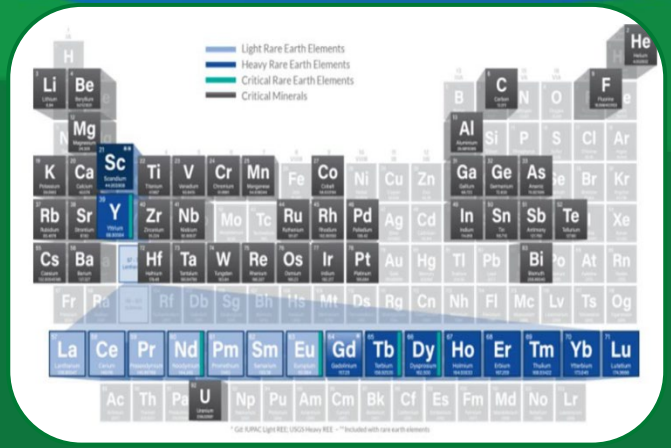
U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

Office of Resource Sustainability

November 30, 2021



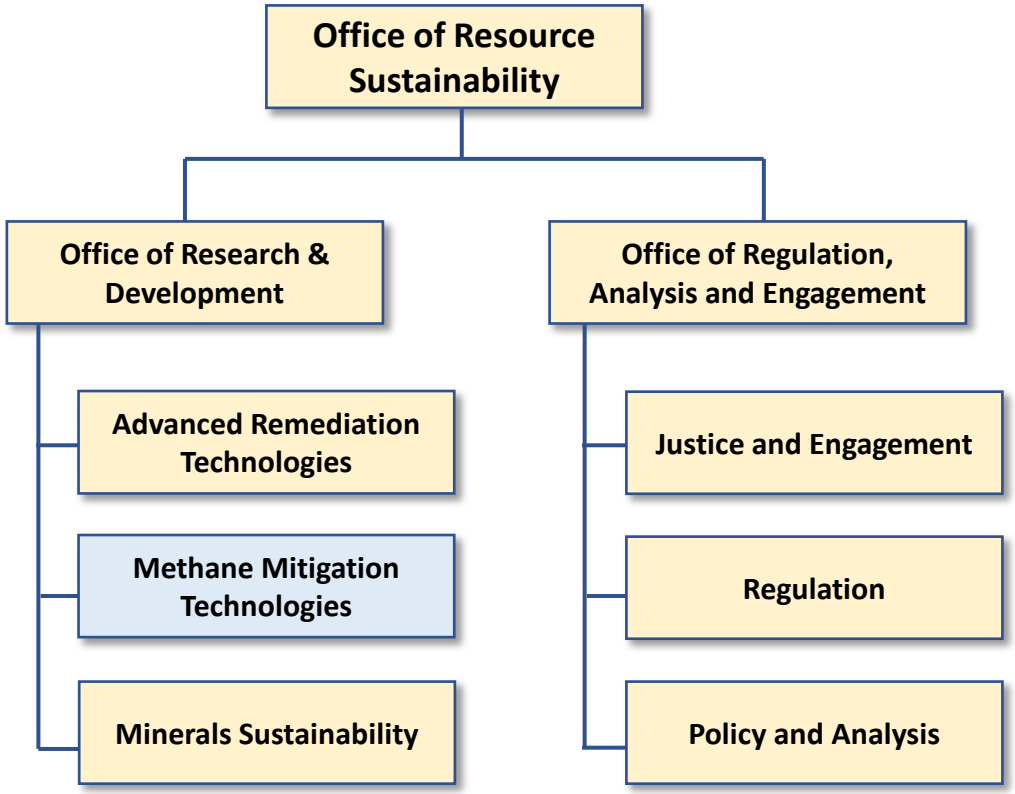
Office of Resource Sustainability

- 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

Office of Fossil Energy and Carbon Management (FECM) Strategic Vision

Focused on meeting the Administration goals:

- 50% emissions reduction by 2030
- 100% clean electricity by 2035
- Net-zero carbon emissions by 2050
- Responsible use of fossil – from extraction to transport to use – addressing frontline community concerns



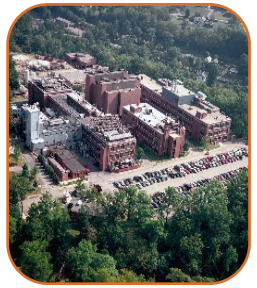
Fossil Energy and Carbon Management Programmatic Priorities

Environmental Impacts of Fossil Fuels

Deploy regional initiatives to advance net-zero goals and minimize the environmental impact of fossil fuels, limiting leakage from natural gas infrastructure, and progressing remediation efforts that promote clean energy jobs & energy justice.

Advancing Carbon Management

Make significant contributions to achieving the Nation's net-zero goals by mid-century, while creating good paying jobs and advancing an equitable transition to net-zero.



National Energy Technology Laboratory (NETL) Capabilities

Strengthen NETL's technical capabilities through investments in talent and infrastructure that advance safe, affordable, and environmentally sound technology innovations to increase efficiency, reduce emissions, and drive down energy costs.

Efficient and Responsible Liquified Natural Gas (LNG) Authorization

Practice an efficient regulatory review of applications to export LNG and ensure that greenhouse gas emissions are properly understood.

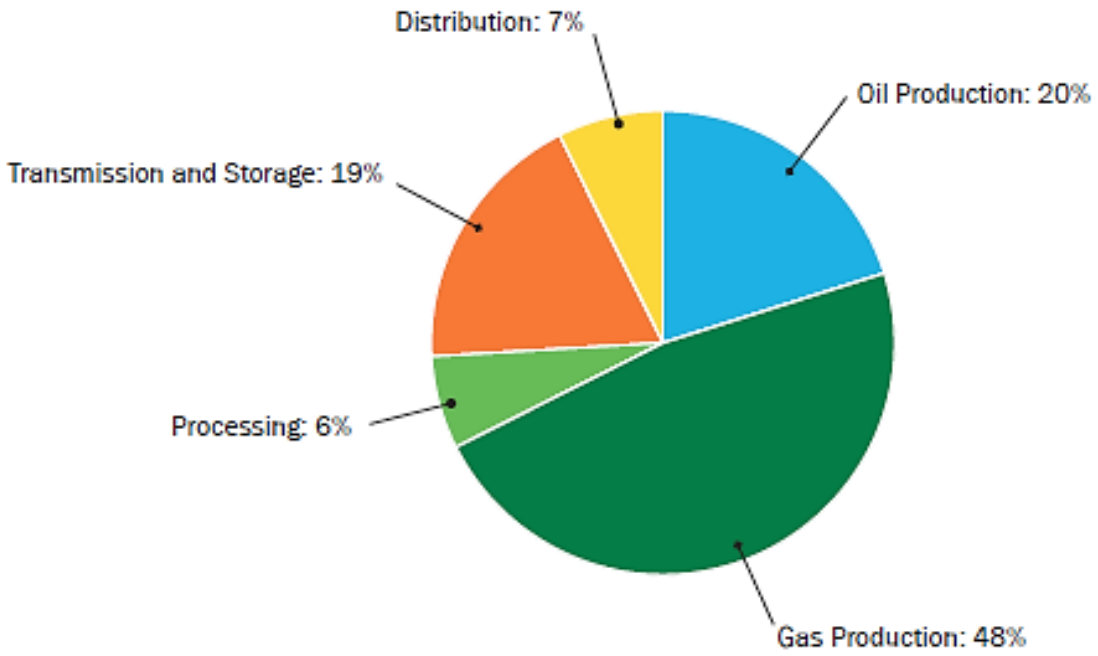
Current Program Areas

Methane Mitigation Technologies	• Reduce or eliminate methane emissions (ex. Leaks) across the natural gas supply chain • Develop advanced technologies to reduce or eliminate of methane emissions across natural gas supply chain, as well as flaring and venting activities
Natural Gas Decarbonization & Hydrogen Research	• Transformational concepts for decarbonized, clean hydrogen from domestic natural gas resources • Identify underground storage infrastructure to handle high volume fractions of hydrogen • Ensure suitability of existing natural gas pipelines and infrastructure for hydrogen transport
Advanced Remediation Technologies	• Environmentally prudent development of unconventional fossil resources • Produced water treatment and reuse technologies • Water management research • Gas hydrates
Minerals Sustainability	• Develop technologies to improve the economical and reduce the environmental impacts of mineral extraction, processing, use and disposal of critical minerals (CM), including rare earth elements (REE), from all raw mining materials to support the power industry and U.S. manufacturing base.
Justice and Engagement	• Represent and advise the Office leadership on environmental and energy justice issues • Support energy justice goals associated with legacy fossil fuel production and use, provide expertise in support of engagements and initiatives with government, non-profit, academia and industry entities
Regulation	• Review applications for the import and export of natural gas, liquefied natural gas (LNG), and compressed natural gas (CNG)
Policy and Analysis	• Analyze fossil energy market developments and trends in support of the Administration's energy transition and other policy goals

U.S. Methane Emissions – Oil and Natural Gas Sector

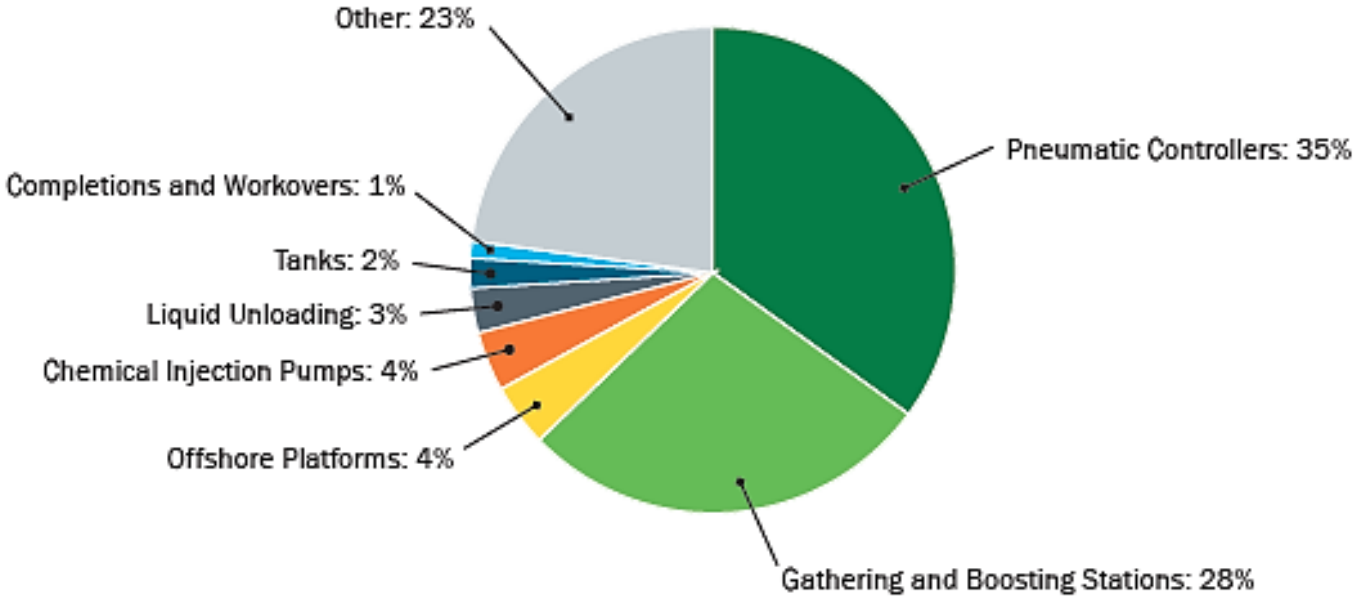
Oil and Natural Gas Supply Chain

2019 Oil and Gas Methane Emissions by Segment (~197 $MMTCO_2e$)



Oil and Natural Gas Production Sector

2019 Oil and Gas Production (~132 $MMTCO_2e$)

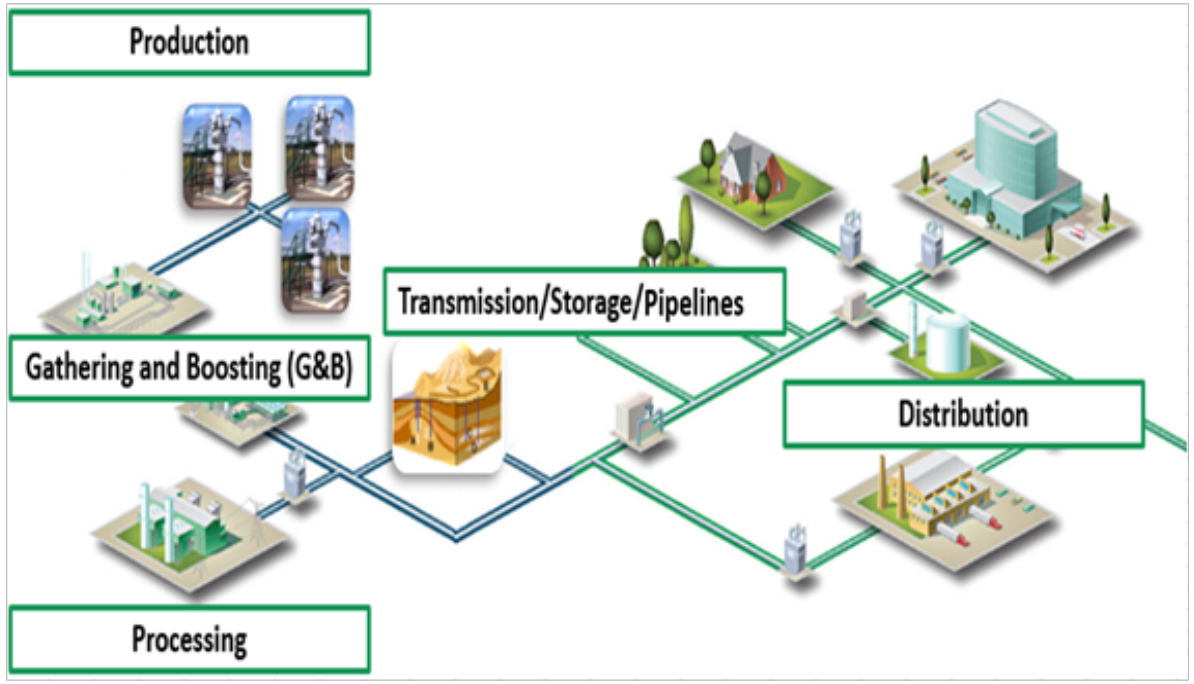


Source: EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2019, April 2021

Methane Mitigation Technologies Program

Goals:

- Develop new technologies to reduce or eliminate methane emissions across the natural gas supply chain in the U.S.
- Develop advanced technologies that will result in a significant reduction of methane emissions from natural gas venting or flaring.



Materials

- Novel coatings
- Sleeves/liners

Transmission & Distribution

- Compressors
- Gathering/Boosting Systems

Emissions Mitigation/ Quantification

- In-line repair tools
- Emissions monitoring and sensor platforms

Natural Gas Conversion

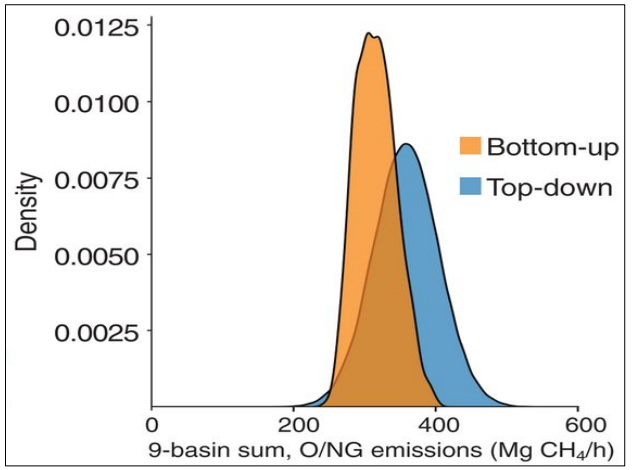
- Single step catalysts
- Process intensification
- Modular solutions

Detection and Quantification Program Goals

- Develop direct and remote measurement sensor technologies for the collection, dissemination, and analysis of emissions data.
  - It estimated that half of biggest emitters in the Permian Basin are due to malfunctioning equipment and by fixing 123 of the largest emitters nearly 55 tons of methane emissions could be mitigated (5.5% of U.S. EPA's estimated total emissions for the U.S.)[1]
- Collect data, conduct research and analytics that support EPA's Greenhouse Gas Inventory.
- Conduct research, technology development, and data analytics on finding and quantifying emissions from orphan wells.

Plume emissions measured from a flyover conducted by NASA JPL for the Methane Source Finder project within the Permian Basin, Texas. Methane Source Finder

Comparison of bottom-up estimates of methane emissions from oil and natural gas sources to top-down estimates in nine U.S. oil and natural gas production areas.[2]



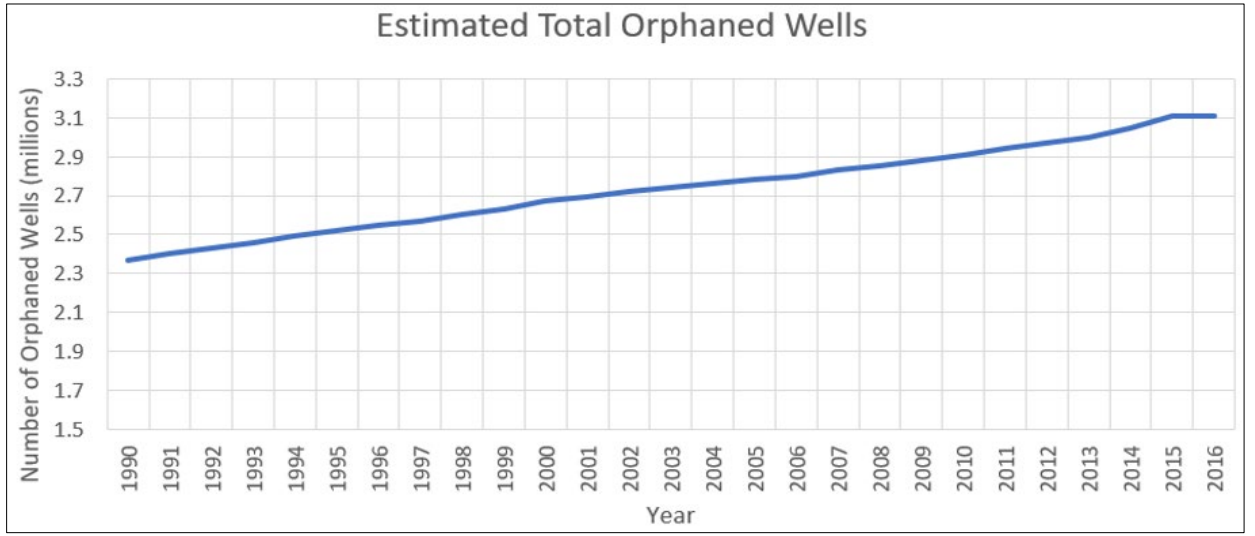
Integrating bottom-up and top-down measurement strategies would combine ground-based, in situ, and aerial-based detection and quantification methods to more accurately identify and quantify methane emissions.

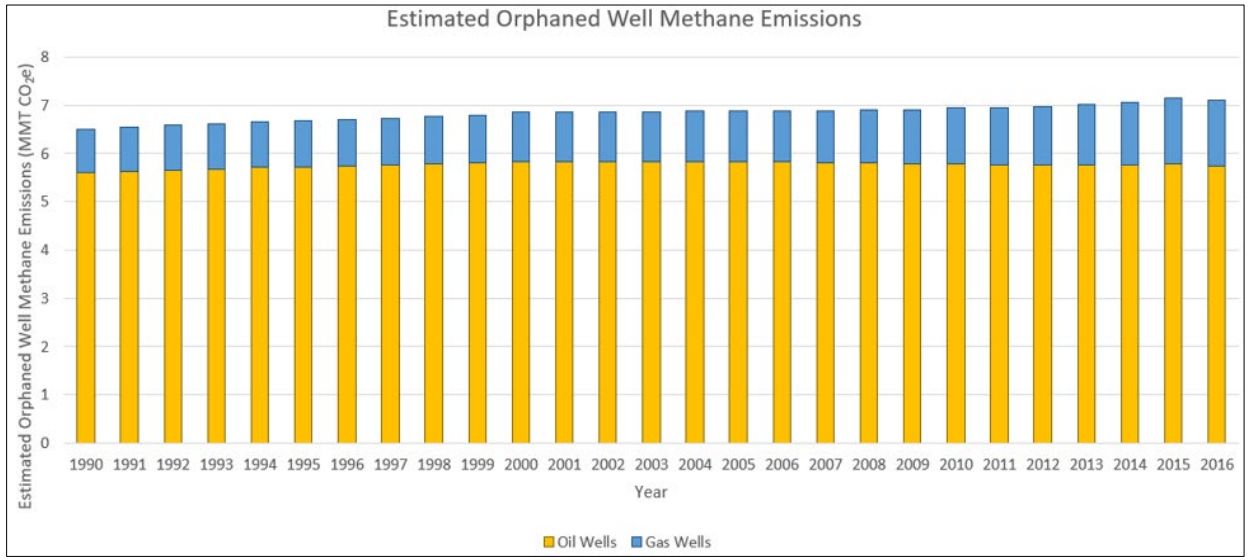
1) Study Identifies Methane 'Super-Emitters' in Largest U.S. Oilfield, NASA, JPL, June 2, 2021, https://climate.nasa.gov/news/3087/study-identifies-methane-super-emitters-in-largest-us-oilfield/
2) Repairing the Damage from Hazardous Abandoned Oil & Gas Wells, Ohio River Valley Institute, April 2021, https://ohiorivervalleyinstitute.org/reports/hazardous-aog-wells/

Emissions Quantification – Motivation for R&D

- A study has found that methane emissions are underestimated by at least 60% within the natural gas supply chain (excluding distribution and end use).[1]
- It is estimated that there are up to 746,000 undocumented orphaned wells leaking methane in the U.S. that need to be located.[2, 3]
- A study showed that annual emissions from orphaned wells are underestimated by at least 20% and are the 11th largest source of anthropogenic methane emissions in the U.S.[4]

Under the Infrastructure Bill just passed, FECM will receive $30M funding in FY 2022 for activities related to locating and remediation of orphaned, abandoned, or idled wells on federal lands





1) Assessment of methane emissions from the U.S. oil and gas supply chain, Ramon A. Alvarez, Et Al., Science 13 Jul 2018: 186-188
2) Management of Abandoned and Orphaned Oil and Gas Wells, The American Association for the Advancement of Science
3) Repairing the Damage from Hazardous Abandoned Oil & Gas Wells, Ohio River Valley Institute, April 2021, https://ohiorivervalleyinstitute.org/reports/hazardous-aog-wells/
4) Methane Emissions from Abandoned Oil and Gas Wells in Canada and the United States, James P. Williams, Amara Regehr, and Mary Kang, Environmental Science & Technology 2021 55(1), 563-570 DOI: 10.1021/acs.est.0c04265

Natural Gas Decarbonization & Hydrogen Technologies Research Program

Hydrogen Production from Natural Gas

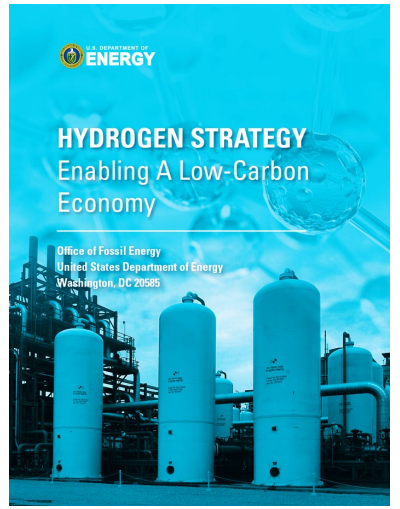
- Natural gas is the “bridge fuel” to enable a hydrogen economy and transformational methods will maintain its relevance as a feedstock even as green hydrogen become cost-competitive.
- Improved methods of decarbonization drive disruption of existing hydrogen production.
- Widespread industrial adoption means even incremental hydrogen production efficiency improvements can have a large impact in the near term.

Hydrogen Transportation in Existing Infrastructure

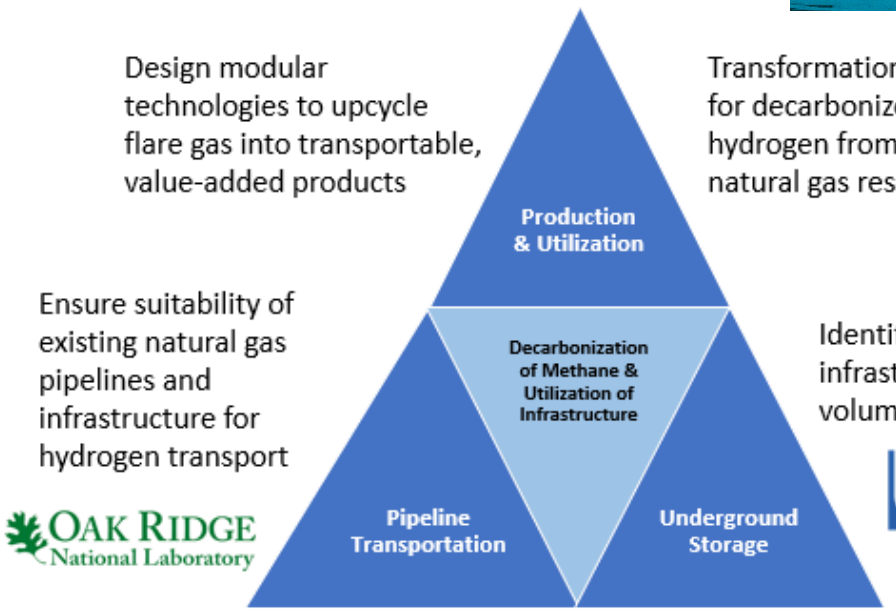
- Near-term improvements in materials to reduce fatigue and embrittlement will enable an improvement in transport capacity from legacy systems.
- Enhanced safety measures (leak detection and mitigation) along with “real-time” in-pipe sensing (blend composition and component integrity) are vital to ensuring resiliency of the transport system.

Hydrogen Storage at Surface Facilities and the Subsurface

- Existing storage mechanisms at refineries or end-use locations are commercial technologies, but safety considerations remain key, particularly at larger volumes.
- Subsurface storage can utilize depleted oil and natural gas reservoirs, as well as salt domes, but long-term storage permanence must be effectively demonstrated through rigorous characterization.



NATIONAL ENERGY TECHNOLOGY LABORATORY



OAK RIDGE National Laboratory

Lawrence Livermore National Laboratory

Pacific Northwest NATIONAL LABORATORY

Technologies for Enabling Safe and Efficient Transportation of Hydrogen in U.S. Natural Gas Pipeline System

- The objective is to develop technologies that improve the cost and performance (e.g., resiliency, reliability, safety, integrity) of hydrogen-natural gas blend (hyblend) transportation infrastructure, including pipelines, compression stations, hydrogen separation technologies, and systems analysis.
- To achieve this, DOE will develop cost-effective methods and technologies for:
  - Safe and effective bulk blending of hydrogen with natural gas and using the natural gas pipeline system;
  - Mitigating hydrogen leaks in pipeline infrastructure and handling equipment;
  - Mitigating the impact of hydrogen concentration on sensing and measurement equipment; and
  - Reducing or mitigating materials fatigue and failure.
- Development of new concepts to advance data management systems and improve infrastructure component flexibility (e.g., compressors, pneumatic controllers, seals, etc.) and advanced sensors and control systems for optimizing downstream use and leak detection will be a priority for safe and effective storage and transmission of blended streams.

Natural Gas Infrastructure & Hydrogen

Goals:

- 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 able to handle 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.
- Design challenges of hydrogen transport and compression include:
  - Materials and coatings
  - Light gas compression
  - Sealing
  - Safety
  - 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**

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Project Objective

- 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.
  - Elucidate **operational risks**, quantify the **potential for resource losses**, develop **enabling tools, technologies, recommended practices**, and develop a **collaborative field-scale test** plan in partnership with at least one natural gas storage industrial partner.
  - Focus on **reservoir performance** and **well component compatibility** in the storage system.
    - Pipelines and surface components upstream from the wellhead are covered by separate DOE research activities.
- Multi-National Lab Effort: Leverages unique capabilities and demonstrated expertise in subsurface energy systems.

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY | Pacific Northwest NATIONAL LABORATORY | Lawrence Livermore National Laboratory

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Key Questions & Outcomes

- How can the **technical and operational risks** associated with subsurface hydrogen storage be mitigated so that operations are protective of humans and the environment?
  - Assess and address the operational risks associated with reservoir storage.
- How can emerging technologies be leveraged to enable a **smart, safe, and efficient H_2 subsurface storage system** (e.g., sensors, reservoir simulators, and screening tools)?
  - Develop enabling technologies and tools.
- What **technical, operational, and techno-economic insights** are needed to enable large-scale subsurface storage for pure hydrogen or hydrogen/natural gas blends?
  - Develop a scientifically informed field test plan to reduce remaining uncertainties in system performance.
- **Accelerate and expand** the use of hydrogen by leveraging existing facilities (e.g., existing natural gas storage facilities) as storage sites across the United States.

Backup Slides

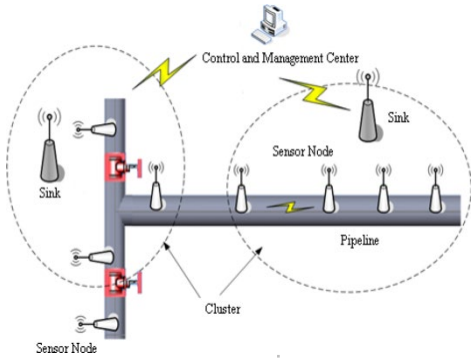
Methane Emissions Mitigation Technology Program

MISSION: Develop new technologies to reduce methane emissions across the natural gas supply chain in the United States.

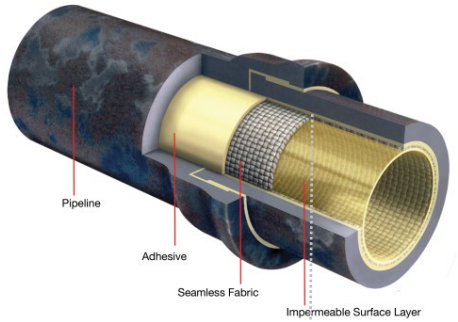
Research Elements

Develop advanced equipment technologies

Develop advanced sensors



Develop next generation pipeline liners and coatings



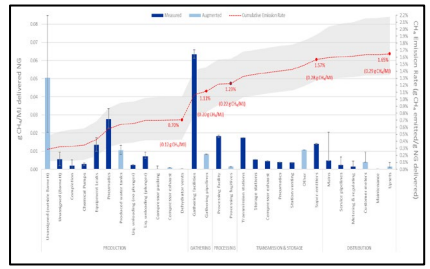
Develop Natural Gas Conversion and Flare Reduction Technologies

Characterize emissions from equipment and legacy wells

NETL – Industry – Universities

Regional differences in methane emissions

Life-Cycle Analysis



Smart Methane Emission Detection System

Objectives

- Develop an autonomous, real-time methane leak detection technology, the Smart Methane Emission Detection System (SLED/M), which applies machine learning techniques to passive optical sensing modalities to mitigate emissions through early detection.
  - Introduce automation to the process of methane leak detection to minimize sources of human error, response time to a leak event, and maximize midstream visibility.
  - Assist in the quantification process by providing a means of collecting temporal and spatial image data of a leak event.
  - Reduce operational costs of emissions detection technologies by significantly minimizing the need for operator involvement.

An autonomous, real-time methane leak detection system that facilitates early detection of emissions before they become a larger problem.

SLED/M Methane Plume Detection (red) of a plume that cannot be readily seen on the MWIR camera (upper photo). SLED/M mounted on a drone platform for aerial, real-time methane leak detection (lower photo).

Hydrogen with Carbon Management

- FECM's strategy to accelerate the energy transition towards a decarbonized economy that utilizes hydrogen as a clean fuel while utilizing suitable energy infrastructure.
- FECM will seek to leverage technologies that can be utilized to both reduce methane emissions and accelerate the availability and use of hydrogen fuel.
- Pathways that convert natural gas or other fossil-based feedstocks into hydrogen must ensure emissions are mitigated through carbon capture and storage (CCS) technologies.
- DOE will support transformational market-disruptive technologies that are needed in the coming decades to move towards net-zero, life-cycle greenhouse-gas emissions, while minimizing cost-differentials between fossil-based feedstocks, renewables, and conventional hydrogen production pathways.

The **Hydrogen Shot** is the first of a series of up to eight Energy Earthshots DOE will be launching over the next year. The Hydrogen Shot sets a goal to reduce the cost of hydrogen to $1 per 1 kilogram in one decade.