

Unlocking Geologic Hydrogen

2025 Edition

**The New American
Energy Gold Rush**



ABOUT US

VISION

The United States Hydrogen Alliance is a 501 (c)(6) non-profit association of members advocating for the development, deployment and utilization of clean hydrogen in all 50 states. We serve the hydrogen industry through state and federal policy advocacy, market development, and community building.

MISSION

Our mission is to leverage the unique attributes of hydrogen to reduce emissions across traditional sectors, increase energy resiliency and diversity, enhance local economies and workforces, and protect the nation domestically and abroad.

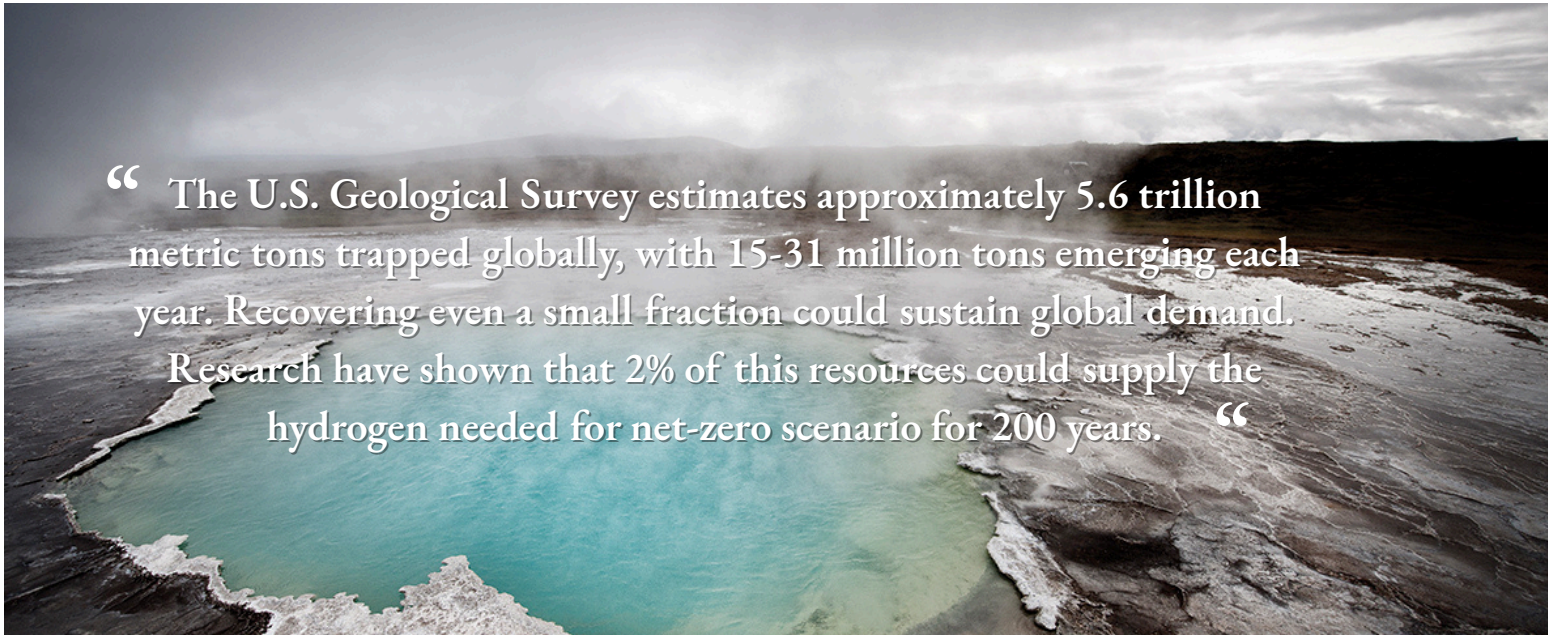
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Introduction



“ The U.S. Geological Survey estimates approximately 5.6 trillion metric tons trapped globally, with 15-31 million tons emerging each year. Recovering even a small fraction could sustain global demand. Research have shown that 2% of this resources could supply the hydrogen needed for net-zero scenario for 200 years. “

Hydrogen is one solution among many that can address exponentially growing energy demand globally, while still achieving decarbonization goals. Unlike manufactured hydrogen, geologic hydrogen is naturally formed and stored within the Earth's crust. Geologic hydrogen is increasingly receiving significant attention as a potential game changer in the energy landscape. Geologists now estimate trillions of tons of natural hydrogen beneath the Earth's surface, with hundreds of millions of tons generated annually. The U.S. Geological Survey (USGS) estimates approximately 5.6 trillion metric tons trapped globally, with 15-31 million tons emerging each year.^[1] Recovering even a small fraction could sustain global demand. Research has shown that 2% of this resource could supply the hydrogen needed for net-zero scenario for 200 years.^[2] However, current understanding of geologic hydrogen as an energy source is still at the nascent stage.

This report provides an overview on geologic hydrogen, introducing its formation mechanism, the production and storage, and the current state of global development. It further dives into the initiatives and key private sector actors in the United States, concluding with the remaining challenges and future outlook to leverage geologic hydrogen as a critical component in the energy mix.

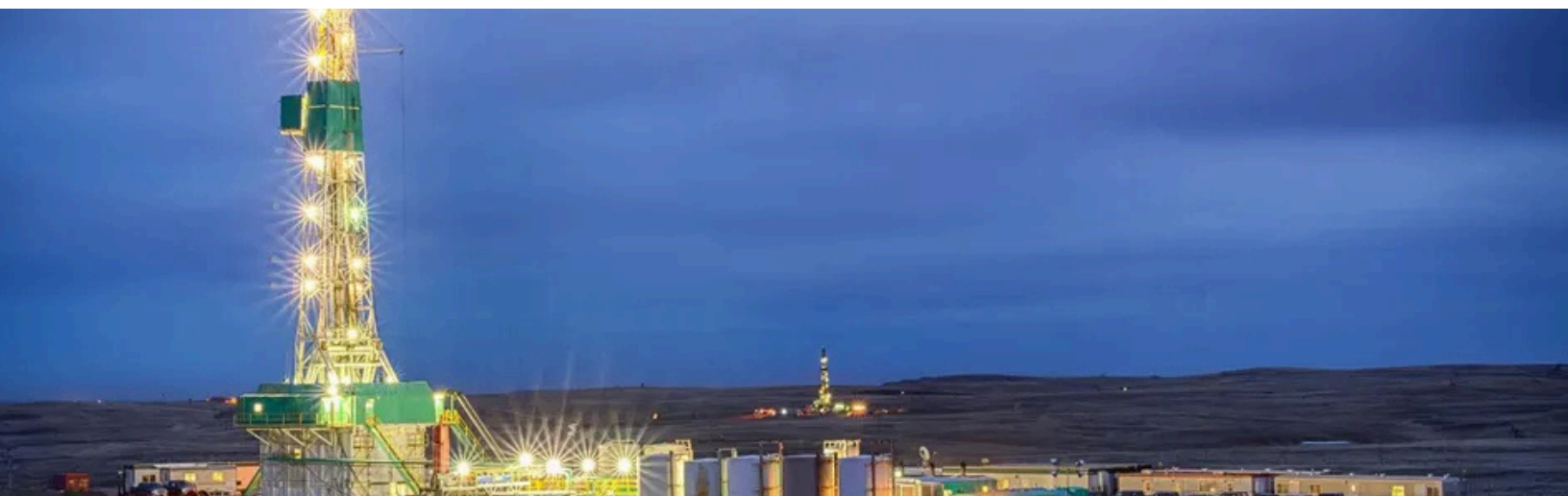
What is Geologic Hydrogen

Geologic hydrogen, also known as natural hydrogen, refers to hydrogen gas found naturally beneath the Earth's surface.^[3] This inherent geological origin fundamentally distinguishes it from hydrogen produced through industrial processes, such as the separation of hydrogen from methane or the electrolysis of water using electricity. Instead, geologic hydrogen is sourced by and stored within rock formations, much like traditional petroleum and natural gas resources. This makes it a primary energy source, rather than merely an energy carrier, a distinction that reshapes its economic and strategic value proposition and has profound implications for the energy transition.

The classification of geologic hydrogen as a primary energy resource is a significant redefinition within the energy sector. Historically, hydrogen has been considered predominantly as an energy carrier, meaning it must be manufactured from other energy sources, similar to how electricity is generated. The discovery and increasing understanding of naturally occurring hydrogen, however, suggest the possibility of direct extraction from natural reserves. This shifting perspective alters the entire energy supply chain, cost structure, and investment landscape in the sense that it implies less energy input is needed, only to extract it.

A notable advantage of geologic hydrogen is its natural storage. Typically, it exists in three forms: 1) as dissolved gas in groundwater; 2) as gas in mineral inclusions; or 3) as free gas, generated and stored in rocks underground. Among the three forms, only hydrogen as a free gas is currently recognized as a potentially viable energy source due to its scale, storage and currently available techniques and technologies. This natural containment can vastly reduce the additional costs associated with building extensive infrastructure for hydrogen storage facilities, lowering capital expenditure and operational complexities of integrating hydrogen into energy grids.^[4]

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How it Forms - Natural Processes

Geologic hydrogen forms through several natural processes within the Earth's crust. The two most commonly studied and promising mechanisms are serpentinization and radiolysis.

Radiolysis

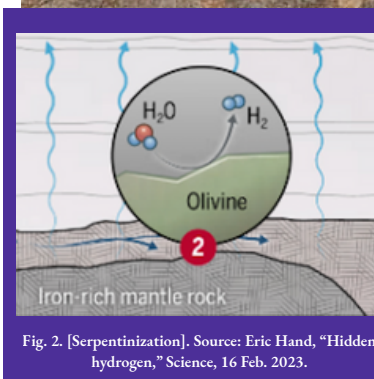
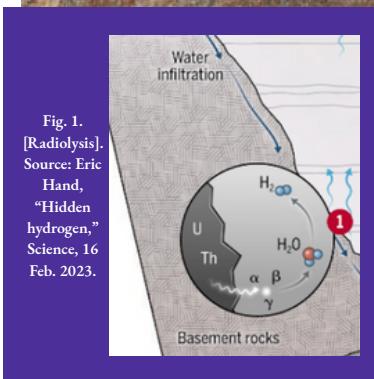
This refers to natural radiation emitted by decaying radioactive elements. This radiation breaks down water molecules to release hydrogen.^[5]

Serpentinization

This refers to the chemical reaction between water and iron-rich rocks, such as olivine and pyroxene, resulting in the liberation of hydrogen gas. This reaction can be observed in geological settings such as tectonic plate boundaries and mid-ocean ridges.^[6]

Comparison

Comparing these two mechanisms, serpentinization is relatively faster in its natural accumulation to produce hydrogen compared to radiolysis, which is important when considering the “renewability” of geologic hydrogen. However, this rate of accumulation and the technological reality of extraction is still an estimate, and has yet to be verified. This means while geologic hydrogen may offer long term sustainability, it may not be a rapid, large-scale replacement at the current stage. Technological advancements and detection of large quickly-replenishing reservoirs will be the key to unlock geologic hydrogen.



Production and Storage

Similar to petroleum and natural gas, the extraction of geologic hydrogen primarily involves drilling into underground reservoirs, utilizing long-established techniques present in the oil and gas industry. For naturally seeping hydrogen, engineers suggest that simply tapping pipelines into the subsurface reserves may be sufficient.

Beyond naturally occurring accumulations, researchers have been actively exploring alternate hydrogen production methods in relation to geologic hydrogen. Two recently studied methods include: injecting fluids into rocks to liberate hydrogen, or by processing mined rocks in industrial facilities to extract hydrogen. For example, Lawrence Livermore National Laboratory is exploring the use of short-chain organic acids to stimulate hydrogen production from olivine-bearing rock assemblages. Undertaking cutting edge research projects and acting on future-forward ideas is a key strategy for geologic hydrogen, as studies such as these accelerate processes and broaden resource pools.

Regarding storage, securing scalable geologic hydrogen is paramount for hydrogen to become a reliable energy source. Storing hydrogen comes with unique challenges due to its physical and chemical properties. The diffusive and reactive nature make it prone to leakage through rock formations or wellbore materials, as well as potential geochemical reactions between other minerals. Thus, effective underground storage solutions are critical to successfully expanding the capacity ceiling for billions of cubic meters of hydrogen. Several types of geological formations are being considered for this crucial role:

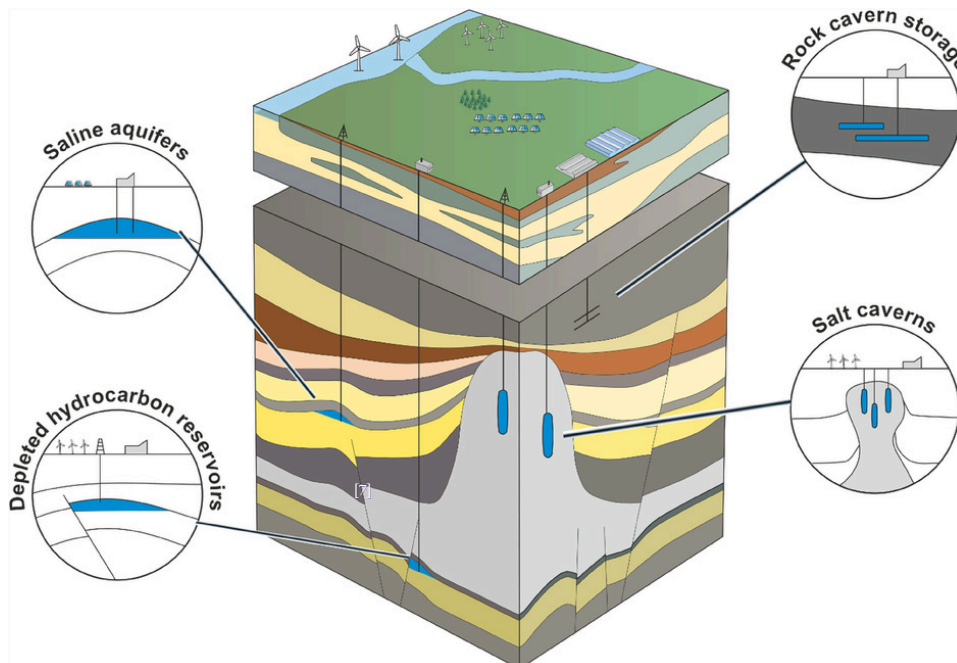


Fig.3. [Subsurface storage]. Source: Miocic et al., “Underground Hydrogen Storage,” Geological Society, London, Special Publications, 2022.

Storage-Subsurface Vessels

SALT CAVERNS

Artificial underground cavities created by dissolving salt deposits through solution mining. Known for their extremely low gas permeability, excellent sealing capacities, and high salinity, these caverns have the potential to prevent interactive activity with other gases that consume hydrogen.^[5]

Operational examples include the Advanced Clean Energy Storage in Utah and the HyPSTER project in France.^[6]

DEPLETED GAS FIELDS

This solution focuses on former natural gas reservoirs that could be repurposed for hydrogen storage once their original resources are extracted.^[9]

The already existing infrastructure is a proven long-term containment solution, and utilizing previously installed infrastructure also cuts costs.^[8]

SALINE AQUIFERS

These are subsurface layers of permeable, porous rock filled with water. Often hundreds of feet deep, these aquifers offer larger storage capacity due to their geological characteristics.

Past projects include Ketzin, Germany, Lobodice, Czech Republic, and Beynes, France.



Global Landscape

The pursuit of geologic hydrogen has rapidly intensified across the globe, given the comparative advantage and cost effectiveness, leading to what many are calling a “white gold rush”. The number of companies actively searching for natural hydrogen deposits has surged dramatically, quadrupling from 10 in 2020 to 40 by late 2023.^[10] Government incentives, such as the U.S. Inflation Reduction Act's Hydrogen Production Tax Credit, further amplify this commercial interest, making low-carbon natural hydrogen projects highly attractive for federal support. This global momentum indicates that policymakers should anticipate increased demand for exploration and development, necessitating proactive and harmonized regulatory frameworks to manage growth and ensure sustainable practices.^[11]

Exploratory efforts are now underway across multiple continents, including Australia, United States, Spain, France, Albania, Colombia, South Korea and Canada.^[12] Key indicators guiding these efforts include shallow circular depressions identified from satellite images in countries like Azerbaijan, Australia, Brazil, Mali, Namibia, Russia and the United States. These formations suggest fluid flow pathways for hydrogen migrating from depth to surface.^[13]

Despite active research and commercialization incentives around the world, there's only one successful operating geologic hydrogen production site with documented data to date—Mali, Africa.

Mali: A Pioneering Journey in Geologic Hydrogen



In the village of Bourakebougou, Mali, the world's *first and only* natural hydrogen site is in operation, demonstrating the incredible feasibility of geologic hydrogen as an energy source.

The story began in 1987, when hydrogen was accidentally discovered during an unexpected explosion in the water well drilling. Laboratory tests later confirmed that the deposit was 98% of pure hydrogen. For the following years, naturally occurring hydrogen became a scientific curiosity. It was not until 2012, the production at the Bourakebougou officially commenced. Led by the company Hydroma, previously known as Petroma, the first pilot project was launched and later developed into a drilling campaign of over 20 drilling wells to the reservoir between 100 meters to 1800 meters of depth below the surface. The production is approximately 5 to 50 tonnes of hydrogen annually, which primarily used to provide electricity power to the local village. This production rate is at max equivalent to 3 barrels of oil per day, and it's less than one-tenth of the energy generated by a single wind-turbine. Although its operation demonstrates the proof of concept for the vitality of extracting natural hydrogen, it is difficult to bring it to scale. Mali's case offers lessons and reference on the purity, flow rates and reservoir information for future geologic hydrogen projects.

United States Current Development

The United States aims to take the leadership position in hydrogen development, seeking to garner robust government support and private sector innovation.

The U.S. Geological Survey (USGS) has taken a foundational step by publishing the first-ever map of prospective geologic hydrogen locations in the U.S. This map reflects a systematic analysis of geological conditions favorable for hydrogen accumulation, including the presence of hydrogen sources, porous reservoir rocks, and effective seals to trap the gas.^[14] Key areas of interest identified include a mid-continent region spanning Kansas, Iowa, Minnesota, and Michigan, the Four corner states (Arizona, Colorado, New Mexico, Utah), the California coast, and areas along the Eastern seaboard.^[15] The USGS's research is dedicated to understanding the natural processes that lead to recoverable geologic hydrogen and is expanding its mapping efforts. Furthermore, the USGS actively collaborates with academic partners, such as the Colorado School of Mines, and a consortium of leading industry actors including BP, Chevron, Fortescue, Petrobras, Koloma and HyTerra.^[16] This collaborative program aims to advance the knowledge of geologic hydrogen and develop cutting edge surface and subsurface exploration technologies to locate deposits.

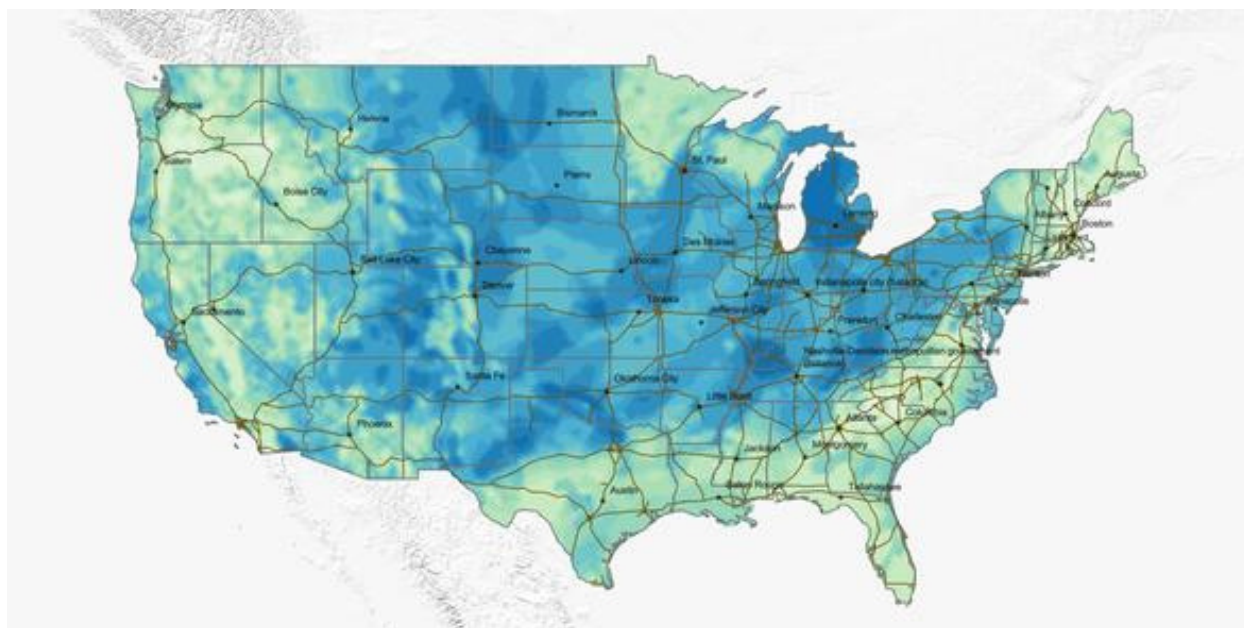


Fig.4. [U.S. prospective map of geologic hydrogen]. Source: U.S. Geological Surveys, 2025

The Department of Energy (DOE) also demonstrates clear commitment to geologic hydrogen beyond its research and funding in the H2@Scale initiative. On February 2024, the DOE announced \$20 million funding across 16 projects dedicated to stimulating research on geologic hydrogen production via subsurface engineering.^[17] This shifting focus and rapid adaptation of policy and funding mechanisms indicate a strong intention to embrace geologic hydrogen as a viable, low-carbon resource. The financial incentives further de-risk private investment and accelerate the sector's growth by signalling federal level support.

United States Commercial Activity

Private companies are also actively pushing forward the frontline of geologic hydrogen exploration and development in the United States, particularly in regions identified as highly prospective by government research.

Key companies and projects include:



HyTerra

The company is advancing natural hydrogen and helium exploration assets. Their 100% owned and operated Nemaha Project in Kansas, located within the emerging Nemaha High play fairway, is a key focus. Historical wells in the Nemaha region have shown high concentrations of hydrogen (up to 92%) and associated helium (up to 3%).^[18] Exploration drilling began in May 2024.



Koloma

The company is exploring hydrogen in the Midwest, and has received significant investment, notably from Bill Gates.^[19] Koloma is also listed as an industry partner collaborating with the USGS and Colorado School of Mines on geologic hydrogen research, effectively building public-private partnerships in order to understand and build out an effective framework for geologic hydrogen.



Natural Hydrogen Energy LLC (NH2E)

NH2E focuses on drilling natural hydrogen and associated helium, targeting at providing a cost-effective boost to the hydrogen economy. They are involved in the Geneva project in Nebraska through a joint venture with HyTerra.

Current U.S. exploration and drilling activities are mostly concentrated along the Midcontinental Rift. This concentration allows for the possible development of specialized regional expertise, localized supply chains, and dedicated infrastructure, potentially leading to the formation of “natural hydrogen hubs”.

Challenges Remain

Despite the promising potential of geologic hydrogen as an abundant, clean and cost-effective energy source, it faces considerable technical, economic, environmental and regulatory hurdles that need to be addressed if we hope for widespread commercialization and integration into the global energy system.

A primary technical challenge lies in accurately locating and characterizing commercially viable deposits. Most discoveries on geologic hydrogen to date have been accidental, highlighting the need for more systematic methods to pinpoint and characterize commercially viable accumulations. The challenge goes beyond finding where hydrogen gas is formed, but where it accumulates and persists in significant quantities and purity. This requires sophisticated predictive modeling and advanced sensing technologies. One such technology is a collection of hydrogen-sensing gas probes capable of detecting hydrogen at depths up to 3,000 meters. This is crucial to understanding the geologic hydrogen system - sources, migration pathways, reservoirs, traps, and seals. This complexity necessitates long-term, integrated research and planning, as well as rendering incentives along the production line.^[20]

Another hurdle: ensuring the purity of extracted hydrogen for commercialization. A higher concentration of at least 60% of the purity with mixed gases is required, while much of the detected hydrogen purity is below 40%.^[21] Even with a higher concentration, it's essential to separate hydrogen from other mixed gases such as methane, helium and nitrogen. Additionally, extracting hydrogen may also impose environmental impacts along the process. The life cycle analysis on greenhouse gas emission intensity of geologic hydrogen production varies depending on gas composition, well productivity and depth and pressure. In one case, researcher has found that greenhouse gas emission is estimated to be lower with a high percentage of hydrogen (85%) and a lower percentage of methane.^[22] The presence of these gases may lower the environmental benefit of hydrogen gas.



Future Outlook

Geologic hydrogen is at the precipice of transforming the global energy landscape. Its inherent advantages, being naturally occurring, potentially continuously generated, and offering a near-zero carbon footprint with significantly lower production costs than industrially manufactured hydrogen- make it an exceptionally promising resource for the clean energy transition. The burgeoning global interest, evidenced by the rapid increase in exploration companies and the pioneering operational site in Mali, underscores the growing recognition of its potential. Within the United States, robust government initiatives, including the USGS's comprehensive mapping efforts and the DOE's targeted funding, coupled with significant private sector investment, are accelerating the understanding and development of this resource. The strategic co-production of valuable helium further enhances the economic viability of these ventures.

However, the path to widespread commercialization is not without its complexities. Technical challenges persist in systematically locating and characterizing commercially viable deposits, ensuring hydrogen purity, and managing its unique properties like high diffusivity and reactivity within extraction and storage infrastructure. The risk of hydrogen embrittlement in materials and the need for hydrogen-specific storage standards highlight critical areas for ongoing research and development. Economically, while initial cost estimates are highly favorable, the scalability of extraction methods and the development of comprehensive regulatory frameworks remain areas requiring concerted effort. Environmental considerations, particularly regarding potential hydrogen leakage into the atmosphere and the careful management of co-produced gases, demand diligent scientific investigation and transparent communication.

Despite these challenges, the outlook for geologic hydrogen is one of cautious optimism. Its potential to decarbonize hard-to-electrify industries, provide energy security, and foster regional economic revitalization in areas with existing geological expertise positions it as a vital component of a diversified clean energy portfolio. To unlock its full potential, sustained investment in interdisciplinary research and development, the establishment of clear and adaptive policy frameworks, and continued collaboration among government, academia, and industry will be paramount. As the world strives for a net-zero future, geologic hydrogen offers a compelling, natural pathway to a cleaner, more sustainable energy economy.

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