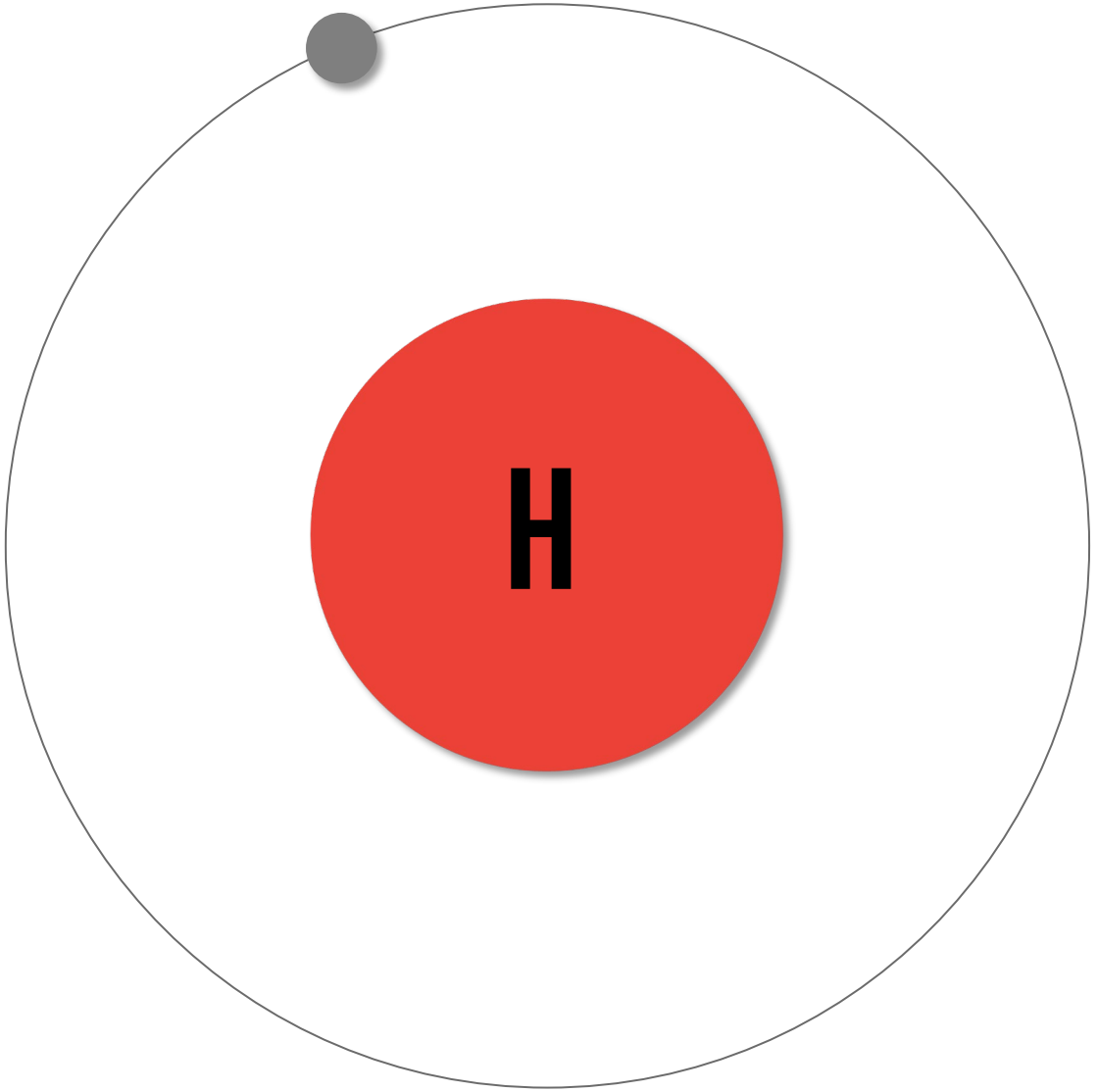
HYDROGEN STORAGE CAPACITY OF SALT CAVERNS IN VARIOUS NORTH AMERICAN SALT DEPOSITS

SMRI 2022 Technical Conference

Authors: Jai Duhan, Samuel Voegeli, Brady Mills, & Joel Nieland

AGENDA

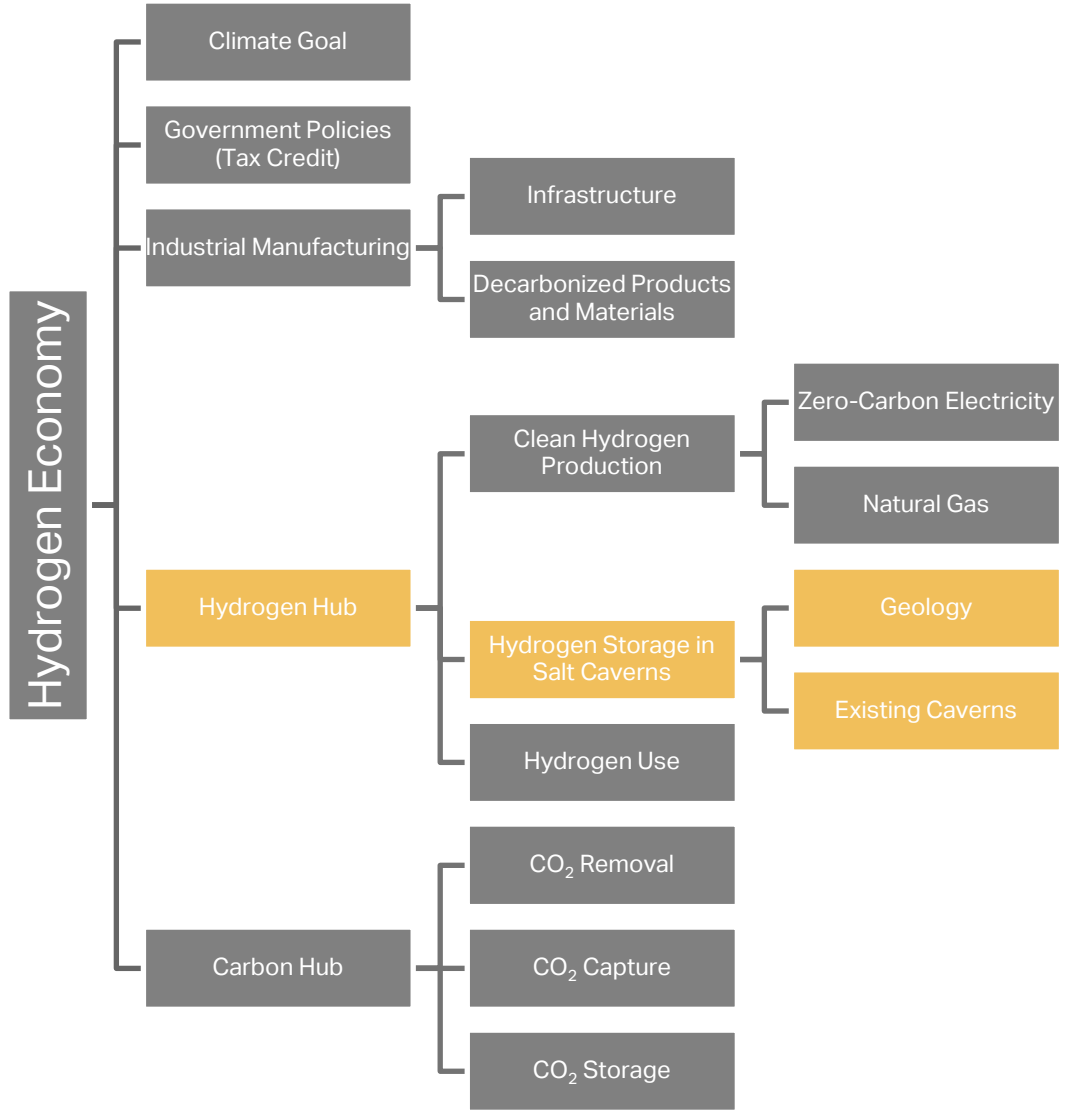
- **BIG PICTURE**
  - Climate goal and hydrogen economy
  - Hydrogen as a decarbonizing solution
  - Salt caverns as a storage solution
- **SALT DEPOSITS IN NORTH AMERICA**
  - Potential hydrogen hubs
  - Locations analyzed in this study
- **APPROACH**
  - Geology and cavern dimensions
  - Operating conditions
  - Thermodynamics principles
- **RESULTS**
  - Working thermal energy
  - Storage density
  - Temperature fluctuation
- **NEXT STEPS**



BIG PICTURE

- Keeping global temperature rise below 1.5-2°C will require world to reach net-zero emissions by 2050
- The level of decarbonization needed will require economywide deployment of hydrogen and carbon capture infrastructure
- In the IEA's net-zero scenario, hydrogen-based fuels account for 13 percent of global energy demand in 2050

- In this study, we will discuss hydrogen storage in salt caverns, which is a crucial component of hydrogen infrastructure

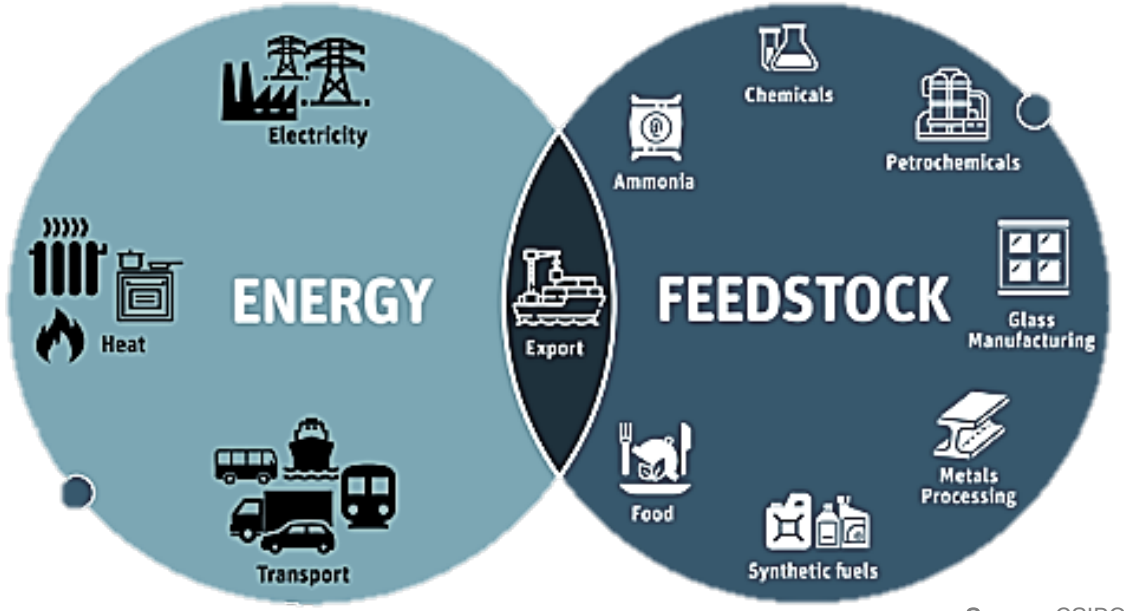


BIG PICTURE

- Hydrogen as a decarbonizing solution:
  - Clean burning (combusted for energy without emitting GHGs)
  - Used for integrating renewables into the energy system
  - Used as transportation fuel
  - Used as high-grade industrial fuel
  - Can be stored for long periods of time

- Why salt caverns?
  - Safe
  - Reliable
  - Cost-effective bulk storage
  - Present near major urban centers
  - Environmentally friendly compared to most storage technologies

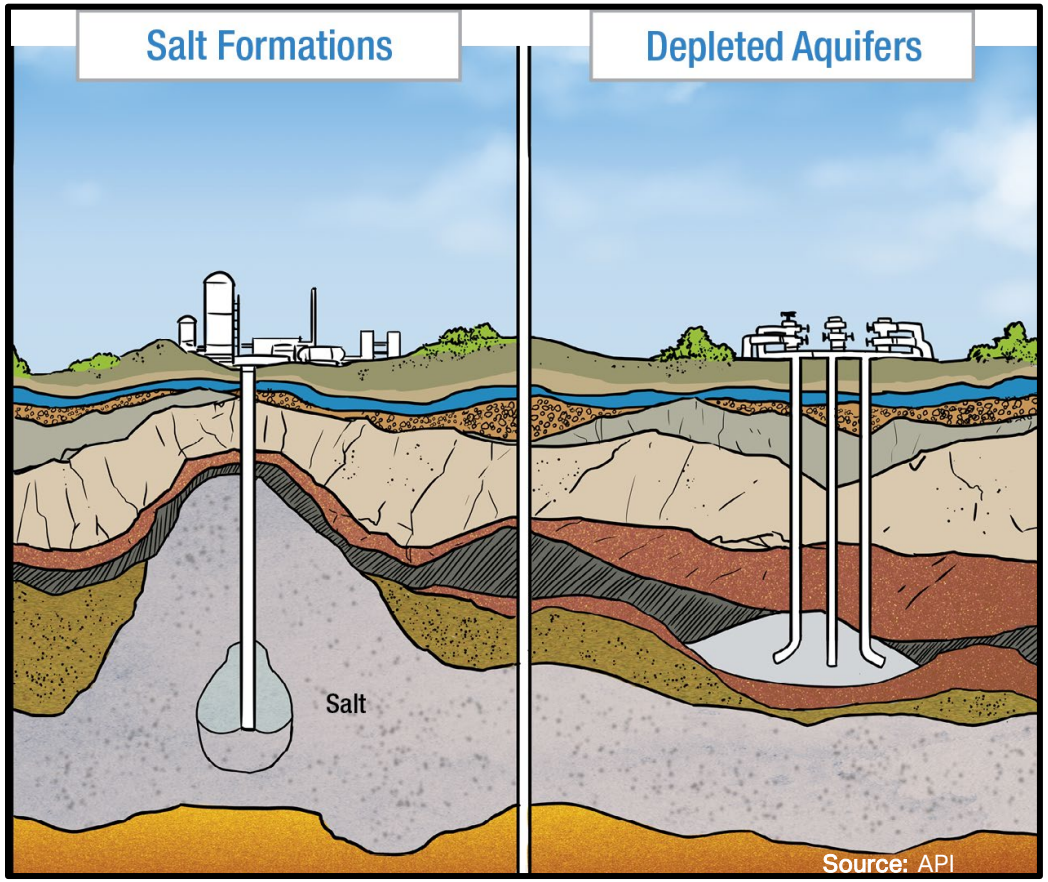
- Upcoming projects:
  - Advanced Clean Energy Storage Project by Mitsubishi Power Americas and Magnum Development
    - 5,500 metric tonnes of hydrogen
    - 150 gigawatt hours (GWh) of carbon-free dispatchable energy



Source: CSIRO

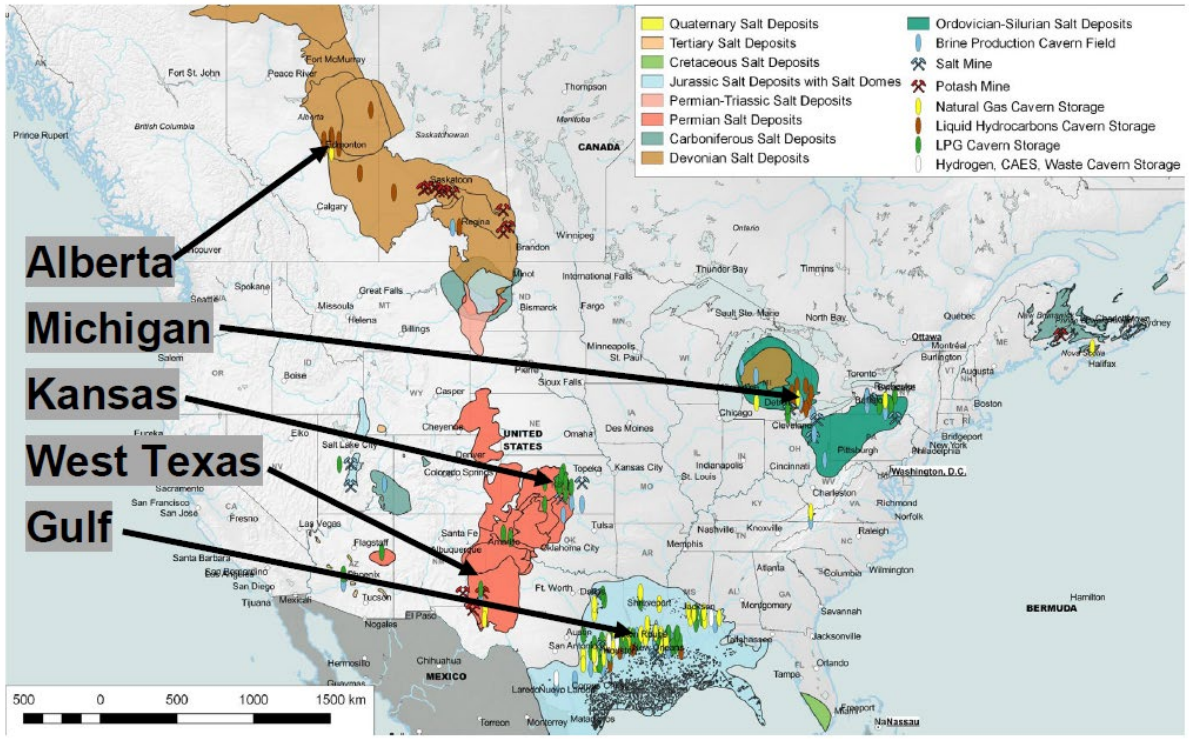
SUBSURFACE HYDROGEN STORAGE OPTIONS

- **Domal caverns**
  - Proven
  - Typically cleaner salt
  - Less variables
- **Bedded caverns**
  - Dirtier salt
  - Nonsalt interbeds, pathways for hydrogen?
- **Porous reservoirs**



SALT DEPOSITS IN NORTH AMERICA

- NORTH AMERICA HAS ABUNDANT AMOUNT OF SALT LOCATED NEAR MAJOR INDUSTRIAL CENTERS
- LOCATIONS FOR CASE STUDIES WERE PICKED BASED ON THE FOLLOWING PARAMETERS:
  - Presence of industry
  - Salt geology
  - Existing caverns



- LOCATIONS ANALYZED IN THE STUDY:
  - Alberta (bedded salt)
  - Kansas (bedded salt)
  - Michigan (bedded salt)
  - West Texas (bedded salt)
  - Gulf Coast (domal salt)

*Not all of the locations that provide hydrogen storage potential are analyzed in this study; some of these areas include Ontario, New York, Utah, Ohio, and the Maritime provinces.

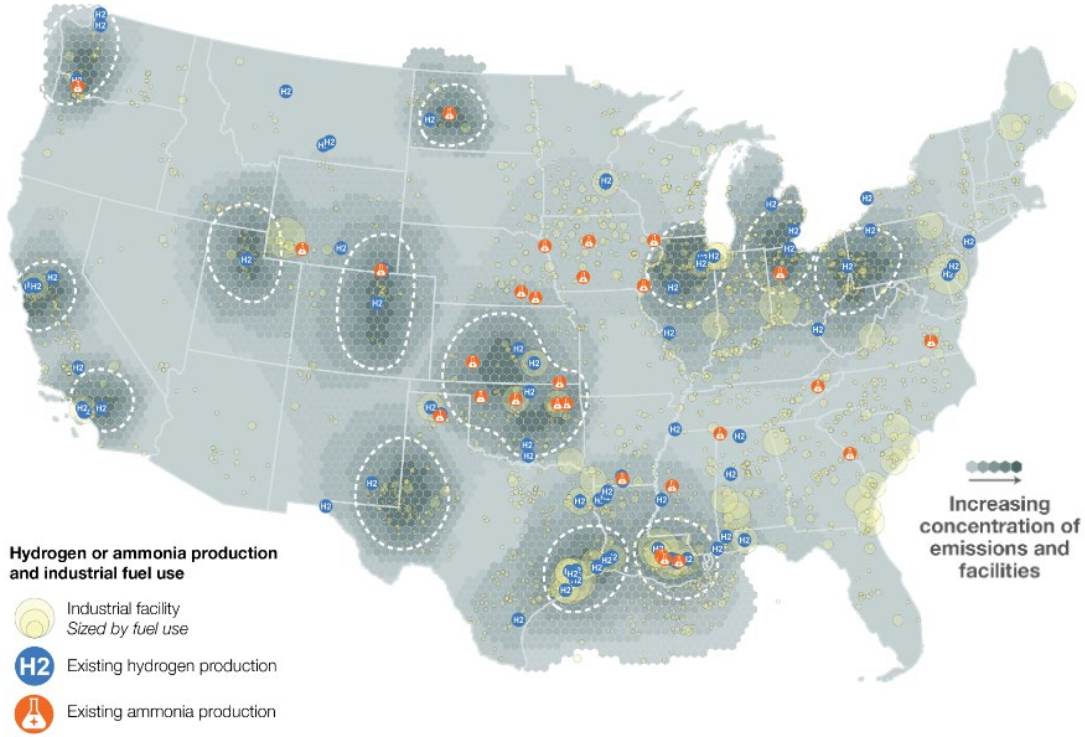
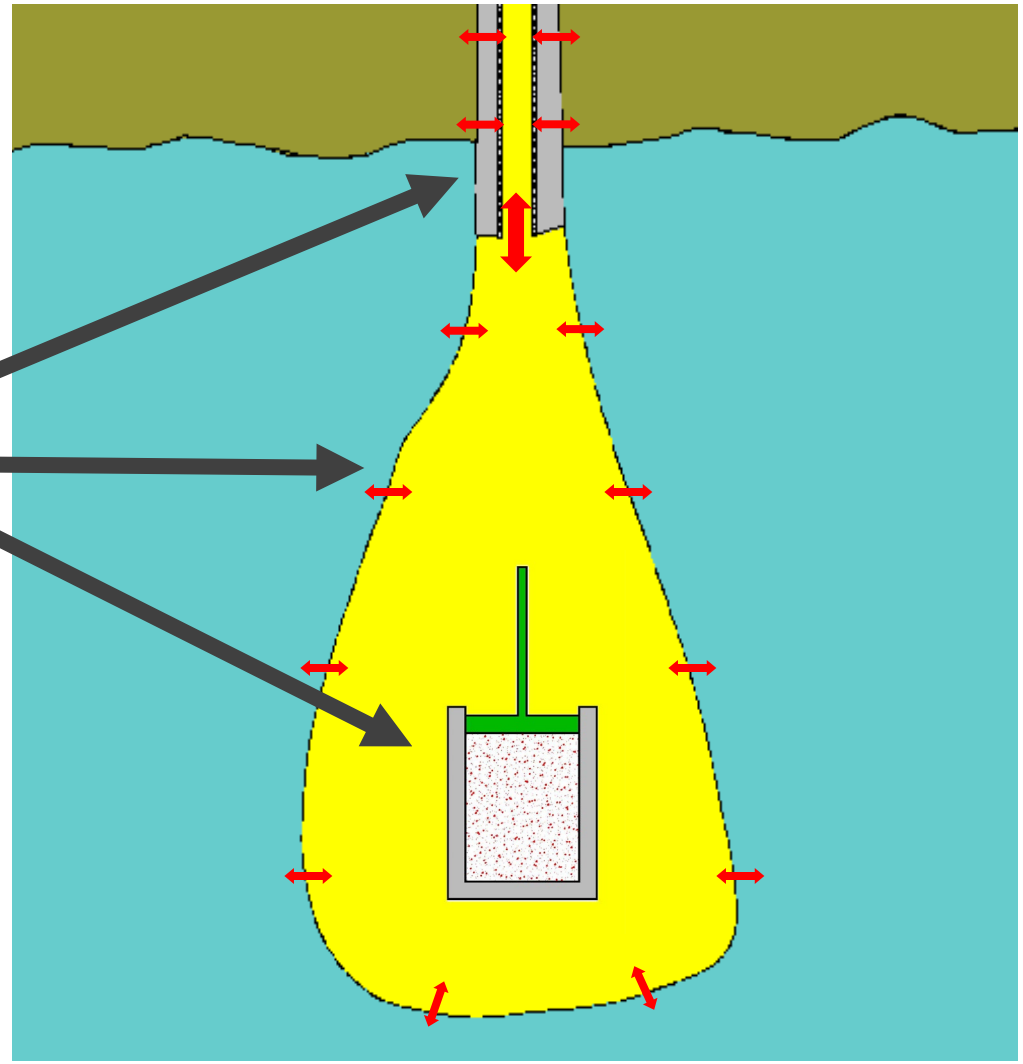


Figure authored by GPI based on McMillan (2019); EPA GHGRP 2019 data (as of August 7, 2021).

APPROACH

- Salt Cavern Thermal Simulator (SCTS) was used to model the thermodynamics of operating hydrogen storage caverns
- The thermodynamic processes involved in a hydrogen storage cavern include:
  - Energy changes caused by mass flow into and out of the cavern
  - Heat transfer between the hydrogen and the surrounding rock
  - Heating and cooling caused by hydrogen compression and expansion
- Operating conditions:
  - Hydrogen turns/year: 1
  - Cavern operational life: 30 years
  - Minimum pressure at the casing seat: 0.25 psi/ft
  - Maximum pressure at the casing seat: 0.80 psi/ft



CAVERN DIMENSIONS

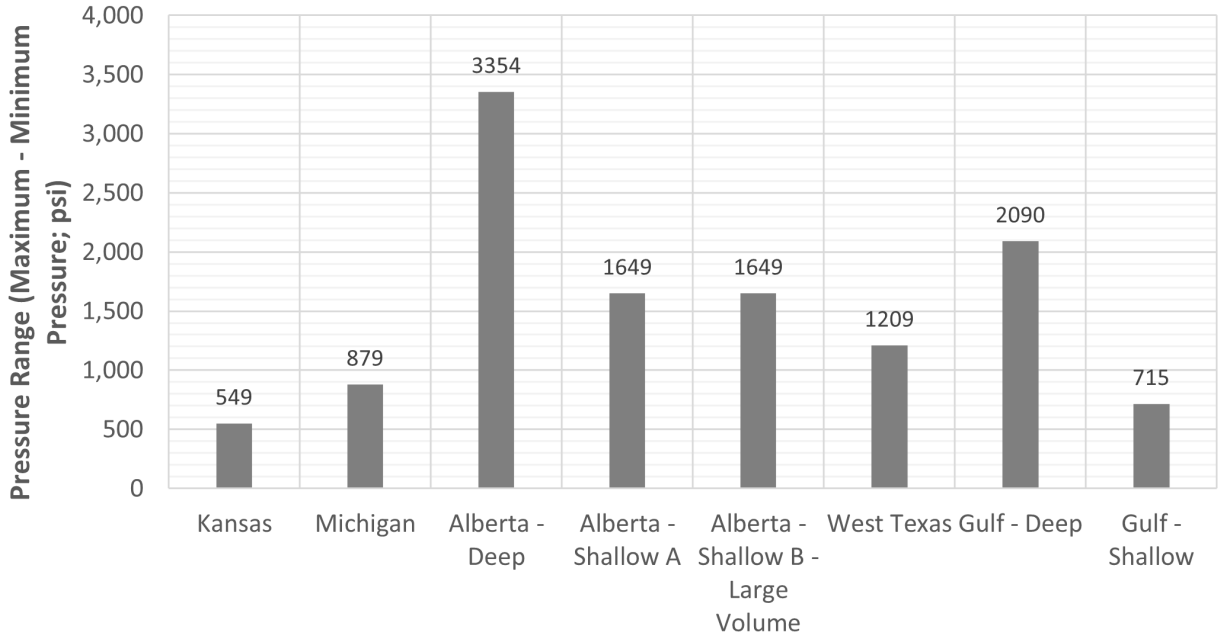
- CAVERN SIZE HAS AN IMPACT ON WORKING GAS CAPACITY
- CAVERN DIMENSIONS WERE BASED ON SALT GEOLOGY
  - Cavern height was based on salt deposit thickness
  - Cavern diameter was limited to 250 ft
- VOLUME:
  - Gulf Coast caverns have the largest volume
  - Caverns in Kansas have the smallest volume
- DEPTH:
  - Caverns in Alberta are the deepest
  - Caverns in Kansas are the shallowest
- NOTE:
  - Salt strata's depth and thickness can vary within the deposit
  - A case study does not represent the hydrogen storage capacity throughout the entire salt deposit.

Table 1. Geology and Cavern Dimensions

	Case Studies							
	Kansas	Michigan	Alberta–Deep	Alberta–Shallow A	Alberta–Shallow B–Large Volume	West Texas	Gulf–Deep	Gulf–Shallow
Top of Salt (ft)	850	1,500	6,000	2,900	2,900	2,100	1,000	1,000
Casing Seat (ft)	1,000	1,600	6,100	3,000	3,000	2,200	3,800	1,300
Cavern Top (ft)	1,000	1,600	6,100	3,000	3,000	2,200	4,000	1,500
Cavern Height (ft)	80	100	175	175	300	100	1,000	1,000
Cavern Diameter (ft)	250	250	250	250	250	250	250	250
Cavern Volume (MMbbls)	0.699	0.874	1.530	1.530	2.623	0.874	8.742	8.742
Volume to Surface Area Ratio	24.4	27.8	36.5	36.5	44.1	27.8	55.6	55.6

PRESSURE RANGE

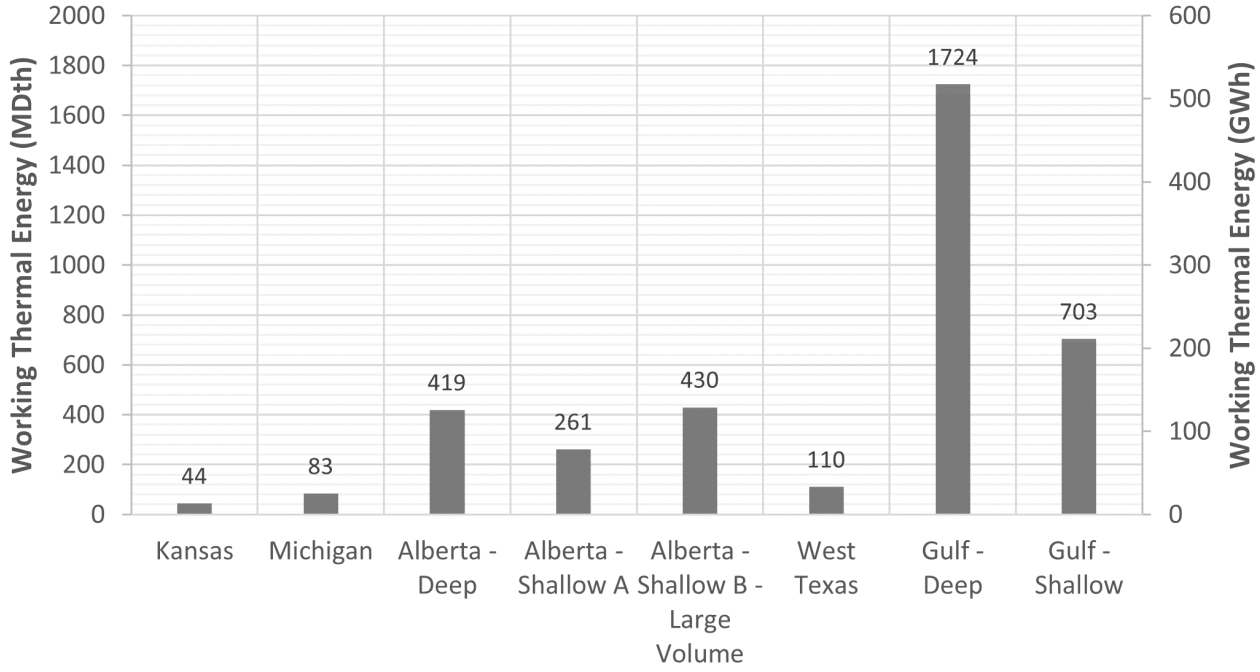
- PRESSURE RANGE HAS AN IMPACT ON STORAGE DENSITY
- MAXIMUM AND MINIMUM PRESSURES ARE DEPENDENT ON THE DEPTH OF THE CAVERN
  - Minimum pressure at the casing seat: 0.25 psi/ft
  - Maximum pressure at the casing seat: 0.80 psi/ft
- PRESSURE RANGE IS LARGEST IN THE DEEPER CAVERNS
  - Caverns is Alberta have the largest pressure range
  - Caverns in Kansas have the smallest pressure range



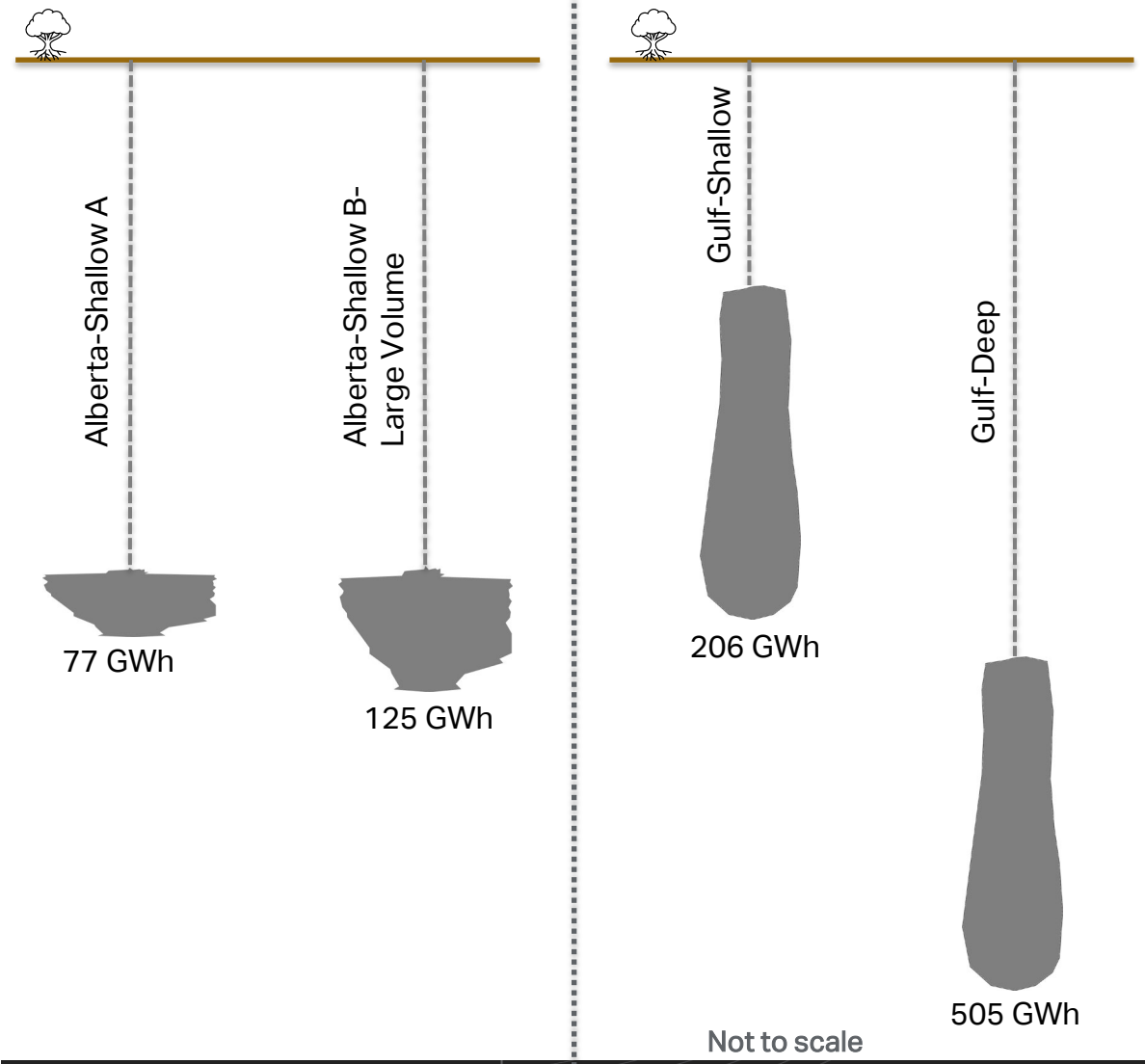
RESULTS
WORKING THERMAL ENERGY: ALL CASES

- **WORKING THERMAL ENERGY:**
  - Calculated from working gas capacity (i.e., volume of hydrogen that can be effectively used for storage)
- **WORKING THERMAL ENERGY IS DEPENDENT ON THE FOLLOWING PARAMETERS:**
  - Size of the cavern
  - Pressure range (max - min pressure)
- **IN THIS STUDY:**
  - Gulf Coast caverns have the largest working thermal energy (505 GWh)
  - Kansas caverns have the smallest working thermal energy (13 GWh)

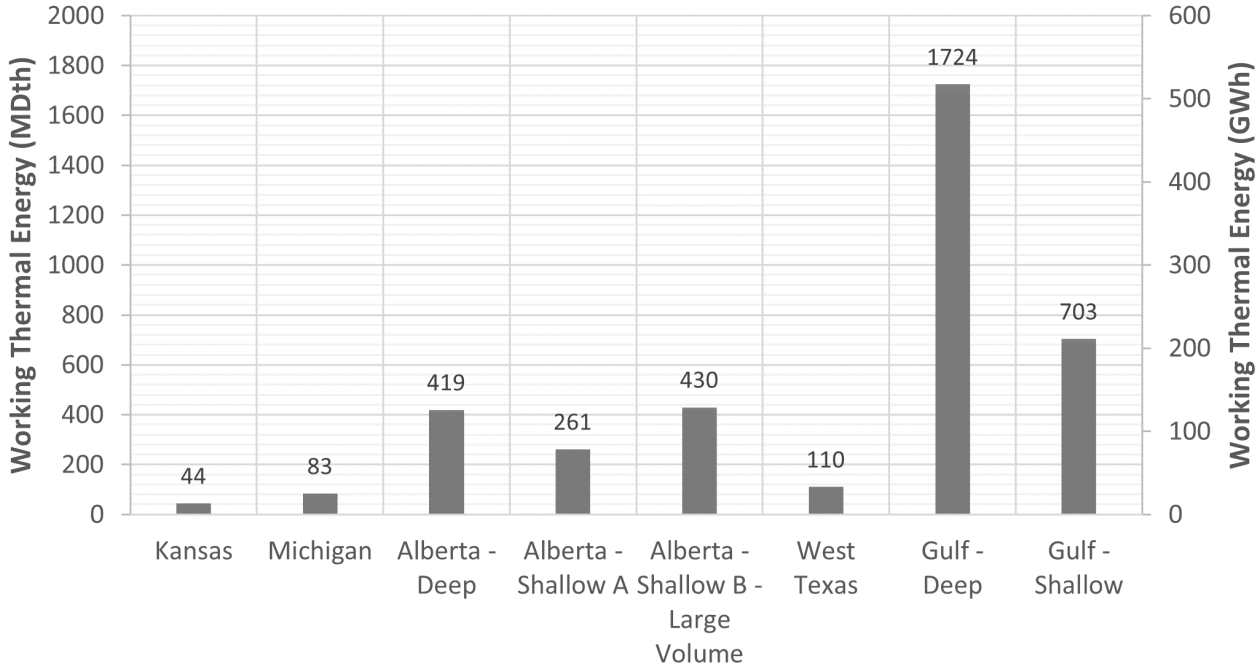
Cavern Volume (MMbbls)							
0.699	0.874	1.530	1.530	2.623	0.874	8.742	8.742
Pressure Range (psi)							
549	879	3354	1649	1649	1209	2090	715



RESULTS
WORKING THERMAL ENERGY: ALBERTA AND GULF COAST

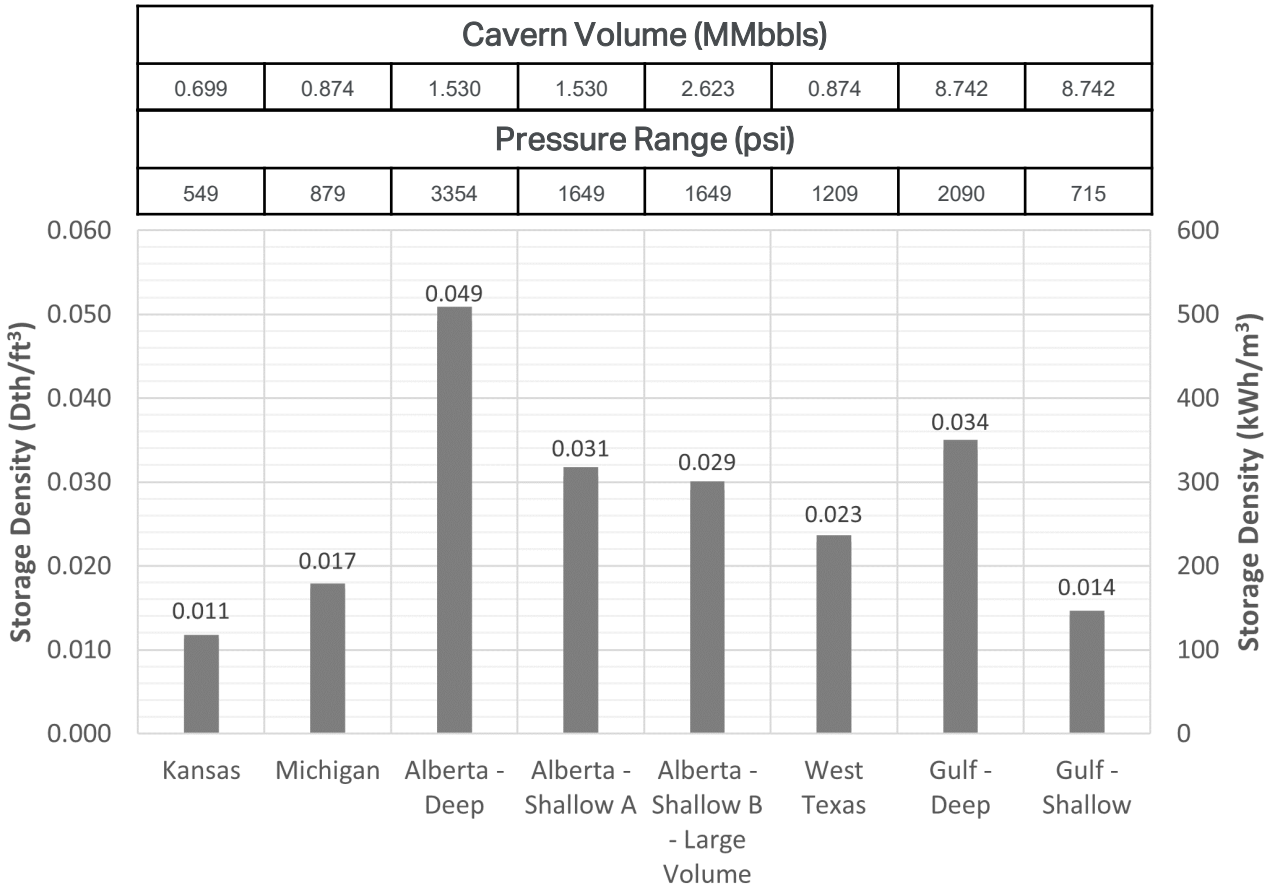


Cavern Volume (MMbbls)							
0.699	0.874	1.530	1.530	2.623	0.874	8.742	8.742
Pressure Range (psi)							
549	879	3354	1649	1649	1209	2090	715

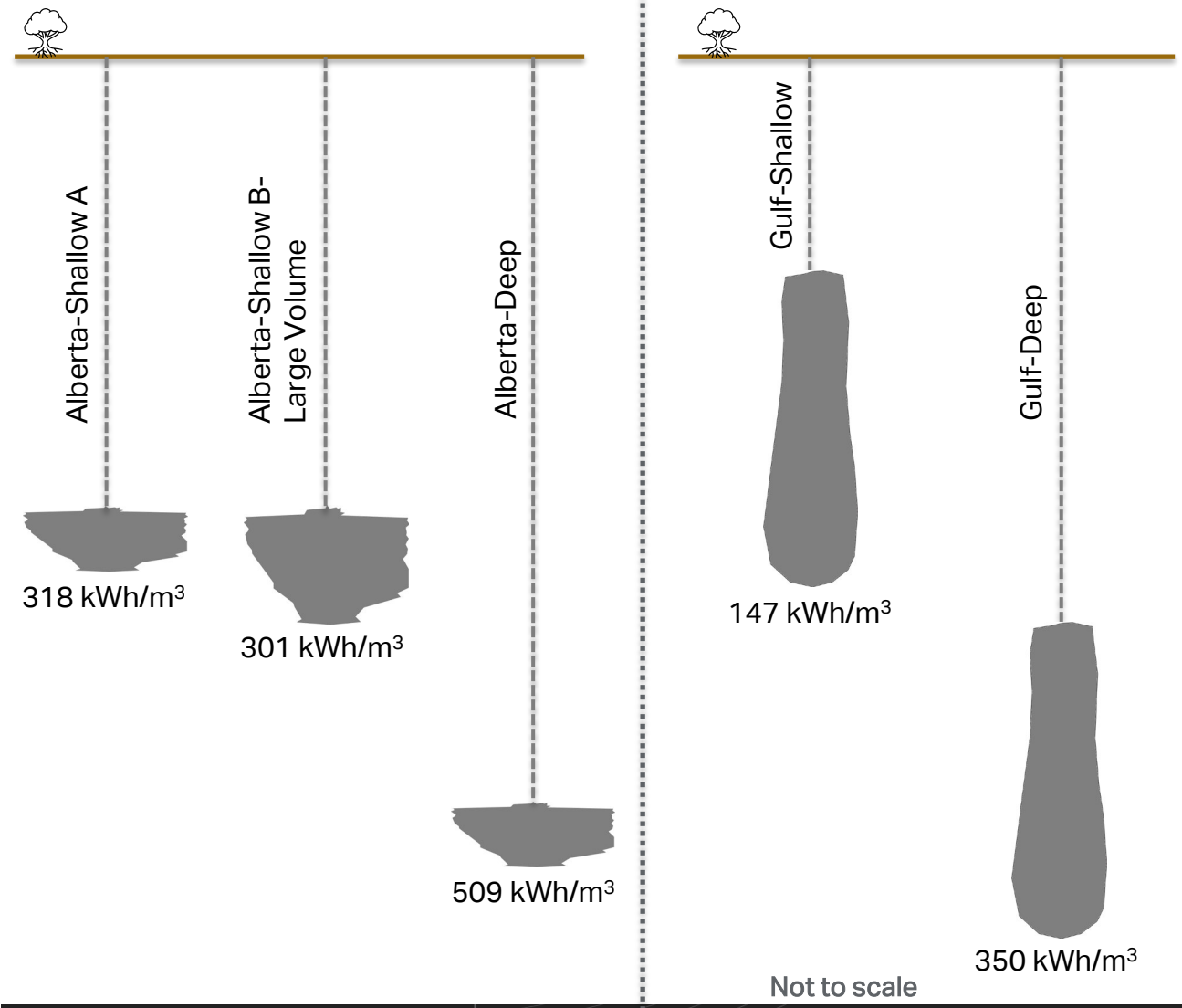


RESULTS
STORAGE DENSITY: ALL CASES

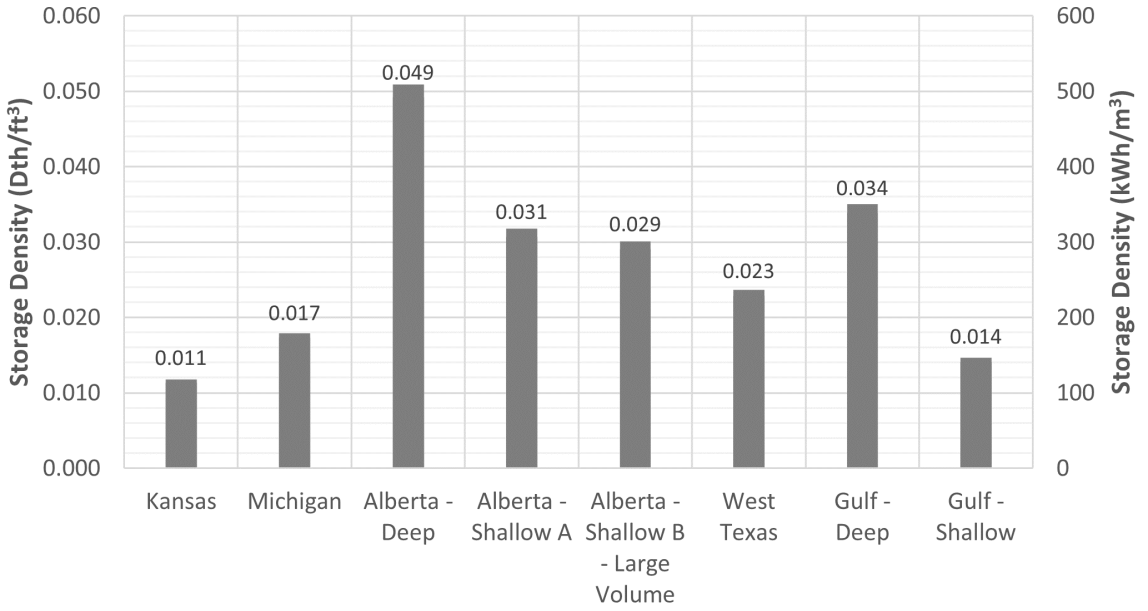
- **STORAGE DENSITY:**
  - Working thermal energy per unit volume of the cavern
  - Better metric of hydrogen storage efficiency as compared to working thermal energy
- **CAVERNS WITH HIGH STORAGE DENSITY ARE PREFERRED IN TERMS OF COST EFFICIENCY**
- **STORAGE DENSITY INCREASES WITH DEPTH AND IS DEPENDENT ON THE PRESSURE RANGE**
- **IN THIS STUDY:**
  - Alberta-Deep case caverns have the largest storage density (509 kWh/m^3)
  - Kansas caverns have the smallest storage density (117 kWh/m^3)



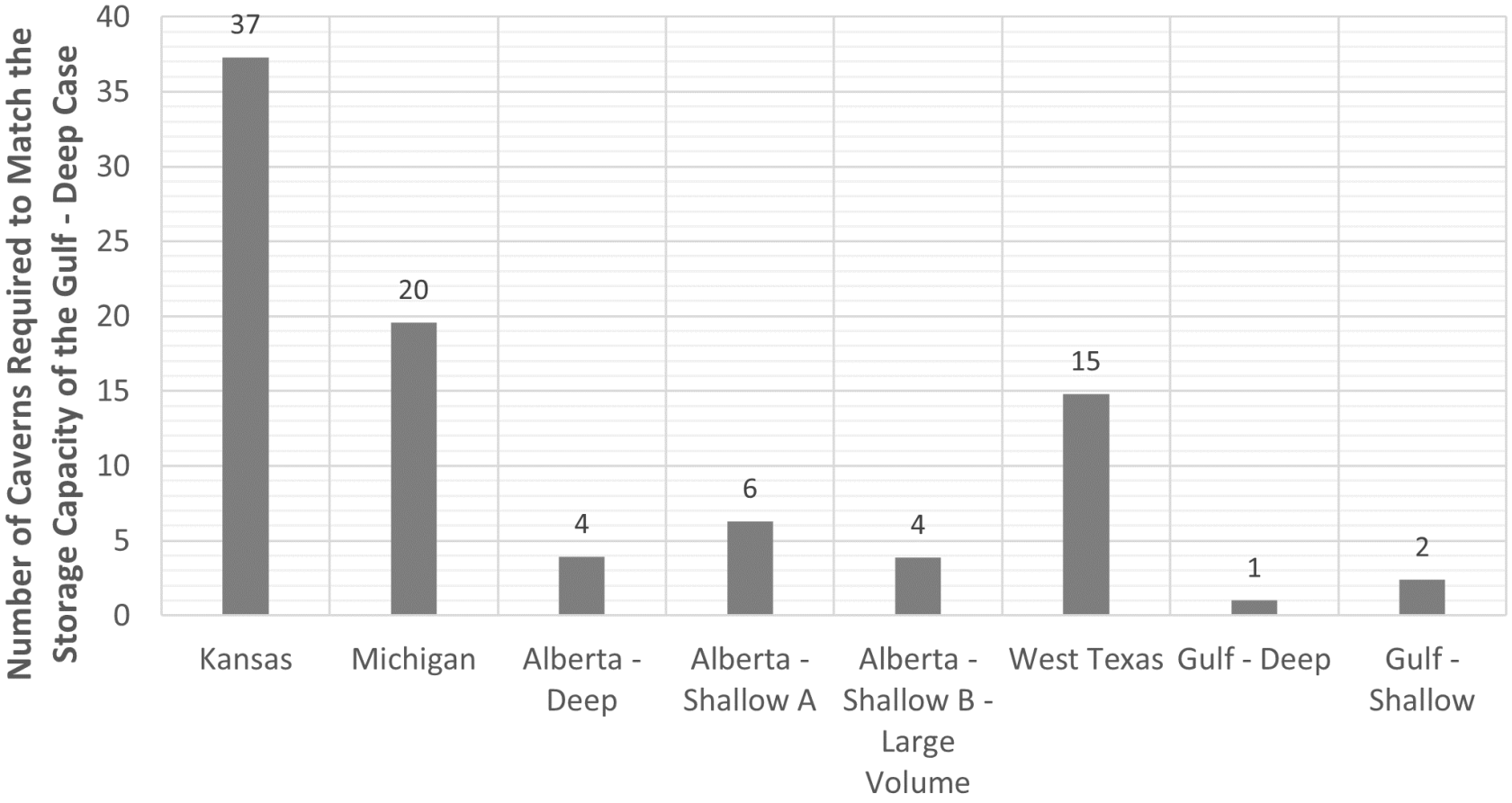
RESULTS
STORAGE DENSITY: ALBERTA AND GULF COAST



Cavern Volume (MMbbls)							
0.699	0.874	1.530	1.530	2.623	0.874	8.742	8.742
Pressure Range (psi)							
549	879	3354	1649	1649	1209	2090	715



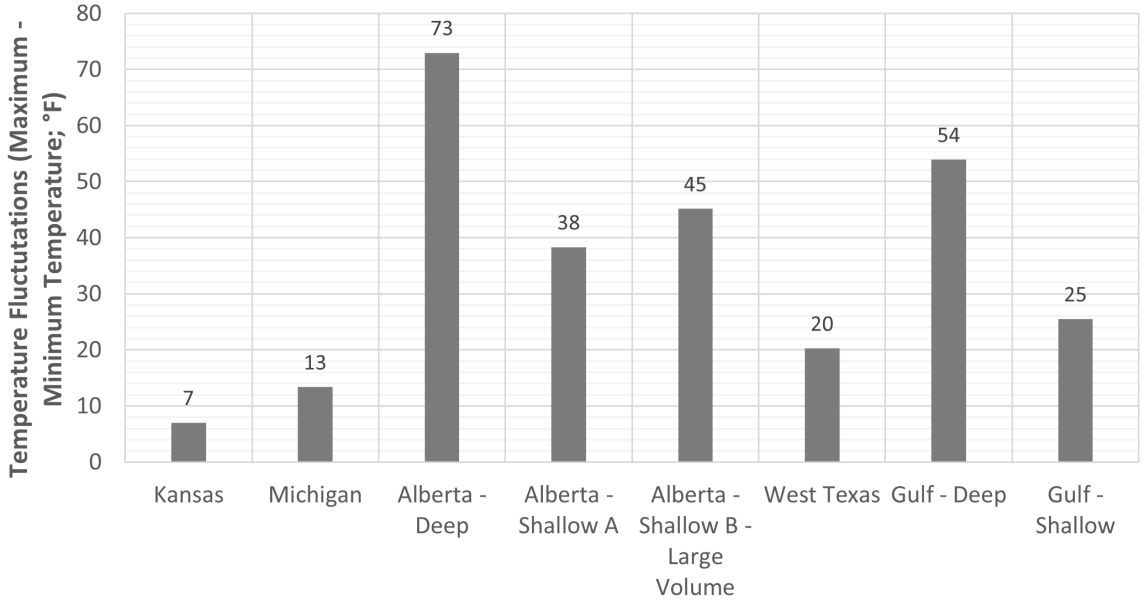
COMPARISON


Number of Caverns Required to Match the Storage Capacity of the Gulf - Deep Case
40
35
30
25
20
15
10
5
0
37
20
4
6
4
15
1
2
Kansas
Michigan
Alberta - Deep
Alberta - Shallow A
Alberta - Shallow B - Large Volume
West Texas
Gulf - Deep
Gulf - Shallow

TEMPERATURE FLUCTUATION

- Temperature fluctuations occur when hydrogen is injected and withdrawn from the cavern
- Large temperature fluctuations should be avoided
- Temperature fluctuations increase with depth
  - Deeper caverns have a larger pressure range, which generally results in a larger temperature range
    - 73°F in Alberta-Deep cavern
    - 38°F in Alberta-Shallow A cavern
- Temperature fluctuations increase with cavern volume
    - 45°F in "Alberta-Shallow B-Large Volume" cavern
    - 38°F in "Alberta-Shallow A" cavern

Cavern Volume (MMbbls)							
0.699	0.874	1.530	1.530	2.623	0.874	8.742	8.742
Pressure Range (psi)							
549	879	3354	1649	1649	1209	2090	715



RESPEC

THANK YOU!

QUESTIONS?