Geologic Storage of Hydrogen

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Sandia National Laboratories
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pd_33_sniderlord
Overview

Timeline
Start – May 1, 2007
Finish – Sept. 30, 2009
75% complete

Barriers
Barrier - Geologic Storage
Target – Geologic Caverns

<table>
<thead>
<tr>
<th>Geologic Caverns</th>
<th>2005 Status</th>
<th>FY 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capital Cost</td>
<td>Assumed equal to natural gas caverns</td>
<td>Equal to natural gas caverns</td>
</tr>
</tbody>
</table>

Budget
Total Project Funding
- DOE share ($200K)
- Contractor share (N/A)
Funding received in FY08 $100K
Funding received in FY09 $0K

Partners
None
Relevance

Objectives

This project will present an understanding of the various types of underground geologic storage available and their suitability for the storage of hydrogen by developing a white paper.

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 the table below.

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Relevance (cont.)

The white paper describes:
• Different storage types
• Advantages and disadvantages of the different storage types
• Includes maps of locations where storage is available
• Discusses operational issues specific to hydrogen

The economic analyses will address:
• Development costs
• Plant costs
• Operational costs
## Approach

### Milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>% Complete</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview of geologic storage</td>
<td>100</td>
<td>White paper written</td>
</tr>
<tr>
<td>Develop maps of available geologic storage in the U.S.</td>
<td>100</td>
<td>Maps are included in white paper.</td>
</tr>
<tr>
<td>Analyze issues related to geologic storage, specific to hydrogen</td>
<td>100</td>
<td>Included in white paper</td>
</tr>
<tr>
<td>Complete as SAND report</td>
<td>95</td>
<td>Pending formatting.</td>
</tr>
<tr>
<td>Develop cost models for: salt, depleted oil/gas reservoir, aquifer</td>
<td>40</td>
<td>Salt model complete. Other models in progress.</td>
</tr>
</tbody>
</table>
Technical Approach

(A) Conduct an extensive literature search.

Collect information pertaining to

- the underground geologic storage options currently in use for natural gas,
- possible alternative storage options currently being tested,
- the advantages and disadvantages of each option,
- the location of these storage types,
- the possible problems that may arise with the storage of hydrogen versus natural gas,
- current examples of underground facilities storing hydrogen gas.
Technical Approach (cont.)

(B) 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
Geologic Storage - Technical Accomplishments

Currently used for the storage of oil, natural gas, and compressed air.

Why underground storage?
Stored energy can be used to:
(1) meet seasonal energy demands and
(2) ensure continuity in supply during accidents or natural disasters
Geologic Storage - Technical Accomplishments

Types of Underground Storage

**Porous Media** (e.g. sandstone)
- Examples: depleted oil/gas reservoirs and aquifers

**Cavern Storage**
- Examples: excavated or solution mined rocks, such as salt, coal, igneous, and metamorphic rocks.

Basic Storage Requirements

High **porosity**, high **permeability**, hold adequate volumes of gas, extract gas at high rates, contain and trap gas, and cushion gas.
# Geologic Storage - Technical Accomplishments

## Types of Underground Storage

<table>
<thead>
<tr>
<th>Salt Caverns</th>
<th>Depleted Oil/Gas Reservoirs</th>
<th>Aquifers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt caverns are solution mined cavities within either salt domes or bedded salts that do not match reservoir volume capacity.</td>
<td>Depleted reservoirs are proven gas reservoirs that are easy to develop and operate due to existing infrastructure.</td>
<td>Aquifers are similar in geology to depleted reservoirs, but have not been proven to trap gas and must be developed.</td>
</tr>
</tbody>
</table>

There are other storage options available currently and in the near future, such as abandoned coal mines, lined hard rock caverns, and refrigerated mined caverns.
Geologic Storage - Technical Accomplishments

Locations of available geologic storage
Hydrogen is a light, small molecule

The molecule characteristics and the hydrogen purity demand may limit storage options. Future analyses may be needed to investigate possible issues with hydrogen storage.

**Issues?**

- Mixing of hydrogen with natural gas? – depleted gas/oil reservoirs
- Flow, diffusion and fingering of hydrogen into water-bearing units? – depleted gas/oil reservoirs and aquifers?
- Hydrogen embrittlement? – all storage options?
- Chemical reactions? – depleted gas/oil reservoirs and aquifers?

Hydrogen storage in **Salt** caverns does not pose significant issues.
Economic Model - Technical Accomplishments

H2 Geological Storage Model

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

Prototype, version 3/2009

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Economic Model - Technical Accomplishments
Economic Model - Technical Accomplishments

Assessing Underground Storage Options for Hydrogen: A Systems Analysis

- Compressor Capital Cost
- Cushion Gas Capital Costs
- Cavern Capital Cost

- Cavern Size: 580,000 m³
- Pressure: 2,000 psi
- Temperature: 311 K
- Mass of H₂: 6,235,514 kg
- Well Costs: $25,134,393
Economic Model - Technical Accomplishments

Assessing Underground Storage Options for Hydrogen: Inventory and Cushion Gas Assessment

- **Compressor Cushion Gas Cavern**
- **Capital Cost** $8.06 per kg
- **Levelized Cost** $1.17 per kg
- **Inventory**
  - 0 kg
  - 3,000,000 kg
  - 6,235,514 kg

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Inventory Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Cushion Gas kg⁻¹</td>
<td>Compressor Discount Rate %</td>
<td>Cushion Gas Percent of Total %</td>
</tr>
<tr>
<td>$4</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>$2</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>$0</td>
<td>0</td>
<td>70</td>
</tr>
</tbody>
</table>

- **Compressor Equipment Lifetime** 20
- **Time to Adjust Production** 7.00 da
- **Time to Stop Production** 1.00 da
- **Time to Change Expected Demand** 1.00 da
- **Time to Correct Inventory** 7.00 da
- **Inventory Coverage** 30.00 da

*Working, Illustrative Prototype Results as of 3/2009*
Collaborations

Looking to incorporate the economic model, which is modular by design, with other larger hydrogen infrastructure assessment models, such as, Argonne National Labs “Wheels to Wells” model.
Future Funded Work

<table>
<thead>
<tr>
<th>Timeline</th>
<th>2008</th>
<th>2009</th>
<th>Spring</th>
<th>2009</th>
<th>Summer +</th>
</tr>
</thead>
</table>

- **Complete:** Salt cavern cost model
  - Developed ‘H₂ Geological Storage Model’ in PowerSim Studio
  - Included capital and operating costs

- **Ongoing:** Salt Cost Model
  - Purification/Dehydration units
  - Leaching plant
  - Pipes
  - Brine disposal
  - Cycle frequency related to demand requirements

- **Future:** Develop similar models for geologic underground storage.
  - Depleted Oil/Gas Reservoir
  - Aquifers
Proposed Future Work

(1) Modularize the existing hydrogen storage model
   • Integrate with surrounding infrastructure
   • Determine how the existing infrastructure could be used to support
     the initial transport of hydrogen to fuel a trial fleet of H₂ vehicles

(2) Investigate further possible operational challenges
   • Due to the possibility of reservoir mixing, hydrogen loss through
     chemical reactions, and the occurrence of hydrogen embrittlement

(3) Incorporate GIS information into the H₂ storage model
   • Allows map data to be extracted that could aid in optimizing
     suitable geographic locations for storage
Summary

Relevance – To understand the various types of geologic storage available for hydrogen and portray the potential costs.

Approach – To develop a white paper and storage cost model.

Technical Accomplishments – Described the advantages and disadvantage of various geologic storage options; created a tool that will be used to develop the costs of salt cavern storage facilities.

Future work – develop similar cost models for depleted oil/gas reservoirs and aquifers.