III.14 Geologic Storage of Hydrogen

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Project Start Date: May 1, 2007
Project End Date: September 30, 2009

Objectives

To determine the suitability and availability of underground geologic storage for hydrogen by 1) developing a white paper that will present an understanding of geologic storage types, and by 2) analyzing the costs to develop and operate these various storage sites. The paper will describe:

- Different storage types
- Advantages and disadvantages of the different storage types
- Include maps of locations where storage is available
- Discuss operational issues specific to hydrogen

The economic analyses will address:

- Development costs
- Plant costs
- Operational costs

Technical Barriers

This project addresses the following technical barrier from the Hydrogen Delivery section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(H) Geologic Storage

Technical Targets

This project will present an understanding of the various types of underground geologic storage available and their suitability for the storage of hydrogen. An economic analysis will portray the probable costs entailed in developing and operating the most viable candidates for the underground storage of hydrogen. This information and analyses will help DOE achieve its technical target for geologic storage as presented in Table 1.

TABLE 1. DOE Technical Target for Geologic Caverns

Category	Current Status	2017 Target
Installed Capital Cost	Assumed equal to natural gas	Equal to natural gas caverns

Accomplishments

- Wrote a white paper describing the various types of underground geologic storage options available for the storage of natural gas.
- Produced four location maps showing the available underground storage sites in the U.S.
- Identified the three most likely geologic candidates for the underground storage of hydrogen, these being, 1) salt caverns, 2) depleted gas reservoirs, and 3) aquifers.
- Identified possible issues with storing hydrogen in geologic formations that may need to be addressed
  - Hydrogen embrittlement
  - Hydrogen mobility
  - Gas mixing
  - Chemical reactions
  - Effect on rock properties

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Introduction

The concept of storing natural gas underground in geologic formations arose from the need to supply gas to consumers during periods of high seasonal demand. The storage of natural gas is also an insurance policy against accidents and natural disasters. There are currently several types of underground storage used for natural gas with the three prominent types being depleted gas reservoirs, aquifers, and mined salt caverns. Understanding these various geologic storage types will help identify what geologic option would be best suited for the storage of hydrogen. Currently there are only three locations worldwide, two of which are in the United States, which store hydrogen. All three sites store hydrogen within salt caverns.

The project has an interest in understanding these types of underground storage options in the hopes of developing an underground facility for the storage of hydrogen, as a low-cost storage option, as part of the hydrogen delivery infrastructure. To date a white paper has been written that gives 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 advantages and disadvantages of the underground facilities as they relate to natural gas. The paper also addresses the possible geological, geomechanical, and operational issues that may be encountered with the storage of hydrogen versus natural gas.

Approach

To achieve the project objective, which entailed writing a paper describing underground geologic storage, an extensive literature search was conducted. The goal of the literature search was to collect information pertaining to 1) the underground geologic storage options currently in use for natural gas, 2) possible alternative storage options currently being tested, 3) the advantages and disadvantages of each option, 4) the location of these storage types, 5) the possible problems that may arise with the storage of hydrogen versus natural gas, and 6) current examples of underground facilities storing hydrogen gas.

Results

The outcome of the literature search and resulting paper provides an understanding of the underground storage options available for hydrogen. In many regions across the nation geologic formations are currently being used to store natural gas underground. Natural gas is stored to meet seasonal demands and to protect against accidents and natural disasters that could cause a disruption in supply. Storage of natural gas is used to meet both base load and peak load requirements. Storage options are dictated by the regional geology and the operational need. See Figures 1-4 for locations of available storage based on rock type.

Currently, depleted gas/oil reservoirs, aquifers, and salt caverns are the three main types of underground natural gas storage in use today. The other storage options available currently and in the near future, such as abandoned coal mines, lined hard rock caverns, and refrigerated mined caverns, will become more popular as the demand for natural gas storage grows, especially in regions were depleted reservoirs, aquifers, and salt deposits are not available.

Underground storage must have adequate capacity and containment of gas. The storage formation must have high permeability in order for gas to be injected and extracted at adequate rates. Porous reservoirs such as depleted gas reservoirs and aquifers must possess an impermeable caprock along with a geologic structure to contain and trap gas. Mined caverns such as salt caverns contain gas by the impermeability of the surrounding host rock.

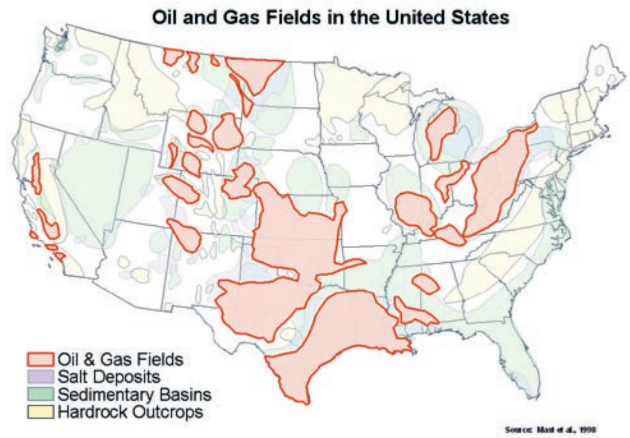

FIGURE 1. Location of Major Oil and Gas Fields across the U.S.

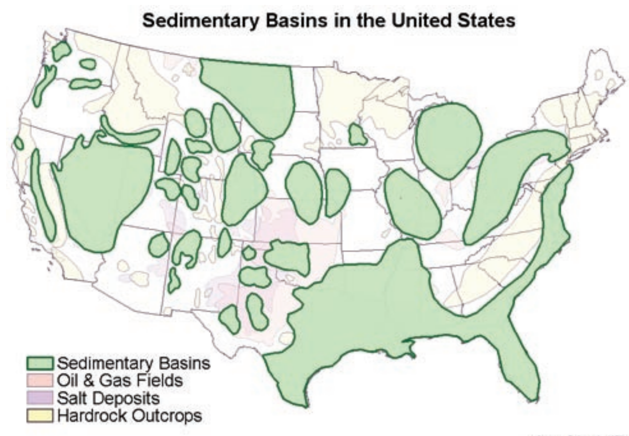

FIGURE 2. Location of Major Sedimentary Basins across the U.S.

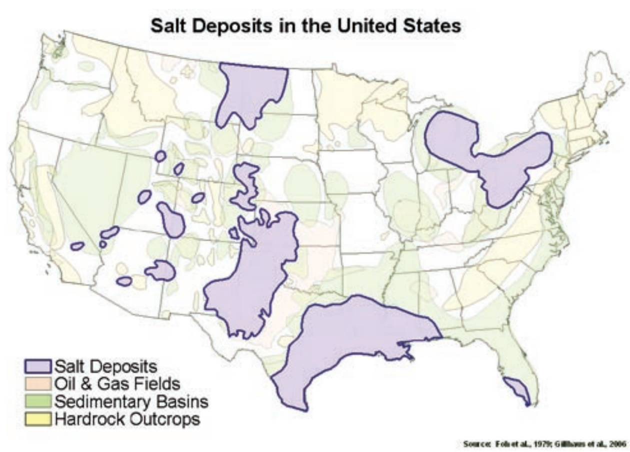

FIGURE 3. Location of Major Salt Deposits across the U.S.

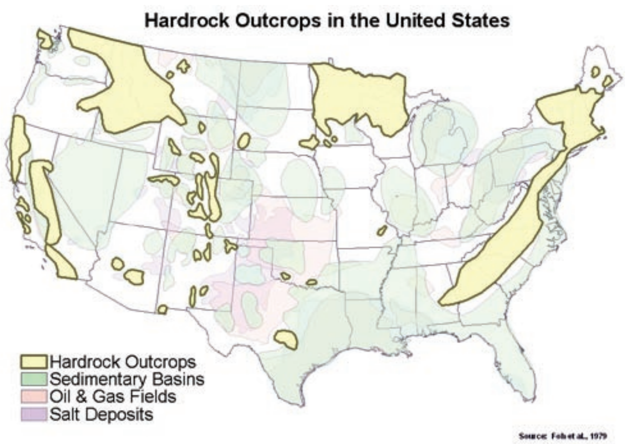

FIGURE 4. Location of Favorable Outcrops of Igneous and Metamorphic Rocks across the U.S.

Aquifers and depleted reservoirs possess the largest capacity and require the greatest volume of cushion gas. The reservoirs are typically cycled once annually and are used to meet base load demand. Unlike depleted reservoirs aquifers must be proven to trap and contain gas.

Salt caverns are solution mined and hold a fraction of the gas volume of depleted reservoirs and aquifers. Salt caverns are typically used to meet peak load demands by possessing multi-cycle capabilities and providing high delivery rates.

Excavated caverns within rocks such as coal and granite contain volumes less than aquifers and depleted reservoirs and are generally developed in regions where reservoirs are not available. Excavated caverns by nature are not completely impervious to gas loss. Several techniques have been developed to insure gas containment, such as lining caverns with steel and increasing the hydraulic pressure surrounding the caverns.

Economically, aquifers cost the most to develop and operate. The major costs contributed are those due to the large cushion gas requirements and the need to verify the reservoirs capability to contain gas. Salt caverns are the most economical, due to their multi-cycle capabilities and high annual throughput of gas. Salt caverns are typically used to meet peak load demands.

The storage of hydrogen within the same type of facilities, currently used for natural gas, may add new operational challenges to the existing cavern storage industry, such as the loss of hydrogen through chemical reactions and the occurrence of hydrogen embrittlement. However, it has been shown that if the underground storage of hydrogen is operated at pressures below 1,200 psi and at temperatures below 500°F there may be little need for concern. It is recommended that all steel used in the storage site be free of defects and posses low-yield-strength.

In the U.S. two companies, ConocoPhillips and Praxair, currently store hydrogen underground. The hydrogen is stored in salt caverns, both which are located within the Clemens salt dome in Texas.

Conclusions and Future Directions

After reviewing the storage options that are currently available for hydrogen the following conclusions have been made.

- There are three probable candidates for the underground storage of hydrogen:
  - Salt caverns
  - Depleted gas reservoirs
  - Aquifers
- Salt caverns are currently the only underground facility used to store hydrogen.
- Degradation resistant materials, such as low-yield-strength steel, should be used for site construction to prevent hydrogen embrittlement and gas leaks.
- Additional research may need to be conducted in the following areas to ensure hydrogen containment and purity:
  - Hydrogen mobility
  - Hydrogen embrittlement
  - Gas mixing
  - Effect of hydrogen on rock properties

The next step in reaching the technical target of maintaining capital costs similar to natural gas storage is to perform an economic analysis on the three types of storage sites being considered for hydrogen. An in depth analysis will include:

- Site development costs
- Plant costs
- Operational costs

FY 2008 Publications/Presentations

1. 2008 Hydrogen Delivery Tech Team Meeting, Columbia, Maryland, February 2008, Presentation entitled: Geological Storage Project Update.

References

1. Foh, S., M. Novil, E. Rockar, and P. Randolph. *Underground Hydrogen Storage Final Report.* Brookhaven National Laboratories, Upton, NY, December, 1979.

2. Gillhaus, A., F. Crotogino, and D. Albes, *Compilation and evaluation of bedded salt cavern characteristics important to successful cavern sealing, Part 1: Worldwide* *bedded slat deposits and bedded salt cavern characteristics*. 2003-5-SMRI. Solution Mining Research Institute Research Project Report, March 2006.

3. Mast, R.F., D.H. Root, L.P. Williams, W.R. Beeman, and D.L. Barnett, *Areas of historical oil and gas exploration and production in the conterminous United States*, U.S. Geological Survey Geologic Investigations Series I-2582, scale 1:3,750,000, 1998.