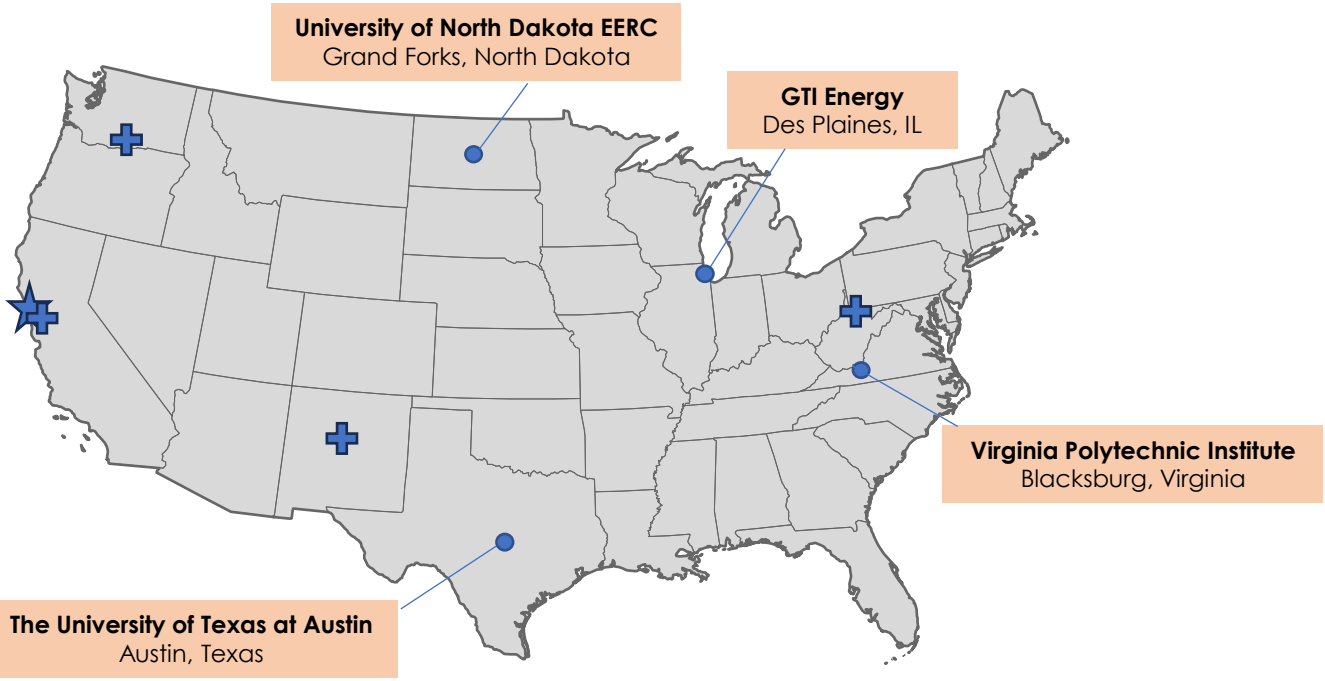
Hydrogen Transportation Projects

Performer	Project Title	DOE Share	Non-DOE Share	Total Cost
Colorado School of Mines	Assessment of Toughness in H-Containing Blended Gas Environments in High Strength Pipeline Steels	$1,499,238	$375,000	$1,874,238
Southwest Research Institute	Technologies for Enabling The Safe and Efficient Transportation of Hydrogen within the U.S. Natural Gas Pipeline System	$1,500,000	$ 375,048	$1,875,048
		$15,958,759	$11,502,283	$27,461,042

Hydrogen Storage Projects

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Performer	Project Title	DOE Share	Non-DOE Share	Total Cost
GTI Energy	Developing & Investigating Subsurface Storage Potential And Technical Challenges for Hydrogen (DISSPATCH H2)	$1,400,000	$350,000	$1,750,000
University of North Dakota EERC	Williston Basin Resource Study for Commercial-Scale Subsurface Hydrogen Storage	$1,500,000	$375,000	$1,875,000
The University of Texas at Austin	Hydrogen Storage in Salt Caverns in the Permian Basin: Seal Integrity Evaluation and Field Test	$1,483,488	$370,873	$1,854,361
Virginia Polytechnic Institute	Assessment of Subsurface Hydrogen Storage in Depleted Gas Fields of Appalachia	$1,500,000	$375,000	$2,250,000
		$5,883,488	$1,470,873	$7,729,361



★ Lawrence Berkeley National Laboratory - New Geophysical Tools for Monitoring Geologic Hydrogen Storage

SHASTA Project Objective and Goals

Identify and **address key technological hurdles** and **develop tools and technologies** to enable broad public acceptance for **subsurface storage** of pure hydrogen and hydrogen/natural gas mixtures

Project Goals:

- ✓ Quantify operational risks
- ✓ Quantify potential for resource losses
- ✓ Develop enabling tools, technologies, and guidance documents
- ✓ Develop a collaborative field-scale test plan in partnership with relevant stakeholders

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

NATIONAL ENERGY TECHNOLOGY LABORATORY

Expertise across subsurface capabilities designed to enable high pressure, high temperature reactor studies that simulate wellbore and subsurface reactions and diffusivity and wettability and interfacial tension, assess the geochemistry and microbiology of reservoir types targeted for H2/CH4 storage, and develop optical fiber sensors capable of measuring H2, CH4, and pH.

Lawrence Livermore National Laboratory

Expertise in geochemical interactions in batch and flowing systems, as well as in the application of high-performance reservoir simulation and geomechanical modeling capabilities.

Pacific Northwest NATIONAL LABORATORY

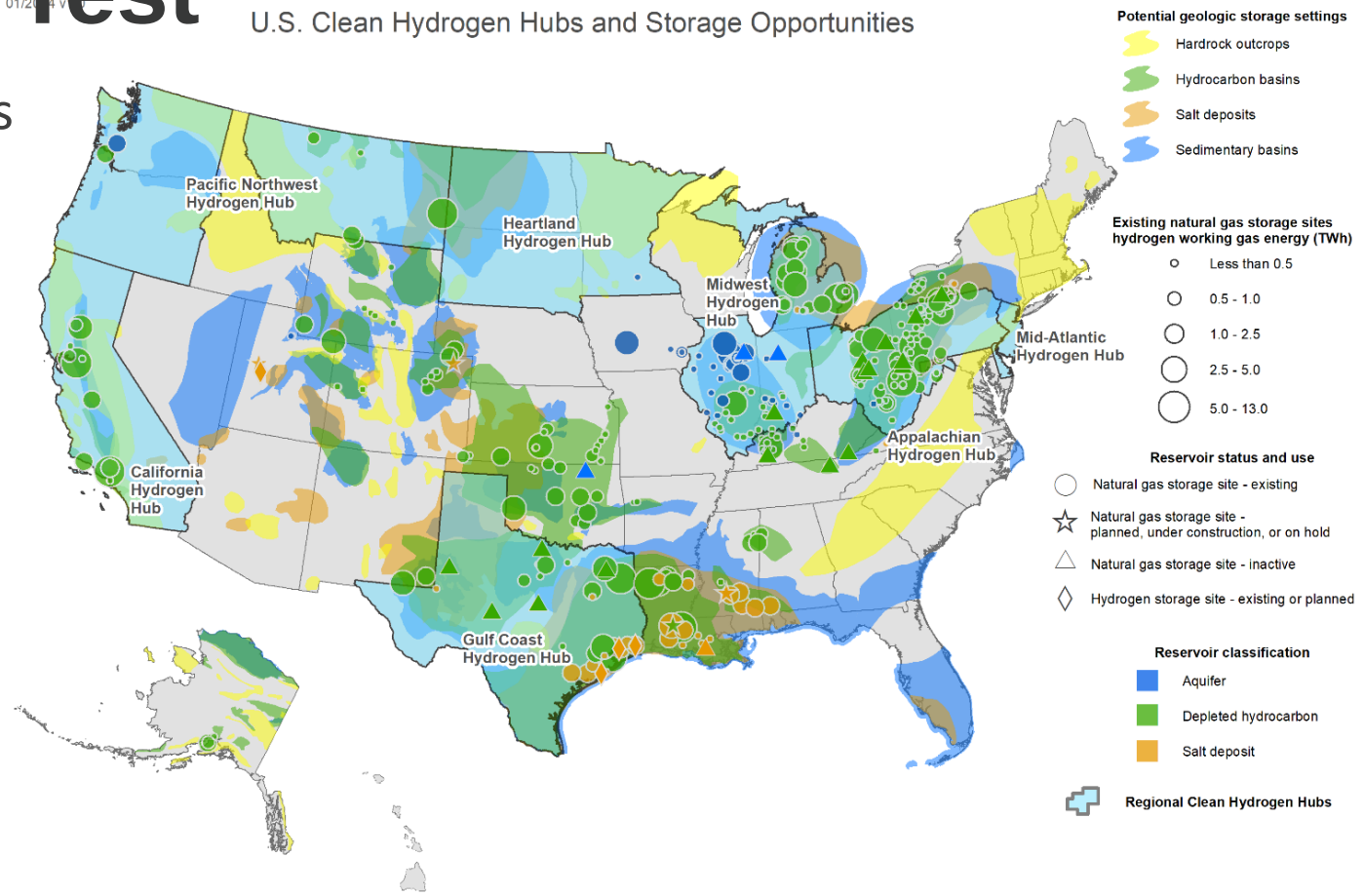
Expertise across the lab related to subsurface flow and transport, biogeochemistry, and technoeconomic analysis.

Sandia National Laboratories

Expertise in applied subsurface geology, permeability testing, geomechanical rock properties testing and imaging, geochemical hydrogen-induced reaction analysis, microbiological testing, hydrogen effects on materials research and multiphaseflow and reactive transport modeling.

Forward Look & Field Test

- SHASTA's ultimate goal is to enable field tests
- Continue to build relationships with industry
- Looking for site owners who may be interested in pilot-scale studies
- Subsurface Hydrogen Assessment, Storage, and Technology Acceleration Workshop, Pittsburgh, PA
  - Connect with complimentary efforts
    - Intra/Inter-Agency R&D
      - FOA-2400 projects
      - HFTO projects
      - H_2 Hubs
      - Partner Government Agencies
    - International R&D
    - Industry & regulatory perspective
  - Discuss next steps/needs in UHS for research, industry, and regulators



Hydrogen working gas energy of active natural gas storage sites from Lackey et al., 2023
Locations of existing natural gas storage sites (source: PHMSA)
Locations of inactive natural gas storage sites (source: EIA, HIFLD)
Generalized locations and capacities of existing Hydrogen storage locations are extracted from web resources
Generalized locations of natural gas storage sites in development represent that of the hosting county (source: EIA, FERC)
Clean Hydrogen Hubs represent the participating states in each Clean Hydrogen Hub announced by OCED.
Potential geologic storage settings from Lord et al., 2014 with additional contributions from Barry Roberts and Nora Wynn (SAND2023-04266R)

SHASTA

NETL Research Innovation Center

- **Enabling the Hydrogen Value Chain Using Natural Gas Resources and Infrastructure**
  1) Transformative production of clean hydrogen from natural gas.
  2) Leveraging the existing natural gas pipeline infrastructure as a cost-effective near-term solution to enable decarbonization through hydrogen and blended gas transport.
  3) Modeling and producing sustainable chemicals and fuels, such as ammonia, from natural gas resources.
- **Production of H2 and Valuable Carbons with Novel NETL Pyrolysis Catalyst**
  - Develop a thermo-catalytic H_2 production process that is more economical than steam methane reforming by producing a valuable carbon co-product with no CO_2 emissions.
  - Understand current and potential global markets for different types of carbon products.
- **Methane Pyrolysis**
  - To provide a techno-economic analysis and life cycle assessment of different pyrolysis technologies for industrial clean hydrogen production.
  - The project evaluates natural gas pyrolysis technologies including catalytic and plasma, and it identifies system-level challenges that affect cost and emissions to inform R&D priorities. Key study metrics include the levelized cost of hydrogen ($/kg H_2) and global warming potential (kg CO_2e/kg H_2).

NETL Research Innovation Center

- **Fossil-Based Ammonia Production**
  - To provide baseline cost and performance estimates for current, industrial, fossil-based ammonia production technologies, including a determination of lifecycle greenhouse gas emissions.
  - The project focuses on ammonia produced from natural gas resources and informs decision makers of priority research areas. A key study metric includes the levelized cost of ammonia ($/kg NH_3).
- **H_2 and NG with H_2 Pipeline Transport Cost Models**
  - The H2_P_COM and NG-H2_P_COM models estimate the costs of building new pure hydrogen pipelines or reusing existing natural gas pipelines for transporting natural gas-hydrogen blends to facilitate the addition of hydrogen to the energy economy.
- **Real-time Sensor Technologies for H_2 Subsurface Storage and Transportation Monitoring**
  - Enabling large-scale H_2 storage and transportation.
  - Early detection of hydrogen leaks to ensure safety and reliability.
  - Wellbore and pipeline integrity monitoring to prevent catastrophic failures.

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Questions?