Prospects for Underground Hydrogen Storage in Saline Reservoirs: A Case Study of Sacramento Basin

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January 15, 2024

Abstract

The objective of this work was to understand the suitability and favorability of saline reservoirs for storing hydrogen and ensuring the maximum amount of hydrogen would be withdrawn. We used the Sacramento basin in California to demonstrate the feasibility. We carried out several numerical simulation studies to understand key factors affecting the storage and withdrawal of hydrogen. We combined the results from the numerical modeling to develop a screening and ranking set of criteria for hydrogen storage in saline reservoirs. We then used the screening and ranking set of criteria to rank the formations in the Sacramento basin.

We studied five formations in the Sacramento Basin. The numerical simulation study showed that to optimize storage and withdrawal of hydrogen, steeply dipping reservoirs up to 15 degrees, reservoirs with low pressures, reservoirs with good porosity (above 20%), and reservoirs with high permeabilities were most favorable for underground hydrogen storage.

This work applies a novel and comprehensive site screening and selection criteria for underground hydrogen storage in saline reservoirs. It builds on a similar work done for carbon dioxide storage and hydrogen storage in depleted gas fields but it considers additional objective of needing to withdraw the stored fluid. The case study in Sacramento Basin can be applied to any other basin.

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Keywords: Green Hydrogen, Underground Hydrogen Storage, Saline Aquifers, Numerical Simulation, Screening Criteria, Site Ranking

Introduction

Objective:

Enabling Net-Zero Energy Infrastructure by increasing the reliability on the renewable energy

Problem:

Grid in-stability due to seasonal nature of Renewables

Solution:

Energy converted to hydrogen & storage/production of H_2 as per the demand

Green hydrogen:

It is produced from water using renewable energy sources, such as wind, solar or hydro power. The main advantage of green hydrogen is that it is a clean, carbon-free energy source.

Positive: Higher energy content per unit mass

Negative: Low density – Huge volume requirement

Problem: Prospects Availability?

Solution:

Subsurface Storage in Porous Media

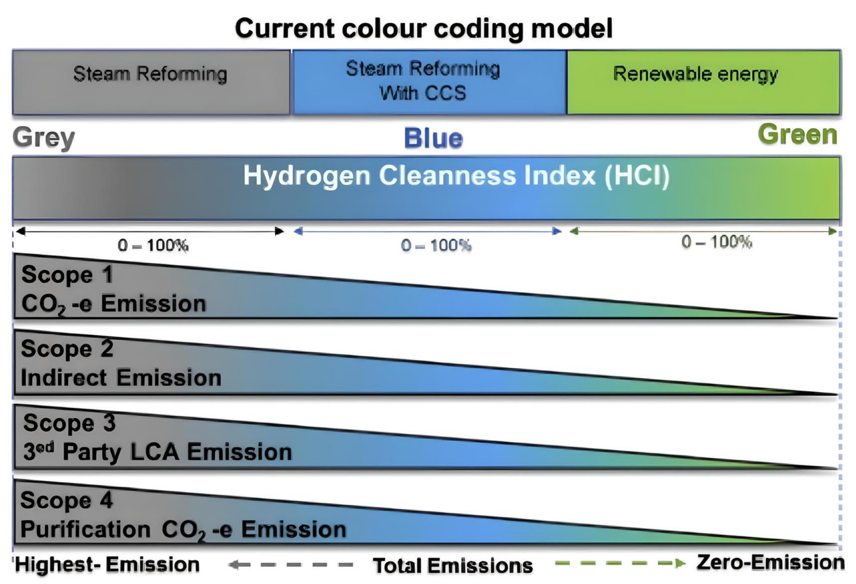


Figure 1. Advantages of Green Hydrogen (Dawood et al., 2020)

Why Hydrogen Storage in Aquifers?

Types of storage in the subsurface: Depleted oil and gas fields, Saline Aquifers

Depleted Oil and Gas Reservoirs: Field no longer economic for oil or gas production.

Limitations

Limitation of oil & gas basins near large cities with high hydrogen demands

Weak sealing effect of the original development well

Residual hydrocarbons can react with the injected hydrogen gas and increase its wettability, facilitating easy adsorption by the rock skeleton

Deep saline formation: Saline water bearing formation sealed by a caprock for permanent storage.

Objective: Efficiency site selection is important for the success of the project.

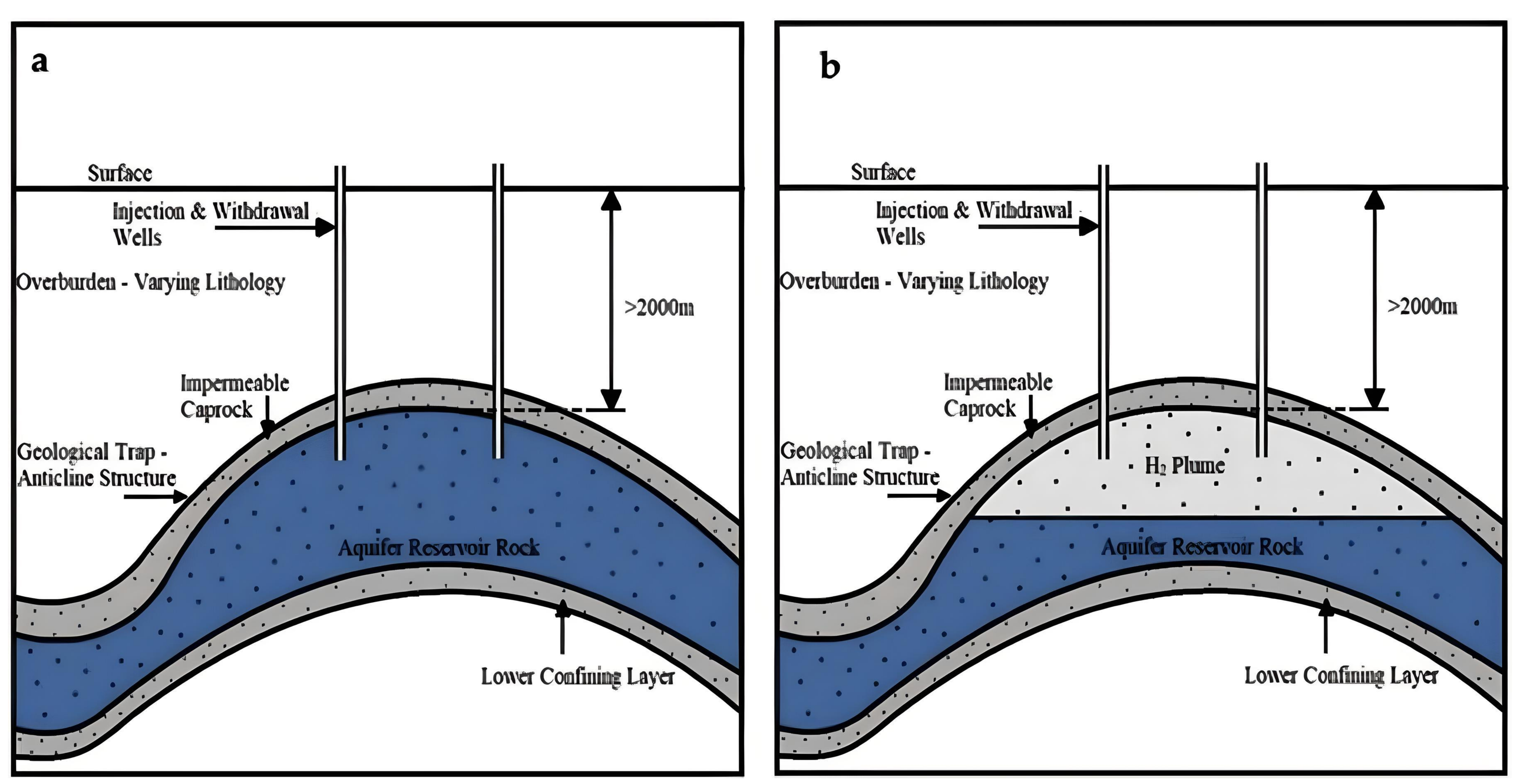


Fig. 2. A schematic of aquifer structure before (a) and after (b) hydrogen storage (Wallace et al., 2021)

3-Dimensional Reservoir Modelling

A 3-Dimensional reservoir model has been developed by parameters value from literature and cyclic injection and production of hydrogen scenarios are implemented

Symbol	Description	Value	Units
ϕ	Porosity	0.2	%
K_H	Permeability - Horizontal	500	mD
K_v	Permeability- Vertical	50	mD
P_r	Average Reservoir Pressure	80	bar
C_r	Rock compressibility	1.0×10^{-4}	bar^{-1}
T	Average Reservoir Temperature	43	C
ρ_f	Water density	999.7	Kg/m^3
C_w	Water Compressibility at Res. Conditions	2.0×10^{-4}	Bar^{-1}
μ_w	Water dynamic viscosity at Res. Conditions	6.18×10^{-4}	Pa*S
V	Polytropic index for hydrogen	0.29	

Table 1: Parameters selected for base-case saline aquifer reservoir model

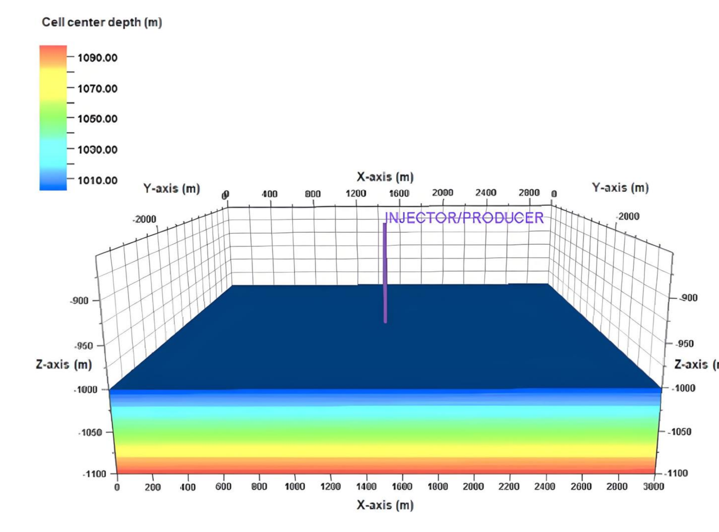


Figure 3: Base-Case Model

Sensitivity Analysis

Then using the disqualifying criteria from literature (Okoroafor et al., 2022) , the parameter ranges for the SA is determined.

Permeability	<50 mD
Thickness	<10m
Porosity	<5%
Geothermal gradient	<12 °C/km

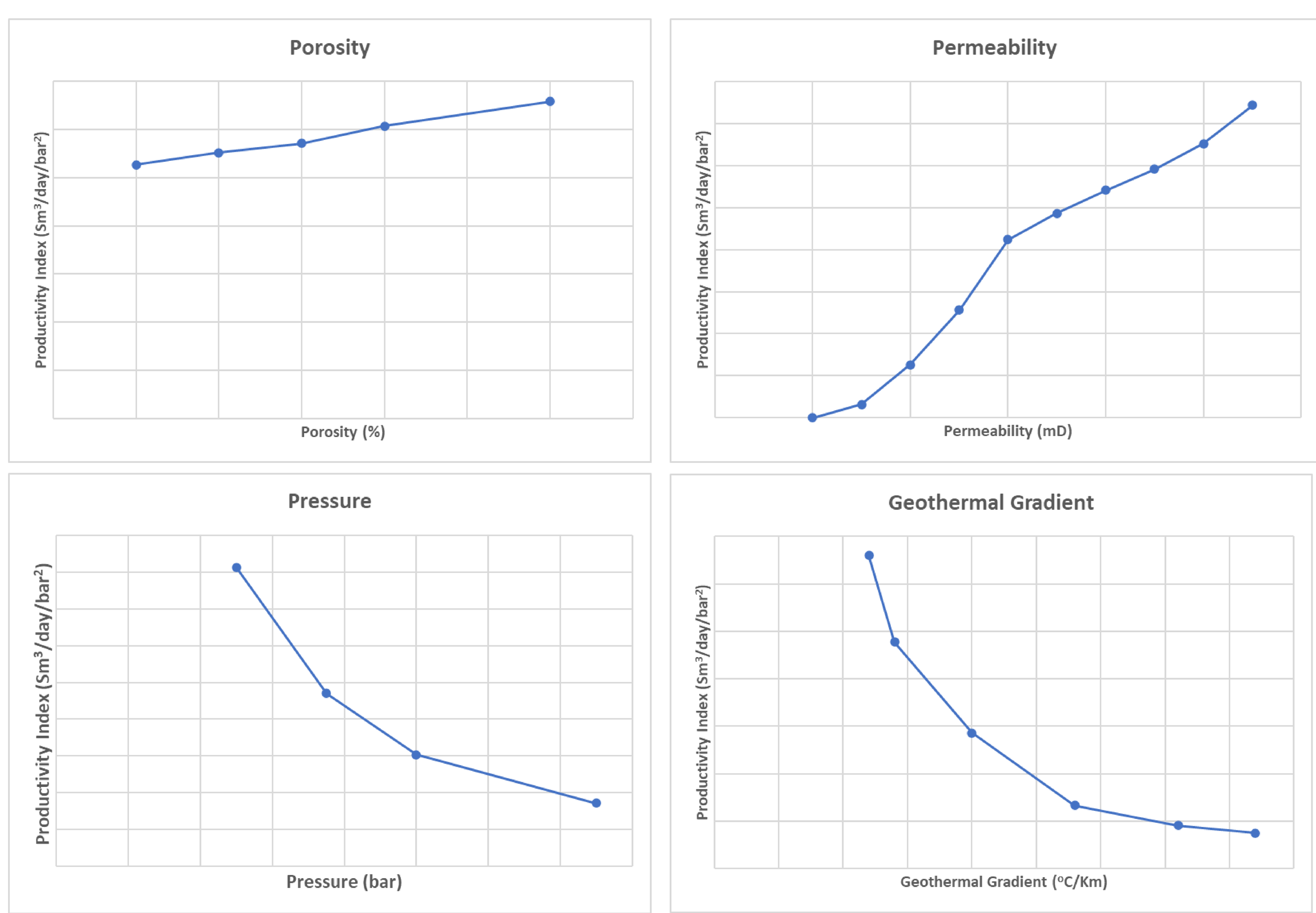
Table 2: Disqualifying Criteria

Parameter	Corresponding Values
Permeability [mD]	50, 100, 250, 500, 1000, 2000
Thickness [m]	10, 30, 50, 100, 150, 200
Reservoir Pressure [bar]	50, 75, 100, 125, 150
Porosity [%]	5, 10, 15, 20, 30
Formation dip [°]	-2, 0, 2, 5, 10, 20, 25
Geothermal Gradient [°C/km]	12, 20, 28, 36, 42

Table 3: Parameters selected to perform the sensitivity analysis

Sensitivity Analysis is done to quantify the effects of various parameters, including porosity, permeability, reservoir thickness, reservoir pressure and area, Formation dip, and geothermal gradient, on the output parameter i.e., productivity index.

Sensitivity Analysis Results and Discussions



Direct impact: Porosity & Permeability

Indirect impact: Pressure & Geothermal Gradient

Screening Criteria

From the sensitivity analysis results the following screening criteria of each parameters on productivity index is drawn.

Parameters/ Rank	1 (worst)	2	3	4	5 (Best)
Dip (Degrees)	< 1	2-5	5-8	8-13 & > 20	13-20
Temperature (°C/Km)	> 30		20-30		< 20
Porosity (%)	< 5		5-20		20-30
Reservoir Pressure (bar)	> 150	100-150	75-100	50-75	< 50
Depth (m)	> 1500	1000-1500	750-1000	500-750m	< 500 m
Flow Capacity (mDm)	10-500	500-5000	5000-22000	22000-110000	> 110000

Table 4: Screening criteria for saline Aquifers

From the screening criteria the following are drawn:

Parameter	Optimum Values
Formation dip [°]	13 to 20 Degrees
Temperature [°C/km]	less than 20 Celsius
Porosity [%]	20 to 30 %
Reservoir Pressure [bar]	less than 50 bar
Flow Capacity [mDm]	greater than 110000 mDm

Conclusion: A saline aquifer with high porosity, an optimum dip of 13 to 20 degrees, a higher flow capacity, smaller pressure and smaller temperature is considered to be ideal for hydrogen storage.

Ranking of the Sacramento basin

Formation	Pressure	Depth	GG	Porosity	Flow Capacity	Total
Starkey Sands of the Moreno Formation	1	1	5	3	3	13
Mokelumne River Formation	1	1	5	3	1	11
Winters Formation	1	1	3	5	2	12
Kione Sands of Forbes Formation	1	1	1	3	2	8
Domengine Formation	1	1	1	3	2	8

Worst Case:
Higher: Pressure, Depth and Geothermal gradient
Lower: Porosity, Dip, Thickness, Permeability, Flow Capacity

Best Case:
Lower: Pressure, Depth and Geothermal gradient
Higher: Porosity, Dip, Thickness, Permeability, Flow Capacity

Formation	Pressure	Depth	GG	Porosity	Flow Capacity	Total
Starkey Sands of the Moreno Formation	3	3	5	5	5	21
Mokelumne River Formation	3	3	5	5	5	21
Winters Formation	3	3	3	5	5	19
Kione Sands of Forbes Formation	3	3	1	5	5	17
Domengine Formation	3	3	1	5	5	17

Formation	Pressure	Depth	GG	Porosity	Flow Capacity	Total
Starkey Sands of the Moreno Formation	1	1	5	5	4	16
Mokelumne River Formation	1	1	5	5	4	16
Winters Formation	1	1	3	5	4	14
Kione Sands of Forbes Formation	2	2	1	5	3	13
Domengine Formation	2	2	1	5	3	13

Since the value of each parameters in sacramento basin we got are in ranges the lowest, highest and the average values of each parameters are considered and the worst case, the best case and the likely case are identified and ranked.

Conclusions and Recommendations

Upon concluding from the ranking of five formations in the Sacramento basin the Starkey Sands of the Moreno Formation and Mokelumne River Formation are considered to have a very high ranking and considered optimum for hydrogen storage.

Additionally, the uncertainty of reservoir properties alters the ranking which can be identified from the difference between the ranks of best, worst and likely cases.

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