INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 15570–15582

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Geologic storage of hydrogen: Scaling up to meet city transportation demands

Anna S. Lord[*], *Peter H. Kobos*, *David J. Borns*

Sandia National Laboratories, PO Box 5800, Albuquerque, NM 87185-0706, USA

ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form
18 July 2014
Accepted 22 July 2014
Available online 22 August 2014

Keywords:
Geologic storage
Hydrogen infrastructure
Hydrogen economy
Technology cost assessment

ABSTRACT

Over the last decade, there has been a growing interest in large-scale use of hydrogen in the transportation and renewable energy sectors. Relatively cost-effective storage options at scale are essential to realize the full potential of hydrogen as an energy carrier. Underground geologic storage of hydrogen could offer substantial storage cost reductions as well as buffer capacity to meet possible disruptions in supply or changing seasonal demands. Several geologic storage site options are being considered including salt caverns, depleted oil and/or gas reservoirs, aquifers, and hard rock caverns. This paper describes an economic analysis that addresses the costs entailed in developing and operating a geologic storage facility. The analysis focuses on salt caverns to illustrate potential city demand for hydrogen using geostorage options because (1) salt caverns are known to successfully contain hydrogen, and (2) there is more geotechnical certainty involved with salt storage as compared to the other three storage options. The main findings illustrate that geologic limitations rather than city demand cause a larger disparity between costs from one city to the next. For example Detroit hydrogen storage within salt caverns will cost approximately three times more than Los Angeles with its larger population. Detroit is located near thinly bedded salt formations, whereas Los Angeles has access to more massive salt formations. Los Angeles requires the development of larger and fewer caverns and therefore has lower costs.

Introduction

In recent years there has been a push to focus on sustainable energy in order for the U.S. to become less reliant on fossil fuels. Hydrogen-fueled vehicles have been suggested as a feasible alternative to fossil-fuel dependence. Viable technologies exist to produce, store, and use hydrogen as a fuel for transportation. The current limiting factor for widespread adoption of hydrogen-fueled vehicles is the lack of necessary supporting infrastructrure—the challenge is in building an infrastructure that is economically feasible. The successful implementation of hydrogen-fueled vehicles requires an economically viable way to produce, transport, store, and deliver the hydrogen to the consumer. This paper examines the options and economics of the storage component within the infrastructure chain, specifically to focus on underground geologic storage. Previous analyses of the hydrogen infrastructure ([1–3]) indicate that there may be an important role for geologic storage to meet demand and reduce costs. The need, similar to fossil–energy stocks, is to buffer seasonal demands, provide continuity in case of disruption in the supply chain, and control congestion in the pipeline system.

* *Corresponding author*. Tel.: +1 505 284 5588; fax: +1 505 844 0240.
E-mail address: acsnide@sandia.gov (A.S. Lord).
http://dx.doi.org/10.1016/j.ijhydene.2014.07.121

Geologic storage is used extensively in the oil, natural gas, and compressed air energy industries. To illustrate the scale of this utilization, approximately 800 million barrels of oil [4] and 1000s of billion cubic feet of natural gas [5] are stored geologically in the U.S. The basic drive for geologic storage is the sizable volume available for storage, which allows buffering of seasonal demands. Geologic storage also can provide a sizable financial asset, continuity of delivery in case of disruption in the supply chain, and control of congestion in the pipeline system [6].

The storage of hydrogen within the same type of facilities, currently used for natural gas, may add new operational challenges to the underground storage industry. Hydrogen is a small, light molecule that reacts with other elements and steel at high pressures and temperatures. Loss of hydrogen could occur through such reactions. The operations of existing storage facilities may need to be adapted to prevent hydrogen embrittlement of the steel infrastructure [7].

The type of rock formation under consideration for hydrogen storage will have profound effects on the physical and economic viability to utilize that site. Four types of geologic storage options were examined for this analysis. Currently salt caverns, depleted oil and gas reservoirs, and aquifers are the three main types of underground storage in use for natural gas today [8,9]. Other storage options available now and in the near future, such as lined hard rock caverns, will become more popular as the demand for natural gas storage grows, especially in regions where depleted reservoirs, aquifers, and salt deposits are not available.

There are four locations worldwide, three of which are in the United States, that store hydrogen. All four sites store hydrogen within salt caverns. However, there have been successful cases of storing both town gas (50–60% hydrogen [10,11]) and helium (another small, light molecule [12]) within aquifers successfully, thus possibly inferring the same media *may* be suitable for storage of hydrogen gas. Future field tests need to be conducted to validate geological storage as an option.

To test the economic viability of specific types of geologic hydrogen storage, the Hydrogen Geological Storage Model (H2GSM) was developed by Sandia National Laboratories (SNL). Fig. 1 illustrates the overarching assessment methodology and analytical framework of the H2GSM model. H2GSM is a prototype analytical framework developed to highlight the major components of a 'gate-to-gate', large-scale hydrogen storage facility (the analysis focuses on the storage infrastructure only). This model illustrates the analysis from a physical infrastructure, hydrogen flow, and cost perspective [13]. The analysis includes four storage options, namely salt caverns, depleted oil and gas reservoirs, aquifers, and hard rock caverns.

H2GSM was adapted to provide geologic storage input for Argonne National Laboratory's (ANL) Hydrogen Delivery Scenario Analysis Model (HDSAM). HDSAM is a hydrogen transport and delivery model, which includes geologic storage of gaseous hydrogen as one of the model components [14,15]. The model was developed to help determine the most cost effective hydrogen infrastructure from supply to demand. SNL was tasked to address the costs entailed in developing and operating an underground geologic storage facility within salt for various city demand scenarios [13]. The analysis focused on salt caverns because (1) salt caverns are known to successfully contain hydrogen, and (2) there is more geotechnical certainty involved with salt storage compared to the other three storage options [16].

Geologic storage options

This section presents an overview of the various types of geologic storage currently in use for the storage of natural gas. The intent is to give an understanding of geologic storage, to describe the different storage types, and to state the

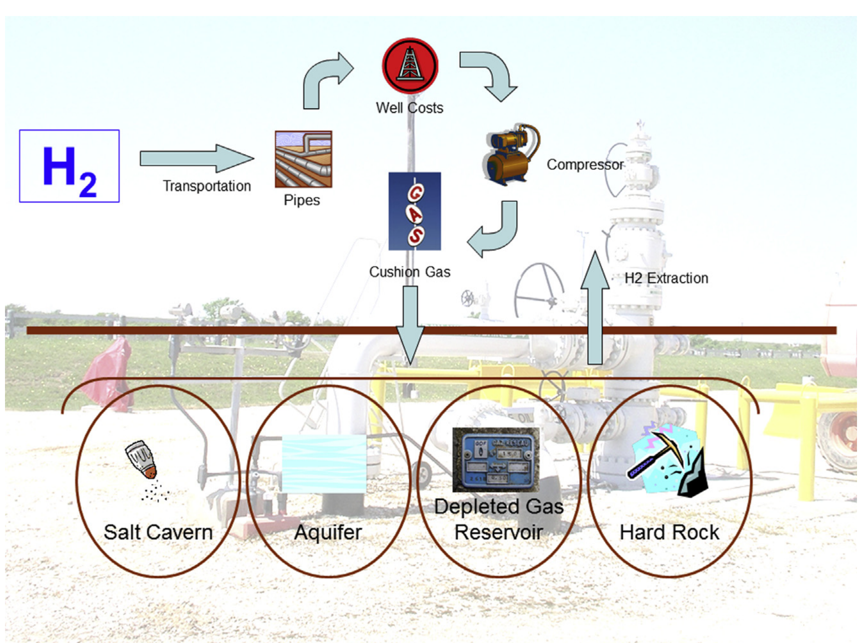

Fig. 1 – The assessment methodology and model framework.