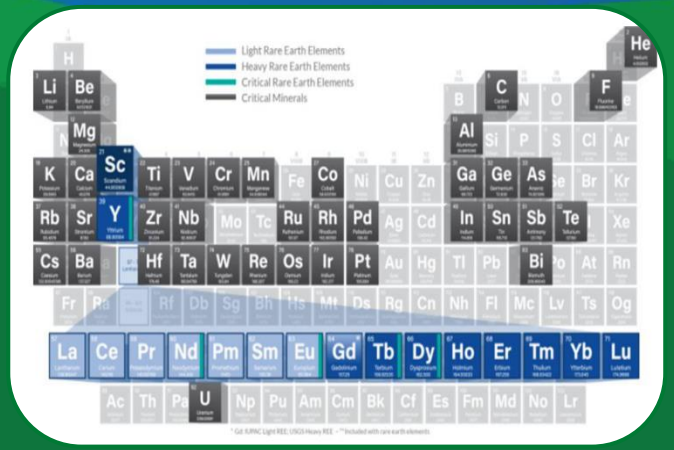
U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

Roadmap for CO2 Transport Fundamental Research Workshop

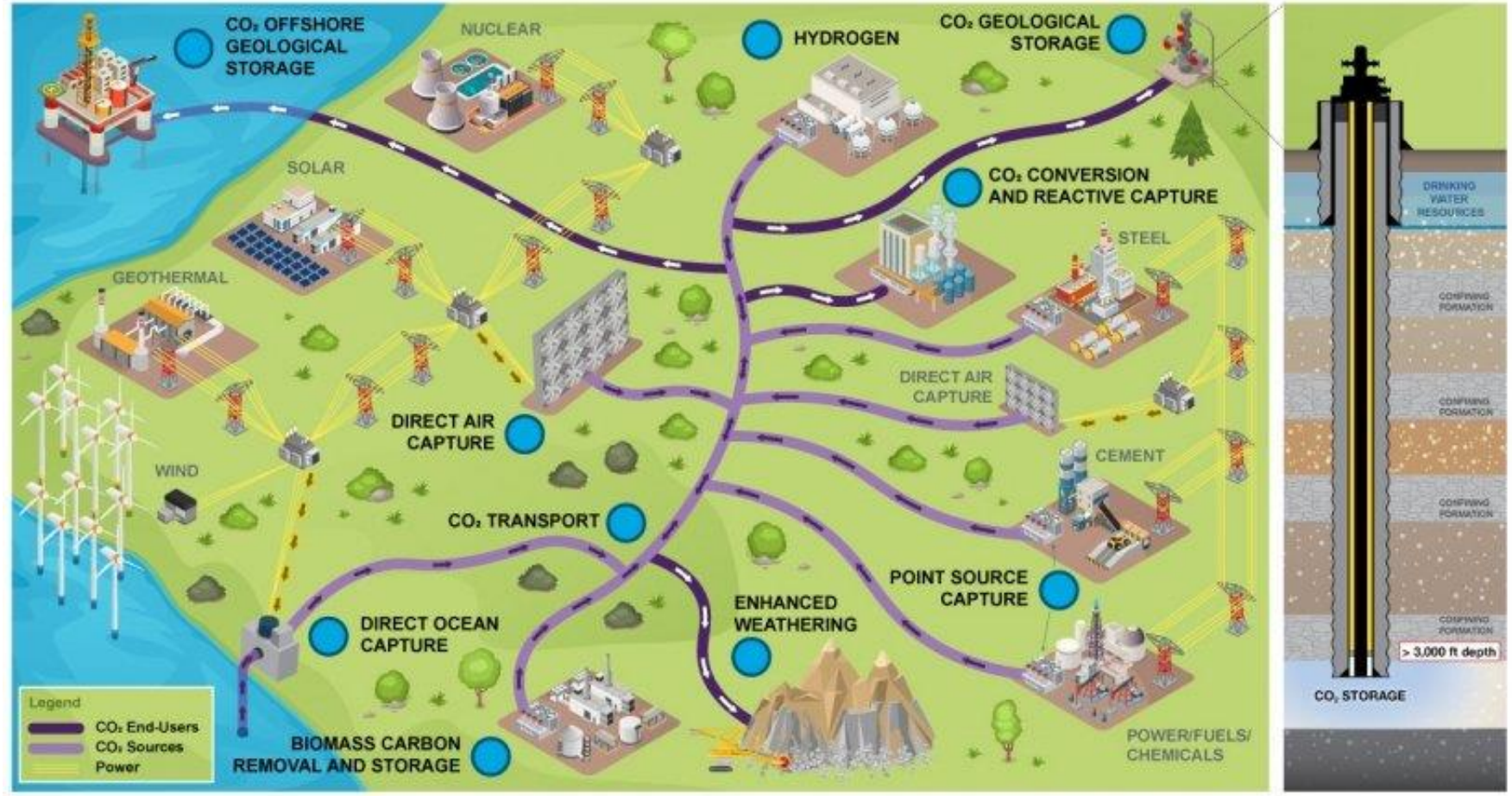
Sarah Leung, Carbon Transport Program Manager

Columbus, OH | February 21-23, 2023



Carbon Management Hubs are Underpinned by CO2 Transport

Interactive Diagram: https://www.energy.gov/fecm/interactive-diagram-carbon-management-provisions



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

Rapid CCUS and CDR Industry Growth Needed for Achieving U.S. Decarbonization Goals

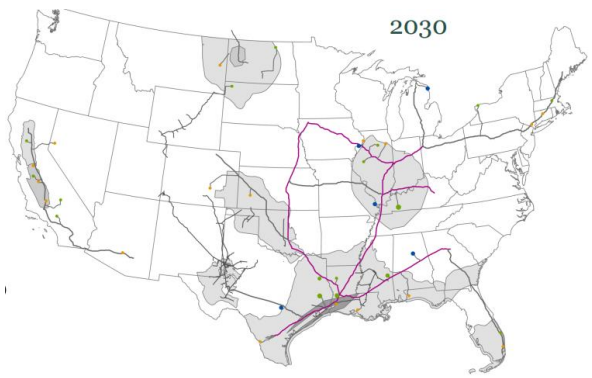
CarbonSAFE Targets	2025 VALIDATION	2030 ACTIVATION	2035 EXPANSION	2040 AT SCALE	. . .	2050 MIDCENTURY
Injectivity	5 million metric tons (MT)/year	65 million MT/year	250 million MT/year	450 million MT/year	. . .	> 1 billion MT/year
Commercial Storage Potential	250 million metric tons (MT)	2,000 million MT	7,500 million MT	13,500 million MT		> 30 billion MT

CO2 Transport Modeling

Today: 5,300 miles of pipelines

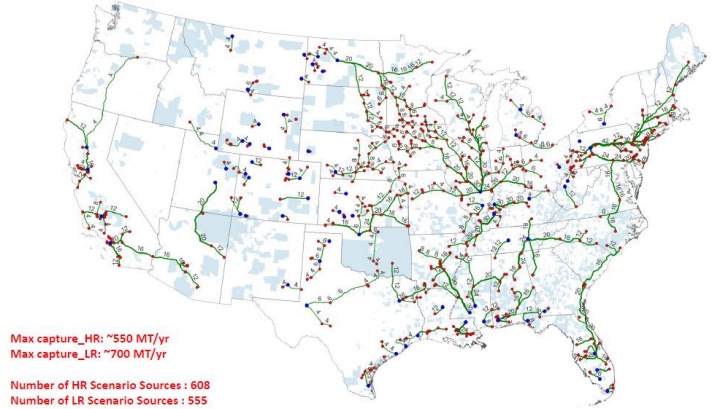
NPC: Meeting the Dual Challenge (2019)

2030: 11,000+ miles of pipelines



Modeling from Princeton's Net-Zero America Study (2020)

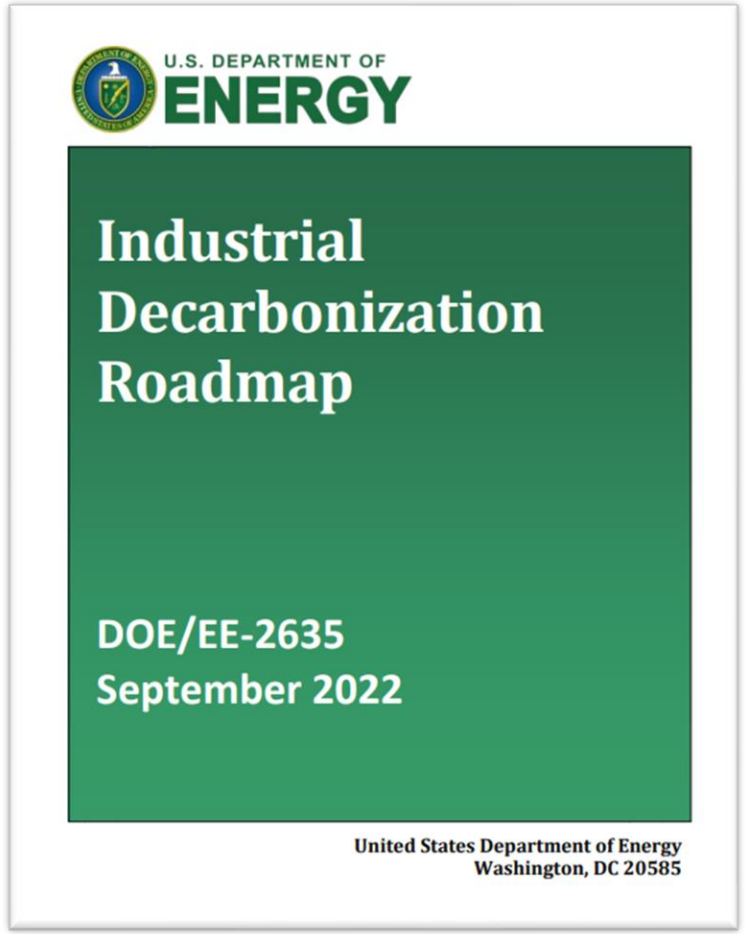
2050: 25,000+ miles of pipelines



Modeling from Los Alamos National Laboratory (2022)

Industrial Decarbonization Roadmap

Carbon Capture, Utilization, and Storage is one of four strategies for decarbonizing US Industry.



- Iron and Steel Manufacturing
- Chemical Manufacturing
- Food and Beverage Manufacturing
- Petroleum Refining
- Cement Manufacturing

https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

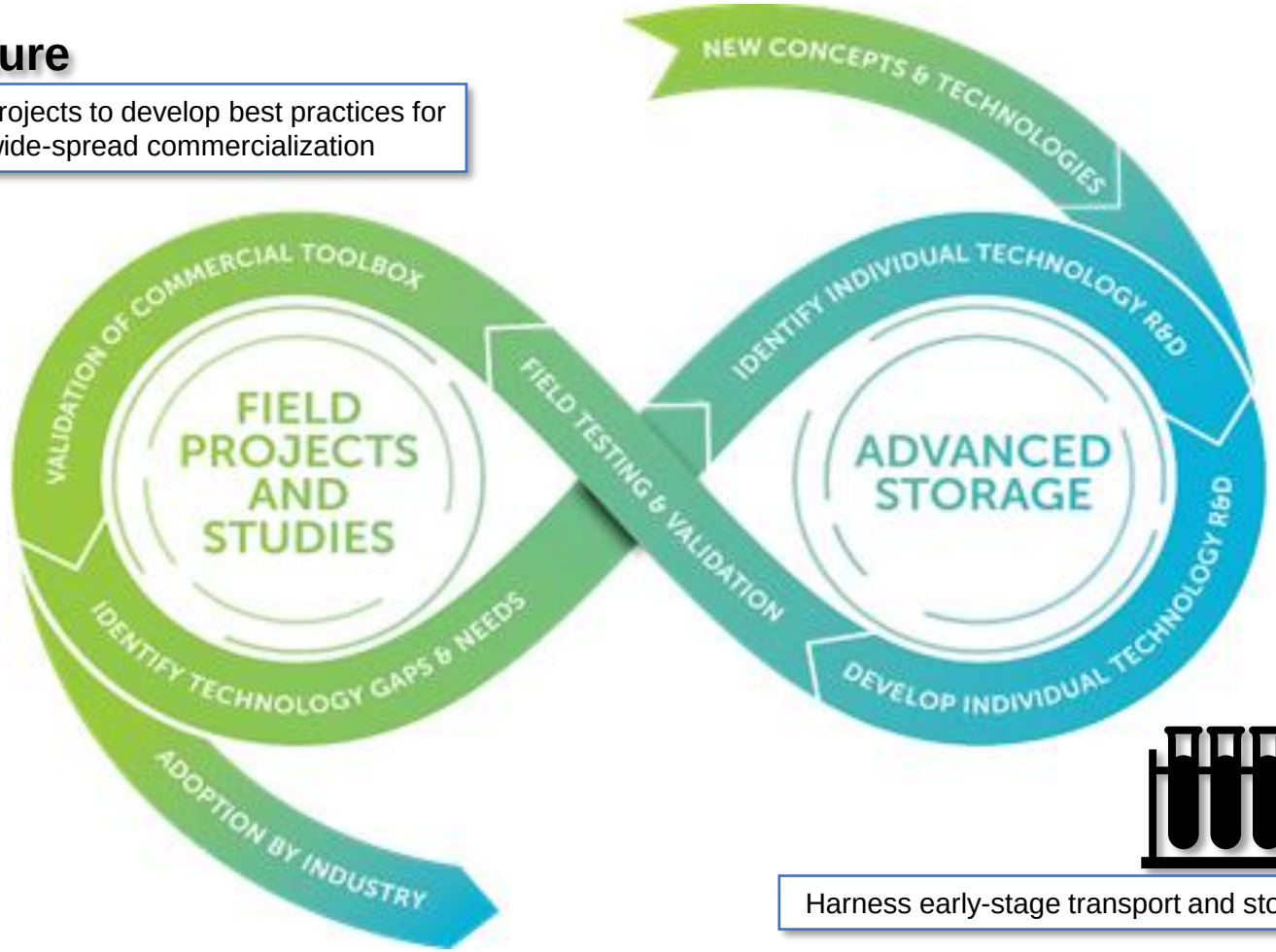
Carbon Transport Program
RD&D: An Iterative Process towards Deployment

Infrastructure

Large-scale demonstration projects to develop best practices for industry and facilitate wide-spread commercialization

Infrastructure Focus

- Bipartisan Infrastructure Law FOAs
- Carbon Management Hubs
- Offshore CCUS
- Transition of O&G infrastructure



Advanced R&D Focus

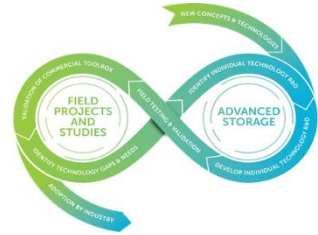
- Material Integrity and mitigation
- Monitoring, verification, and accounting
- Lab-based and pilot scale testing and demonstration

Advanced R&D

Harness early-stage transport and storage concepts to technology demonstration

Bipartisan Infrastructure Law (BIL) Overview

CO2 Transport Infrastructure is an integral component to several BIL Provisions listed in Green.



- **$12 billion** in new carbon management RD&D: **$7B** Managed directly by FECM
- **$9.5B** for hydrogen hubs and RD&D
- Generally, cost share is 80% government/20% applicant for early TRL R&D and 50%/50% for demonstration projects

Point Source Capture and Direct Air Capture

Regional Direct Air Capture Hubs: $3.5 billion

DAC Technology Prize Competition: $115 million

CCUS Integrated Demos: $2.5 billion (OCED)

Carbon Capture Large Pilot: $1 billion (OCED)

Hydrogen

Hydrogen Hubs: $8 billion (OCED)

Hydrogen Recycling Program: $500M

Hydrogen Electrolysis: $1 billion

Carbon Dioxide Utilization, Transport, and Storage

Carbon Storage Validation and Testing: $2.5 billion

Carbon Utilization Program: $310 million

Carbon Transport Systems

FEED Studies for Transport Systems: $100 million

CIFIA – Loans and Future Growth Grants: $2.1 billion

Critical Minerals and Materials

Rare Earth Element Demonstration: $140 million

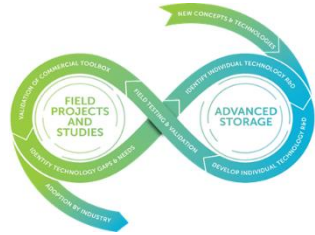
Rare Earth Mineral Security: $127 million

https://www.energy.gov/fecm/solicitations-and-business-opportunities

FECM Strategic Vision: Strategies and Research Priorities for CO2 Transport & Storage

		5 Year Goal 2030 ACTIVATION	10 Year Goal 2035 EXPANSION	15 Year Goal 2040 AT SCALE
Carbon-SAFE	Com-mercial Storage Capacity	2,000 Million MT over 30 years	7,500 Million MT over 30 years	13,500 Million MT over 30 years
	Injectivity	Injection of 65 Million MT/yr	Injection of 250 Million MT/yr	Injection of 450 Million MT/yr
Contingent Storage Resource		Identify 5,500 Million MT	Identify 6,000 Million MT	Identify 7,500 Million MT
Repurposing Storage Infrastructure		FEED studies for repurposing onshore and offshore infrastructure (depleted oil/ gas fields, wells, pipelines, etc.)		
CO_2 Transport Infrastructure		Support design studies of regional infrastructure; feasibility studies of national network	Support pre-FEED studies of trunk lines to interconnect regional hubs	Support development of trunk lines and feeder lines
Advanced R&D		Develop tools for basin-scale management of storage resources Develop and deploy tools to reduce cost, risk and uncertainty in storage projects Establish CarbonSTORE facilities in multiple different geologic settings Integration of Science-informed Machine learning to Accelerate Real Time decisions for Carbon Storage (SMART-CS) and National Risk Assessment Partnership (NRAP) tools into commercial storage applications		
Crosscutting Synergies		Develop programs to provide technical assistance and make information readily available to agencies and stakeholders		

CO2 Transport: 3-5 Year Roadmap Strategy



	Year 1		Years 2-3		Year 4-5	
Topic 1	What	Who	What	Who	What	Who
Topic 2						
Topic 3						
Topic 4						

Examples of DOE Programmatic Roadmaps

DOE's Industrial Decarbonization Roadmap

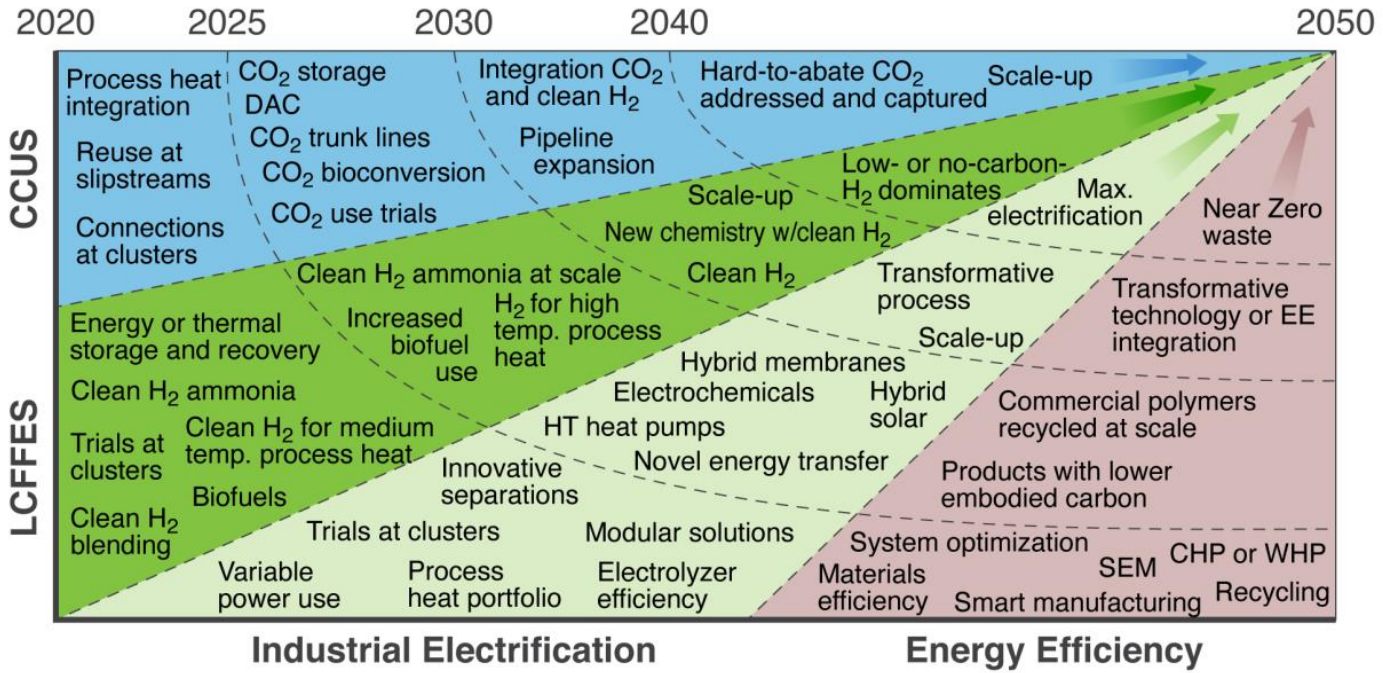


FIGURE 30. LANDSCAPE OF RD&D ADVANCEMENT OPPORTUNITIES BY DECADE AND DECARBONIZATION PILLAR FOR THE U.S. CHEMICAL MANUFACTURING SUBSECTOR NOTED BY ATTENDEES AT THE ROADMAP VIRTUAL SESSIONS.

DOE's Clean Hydrogen Strategy Roadmap (Draft)

Actions to support safe, efficient, and reliable clean hydrogen delivery and storage infrastructure

Delivery and Storage Infrastructure

2022-2025

- Develop and update rigorous analytical models and tools to assess delivery and storage pathways, determine gaps, and prioritize strategies.
- Develop technologies to tightly monitor and mitigate hydrogen leaks and boil-off.
- Assess compatibility of pipeline and component materials with hydrogen and hydrogen blends with natural gas.
- Advance novel approaches for low cost, high efficiency hydrogen liquefaction and boil-off mitigation.
- Conduct discovery and development of hydrogen carrier materials for use in bulk storage and distribution
- Identify geologic formations that can be used for bulk hydrogen storage, and associated development and operating requirements.
- Develop and optimize designs for hydrogen infrastructure in key applications, such as industry and energy storage.
- Develop technologies for high throughput dispensing of hydrogen for heavy-duty vehicles.
- Develop and harmonize fueling protocols for heavy-duty and off-road vehicles for which hydrogen is the optimal solution.
- Accelerate RDD&D to reduce the cost of high pressure and liquid hydrogen storage tanks, including carbon fiber composite vessels.

2026-2029

- Validate and refine analyses, models, and tools to prioritize delivery and storage pathways for various applications.
- Demonstrate efficient and reliable hydrogen pipeline compressor operation.
- Quantify loss rates from gaseous and liquid hydrogen infrastructure to inform mitigation requirements in large-scale deployments.
- Develop designs for commercial-scale novel, high efficiency systems for hydrogen liquefaction.
- Advance promising concepts for hydrogen carriers and design reliable, low-cost regenerator systems.
- Initiate regional bulk hydrogen storage demonstrations, including underground approaches, and ensure local and regional benefits.
- Demonstrate novel, efficient, and low-cost approaches to bulk hydrogen delivery.
- Deploy scalable hydrogen fueling stations to support early fleet markets, such as heavy-duty trucks and buses.
- Ensure monitoring systems and data collection are in place for potential hydrogen and other emissions/releases

2030-2035

- Design networks of hydrogen infrastructure optimized for regional supply and demand, in collaboration with local communities and stakeholders to maximize benefits and ensure energy, environmental, and equity goals are addressed.
- Demonstrate advanced liquefaction with double the efficiency of current concepts.
- Develop long term storage plan/strategic hydrogen reserve to ensure resiliency of supply.
- Deploy at least 4 regional clean hydrogen hubs with advanced low-cost clean hydrogen storage and infrastructure.
- Collect data, including emissions data, from demonstrations of bulk hydrogen distribution (e.g., through pipelines or carriers) in real-world environments to inform RDD&D that reduces cost and improves reliability.
- Continue collecting data to inform scale up of optimal delivery and storage pathways and RDD&D.
- Ensure any safety or other best practices related to hydrogen infrastructure are shared across diverse stakeholders to enable continuous improvement.

Workshop Intent

- The purpose of today's meeting is to ask for your input regarding **CO2 Transport Fundamental Research**. To that end, it would be most helpful to us that you provide us, based on your personal experience, your individual advice, information, or facts regarding this topic.

- **It is not the object of this session to obtain any group position or consensus.**

- **Rather, the Department is seeking as many recommendations as possible from all individuals at this meeting. To use our limited time most effectively, please refrain from passing judgment on another participant's statements or advice and instead concentrate on your individual experiences.**

Workshop: Rules of Appropriate Behavior

- DOE encourages open and honest sharing of individual advice, facts, and information in order to provide a welcoming and inclusive atmosphere at every meeting—we ask that all participants be respectful to one another.
- DOE understands people's passion with these topics. We ask that you funnel your passion into free sharing of individual advice, facts, and information, and refrain from disrespecting or disparaging others simply because they hold other perspectives and viewpoints.
- DOE cannot tolerate illegal acts at any meeting location, including violations of applicable laws including those pertaining to destruction of property or harassment of any kind.
- DOE condemns inappropriate or suggestive behavior or comments that demean another person by reason of his or her gender, gender identity or expression, race, religion, ethnicity, age, or disability or that are unwelcome or offensive to other members of the community or their guests.
- Please pay attention, listen, and engage in today's discussion while being mindful and respectful of others.
- Thank you for your interest and in taking time out of your busy schedule in order to join us here today. Please email us with any questions, concerns, or to schedule a meeting to discuss specific issues at carbonmanagement@hq.doe.gov.

Agenda At A Glance

DAY 1 - Tuesday

- Introduction
- Ongoing Initiatives: Building a consortia to complement partnerships that exist today (1.5 hours)
  Session Moderators: Shawn Bennett, Battelle and Joshua James, EWI
- Topic 1: CO2 Impurities and Impact to Integrity (2 hours)
  Session Moderators: Rick Noecker, ExxonMobil and Srdjan Nesic, Ohio University

Carbon Transport Team at DOE HQ and DOE-NETL


Sarah Leung, DOE HQ


Kevin Dooley, DOE HQ


Bill Aljoe, DOE-NETL


Josh Hull, DOE-NETL


John Moore DOE-NETL


Matt Kaminski, DOE-NETL

Agenda At A Glance

DAY 2 – Wednesday

Topic 2: CO2-Specific Leak Detection and Emergency Response Protocol (1.5 hours)

Session Moderators: Bill Caram, Pipeline Safety Trust and Ruth Ivory-Moore, Global CCS Institute

Topic 3: Repurposing of Existing Infrastructure for CO2 Service (1.5 hours)

Session Moderators: Darshan Sachde, Trimeric and Florent Bocher, SWRI

Topic 4: Developing and Connecting with Other Modes of CO2 Transport/Intermodal Hubs (1.5 hours)

Session Moderators: Richard Middleton, Carbon Solutions LLC and Erick Danyi, BP

Key Takeaways and Next Steps (1 hour)

Session Moderators: Neeraj Thirumalai, ExxonMobil and Edgar Lara-Curzio, ORNL

DAY 3 – Thursday (Optional)

DNV Lab Visit

POC: Ramgopal Thodla, DNV

ICMT Lab Visit

POC: Marc Singer, Ohio University

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Questions?

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