EXECUTIVE SUMMARY

Hydrogen Separation Technologies

Purification of Hydrogen Stored in a Depleted Natural Gas Field

PRIMARY AUDIENCE

Companies interested in leveraging underground hydrogen storage resources. Midstream natural gas transmission and underground storage operators who are considering market expansion into hydrogen and the challenges faced when developing underground hydrogen storage facilities or converting existing underground natural gas storage facilities to hydrogen service.

SECONDARY AUDIENCE

Industrial end users, including electric utilities, who are potential large-scale hydrogen consumers in the future and need a reliable, resilient supply of hydrogen.

KEY RESEARCH QUESTION

Injecting hydrogen into a depleted natural gas reservoir or repurposed underground natural gas storage facility will result in hydrogen and natural gas mixing in the subsurface. Upon withdrawal, the gas mixture may need to be processed to remove the natural gas to produce the relatively pure stream of hydrogen needed for various end uses. This project focuses on answering the following research questions:

1. What contaminants might potentially be present, and what commercially available technologies are best suited for hydrogen separation at the storage facility or point of use?
2. Where does it make most sense to separate hydrogen from natural gas for applications that cannot tolerate contaminants?
3. What are the estimated costs for different separation technologies?

RESEARCH OVERVIEW

With the rise of low-carbon energy solutions, the hydrogen market has grown significantly in recent years. Underground hydrogen storage in depleted oil and gas reservoirs is a key technology that could enable large-scale hydrogen deployment by balancing hydrogen supply with demand on a daily to seasonal basis. Converting the U.S. underground natural gas storage fleet to hydrogen service could provide up to 9.8 million metric tonnes of hydrogen storage capacity. However, when the gas is produced or withdrawn from storage, it will consist of a mixture of hydrogen and natural gas that may need to be separated before end use. This report summarizes the current commercially available hydrogen separation technologies, including pressure swing adsorption (PSA), polymer membrane, cryogenic distillation separation, and potential alternative technologies with lower technology readiness levels.

Current sources of hydrogen are predominantly from large-volume production processes involving natural gas reforming and gasification. Electrolysis (splitting water) is another way to produce hydrogen. From these production methods, hydrogen is available in two main forms: a high-purity hydrogen product and a less purified syn gas, or town gas. The high-purity hydrogen is typically obtained through a PSA process following natural gas reforming or gasification, or directly from the electrolysis process. For the less purified form, syn gas from steam reforming of natural gas or town gas produced from coal gasification is stored without further purification, then purified after storage. Syn gas contains high levels of toxic carbon monoxide (CO), however, which represents a significant health and safety risk if a transmission pipeline connecting the production and storage facilities is damaged or fails. Therefore, even though there are global examples of underground storage of syn gas, it may be safer to transmit and store hydrogen instead.

The results from a LCRI modeling study on underground hydrogen storage in a depleted natural gas reservoir (EPRI report 3002028476) are used as input to the gas separation study described herein. The prior study showed that upon withdrawal from the underground storage reservoir, the gas mixture contained hydrogen concentrations (purities) ranging from 65 to 99%. The maximum withdrawal pressure ranged from 60 to 150 bars for various reservoir depths. In such cases, PSA and cryogenic distillation are suitable for purification, as these methods are often used with high hydrogen concentrations in the feed gas.

In this study, PSA and cryogenic distillation systems have been modeled to estimate the capital and operational costs to produce 25,000 kg/hr of hydrogen, similar to the amount produced by a typical steam methane reforming (SMR) or autothermal reforming (ATR) system. The capital cost of PSA hydrogen purification is estimated to be \$0.002–\$0.02/kg hydrogen, and the O&M cost of the PSA system is estimated to be \$0.001–\$0.02/kg hydrogen. The cost of cryogenic distillation hydrogen purification ranges from \$0.015 to \$0.03/kg hydrogen for a total hydrogen removal rate of 95–70%. The operation and maintenance (O&M) cost of the cryogenic system is estimated to be \$0.01–\$0.13/kg hydrogen, with cooling duty being the largest cost item.

Based on the technical parameters investigated across various pathways and technologies, it appears PSA could meet higher purity requirements at a lower cost for large hydrogen volumes associated with underground storage. The PSA purification step can ensure the safe and efficient utilization of hydrogen from underground storage, contributing to the broader transition towards a sustainable hydrogen economy.

KEY FINDINGS

- The Impurities in hydrogen withdrawn from large underground storage facilities originate from several sources, including the initial hydrogen production; mineral, biological, and thermal decomposition; and hydrocarbons.
- There are three main types of hydrogen separation technologies: PSA, cryogenic distillation, and membrane.
- The capital cost of PSA hydrogen purification is estimated to be \$0.002–\$0.02/kg hydrogen, and the operation and maintenance (O&M) cost of the PSA system is estimated to be \$0.001–\$0.02/kg hydrogen.
- The cost of cryogenic distillation hydrogen purification is \$0.015–\$0.03/kg hydrogen for a total hydrogen removal rate of 95–70%. The O&M cost of the cryogenic system is estimated to be \$0.01–\$0.13 /kg hydrogen, with cooling duty being the largest cost item.
- Based on the technical parameters investigated, PSA appears suitable for separating hydrogen from large underground storage.

WHY THIS MATTERS

Hydrogen separation technologies downstream of large underground storage systems ensure that hydrogen meets the necessary purity standards for various hydrogen end use applications. Safety, pipeline compatibility, efficiency and performance, regulatory compliance, economic value, and environmental impact are the key parameters in determining the hydrogen purity requirements.

Hydrogen separation after underground storage is essential for ensuring the safety, efficiency, and economic viability of hydrogen as an energy carrier and industrial feedstock. It plays a critical role in the broader adoption and success of hydrogen technologies in the transition to a low-carbon economy.

HOW TO APPLY RESULTS

The report reviews the value chain for current hydrogen production to end use. It provides guidance for purification technologies for gas withdrawn from large underground storage.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- This report includes an overview of current hydrogen separation technologies.
- The report identifies methods and provides evaluations of technologies that could be applied to large-scale underground hydrogen storage and gas purification requirements for transmission and use.

THE LOW-CARBON RESOURCES INITIATIVE

This report was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of EPRI and GTI Energy addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

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