U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Hydrogen Production and Infrastructure R&D Opportunities and Challenges

Mark Richards – Technology Manager, Hydrogen and Fuel Cell Technologies Office

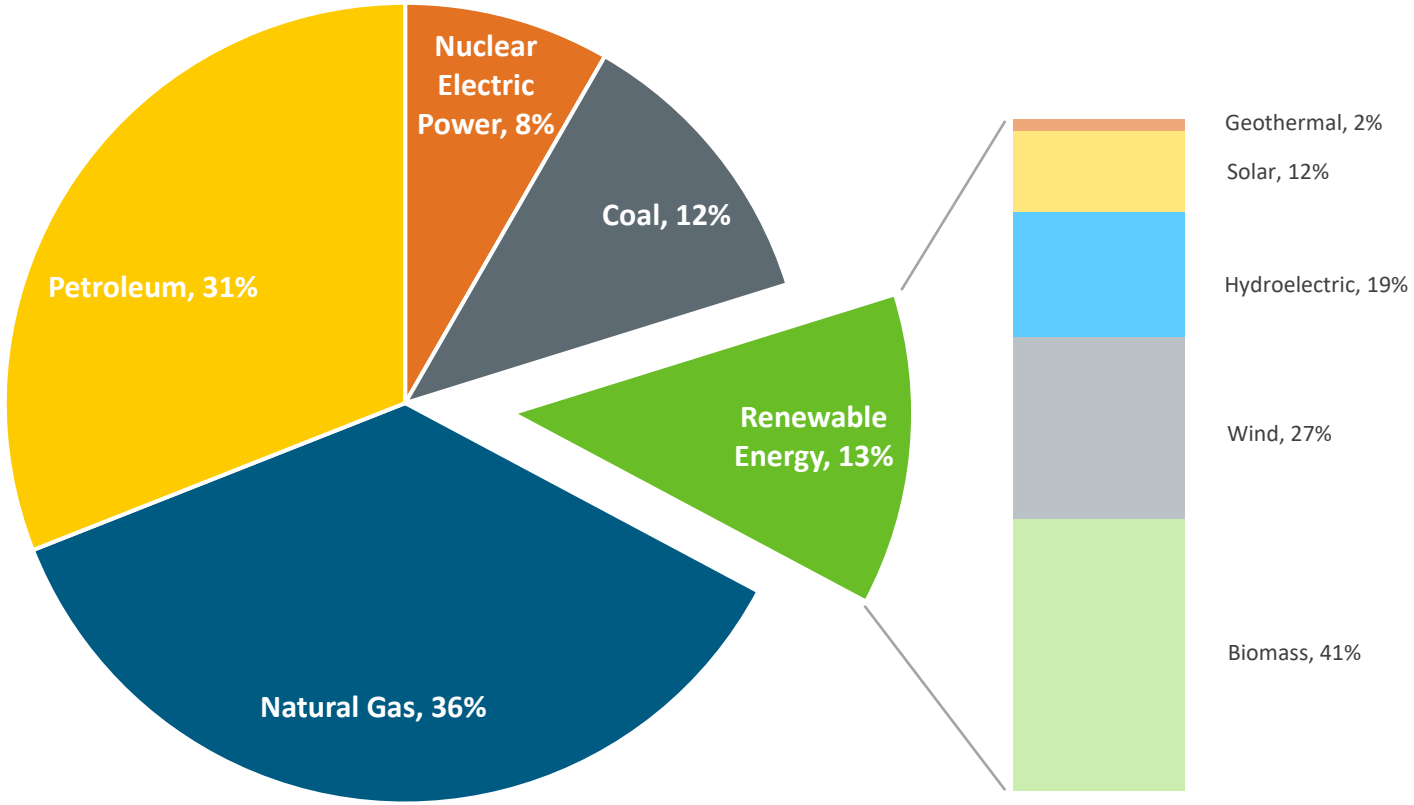
PHMSA Public Meeting 2022

14 December 2022

U.S. Energy Landscape and Key Goals

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

Total = 97.8 quadrillion British thermal units (Btu)



Total = 12.3 quadrillion 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:

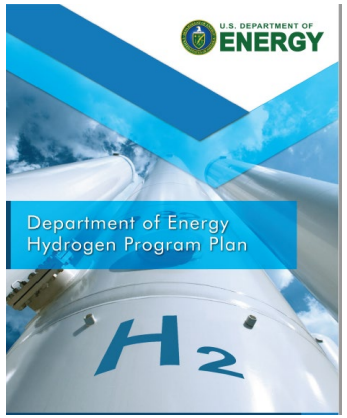
- Net-zero emissions economy by 2050 and 50–52% reduction by 2030
- 100% carbon-pollution-free electric sector by 2035

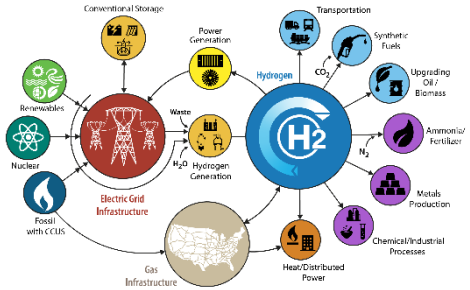
Priorities: Ensure benefits to all Americans, focus on jobs, EJ40: 40% of benefits in disadvantaged communities

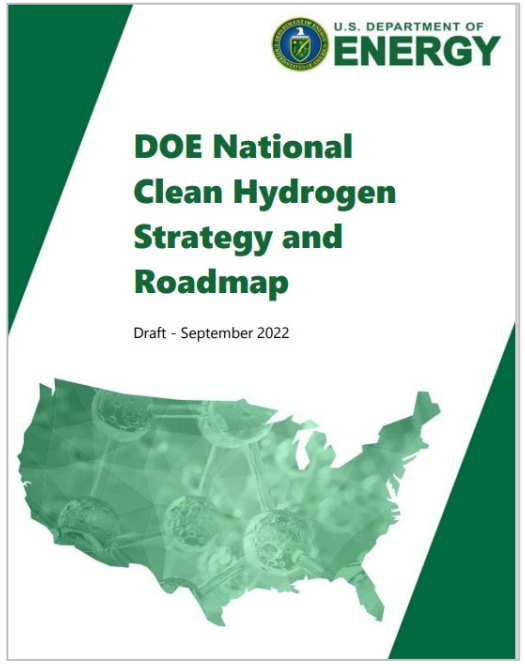
EJ: Environmental Justice

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

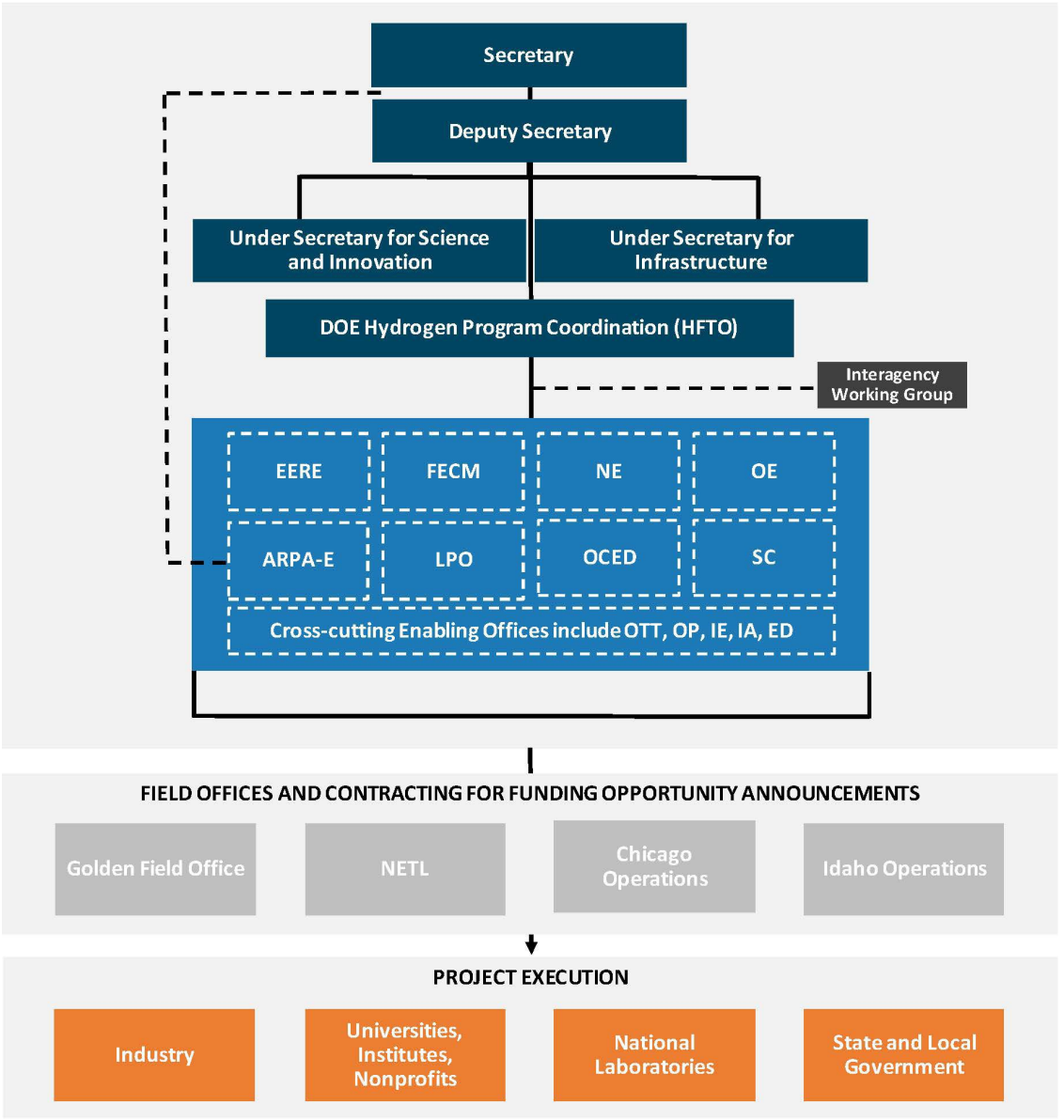




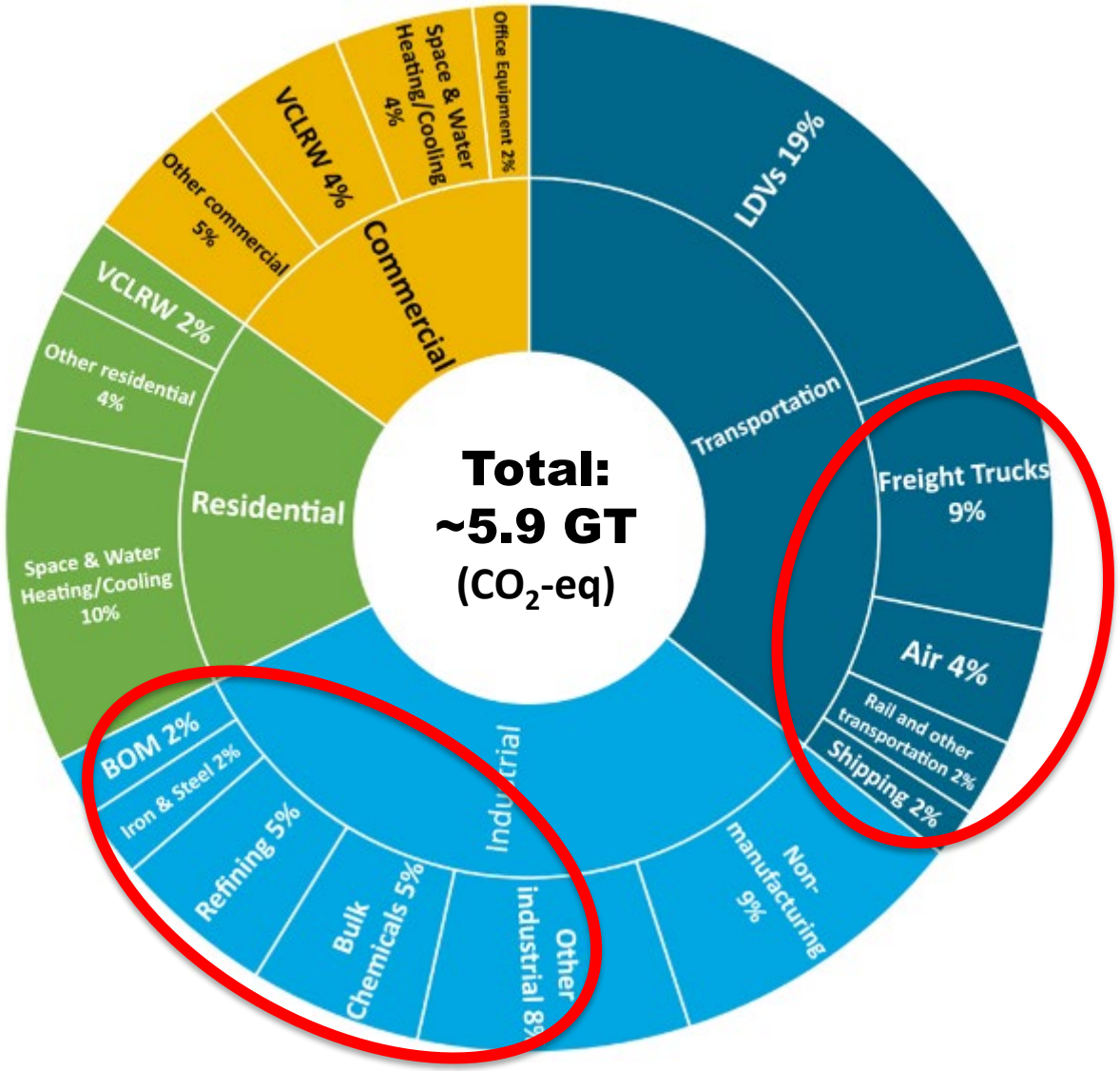


www.hydrogen.energy.gov

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



U.S. Energy Related CO_2 Emissions by Sector End Use



Hydrogen can provide benefits particularly in hard to decarbonize sectors: industry, heavy duty transport, and to enable energy storage

VCLRW - Ventilation, Cooking, Lighting, Refrigeration & Washing
BOM - Balance of Manufacturing

Other industrial: aluminum, cement and lime, construction, agriculture, plastics, wood, electrical equipment, transportation equipment, computing and electronics equipment, paper products, glass ,etc.

Note: Sum of sectors may not equal 100% due to independent rounding
Source: M. Koleva, DOE HFTO, NREL, adapted from EIA, 2020, U.S. Energy Information Administration - EIA - Independent Statistics and Analysis

Key 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**

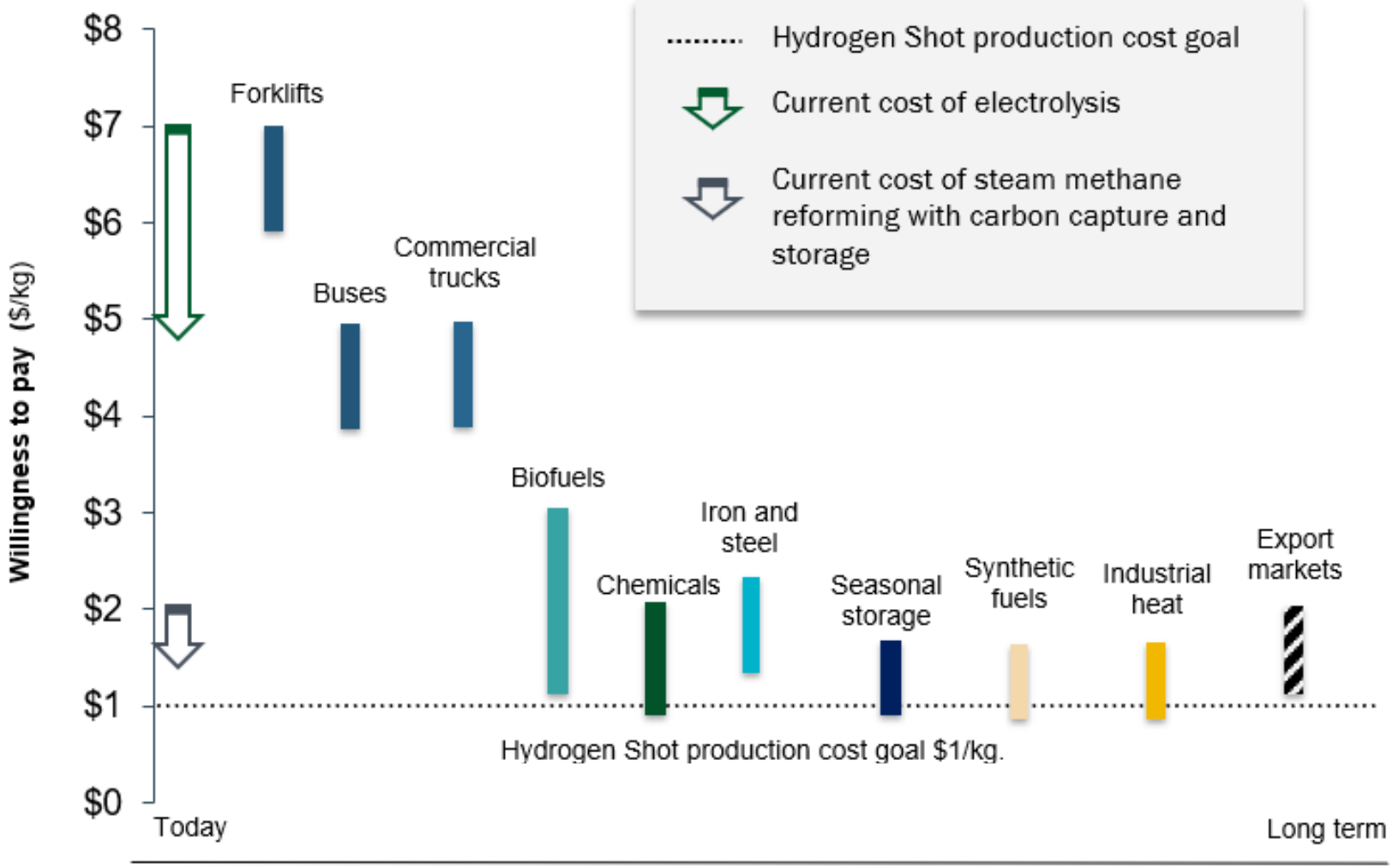
President Biden Signs the **Bipartisan Infrastructure Bill** on November 15, 2021. Photo Credit: Kenny Holston/Getty Images

Inflation Reduction Act

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

Threshold Costs for Hydrogen to be Competitive Across Sectors

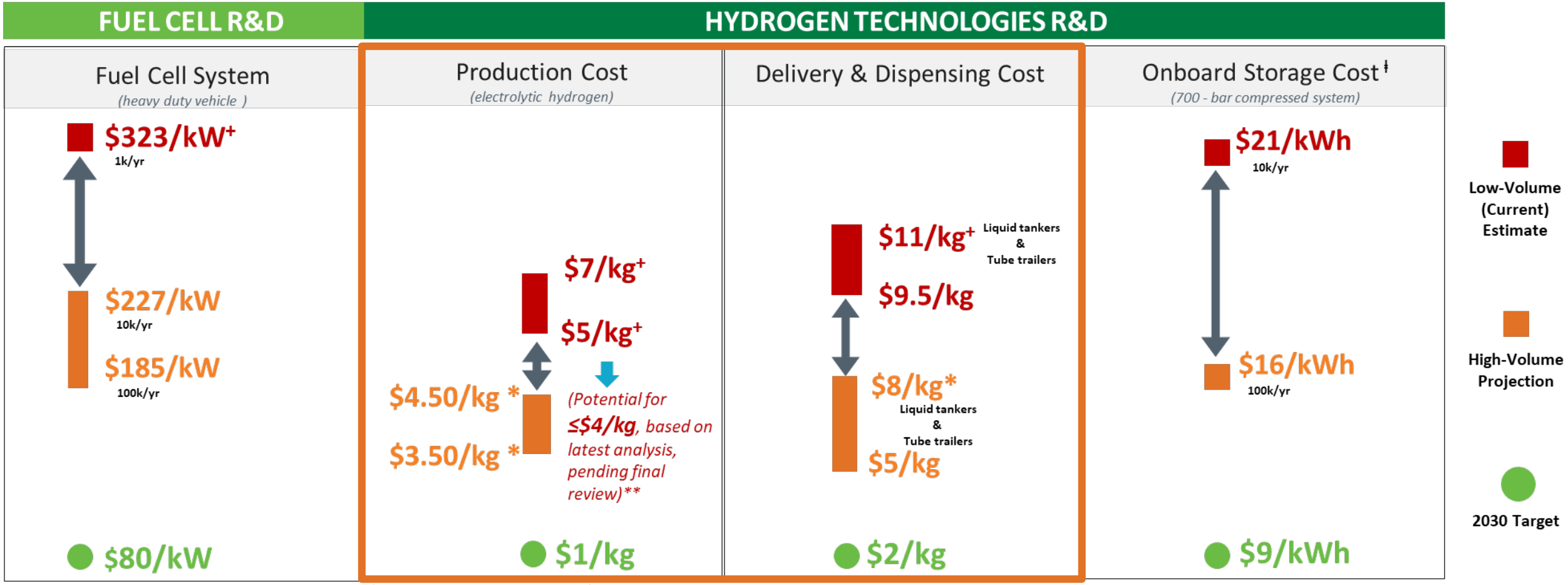
Some applications can start to be competitive at a higher threshold cost and can jumpstart the market



Threshold cost for each application includes cost of production, delivery, storage, compression/processing/dispensing, as required, to the point of use for each application

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

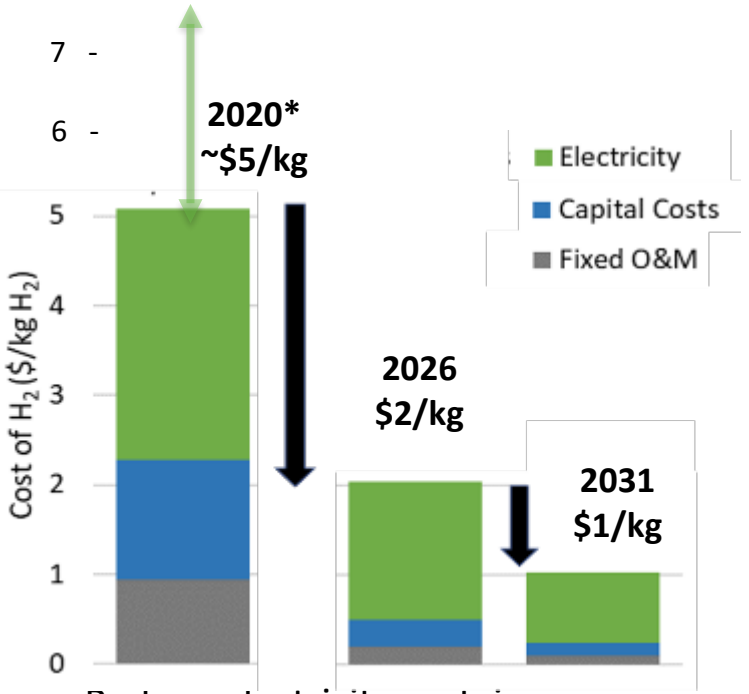
All costs based on $2016

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

Hydrogen Production Pathways

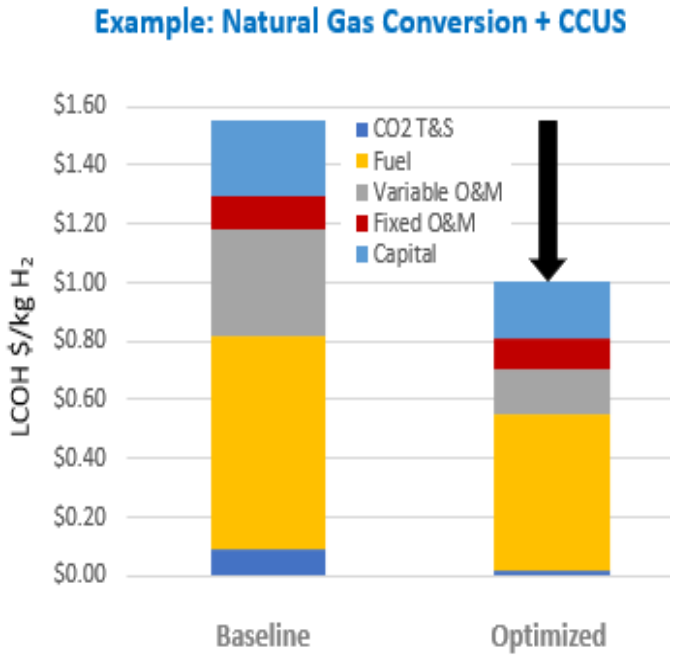
Strategies and scenarios being developed to reduce cost and emissions across pathways

H_2 from Electrolysis



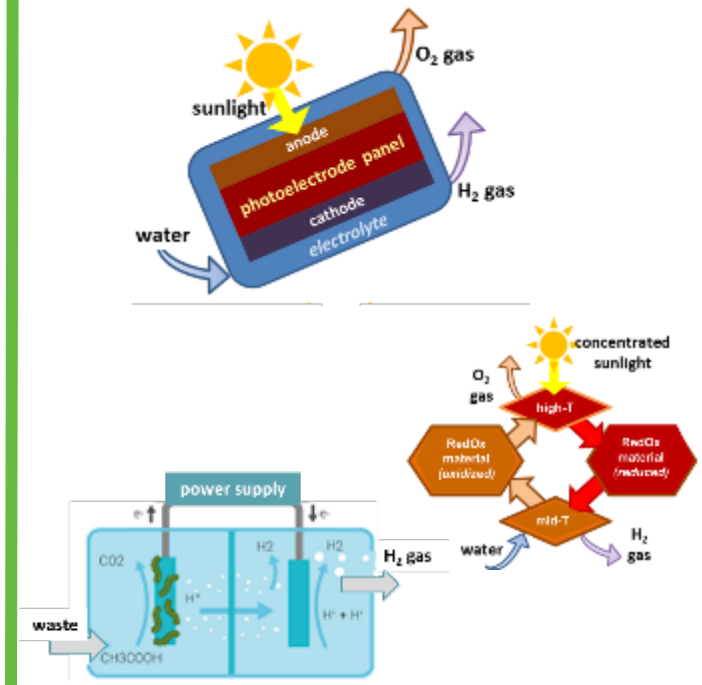
- Reduce electricity cost, improve efficiency and utilization
- Reduce capital cost >80%, operating & maintenance cost >90%

Thermal Conversion



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

Advanced Pathways



- Photelectrochemical (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

Cross-cutting Materials Compatibility R&D

H-Mat℠ Hydrogen Materials Compatibility Consortium

H-Mat Consortium conducts cross-cutting R&D on hydrogen effects on polymers and metals

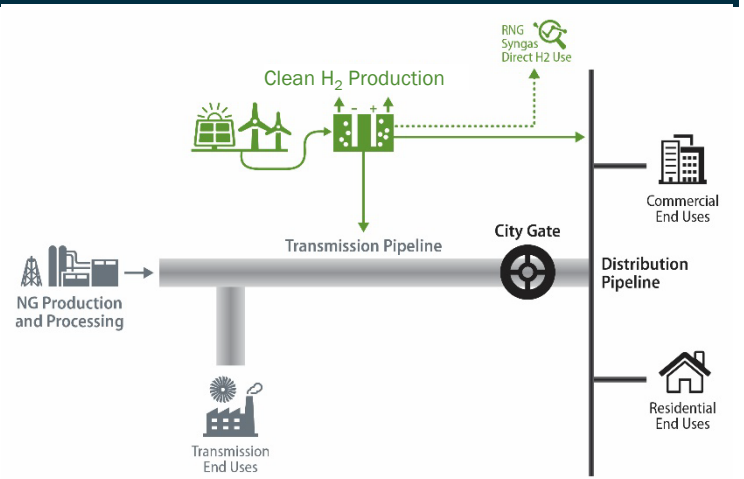
- **Collaborations**
  - Pre-competitive data sharing through databases at https://h-mat.org
  - MOU with Kyushu University signed in 2022
- **Focuses of current activities include**
  - Assess performance of pipeline materials in blends
  - Generate “master curves” to inform pipeline codes and standards and accelerate adoption of new materials
  - Reduce expansion of seals in hydrogen by 50%
  - Enhance life of vessels by 50% through improved understanding of crack nucleation
  - Enhance fracture toughness of high-strength (>950 MPa) steels by 50%
  - Develop and validate NDE technologies for pressure vessels

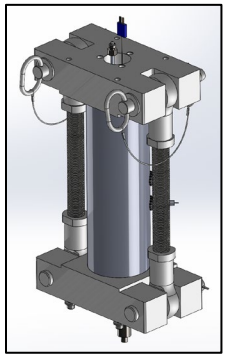
Sandia National Laboratories · Pacific Northwest National Laboratory · Oak Ridge National Laboratory · Savannah River National Laboratory · Argonne National Laboratory

HyBlend™ Initiative: Hydrogen Blending into Natural Gas Pipelines

Initial Project: Pipeline Blending CRADA – ~30 Industry Partners, 6 National Labs

- **Goals**
  - Test materials in varying blends
  - Develop public model of pipeline integrity to inform operating conditions
  - Technoeconomic and life cycle analysis relative to renewable natural gas
- **Recent Activity**
  - Completed technical report summarizing ASME and NFPA codes and standards relevant to blending[1]
  - Developing master curves to characterize life of pipeline materials and mitigate future test requirements prior to deployment
  - Testing of metallic and polymer vintage and modern materials in gaseous hydrogen
  - Testing planned for over 10 different pipeline and weld materials in up to 200 bar
  - Test loop under development to validate material behavior in a piping configuration (engineered defects in pipe at the laboratory scale, up to 50mm OD)
  - Completed literature review describing components of natural gas pipeline system
- **Continuation of Pipeline Blending CRADA under discussion**





High-pressure test loop rendering

1. Available at Hydrogen Safety, Codes, and Standards : Sandia Energy

Safety, Codes, and Standards Goals & Approaches

Codes & Standards

- **Goal**: Support and facilitate development of **essential codes and standards** to **enable widespread deployment** of hydrogen and fuel cell technologies and completion of essential regulations, codes and standards
- **Approach**: Conduct **R&D to provide scientific basis** needed to define requirements in developing codes and standards

Safety

- **Goal**: Support **best safety practices** for hydrogen and fuel cell deployments and ensure their use in DOE-funded projects
- **Approach**: Develop and enable **widespread sharing** of **safety-related information resources** and lessons learned with key stakeholders

Thank You

Save the Date!

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

Mark Richards

Technology Manager

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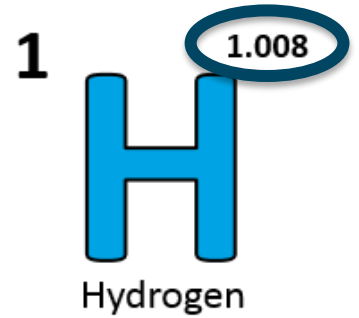
U.S. Department of Energy

Hydrogen and Fuel Cells Day
October 8

Held on hydrogen's very own atomic weight-day



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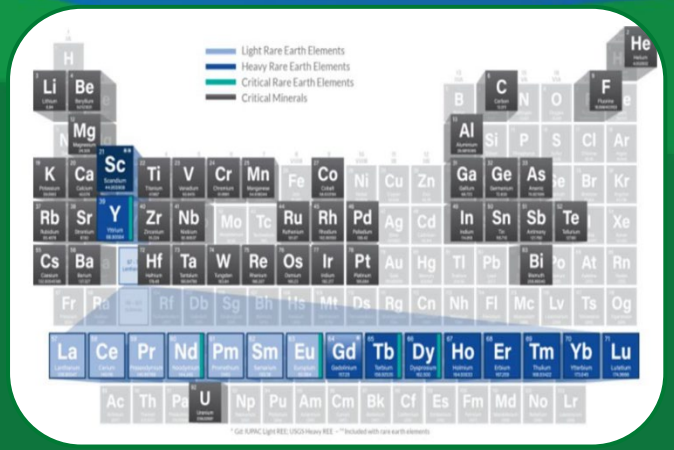
U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

Natural Gas Decarbonization and Hydrogen Technologies Program Overview

Evan Frye, Program Manager
Division of Methane Mitigation Technologies
Office of Resource Sustainability

December 14, 2022



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

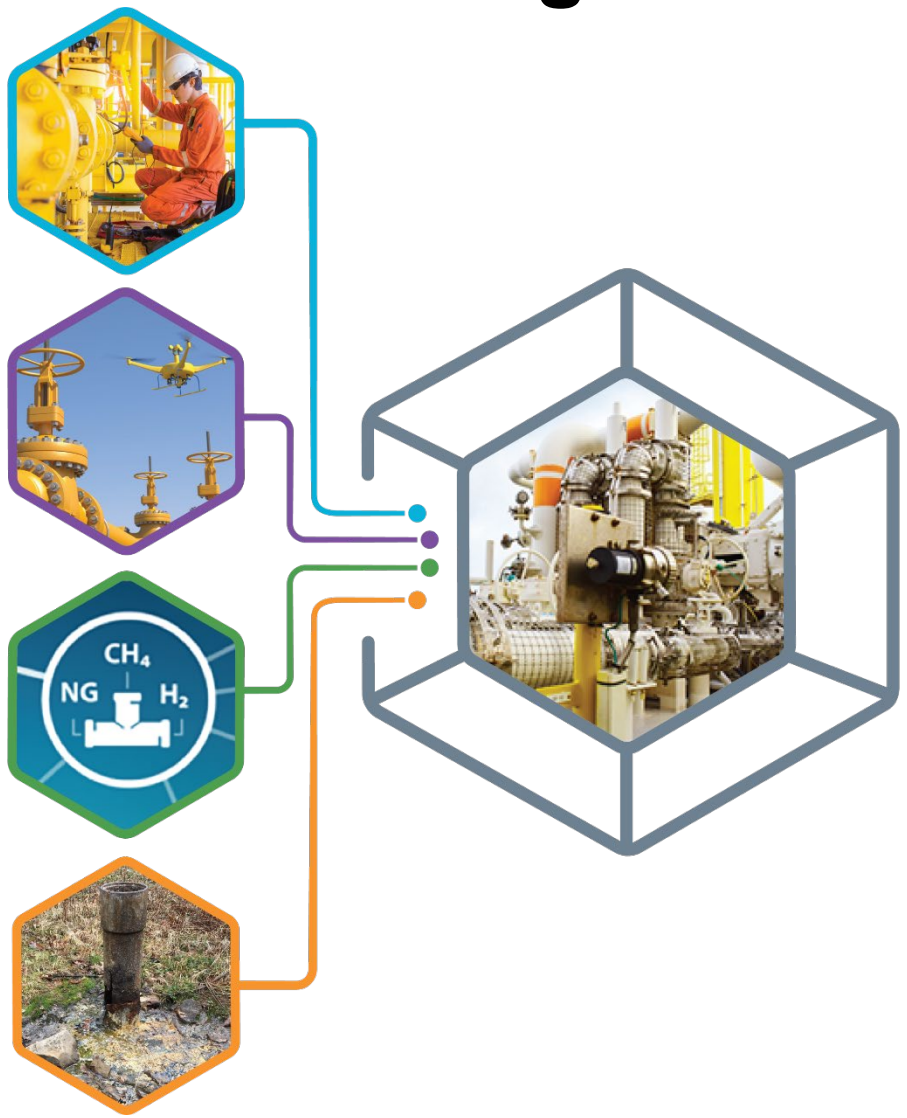
Direct and remote measurement sensor technologies and collection of data, research, and analytics that quantify methane emissions from point sources along the upstream and midstream portion of the natural gas value chain.

Natural Gas Decarbonization and Hydrogen Technologies (NGDHT)

Decarbonization of natural gas supply chain to support a clean hydrogen-enabled economy. Technologies for carbon-neutral hydrogen production, large-scale, safe and efficient transport, and geologic storage technologies supported by analytical tools and models.

Undocumented Orphaned Wells

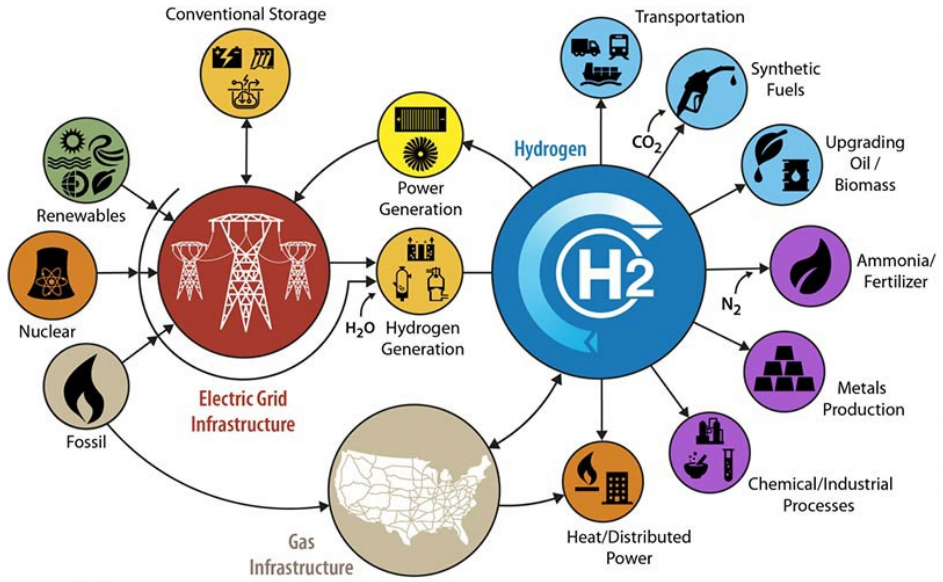
Locating and characterizing undocumented orphaned wells; determining physical locations, methane emissions, wellbore integrity, and other environmental impacts; inform prioritization for remediation by State and Federal agencies.



DIVISION OF METHANE MITIGATION TECHNOLOGIES

Natural Gas to H2: Motivation for R&D

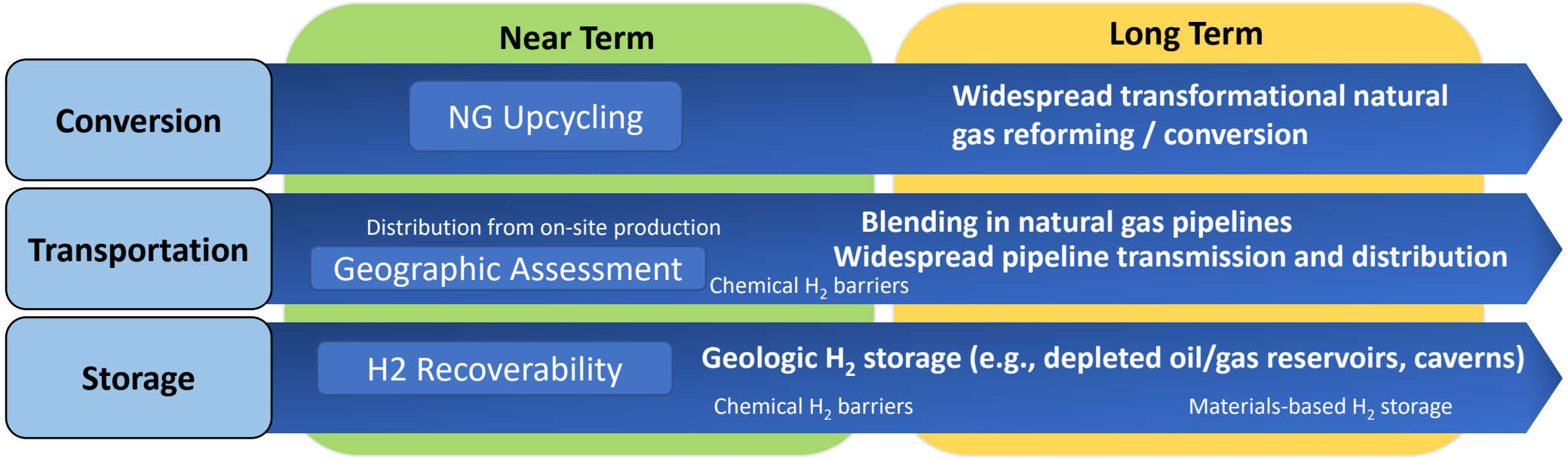
- Transformative Hydrogen Production
  - Supports DOE Hydrogen Earthshot initiative target of 80% reduction in the cost of clean hydrogen - $1 per 1 kg of clean H2 by 2030
  - Enables discovery of conversion pathways with lower energy requirements, simpler purification, and isolated carbon
  - Develops alternatives to electrolysis when water is needed elsewhere by leveraging the benefit of natural gas as feedstock
- Hydrogen Transport
  - Support research related hydrogen and natural gas blending
  - Develop advanced materials and components for safe and reliable transportation through existing natural gas pipeline transportation systems
- Hydrogen Storage
  - Develop large-scale, geologic storage solutions for hydrogen
  - Characterize and develop regional hydrogen storage options for efficient and long-term hydrogen storage
  - Develop comprehensive risk and feasibility assessments for regional hydrogen storage



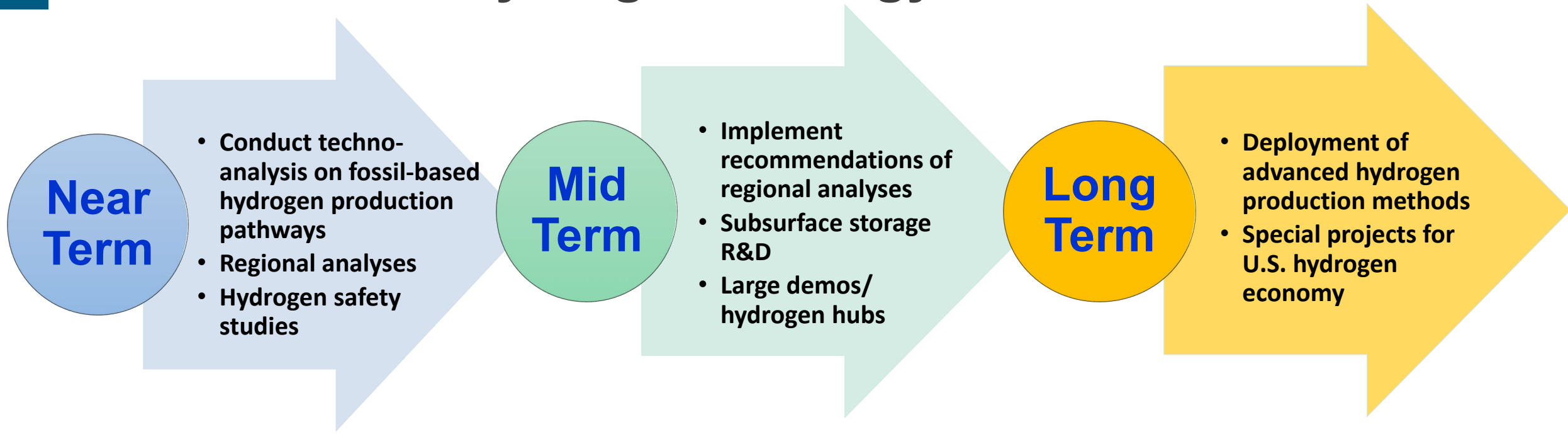
https://www.nrel.gov/news/program/2020/study-shows-abundant-opportunities-for-hydrogen-in-a-future-integrated-energy-system.html

Natural Gas Decarbonization and Hydrogen Technologies

- The **Natural Gas Decarbonization and Hydrogen Technologies** (**NGDHT**) Program was formally initiated in 2022 Omnibus.
- NGDHT 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 transport, 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.



FECM's Clean Hydrogen Strategy



Continue to work across DOE offices to understand market opportunities and challenges in various regions of the U.S. to best deploy Federal resources.

Scale up the subsurface storage of hydrogen to support hydrogen markets.

Maintain and achieve the Administration's goals and providing safe, reliable, and secure energy resources to the American public.

Coordinate R&D across Department and leverage program funds within larger hydrogen initiatives.

Subsurface Hydrogen Storage

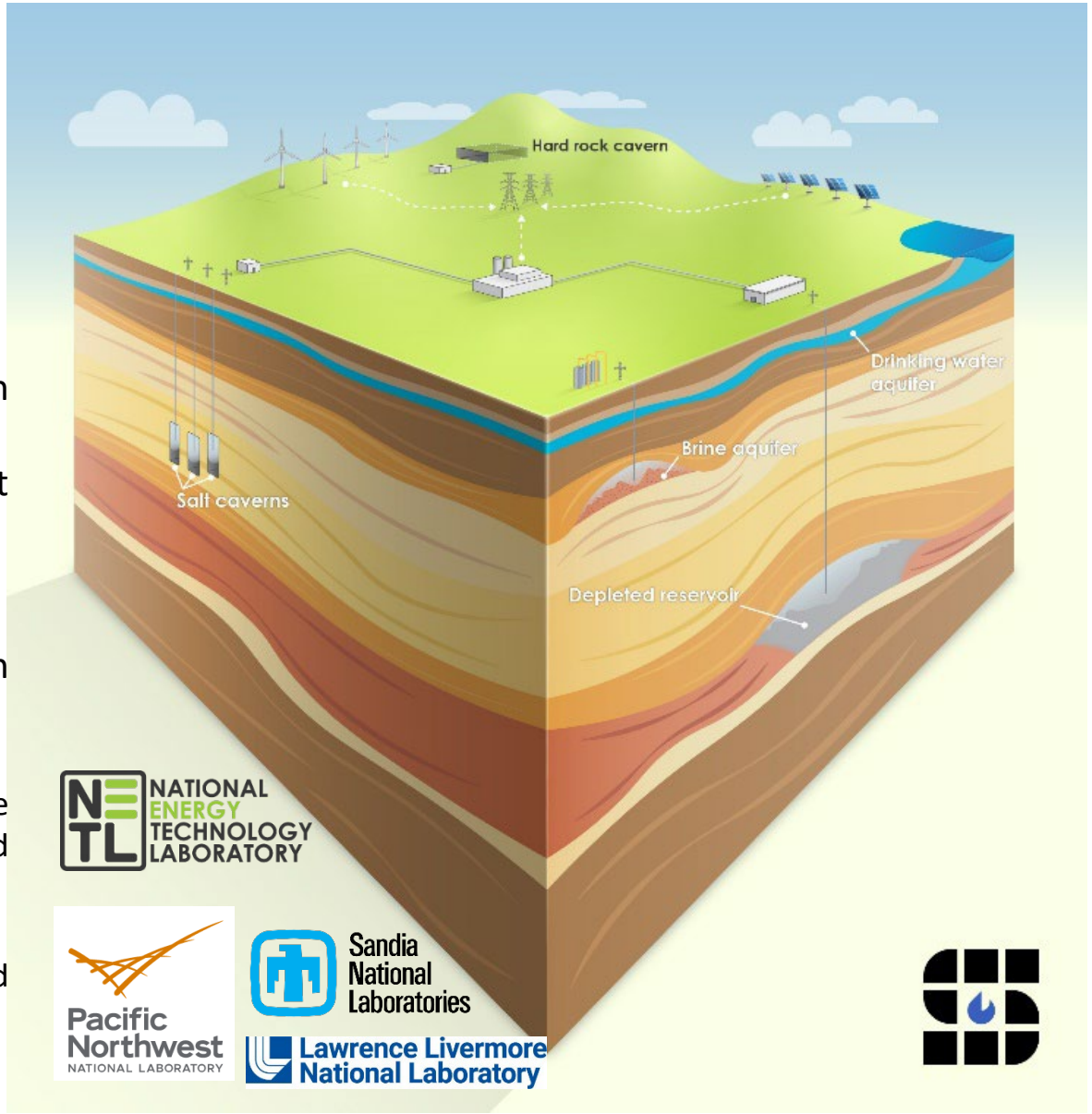
SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Current Status

- Subsurface hydrogen storage is domestically limited to salt cavern storage facilities.
- Exploring the expansion of subsurface hydrogen storage to different geologies and geographies.

Goals & Objectives

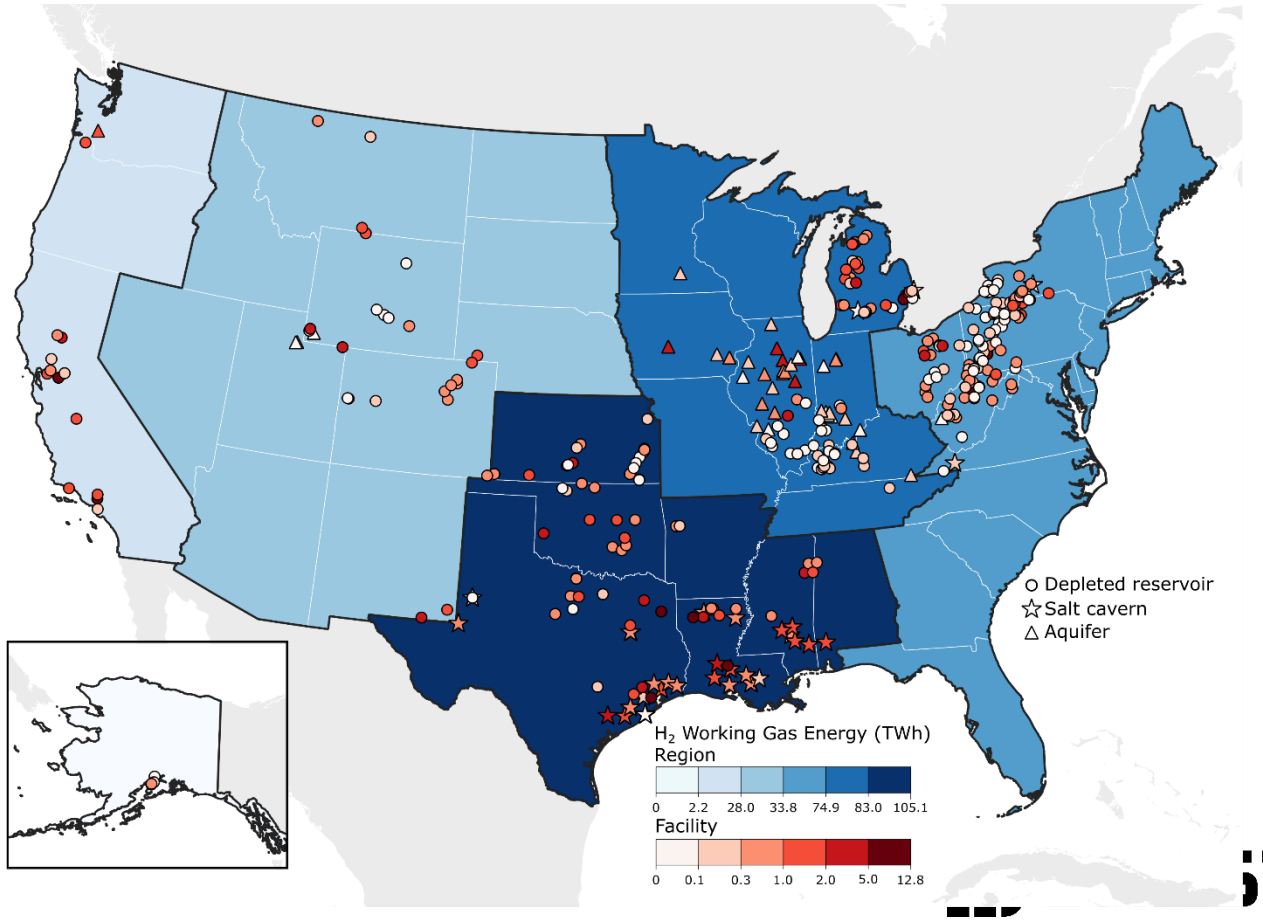
- Leverage a multi-lab team to address technical hurdles and broaden public acceptance of hydrogen and natural gas storage and transport.
- Subsurface geologic characterization
  - Determine geophysical and geochemical interactions between pure hydrogen and blended gas storage and effects on structural integrity and microbial communities.
- Subsurface geochemical interaction characterization and validation
  - Determine viability, safety, and recoverability of pure hydrogen or blended gas storage by conducting pilot demonstrations.



SHASTA Enabling Technologies: *Site-Screening Tool*

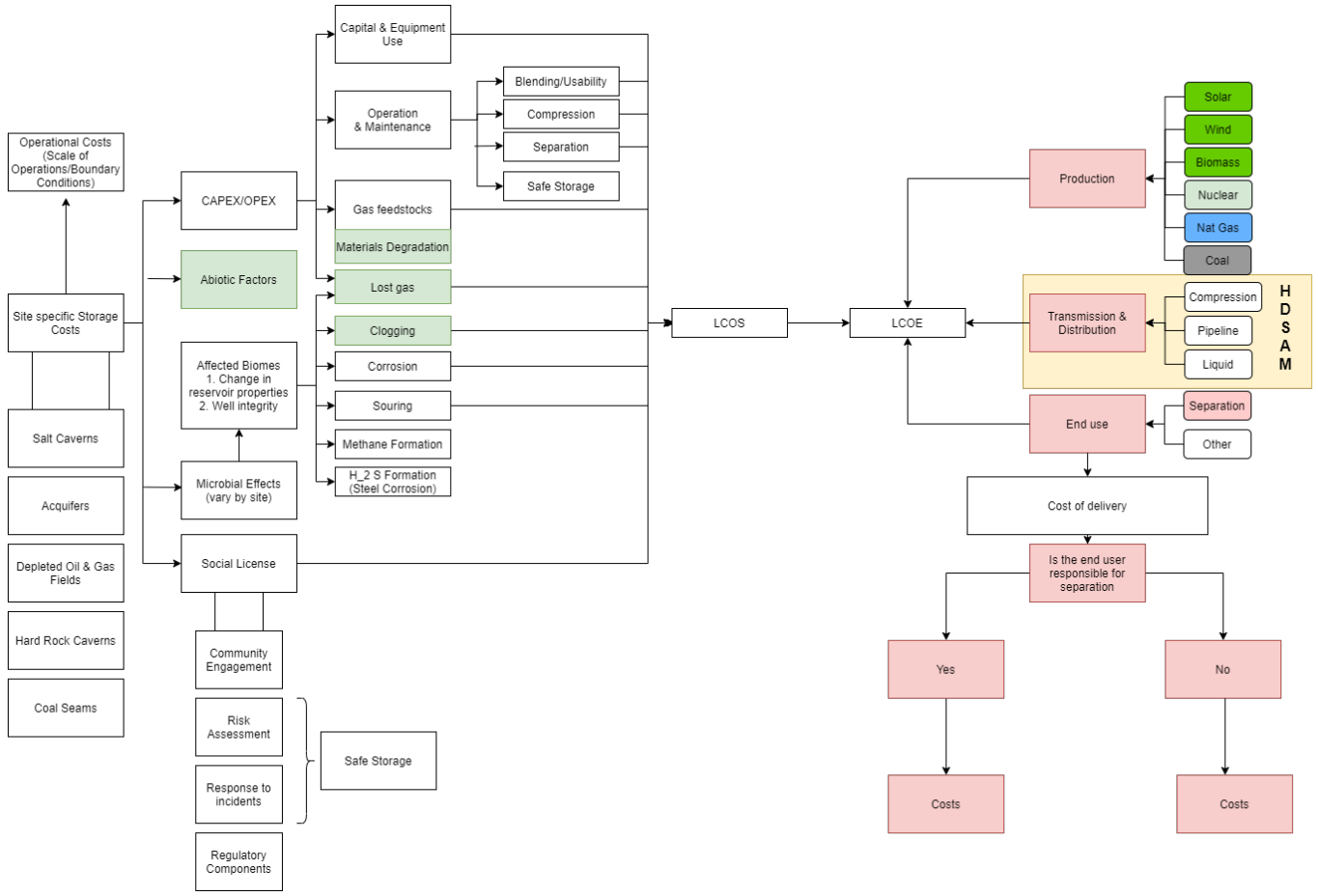
- What is impact of H_2 blending on underground energy storage?
- Can existing UGS facilities sufficiently buffer prospective H_2 demand?

- Pure H_2 working gas
- Cumulative WGE: 327.1 TWh
- South Central (105.1 TWh) – Pacific (28 TWh)
- <u>Reservoir type:</u>
  - Depleted reservoir: 270.1 TWh
  - Aquifer: 27.4 TWh
  - Salt Cavern: 29.5 TWh
- Median facility size: 0.3 TWh



SHASTA: *Techno-Economics and Business Case*

- Preliminary framework to assess economic viability of subsurface hydrogen storage
- Entails:
  - Value chain construction: Production, Site-Specific-Storage, Transmission and Distribution, End Use
  - Identification and imputation of $ values on all processes
  - Marries existing capabilities with new ones
  - Economics of Transmission and Distribution comes from ANL's HDSAM Model
  - Lifecycle cost analysis spanning the lifetime of the project under site-specific scenarios
  - Spatial analysis to cover the entire continental U.S.
- **Goal:** Technical report and peer reviewed articles detailing our approach and results



SHASTA

Subsurface Hydrogen Storage

Expanding Subsurface Storage Footprint for Expanded Utilization

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Risk quantification (experiment & simulation)

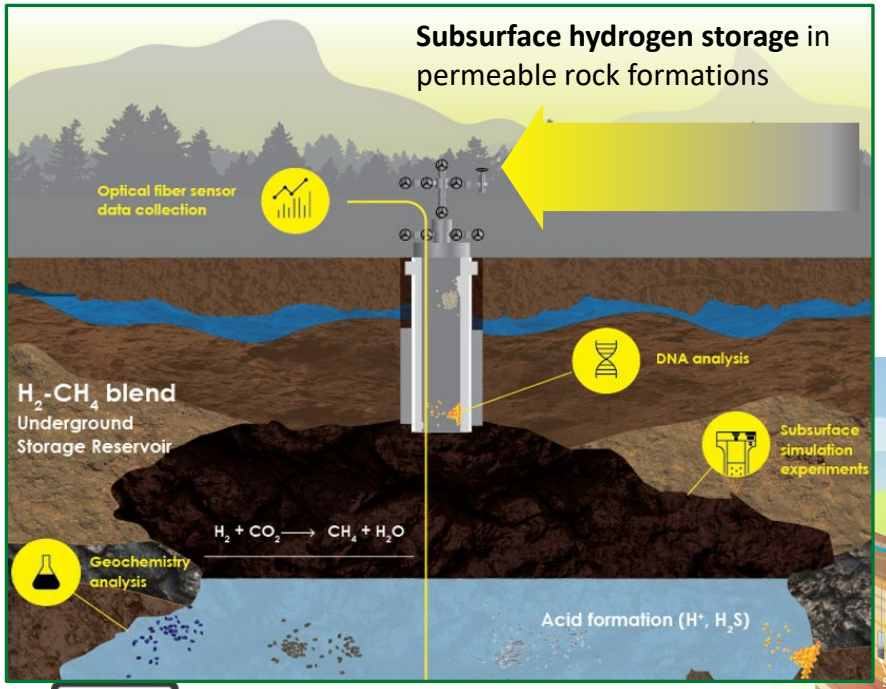
- Survey state of knowledge
- Capabilities establishment
- Fundamental work
- Risks

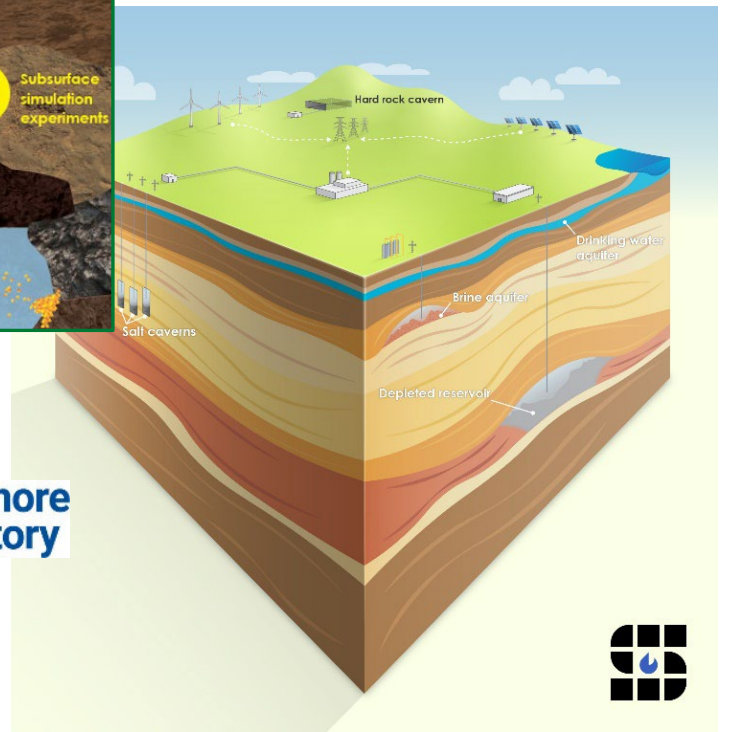
Enabling technologies to manage H2 storage

- Technology Transfer through Software Development
- Advanced Technology Suite to support H2 Subsurface Storage System

Recommended practices and industry engagement

- Knowledge transfer through Recommended Practices
- Techno-economics and the Business Case
- Industry Engagement and Pilot Study Preparation





NATIONAL ENERGY TECHNOLOGY LABORATORY

Lawrence Livermore National Laboratory

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

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

This FOA is broad in scope and will be used to solicit research and development (R&D) for 17 specific areas of interest (AOIs) aligned with the seven program areas.

- Over a period of three years, this FOA will be used to solicit R&D for specific AOIs aligned with the seven program areas.

- It is anticipated that the FOA will be amended to allow for additional applications as funding becomes available, to address information gaps and status changes, or to incorporate additional AOI's.

Activities will be coordinated with work within EERE and other offices to avoid duplication, leverage resources, and maximize effective use of Federal funding.

FECEM30 AOIs TRL 4 → 6
~Strong pool of applications → 4-11 selections anticipated

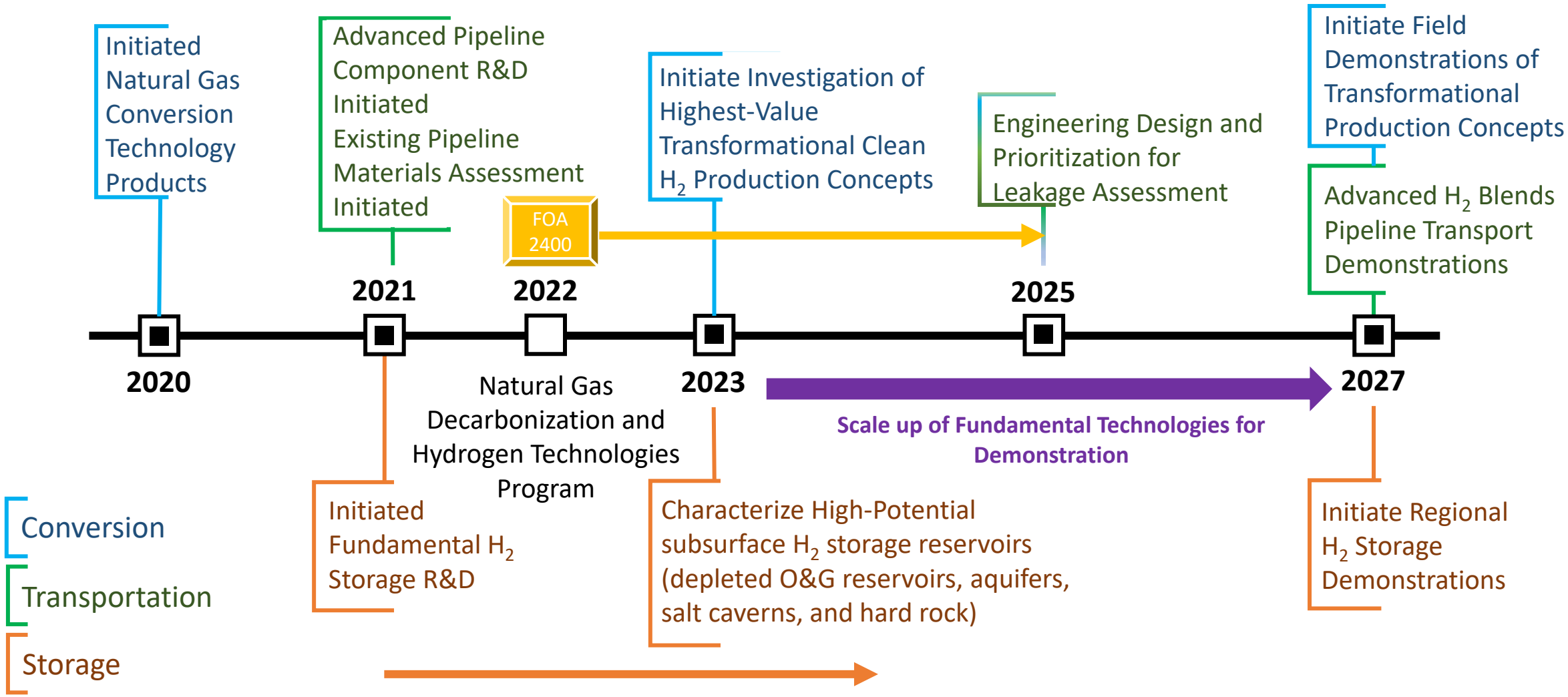
AOIs Part of this Closing

- **AOI 4 - Advanced Air Separation for Low-Cost H_2 Production via Modular Gasification**
- **AOI 14 – Clean Hydrogen Production and Infrastructure for Natural Gas Decarbonization**
  - **AOI 14a – Methane pyrolysis/decomposition, in situ conversion, or cyclical chemical looping reforming**
  - **AOI 14b – Hydrogen Production from Produced Water**
- **AOI 15 - Technologies for Enabling the Safe and Efficient Transportation of Hydrogen Within the U.S. Natural Gas Pipeline System**
- **AOI 16 - Fundamental Research to Enable High Volume, Long-term Subsurface Hydrogen Storage**

AOIs Reserved for Future Closing

- **AOI 3 -** Novel High-Purity Hydrogen Separations
- **AOI 6 -** SOFC and SOEC Component Materials Thermodynamic Database
- **AOI 10 -** Pre-commercial Testing of a Hydrogen Fueled Gas Turbine
- **AOI 13 -** Data Gathering and Baseline Assessment for Regional Hydrogen Hubs
- **AOI 14c -** Additional Transformational Clean Hydrogen Production Methods
- **AOI 17 -** Hydrogen Compression for Pipeline Transportation and Subsurface Storage

NGDHT - Conversion, Transport, and Storage R&D Timeline



Questions?

Fossil Energy and Carbon Management
https://www.energy.gov/fecm/office-resource-sustainability

SHASTA
https://edx.netl.doe.gov/shasta/