

The Strategic Role of Hydrogen in Oil and Gas And the Potential for Geologic Hydrogen

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INTRODUCTION

Hydrogen has been a versatile and indispensable commodity within the oil and gas sector for almost as long as the industry has existed. Historically, it has underpinned key refining processes; more recently, its importance has been magnified by industry-wide commitments to reducing emissions and meeting stringent product-quality standards. Already an established player in various downstream processes and markets, hydrogen storage caverns and pipelines are a small but growing part of the midstream, with recent success in geologic hydrogen exploration representing a nascent upstream market (Figure 1). This discussion explores the multiple ways in which hydrogen adds value — enhancing operational efficiency, enabling deeper emissions reductions, and opening new revenue streams — for upstream, midstream, and downstream segments of the oil and gas value chain.

Scientist J.B.S. Haldane originally proposed the concept of using hydrogen to store energy in 1923. In 1970, John Bockris, a chemist at General Motors, envisioned a multi-faceted “hydrogen economy” where hydrogen could serve as an energy medium and industrial feedstock to meet a number of transportation, industrial, and domestic needs. The International Association for Hydrogen Energy and the Hydrogen Council were later established in 1974 and 2017, respectively, to advance the development and deployment of the hydrogen economy globally.

Through various initiatives since 1992, Congress and the U.S. Department of Energy (DOE) have invested in research and development to reduce the cost of hydrogen production, advance steam-methane reforming with carbon capture, optimize high-performance electrolyzers, study long-duration storage solutions, and field-test safe distribution networks. The U.S. Energy Information Agency estimates that hydrogen demand will increase 80% by 2050, with the majority being produced from natural gas (EIA, 2025). The following sections describe the traditional uses of hydrogen in the oil and gas industry, economic and

strategic advantages of incorporating hydrogen, and the potential for geologic hydrogen to help meet growing demand.

TRADITIONAL USES OF HYDROGEN IN THE OIL & GAS INDUSTRY

Downstream: Refining and Upgrading of Petroleum

One of the enduring and primary uses of hydrogen lies in the oil and gas downstream sector for hydrotreating and hydrocracking units that transform crude oil marketable products.

- **Hydrotreating** removes sulfur, nitrogen, and other contaminants from middle distillates (like diesel and kerosene) by converting them into hydrogen sulfide (H_2S), ammonia (NH_3), and light hydrocarbons. This step is essential for meeting ultra-low-sulfur fuel mandates.
- **Hydrocracking** breaks heavy hydrocarbons into lighter, higher-value products (e.g., gasoline, jet fuel) at high pressure and moderate temperature in the presence of hydrogen and catalysts. The selectivity and yield of desirable products critically depends on the partial pressure of hydrogen and its purity.
- **Refinery Energy** can be created by burning hydrogen in refinery boilers or turbines either as pure hydrogen or co-fired with natural gas. Over time, incremental hydrogen co-firing can help meet internal emissions targets and reduce exposure to taxes or emissions-trading costs.

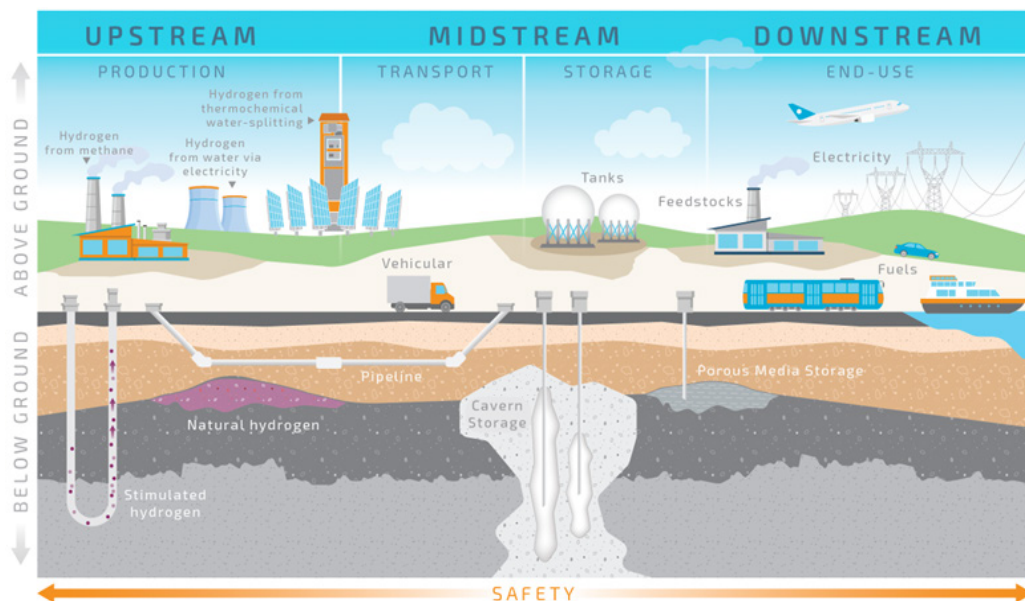


Figure 1. The Hydrogen Economy mimics the upstream-midstream-downstream sectors of the traditional oil and gas industry.

By supplying high-purity hydrogen, refineries can maximize conversion rates, reduce coke formation on catalysts, and extend catalyst life. This translates directly into improved plant availability, lowered downtime for maintenance, and better margins on refined products.

Midstream: Blending and Transport

- **Pipeline blending** of natural gas with hydrogen (up to 10–20%) reduces the carbon intensity of the delivered gas, which appeals to industrial consumers aiming for lower-emission feedstocks. By taking advantage of the ~1600 miles of existing hydrogen pipelines in the U.S., midstream operators can accommodate a gradual shift to lower-carbon gas without major infrastructure replacement. Honolulu, Hawaii, is already served by a blend of 85% methane and 15% hydrogen (Hawaii Gas, 2025).
- **Hydrogen carriers and storage**, such as liquid organic hydrogen carriers (LOHCs), methanol, or ammonia, can transport hydrogen over long distances. Significant research has been done in developing safe above- and below-ground storage systems, with the largest being three salt caverns on the Gulf Coast that have been in operation for decades.

By integrating hydrogen blending and transport, midstream operators diversify their product offerings and position themselves for a future hydrogen economy.

Upstream: Enhanced Oil Recovery (EOR) and Reservoir Management

In the upstream sector of the oil and gas industry, hydrogen can serve as a working fluid or reaction partner to improve hydrocarbon recovery:

- **Hydrogen-assisted steam-drive processes** reduce steam requirements by generating in-situ hydrogen via catalytic reactions with reservoir minerals, enhancing sweep efficiency.
- **Microbially enhanced oil recovery** leverages hydrogen as an electron donor to stimulate specific bacteria that generate biosurfactants, which lower interfacial tension and mobilize residual oil.

These innovative techniques can extend the economic life of mature fields, increase ultimate recovery factors, and defer the need for new exploration — thereby optimizing capital expenditure and reducing the cost per barrel produced.

ECONOMIC AND STRATEGIC ADVANTAGES OF HYDROGEN

Incorporating hydrogen into oil and gas operations can yield several benefits. First, producing and selling hydrogen opens new high-value markets — fuel-cell vehicles, industrial heat, and even export markets via methanol and ammonia — leading to **revenue diversification**. Second, refineries and petrochemical complexes often capture byproduct hydrogen; optimizing onsite reformers and purifiers reduces

feedstock costs for hydrotreaters while generating excess hydrogen that can be monetized, creating **cost synergies**.

Finally, there is the potential for **asset optimization**. Regional clusters of hydrogen producers and consumers linked by pipelines enable economies of scale, shared infrastructure, and risk pooling among multiple oil and gas players. The Gulf Coast has one of the key existing hydrogen clusters in the US where several salt cavern hydrogen storage facilities anchor a multi-hundred-mile hydrogen pipeline serving many petrochemical plants across the region.

Strategically, early investment in hydrogen infrastructure and markets provides incumbents with a competitive edge, safeguarding their role as reliable energy suppliers as the global energy mix evolves.

THE POTENTIAL OF GEOLOGIC HYDROGEN

Geologic hydrogen is an emerging upstream opportunity for the oil and gas industry who can apply traditional exploration and stimulation techniques to produce hydrogen from natural deposits. Exploration efforts for natural hydrogen pools are currently underway in Kansas, Nebraska, and Iowa, as well as in Australia, France, and elsewhere. Test wells in Kansas have also identified significant percentages of helium. Companies are also prospecting for iron-rich rocks that can produce stimulated hydrogen through the injection of catalysts, brine, or microbes with mechanical, thermal, or electrical processes.

The U.S. Geological Survey has asserted that the amount of natural hydrogen in the U.S. is equivalent to twice the amount of natural gas discovered to date and is broadly distributed across the nation (Ellis and Gelman., 2024; Gelman et al., 2025). This assessment does not cover stimulated hydrogen.

Geologic hydrogen development directly advances three of the DOE Secretary's priorities (DOE, 2025; Figure 2):

1. Increases American energy (Priority #1) by expanding the amount of energy available in the U.S. If we can locate it, geologic hydrogen may be the fastest energy source we can bring to market when compared to, for example, geothermal and nuclear options. It also expands where the current oil and gas industry can explore, with the potential for drilling in areas where oil and gas operations do not currently occur.
2. Exemplifies American energy innovation (Priority #2) by creating a new energy industry where our innovative oil and gas sector can directly apply their existing expertise.
3. Strengthens American grid reliability and security (Priority #8) by promoting more geographically distributed energy production, which minimizes reliance on centralized power generation.

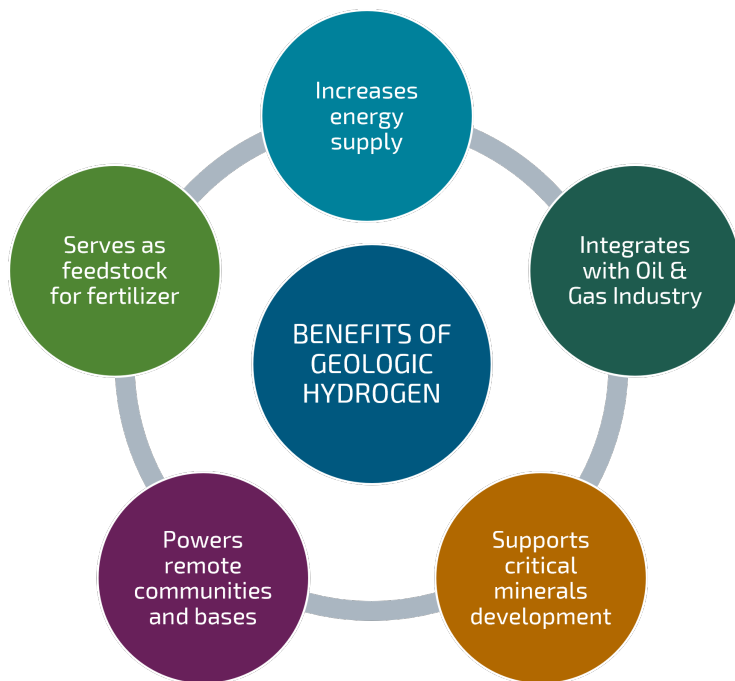


Figure 2. Major benefits of geologic hydrogen

Geologic hydrogen also supports Executive Order priorities:

4. Expanding American energy production (EO 14154)
5. Providing energy to develop American critical mineral resources, including in remote areas (EO 14241)
6. Developing energy and critical minerals in Alaska (EO 14153)

Finally, geologic hydrogen can address longstanding energy issues by:

7. Helping power remote communities and military installations (DOD Installation Energy Strategy, 2025), including those in Alaska and the Pacific Islands.
8. Supporting American agriculture as hydrogen is a vital feedstock for making ammonia-based fertilizers (Alexander, 2023; Widmar, 2025).

A significant amount of the science and technology developed for the underground storage and pipeline transport of hydrogen can also be applied to geologic hydrogen. This knowledge base includes techniques for characterizing, modeling, and modifying microbial communities in the subsurface to prevent hydrogen degradation; research to characterize the effects of hydrogen on reservoir rocks and caprocks; and reservoir simulation codes that can be modified to account for the flow of hydrogen in subsurface porous media. Another focus is the development of wellbore and pipeline materials for hydrogen service and sensors.

CONCLUSION

Hydrogen stands at the nexus of traditional oil and gas operations and new energy technologies like geothermal and critical minerals. Its proven value in refining — removing contaminants, upgrading heavy fractions, and boosting product yields — remains indispensable. Simultaneously, many pathways for finding or generating hydrogen reduce atmospheric emissions, comply with tightening regulations, and access emerging markets in transportation and industry. In the midstream, blending and carrier technologies leverage existing pipelines and terminals. In the upstream, creative EOR methods extend field life while geologic hydrogen may provide abundant hydrogen from natural deposits. By embracing hydrogen strategically, oil and gas operators can transform legacy assets into pillars of a diversified, low-emissions portfolio — ensuring resilience and profitability in a rapidly changing energy landscape.

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For More Information

Visit sandia.gov/geologic-hydrogen or send an email to geohydrogen@sandia.gov.