GEOGULF2021
AUSTIN
October 27–29, 2021

Hydrogen Geological Storage Valuation Framework

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ABSTRACT

As hydrogen technology and market landscape evolve quickly, there is a real sense of urgency in research and development of hydrogen storage technology solution that would fit the needs of U.S. energy and economic system. Storage plays a critical role to provide cost-effective and reliable fuel options to connect various production pathways to emerging market applications. Underground geological storage of hydrogen has the potential of cost-effective seasonal or longer-term storage as needed to respond to variations in supply and demand and compares favorably to above-ground storage options in term of storage capacities, cost, and safety.

This work is part of the integrated infrastructure analysis research under the GeoH_2 group at the University of Texas Bureau of Economic Geology, as the group focuses on multidisciplinary research leveraging both subsurface fundamental research and market analysis to bring solutions to scaling up a hydrogen economy.

The goal of this study is to develop a robust framework that provides data driven valuation of hydrogen geological storage options. This framework delivers a techno-economic analysis and includes two major components: (1) a project specific life cycle analysis of a geological storage unit, including depleted reservoir and aquifer options for hydrogen storage, besides the proven option of salt cavern; and (2) a market and application-based demand assessment for the storage project. This study combines existing literature and previous research, with up-to-date technical parameters and broadened scope of downstream market applications. It is designed to be a user-friendly simulation framework that could be easily modified and leveraged with other hydrogen related research.

Araque-Martinez, A., and N. Lin, 2021, Hydrogen geological storage valuation framework: GeoGulf Transactions, v. 71, p. 3–10.

INTRODUCTION

Hydrogen as a gas offers a very simple energy carrier and storage option. It can be used directly for energy generation through combustion or fuel cells or as feedstock for industrial manufacturing of hydrogen-based solid and liquid compounds. Because of hydrogen's relatively low energy density by volume (about one-third of the energy per unit volume of natural gas), hydrogen storage and transportation are critical for large-scale utilization.

In the U.S., an extensive natural gas pipeline network provides an excellent leverage point in terms of infrastructure options and knowledge for hydrogen transportation and distribution. For the natural gas market in the United States, underground storage provides sufficient flexibility and hedging capabilities between supply and demand, with over 400 facilities spread across 31 states. Depleted oil and gas fields provide about 80% of the working gas storage capacity, with the remaining storage capacity from aquifers and salt cavern. Based on recent years data, total working underground working gas storage capacity in the U.S. represents anywhere between 13–18% of US annual natural gas consumption.

Drawing reference from the development of natural gas market, large-scale geological storage will need to be developed for hydrogen to allow for supply beyond current industrial usage. Furthermore, geological storage of hydrogen in salt (dissolution) caverns, depleted oil and gas fields, and saline aquifers affords the potential for large- volume storage capacity of hydrogen gas.

Hydrogen storage in salt caverns is the only currently commercially deployed and tested technology for seasonal storage of hydrogen at industrial quantities. Salt cavern storage is employed at three sites in the U.S. Gulf Coast region resulting in a combined storage capacity of 14,320 tons of H_2, providing hydrogen as a catalyst for oil refining operations. While salt cavern storage represents the lowest-cost solution for seasonal large volume hydrogen storage compared to other existing technologies, deployment is limited by the natural occurrence of salt bodies of sufficient thickness, referred to as salt domes, suitable for solution mining of large caverns. The distribution of salt domes thus limits salt cavern storage to specific geographic regions such as the U.S. Gulf Coast. Subsurface storage in porous media including saline aquifers and depleted oil and gas fields offer a cost-effective alternative to salt domes. Porous reservoirs are widespread and scalable from single-well operations to multiple wells are the reservoir to regional or basin scale.

Shuster et al. (2021) highlighted some of the infrastructure challenges required for development of a hydrogen economy in the U.S., including storage and market uncertainty, and suggested that research on geological storage with scenario-based market modeling would be a path for future research. The goal of this study is to develop the robust framework that provides data driven valuation of hydrogen geological storage options.

METHOD

The first component of the study is to generate a Hydrogen Storage Cost Analysis Tool, extending from Lord et al. (2011) at Sandia National Laboratories. For the first component of cost analysis model, this study includes a 3–stage workflow as shown in Figure 1. The workflow starts with stage I that included reviewing Lord et al.'s (2011) model and conducting a literature survey for available references to confirm assumptions and costs.

Then, the hydrogen underground storage cost tool (H_2USCT) was built in stage II following the same format as in Lord et al.'s (2011) work. A final version of H_2USCT was built and evaluated in stage III, including some modifications from previous work (Lord et al., 2011, 2014). The cost analysis modules include the entire process of receiving to distribution of hydrogen gas at storage site, assuming the site is connected from and to other infrastructure, like pipeline or trucks, to downstream market. It includes the following cost components with regards to the storage operation process:

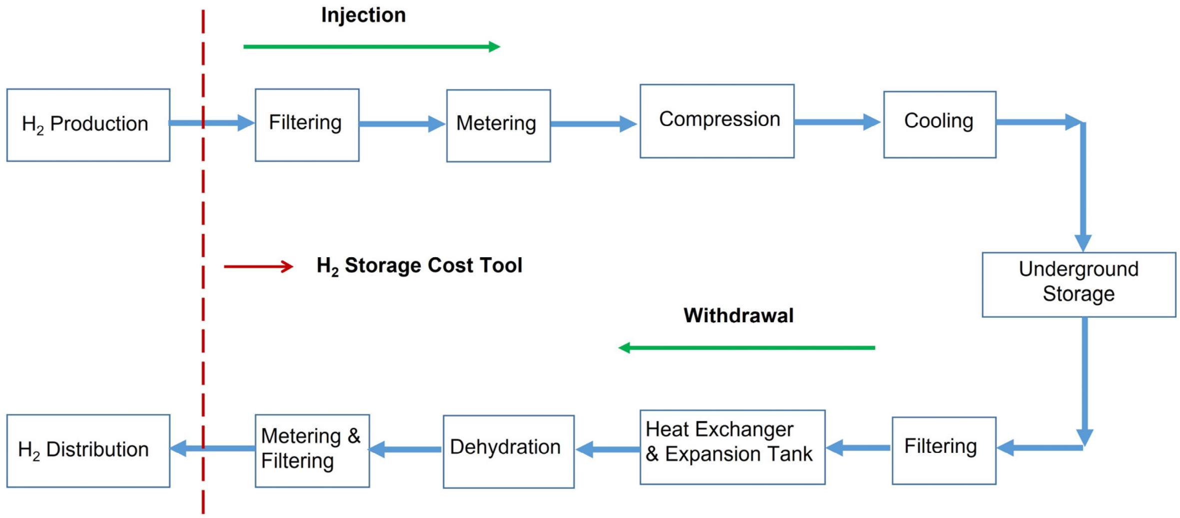

Figure 1. Hydrogen storage schematic.

- Compressor (injection/withdrawal rate, number of compressors, performance parameters of compressors)
- Dehydration and cooling.
- Electricity and water cost
- Wells and surface piping (Base length, site injection rate, well depth, and number of wells)
- Site development (mining, leaching, etc)
- Cushion Gas (weight percent of total stored hydrogen mass)

With the completion of the cost analysis model, the second component focuses on building the storage valuation, which includes a net-present-value (NPV) and internal-rate-of-return (IRR) calculations. Different demand scenarios based on industrial power or peak transportation needs would define the demand quantity and the desired withdrawal rates for the storage sites.

RESULTS

The H_2USCT is a modular tool as presented in Figure 2. There are different modules with different input data to evaluate all processes included in the cost analysis for final NPV and IRR calculations. The H_2USCT in an Excel worksheet is structured with different tabs as follows:

- Input tab
- Cost calculations tab by storage type site
- NPV tab by storage type site
- Output charts tab
- Tabulated output tab
- Consumer price index (CPI) data tab

Input tabs has included detailed assumptions covering parameters for engineering, subsurface, and economic modeling presented in Figure 3. The cost calculation tab by storage-type site calculates all relevant costs included in the economic analysis. These costs are:

- Total Capital Costs
- Compressor Capital Cost
- Wells Capital Cost

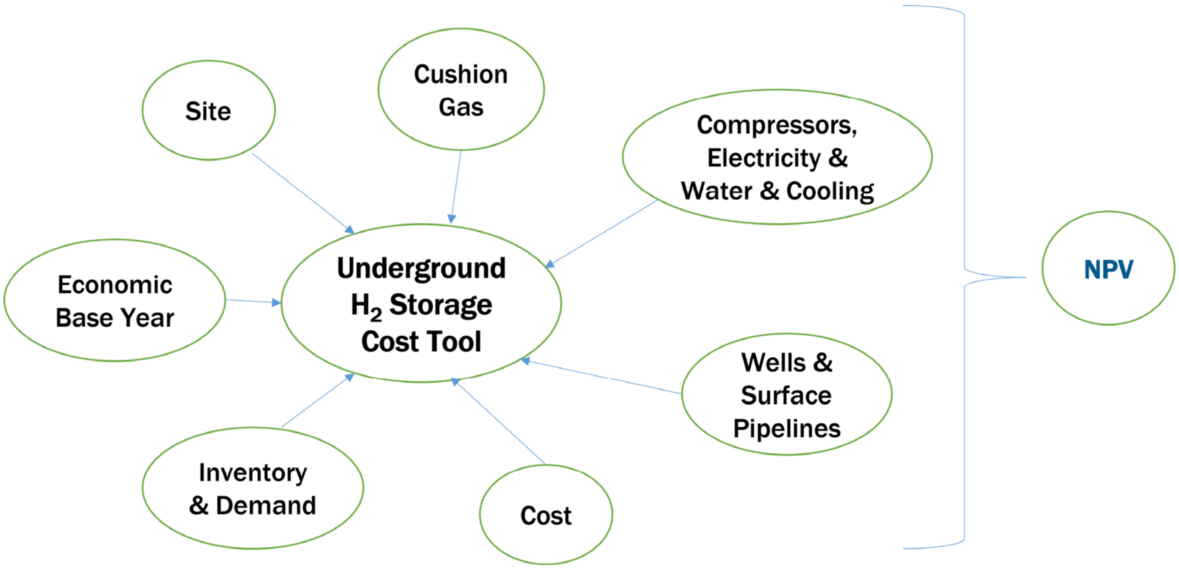

Figure 2. H_2USCT modules.

- Annualized Capital Costs
- Well O&M Cost
- Compressor O&M Cost
- Total O&M Costs
- Levelized Total O&M Costs
- Levelized Total Capital Costs
- Levelized Cost of H_2

The NPV tab by storage type site evaluates the NPV and IRR for the specific scenario based on all pre-tax (no tax included) and after tax (tax cut including tax incentives if any) costs from the cost calculation tabs. The results are displayed in tabulated and graphical form in the tabulated results and in the charts results tabs, respectively.

Current charts displayed in the output charts tab are:

- Total Capital Cost by Site Type (bar chart)
- Total Capital Cost by Market Penetration % (bar chart)
- Total Capital and O&M Cost (bar chart)
- Main Costs incurred per each Site Type (pie charts by site type)
- Pre-Tax and After-Tax NPV results by Site Type (bar chart)
- Pre-Tax and After-Tax IRR results by Site Type (bar chart)

Results are also tabulated for total capital costs, total O&M costs, H_2 demand in tons and MW, total levelized capital cost, total levelized O&M cost, levelized H_2 cost, salt cavern costs, depleted oil and gas reservoirs costs, aquifer costs and lined cavern costs. Figures 4–6 shows some of the mentioned outputs of the model.

In the current study, there are two demand scenarios defined. One is the downstream peak transportation needs in a metropolitan area, which was first defined from Lord et al. (2011). This demand case describes the needs to provide peak demand for transportation sector during three months of the summer, while there is a penetration assumption of 5%, 10%, 25%, and 100% of the entire transportation sector market located in one of the four large cities in the U.S. The main intention to include this demand scenario is to enable direct comparison to validate the

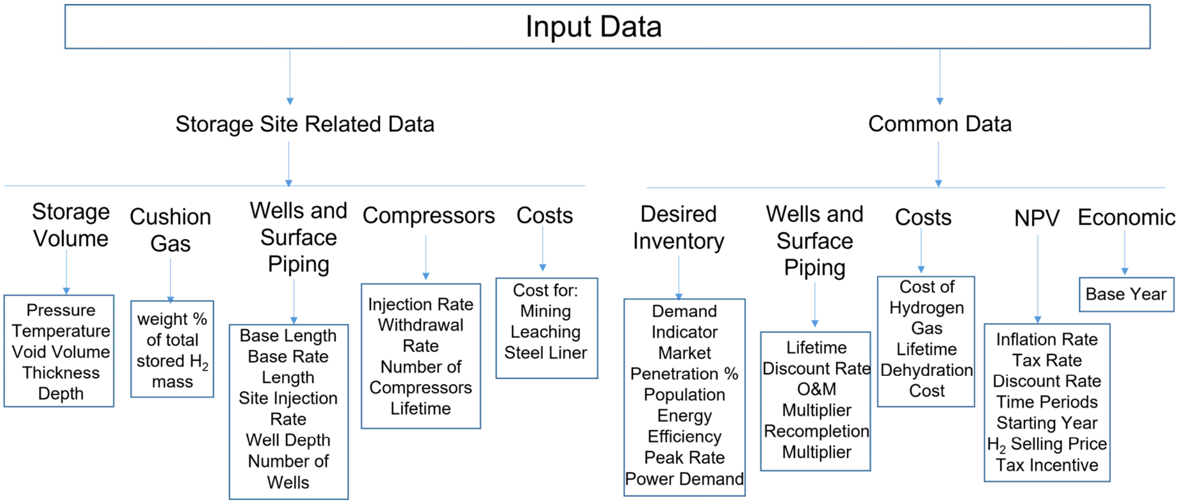

Figure 3. Input data structure.

calculation and structure of the updated cost analysis model and to provide a firm ground to further improvements.

A second demand case defined in this study is to estimate the storage needs for providing distributed electric load to oil and gas related activities in West Texas. Due to the oil and gas activities increases, there is a growing gap of electric load needed for field activities in remote well pads and currently available grid delivered power. According to a recent IHS Markit (2020) study for Oncor and ongoing internal research for ERCOT by Bureau of Economic Geology, the estimated underserved load for oil and gas activities could be in the magnitude of 800 MW or more for the entire Permian Basin (Texas portion).

SUMMARY AND CONCLUSION

A Hydrogen Storage Cost Analysis Tool in Excel-like format based on the work by Lord et al. (2011) at Sandia Laboratories was generated, and all input data was reviewed and confirmed through a comprehensive literature survey

As an improvement, current study adds an NPV calculation to the Hydrogen Storage Cost Analysis Tool, with simulation capability for different demand scenarios based on on industrial power or transportation needs. Current study presented the cost and valuation analysis results in an intercave excel module, which provides foundation for future extension.

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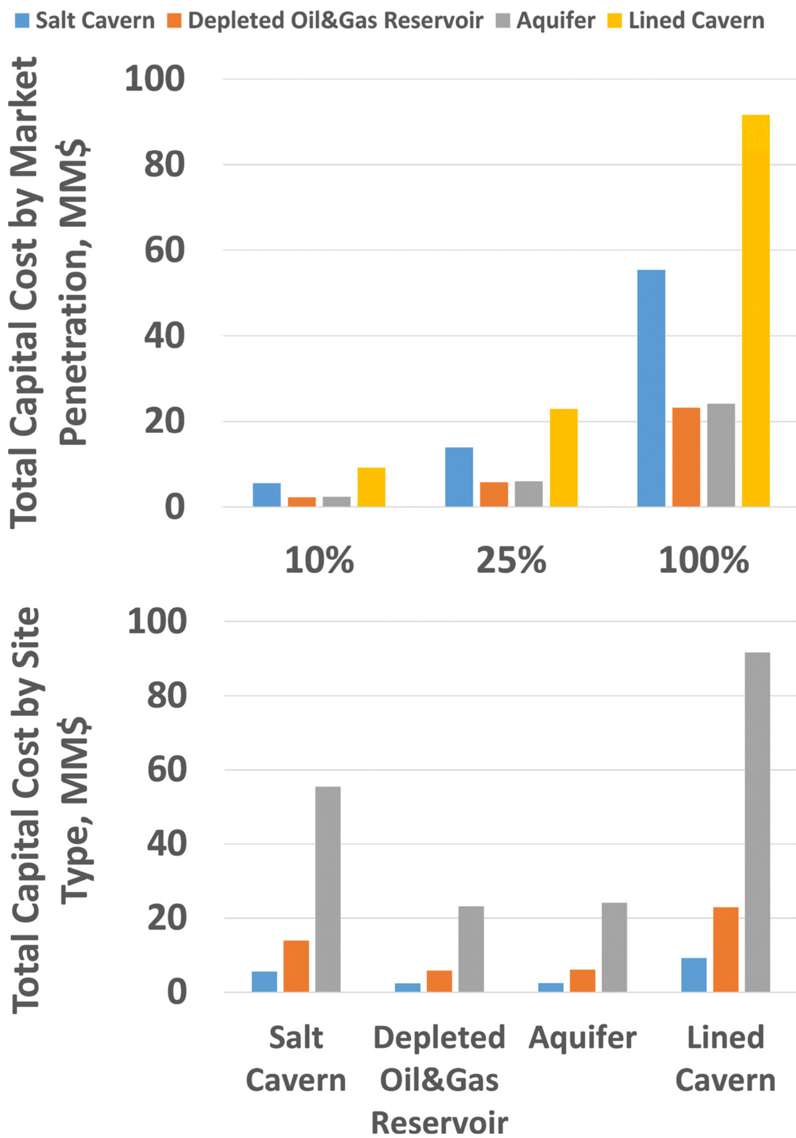

Figure 4. Total capital cost by market penetration (top) and by site type (bottom).

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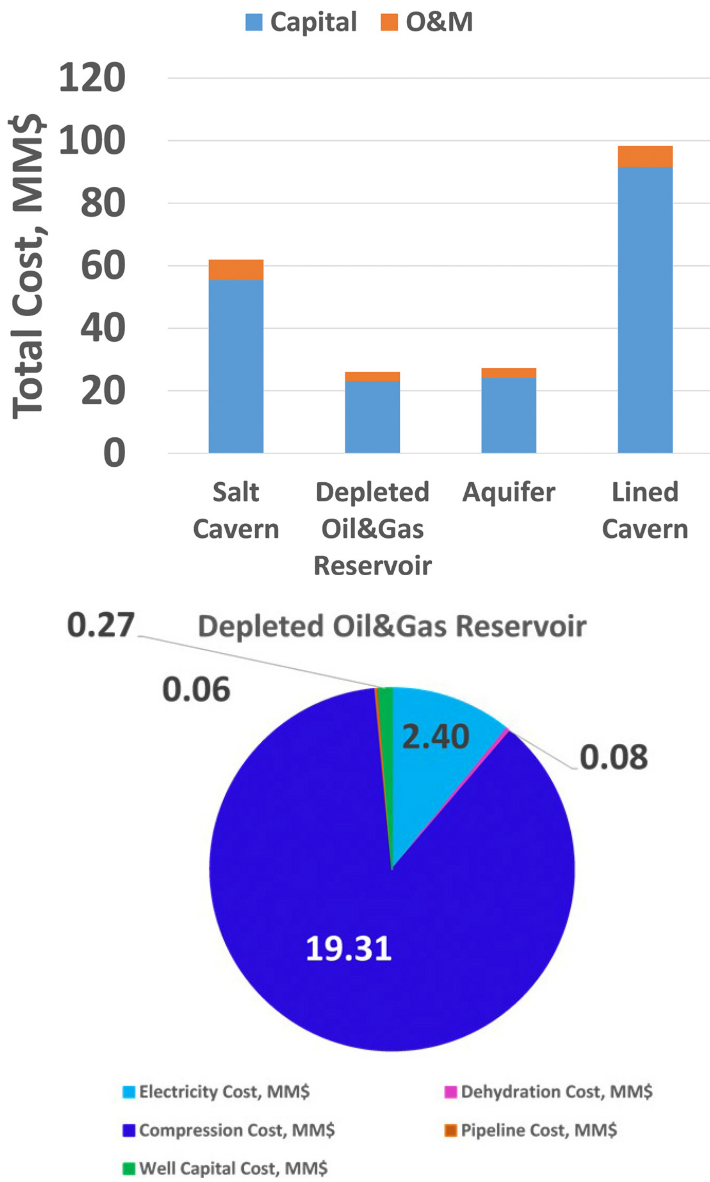

Figure 5. Capital and O&M cost by site type comparison (top) and depleted oil and gas reservoir costs (bottom). Aquifer costs (not shown here) are very similar to those costs for oil and gas reservoirs.

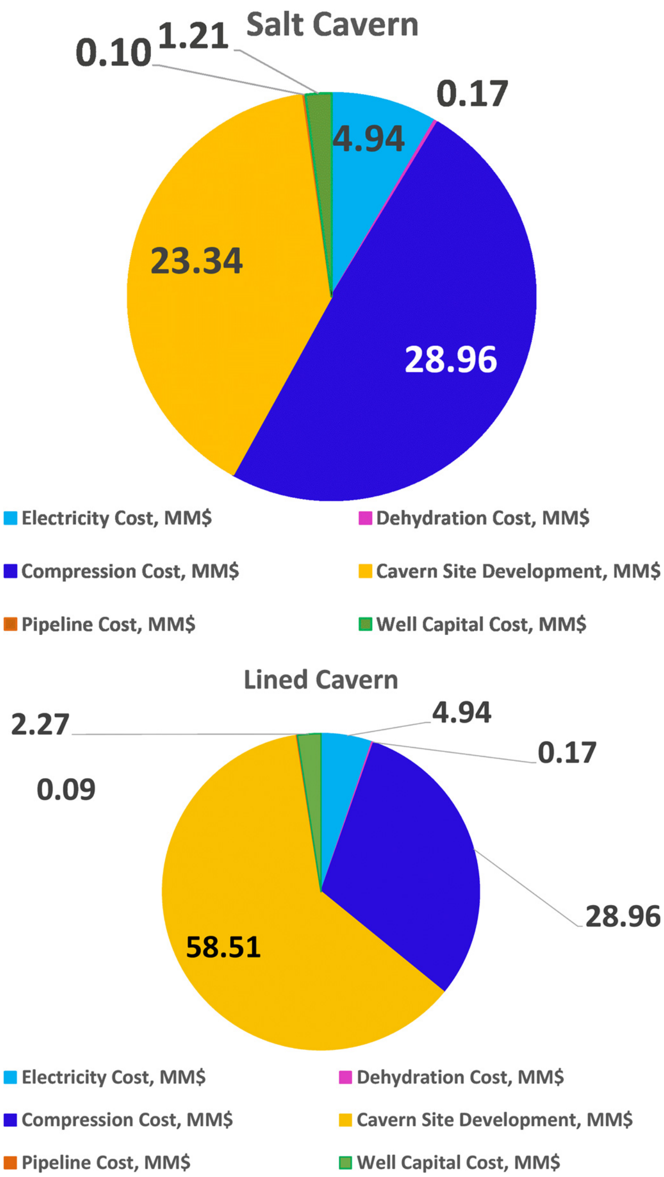

Figure 6. Salt cavern costs (top) and lined cavern costs (bottom).