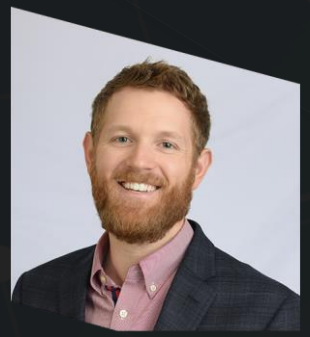
UNDERGROUND HYDROGEN STORAGE

WHAT ARE THE CHALLENGES?



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OCTOBER 18, 2021

AGENDA

- INTRODUCTION
- HYDROGEN THERMODYNAMICS
- GEOLOGY
- MATERIAL COMPATIBILITY
- STATE-OF-THE-ART RESEARCH

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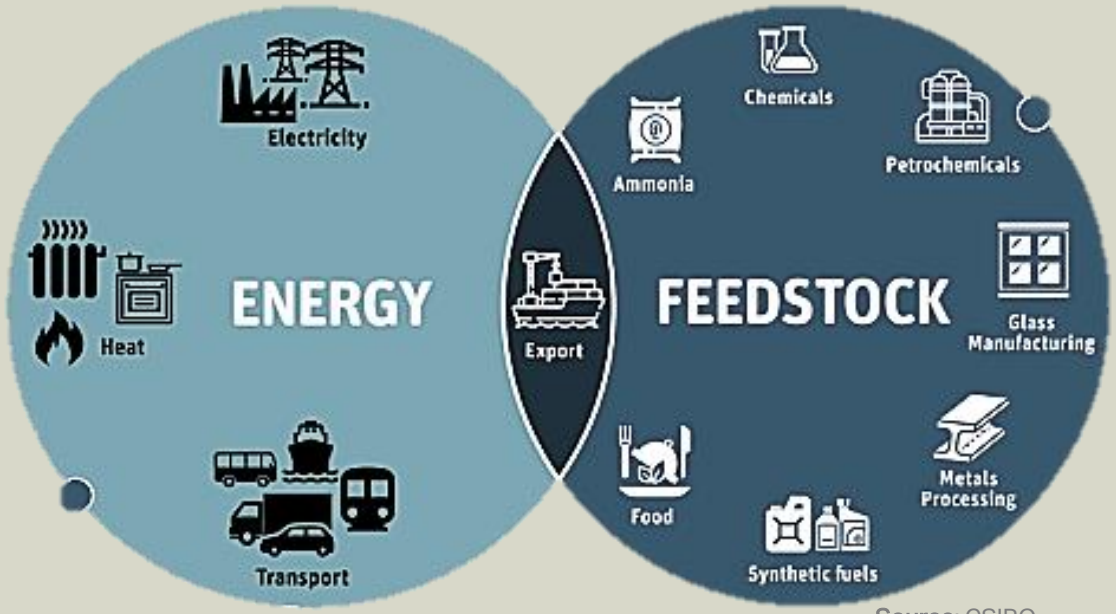
WHY HYDROGEN?

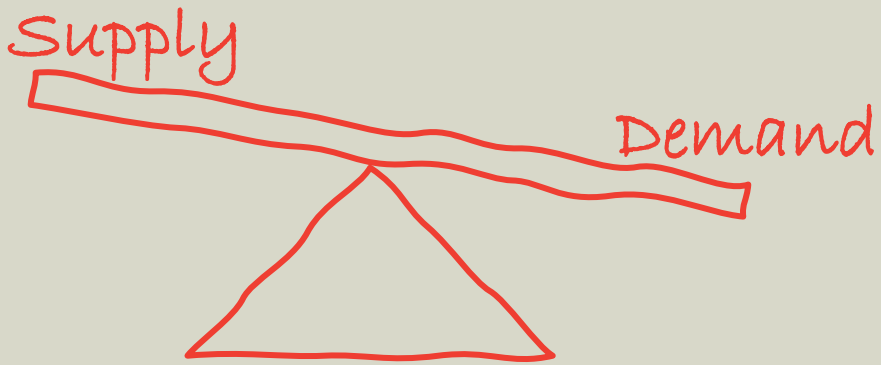
Applications for Hydrogen



Source: CSIRO

- Carbon emissions free
- Significant interest in hydrogen to meet net-zero carbon goals
- Integration with renewable energy
- New fuel for the fossil energy industry

HYDROGEN STORAGE



Alleviate supply and demand issues

Unique interest in renewable energy integration "power to gas"

Short and long-term storage to balance intermittent renewable energy (wind / solar)

HYDROGEN STORAGE

LOW DENSITY

Hydrogen has 3x more energy per pound than hydrocarbons (natural gas, gasoline, etc.)

BUT...
Hydrogen has a low density

HIGHER VOLUME

Hydrogen has ⅓ the energy compared to natural gas on a per cubic foot basis.

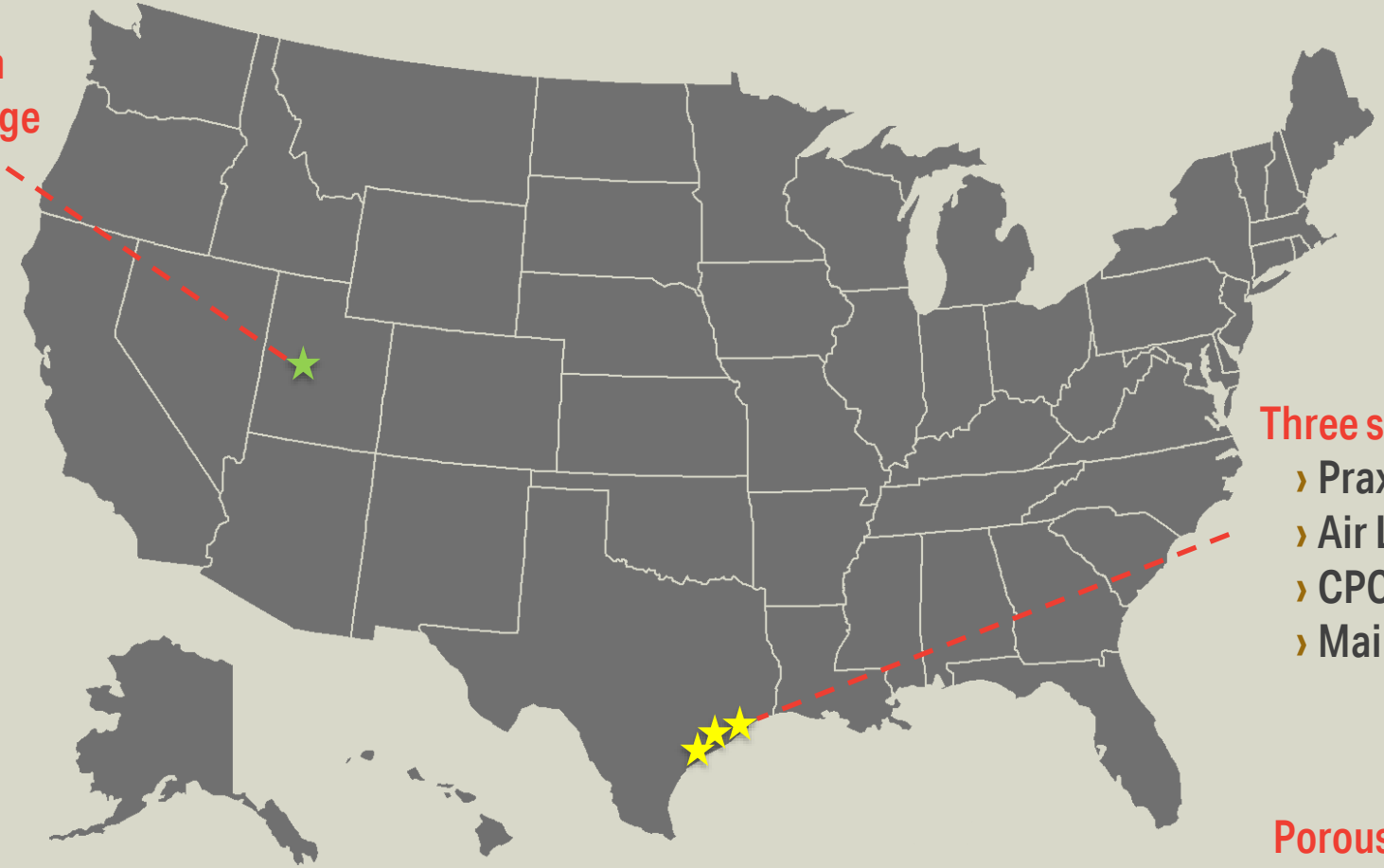
More storage volume to equal the same energy content

Bulk surface storage is difficult

Underground storage is the immediate target for hydrogen

HYDROGEN STORAGE

New salt cavern hydrogen storage project in Utah



Three salt caverns in TX and one in the UK

- Praxair (Moss Bluff)
- Air Liquid (Spindletop)
- CPChem (Clemens) - since 1986
- Mainly used for industrial purposes (refining)

Porous Reservoir Storage

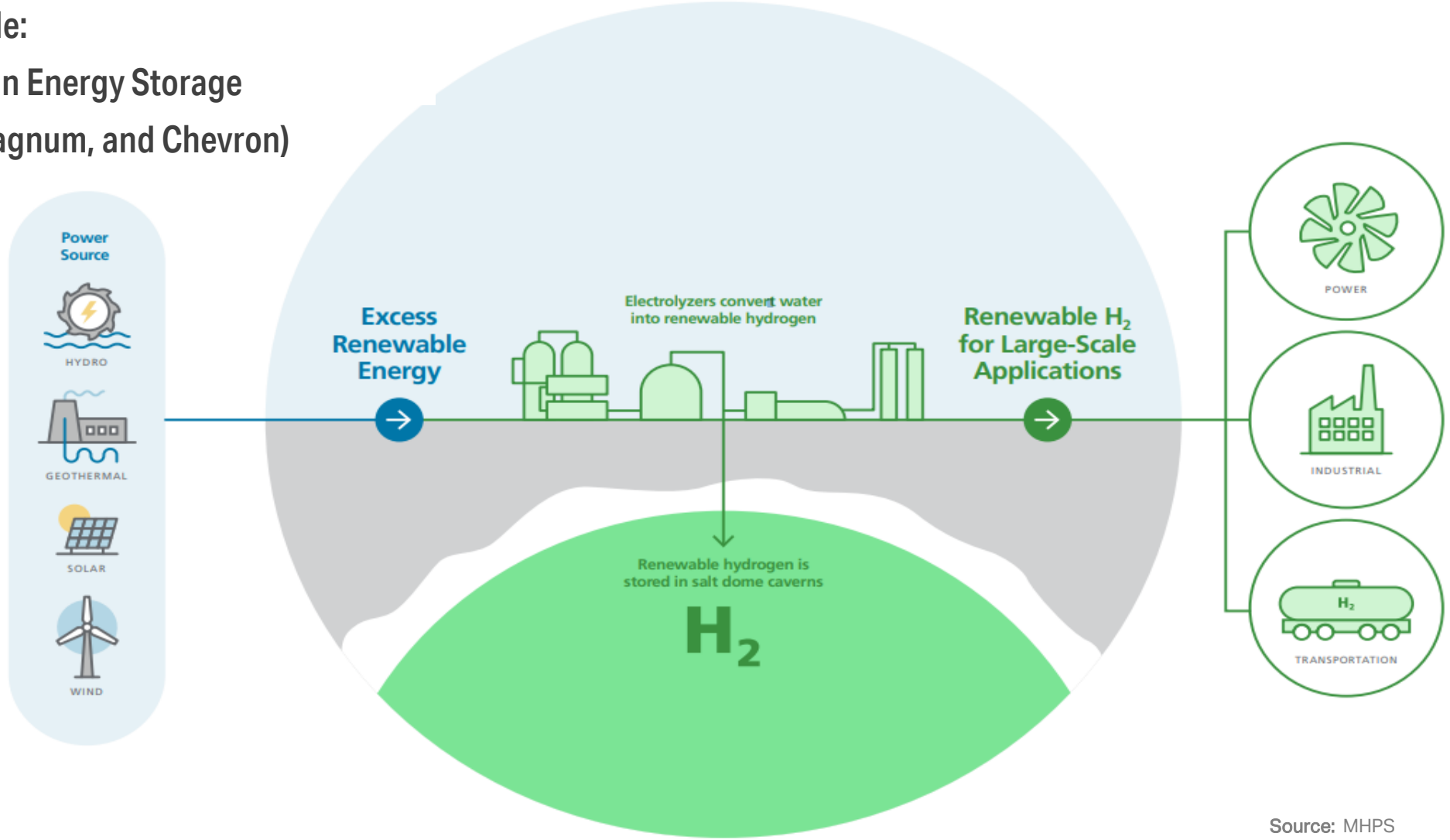
- Historically used for "town gas" hydrogen
- Not currently used for hydrogen

HYDROGEN STORAGE

Project Example:

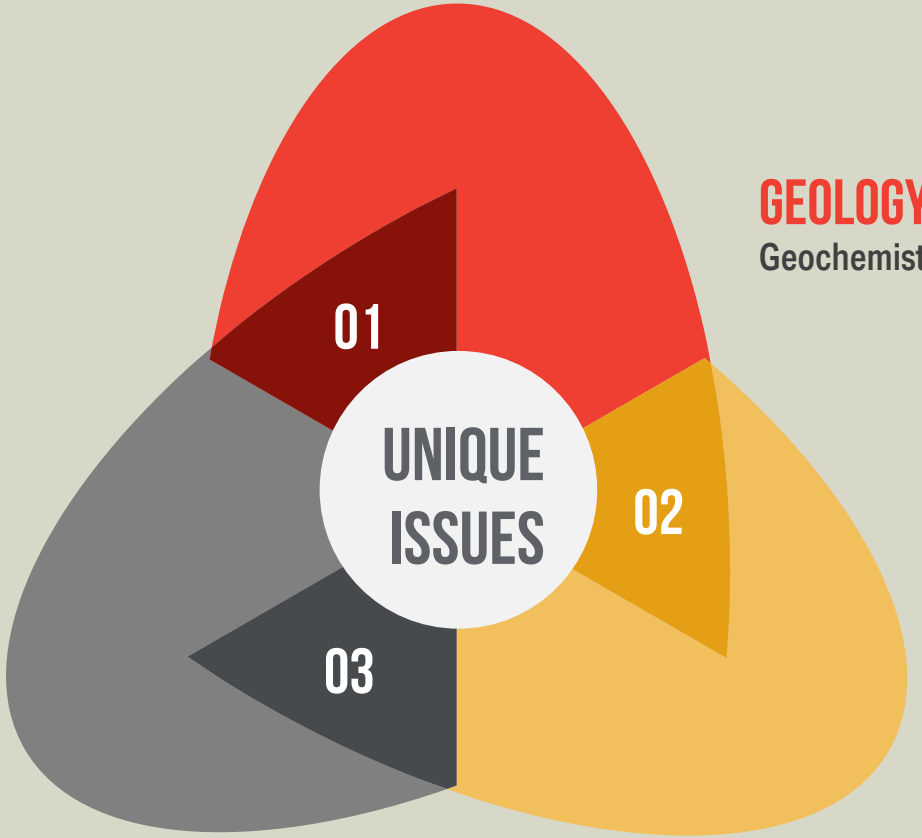
Advanced Clean Energy Storage

(Mitsubishi, Magnum, and Chevron)



Source: MHPS

WHAT ARE THE STORAGE ISSUES?



GEOLOGY
Geochemistry, microbial activity, permeability

THERMODYNAMICS
Compressibility, high frequency pressure cycling

MATERIAL COMPATIBILITY
Hydrogen embrittlement, seals, casing selection

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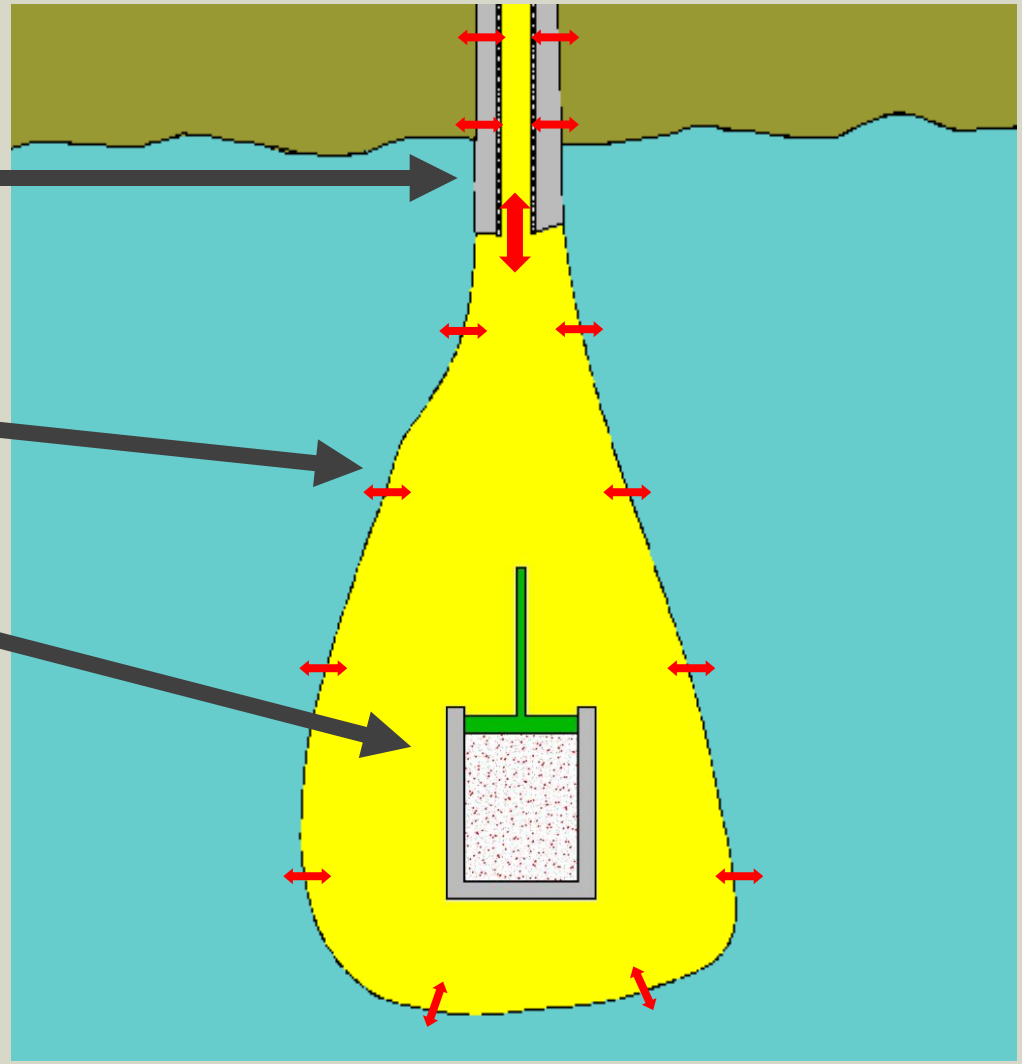
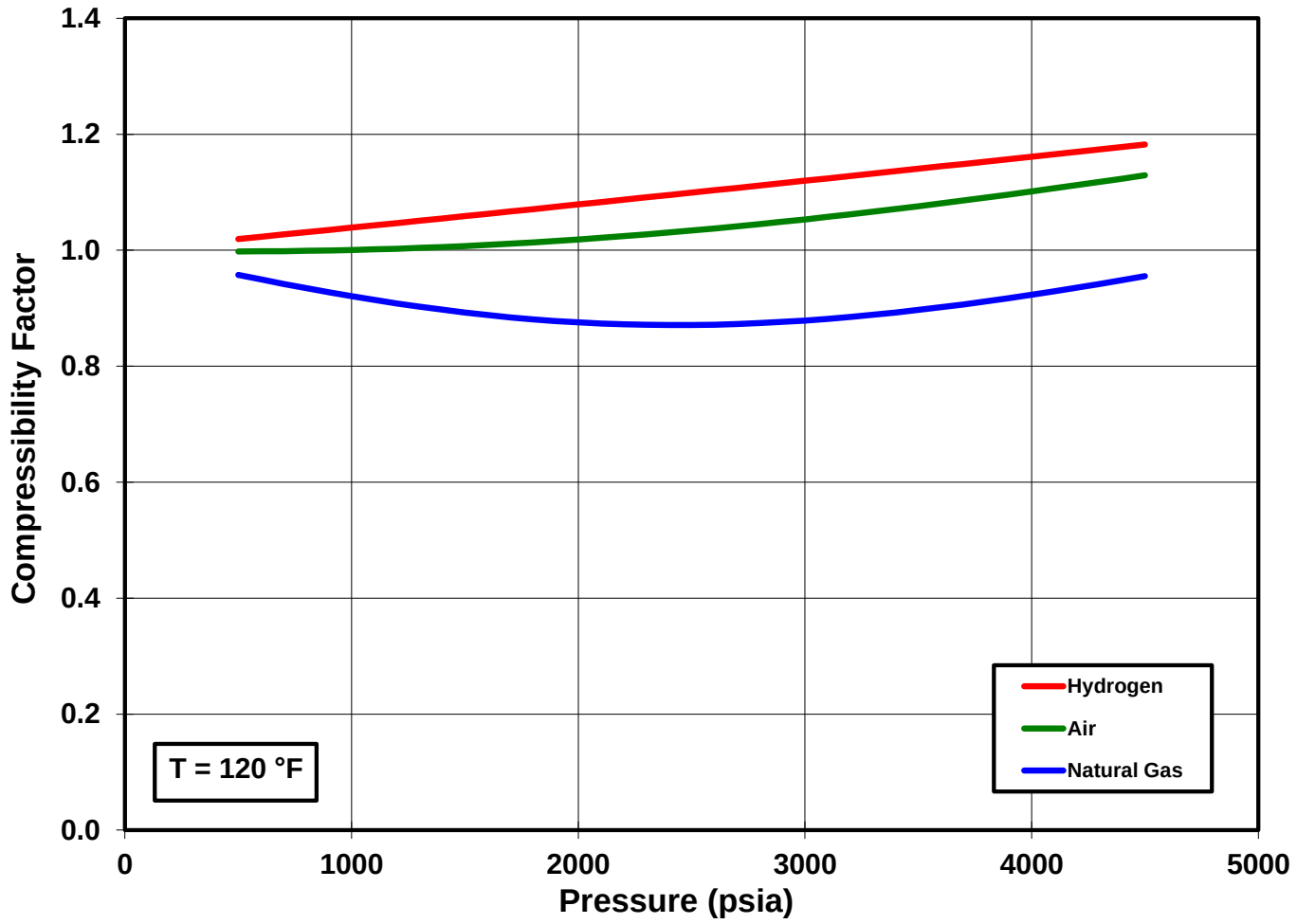
HYDROGEN THERMODYNAMICS

- Heat Gain/Loss due to Mass Flow in and out of Cavern
- Heat Transfer with Surrounding Salt
- Compression/ Decompression of the Gas



HYDROGEN THERMODYNAMICS

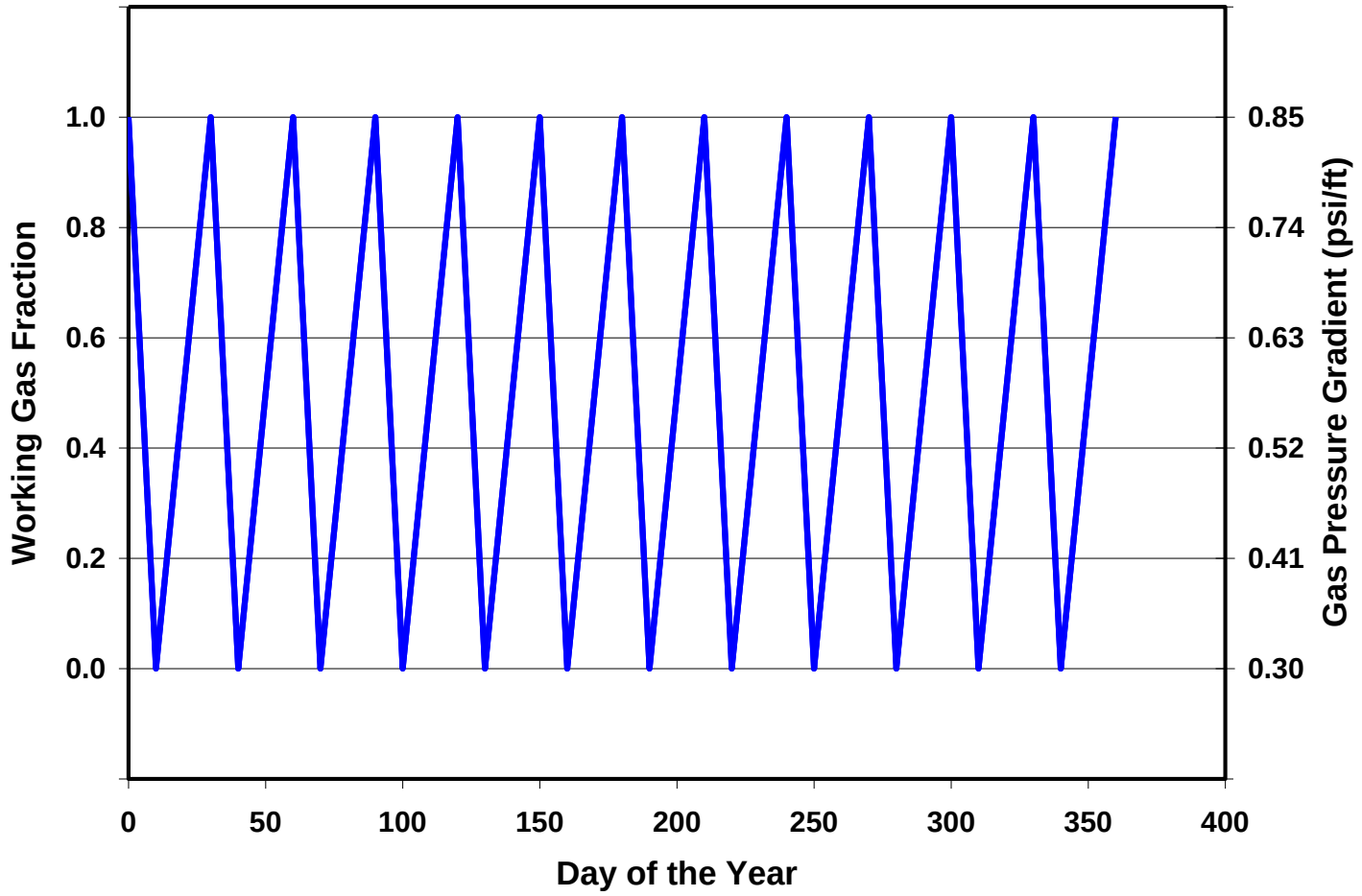
- Hydrogen is harder to compress than natural gas
- Compressibility factor > 1.0
- Less "bang for your buck" as pressure increases



Nieland, J. D., 2021. "Cavern Thermodynamics," Prepared by RESPEC for the Solution Mining Research Institute Fall Meeting, Galveston, TX, October 19-21.

HYDROGEN THERMODYNAMICS

- Example storage cycle (cavern)
- 1 -12 turns per year
- Max to min working gas
- Max to min pressure
  - 0.85 psi/ft to 0.30 psi/ft



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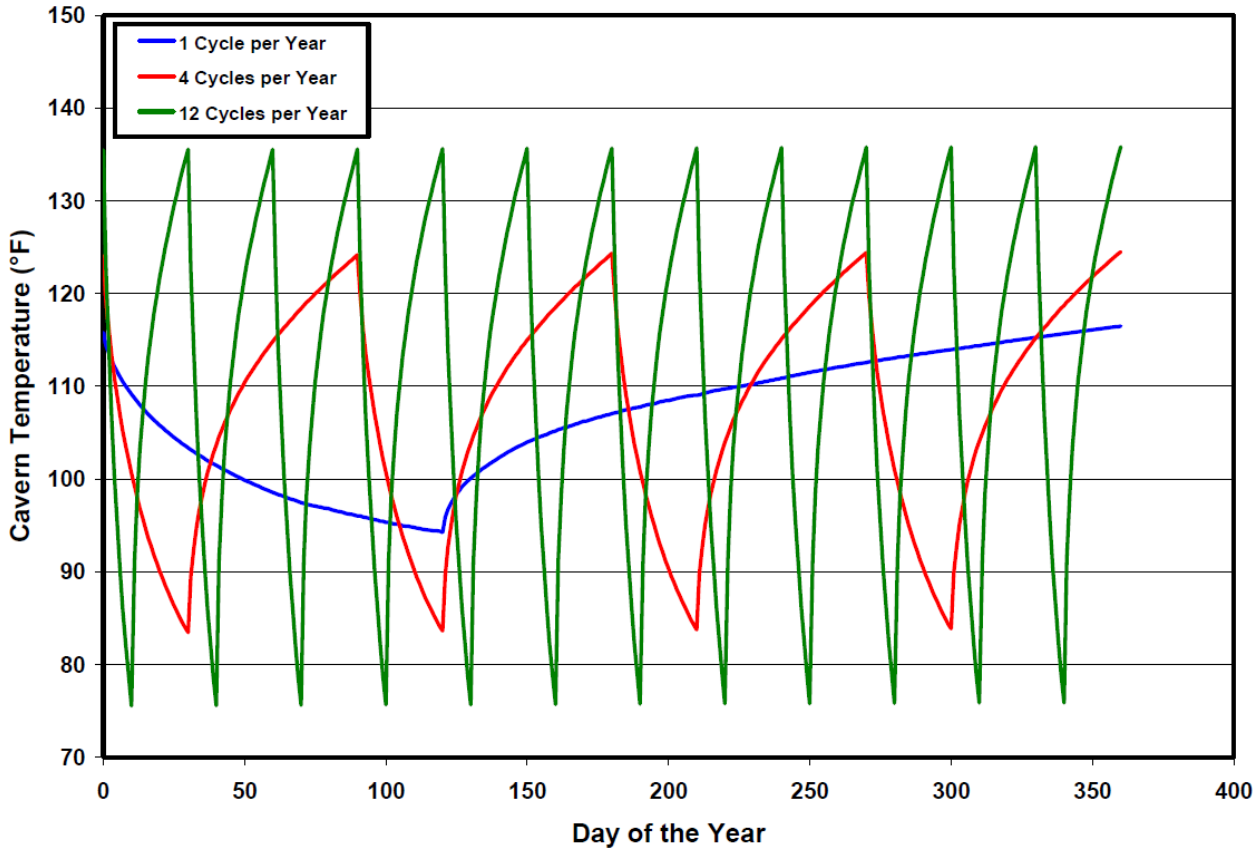
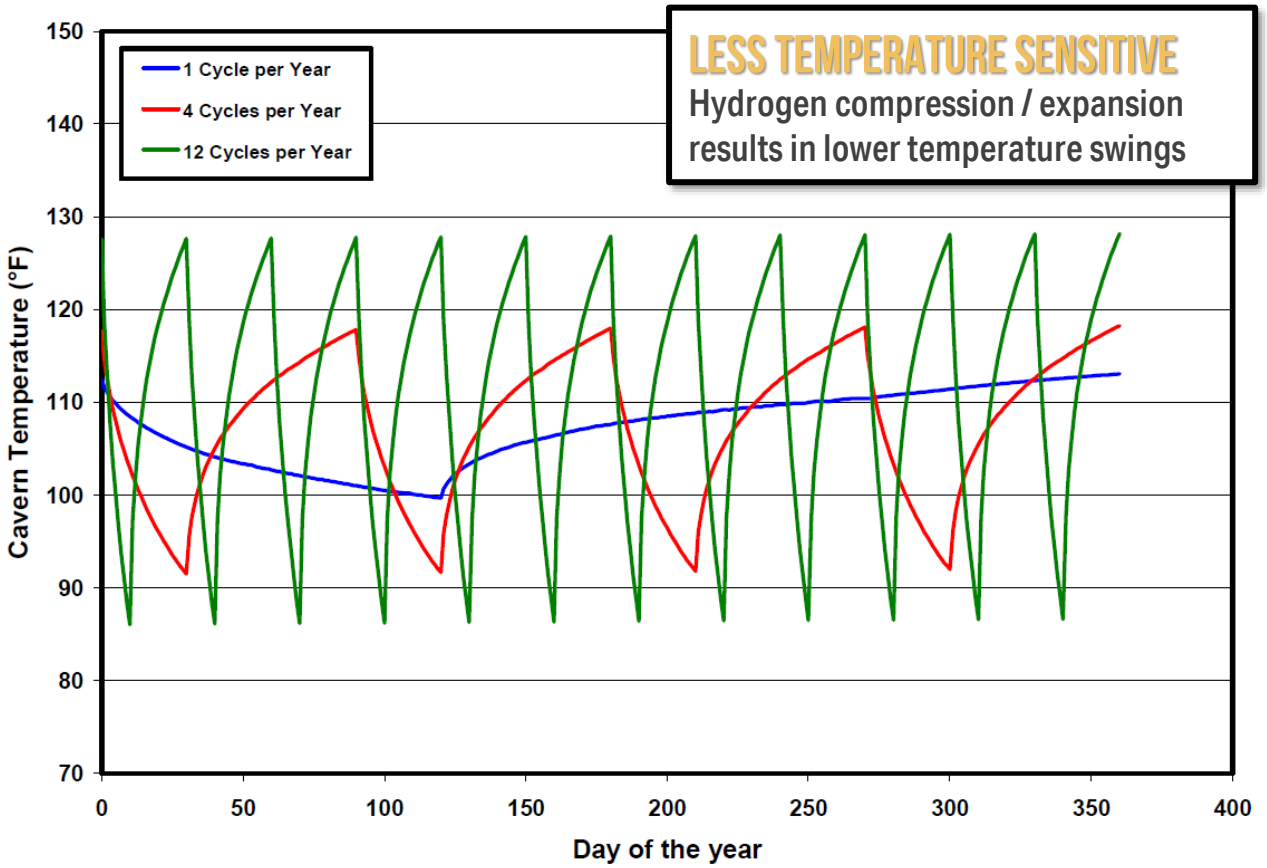
HYDROGEN THERMODYNAMICS

NATURAL GAS



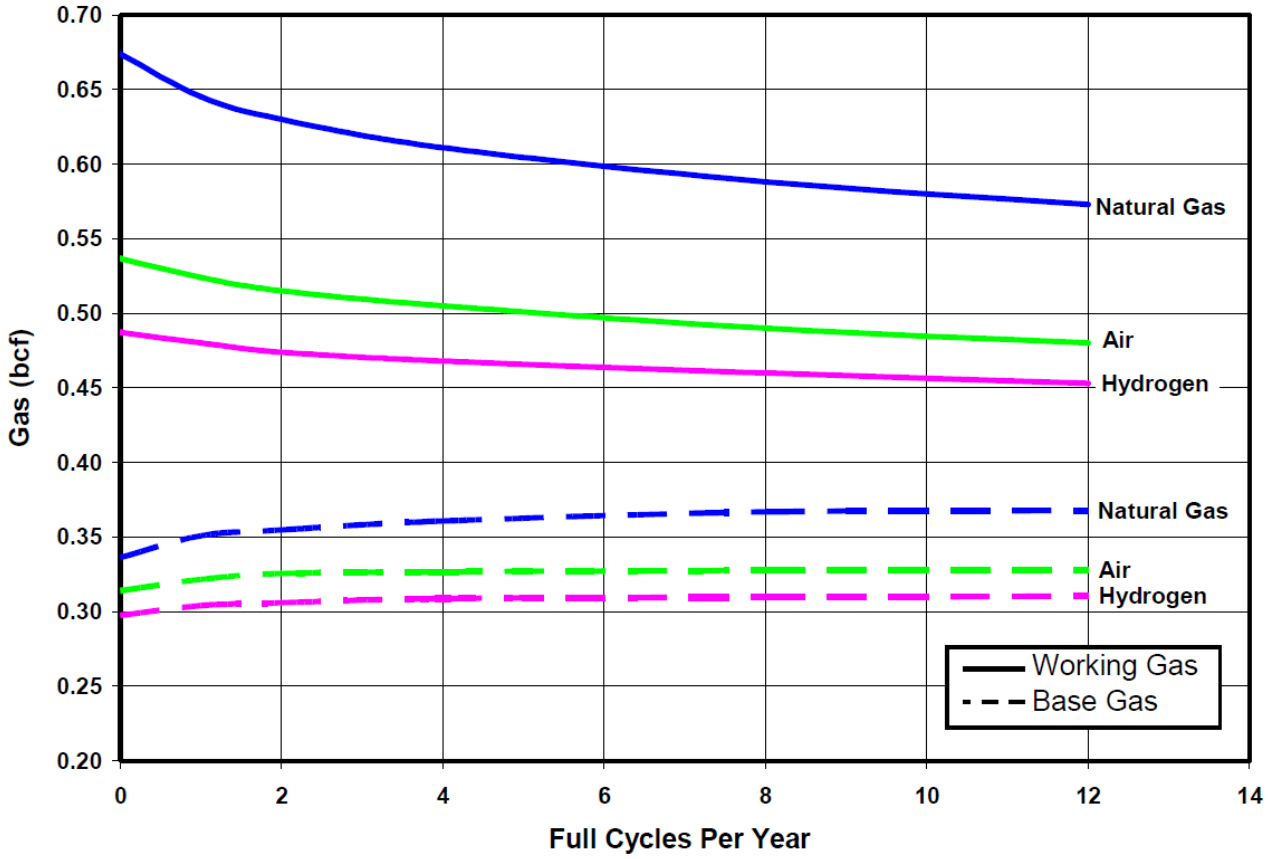
HYDROGEN



Nieland, J. D., 2021. "Cavern Thermodynamics," Prepared by RESPEC for the Solution Mining Research Institute Fall Meeting, Galveston, TX, October 19-21.

HYDROGEN THERMODYNAMICS

- What about working and base gas capacities?
- Primarily a function of the hydrogen compressibility factor > 1.0
- Less usable hydrogen volume from underground storage



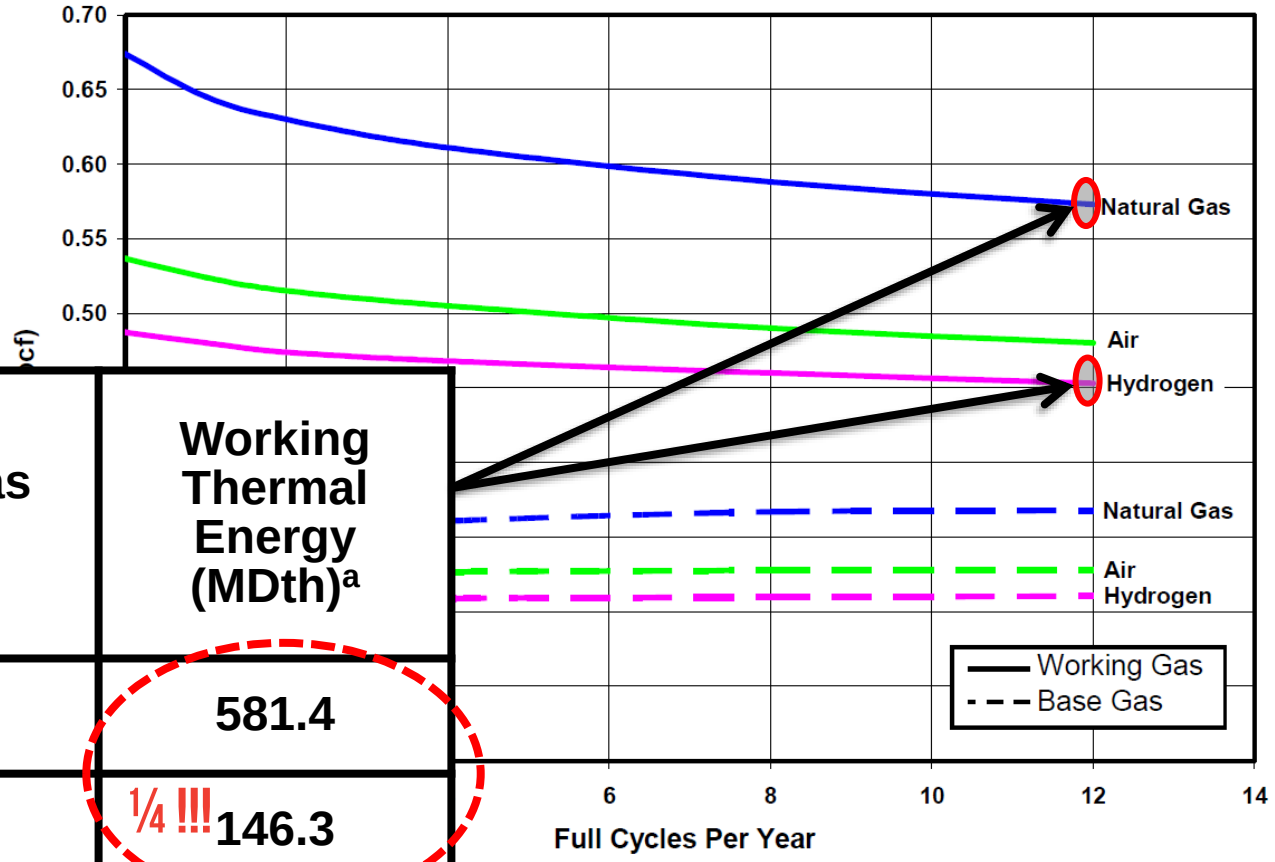
Nieland, J. D., 2021. "Cavern Thermodynamics," Prepared by RESPEC for the Solution Mining Research Institute Fall Meeting, Galveston, TX, October 19-21.

HYDROGEN THERMODYNAMICS

- Hydrogen is less efficient to store –AND– has less energy per unit volume

Gas	Working Gas (bcf)	Base Gas (bcf)	Working Thermal Energy (MDth)[a]
Natural Gas	0.57	0.37	581.4
Hydrogen	0.45	0.32	¼ !!! 146.3

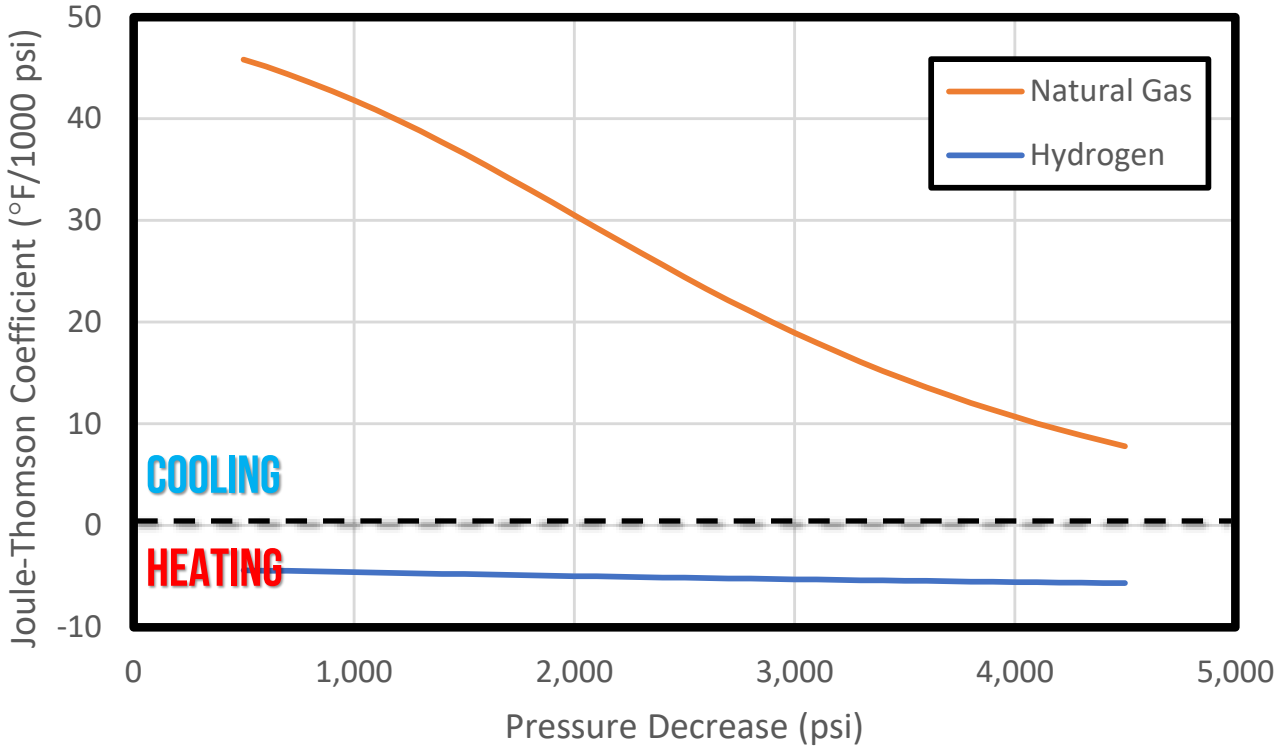
a) Assumes 1020 Btu/scf for natural gas and 325 Btu/scf for hydrogen



Nieland, J. D., 2021. "Cavern Thermodynamics," Prepared by RESPEC for the Solution Mining Research Institute Fall Meeting, Galveston, TX, October 19-21.

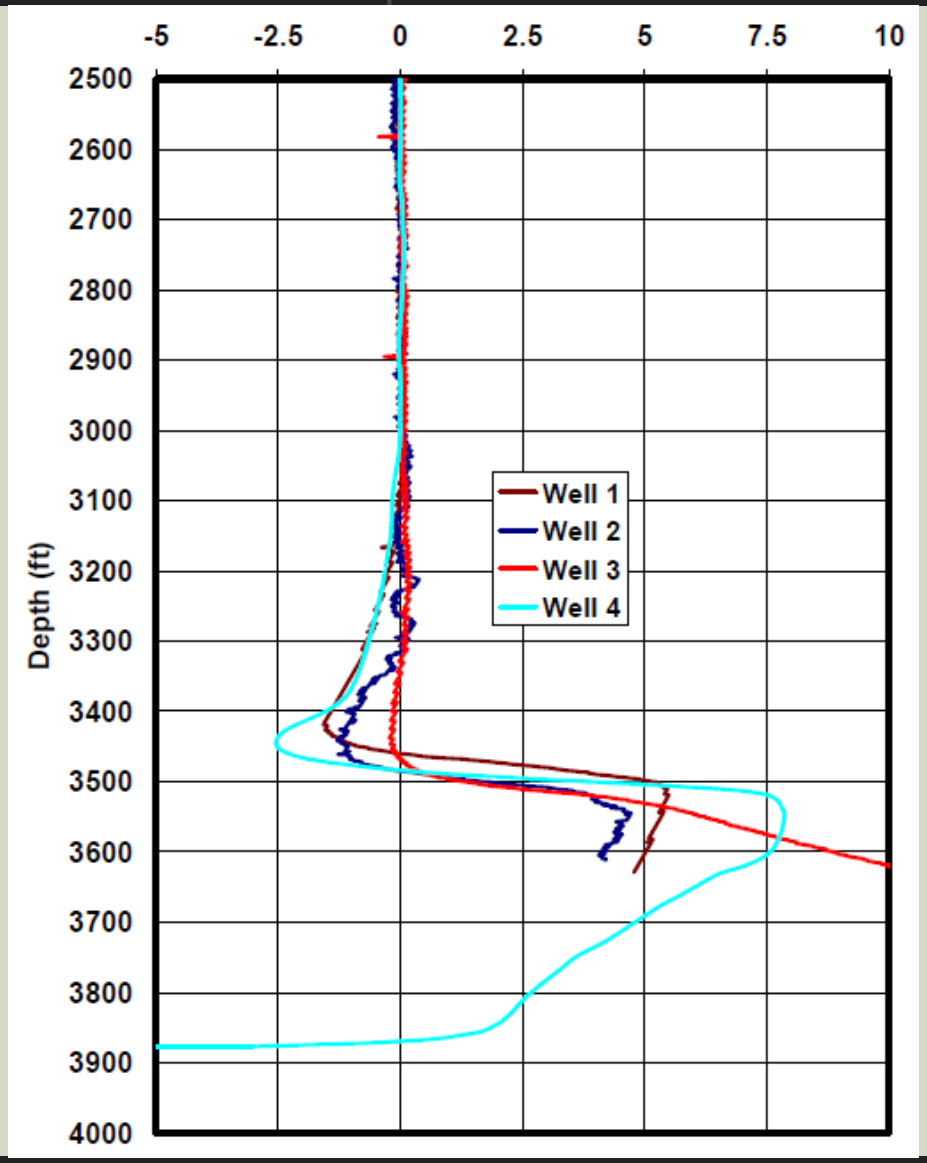
HYDROGEN THERMODYNAMICS

- Hydrogen has a negative Joule-Thomson coefficient = it warms when expanded through a throttling valve (i.e., a leak)
- But the Joule-Thomson effect is weak for hydrogen
- For a 1,000 psi expansion, hydrogen will warm by about 5°F heating… compared to 25°F of cooling for natural gas



HYDROGEN THERMODYNAMICS

- Mechanical Integrity Tests (MIT) in hydrogen should experience less variation… not as sensitive to temperature = less density variation.
- Faster to reach thermal equilibrium
- Hydrogen results in higher wellhead pressure for a given casing seat test pressure gradient



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HYDROGEN GEOLOGY

PERMEABILITY

Hydrogen is such a small molecule, permeability out of the storage cavern / reservoir may be a concern in certain geologies

GEOCHEMISTRY

Hydrogen is highly reactive and may lead to unwanted chemical processes in certain geologies and water environments.

MICROBIAL

Microbial organisms can consume hydrogen and produce unwanted byproducts. Need high temperatures and salinities to avoid growth.

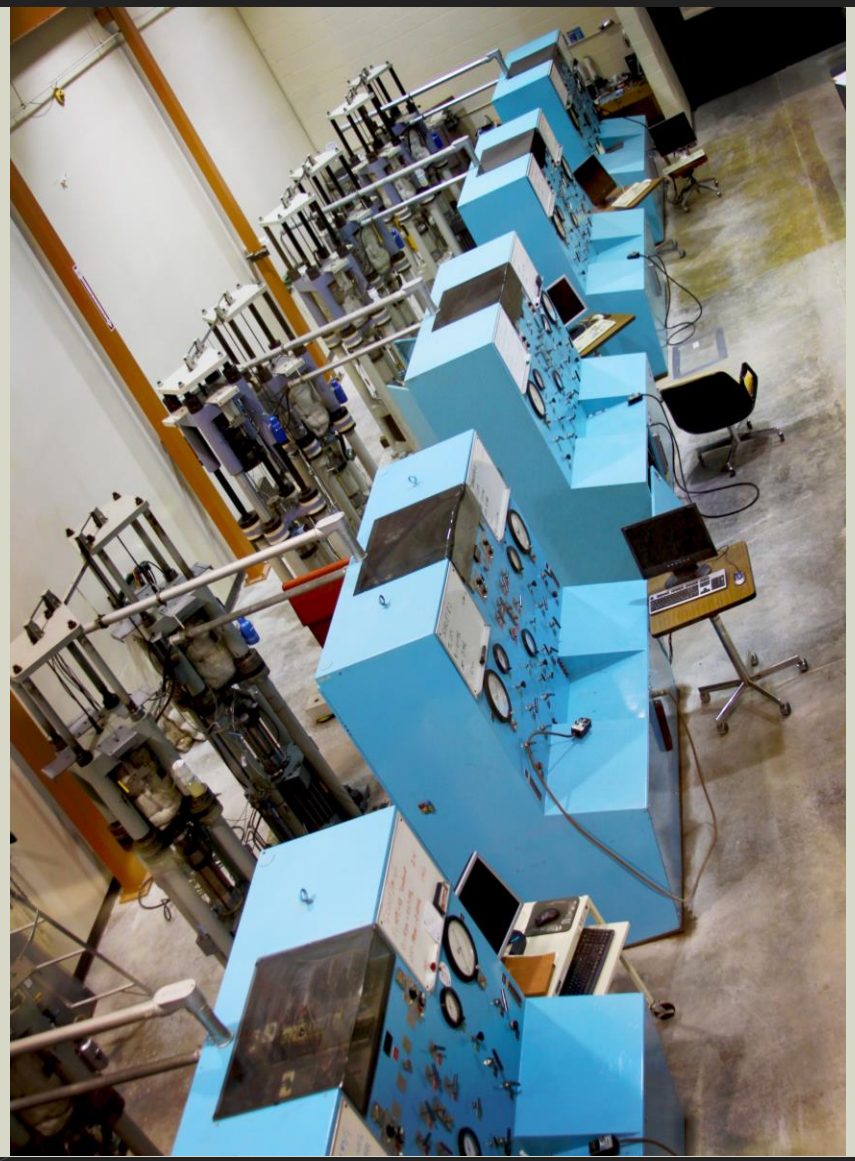
DIFFUSION

Hydrogen can diffuse into the molecular structure of the host geologic formation

HYDROGEN GEOLOGY

SMALL MOLECULES

Increased concern for permeation into subsurface formations

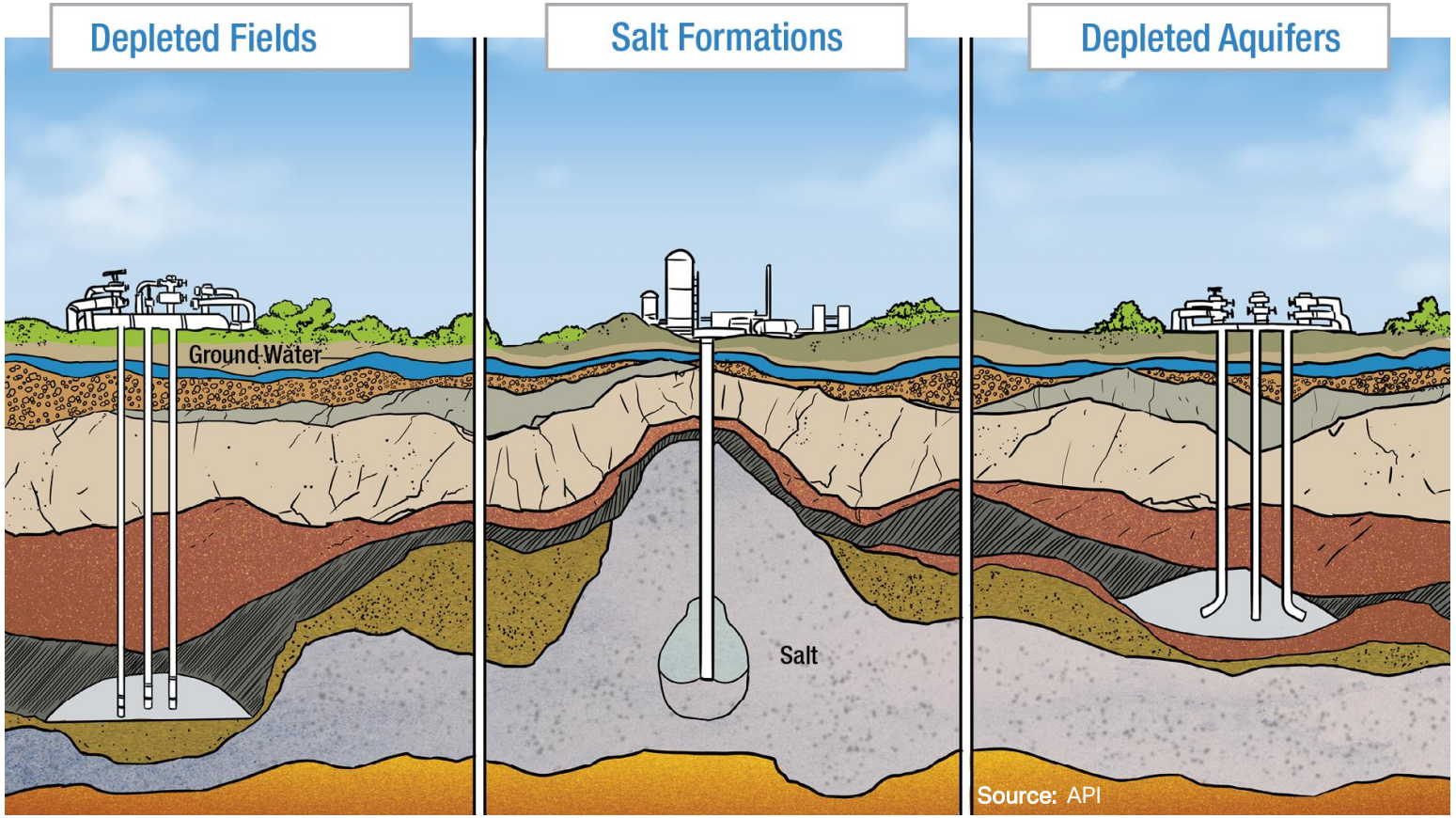


PERMEABILITY TESTING

RESPEC recently upgraded our laboratory equipment to specifically perform permeability testing in support of hydrogen storage

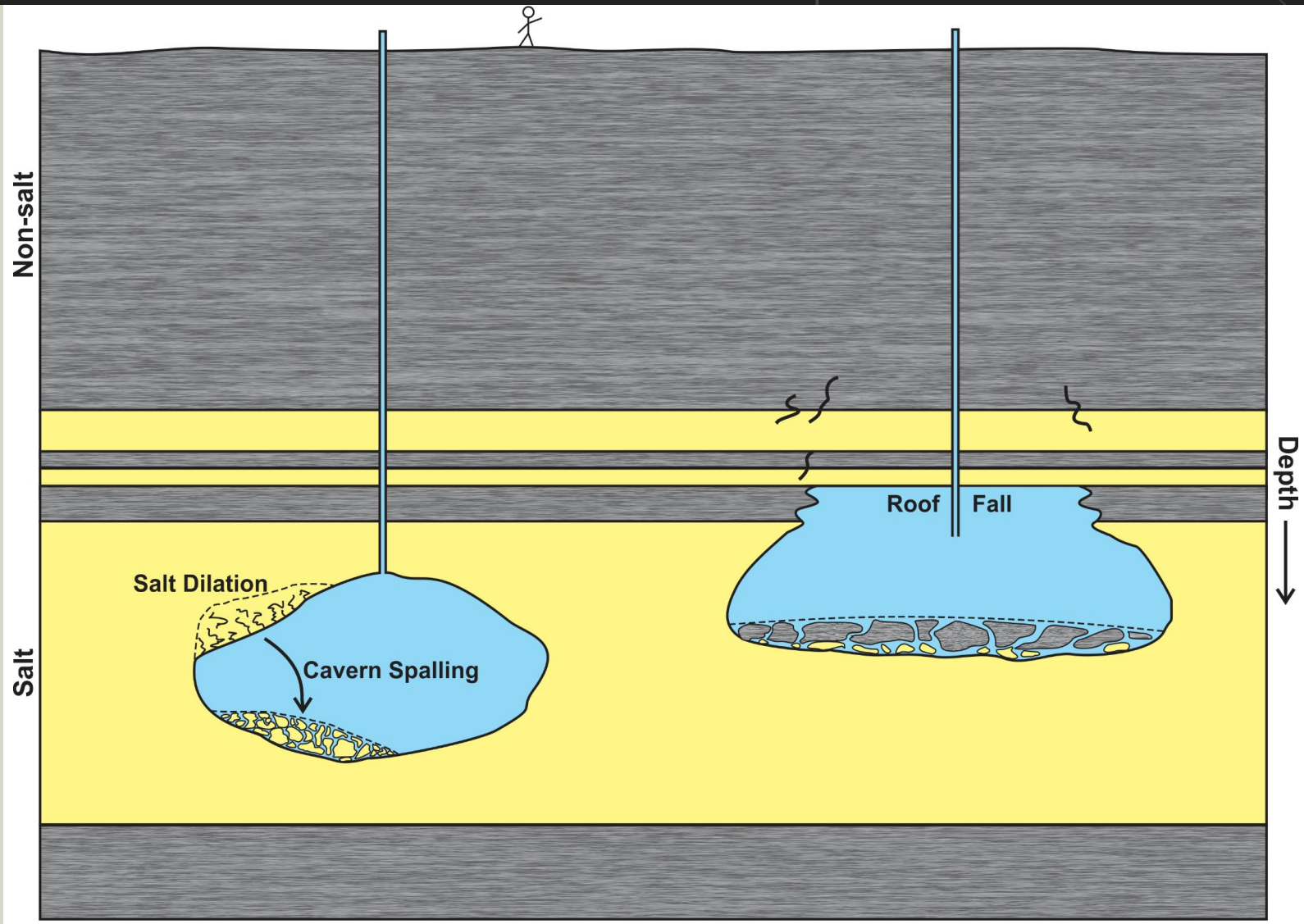
HYDROGEN GEOLOGY

- Domal caverns
  - Proven
  - Typically cleaner salt
  - Less variables
- Bedded caverns
  - Dirtier salt
  - Nonsalt interbeds, pathways for hydrogen?
- Porous reservoirs
  - Complex geochemistry
  - Microbial concerns
  - Caprock interactions



HYDROGEN GEOLOGY

- For geologic stability and integrity (salt & caprock)
  - A pressure is a pressure
  - Doesn't matter if it is hydrogen or natural gas
- Big difference with hydrogen is how the storage will be operated
  - ¼ energy content = more aggressive storage?
  - Desire to increase pressure envelope to maximize storage capacity



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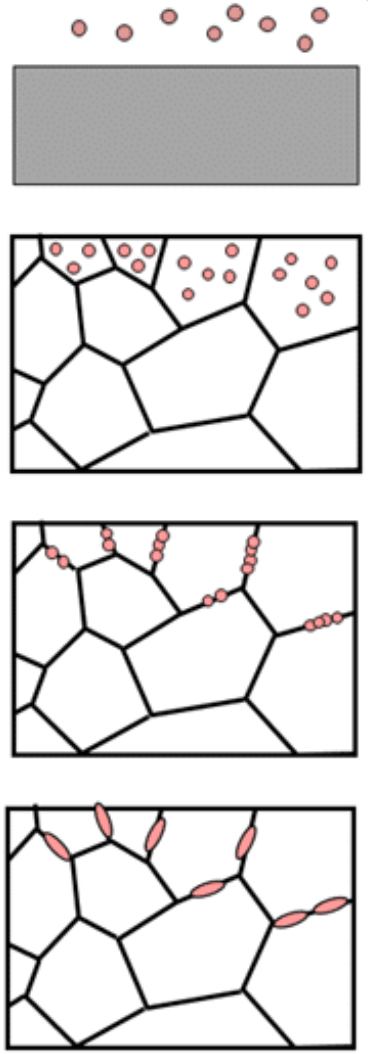
MATERIAL COMPATIBILITY

- Material compatibility issues
- Hydrogen embrittlement
- Hydrogen can diffuse into metals
- Importance of **stress**

MATERIAL COMPATIBILITY

Casing selection

- Low strength steels (TS < 900 MPa) should be less susceptible to hydrogen compared to high strength steels (TS > 900 MPa)
- For high strength, L-80 pipe can be considered for hydrogen
- For low strength, X-52/56 can be considered (low carbon content)

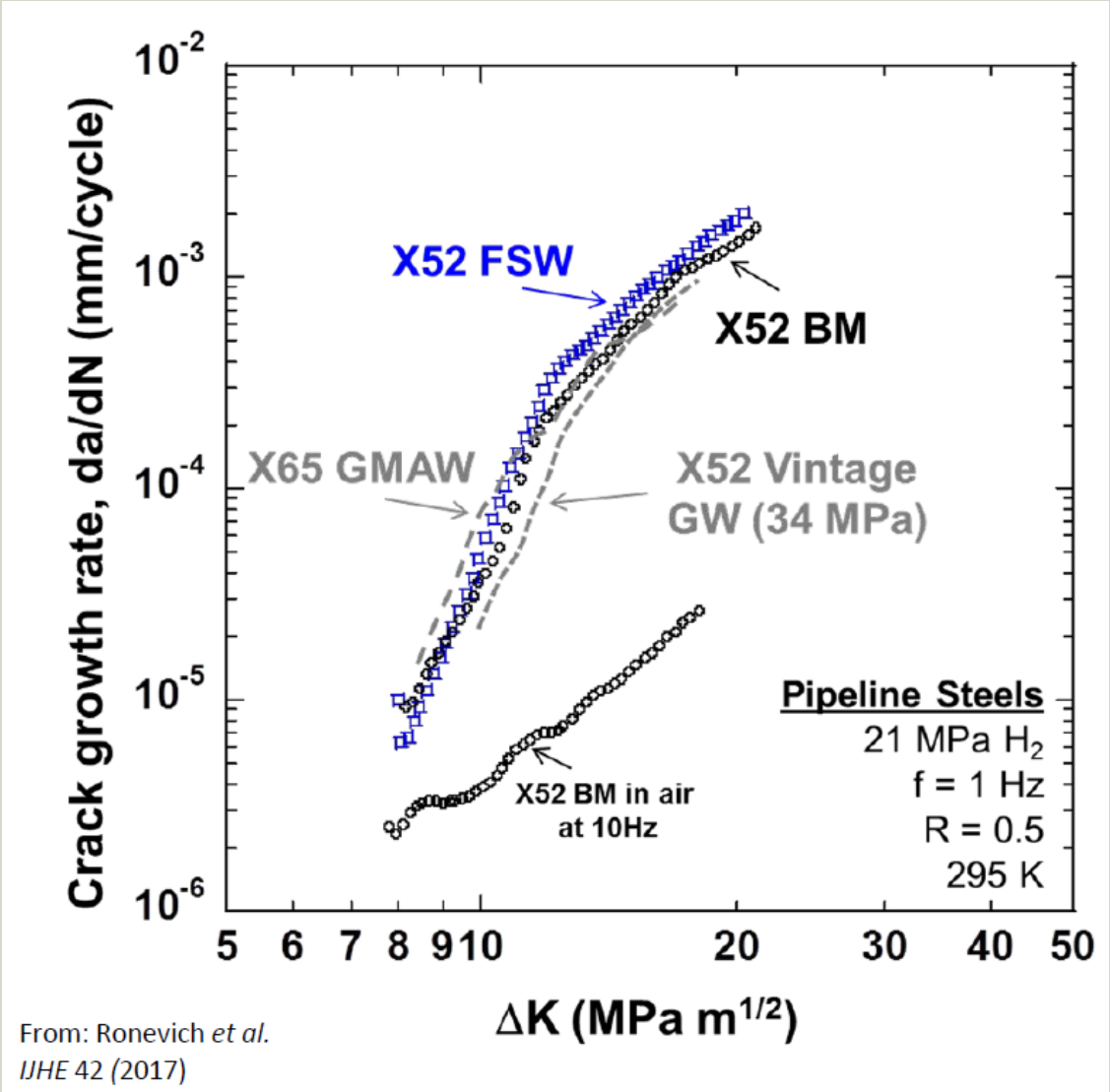


Source: IMETX

MATERIAL COMPATIBILITY

Casing connections

- Welded connections should be considered
- The welding process and heat effected zone are important for hydrogen… creates areas of concentrated carbon and residual stress
- May need to post-anneal the weld to allow carbon to diffuse and stresses to relax… longer connection times



From: Ronevich *et al.* *IJHE* 42 (2017)

MATERIAL COMPATIBILITY

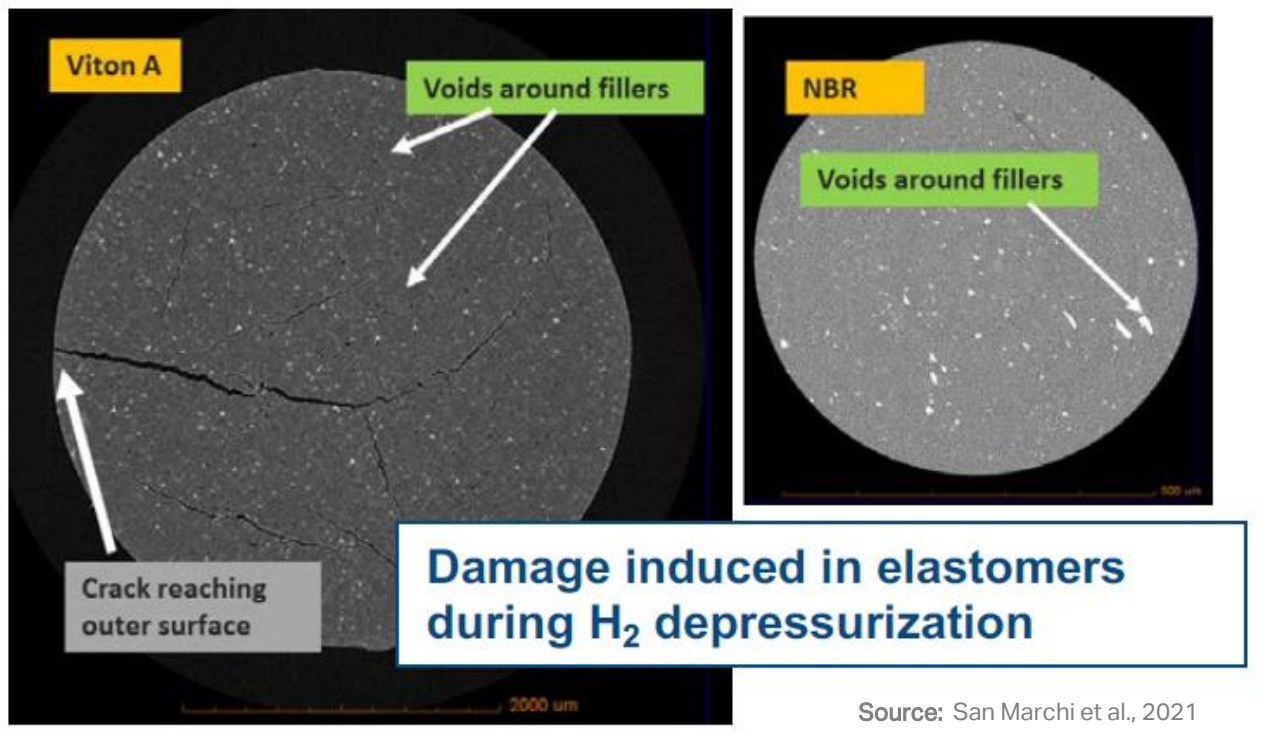
Wellhead

- PSL-3G level components
- Spec'd for sour gas
- Low carbon materials are preferred
- Ideally test with hydrogen, but maybe consider helium

MATERIAL COMPATIBILITY

Sealing elements

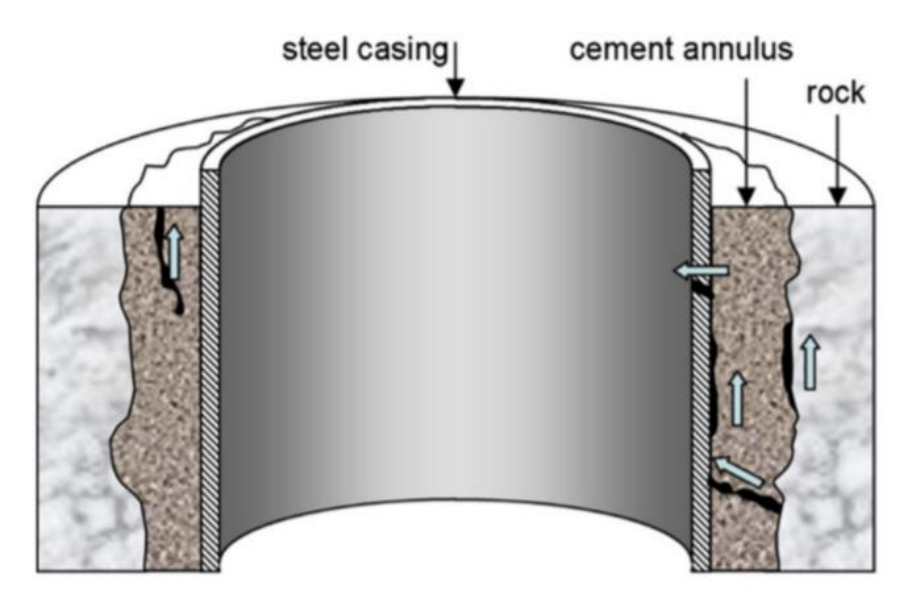
- Consider metallic seals for primary elements
- Secondary seals can be elastomeric, but consider redundant seals and specific materials (HNBR, FKM, PTFE)
- Filler material is seals is important



MATERIAL COMPATIBILITY

Cement

- Conventional cement with gas migration blocker additive
- Can include dry latex, improved sealing and bond
- Resin based cement… likely best option but $$$
- Consider a hybrid of dry latex and resin for production / intermediate / surface



Source: Tao, C., et al., 2021

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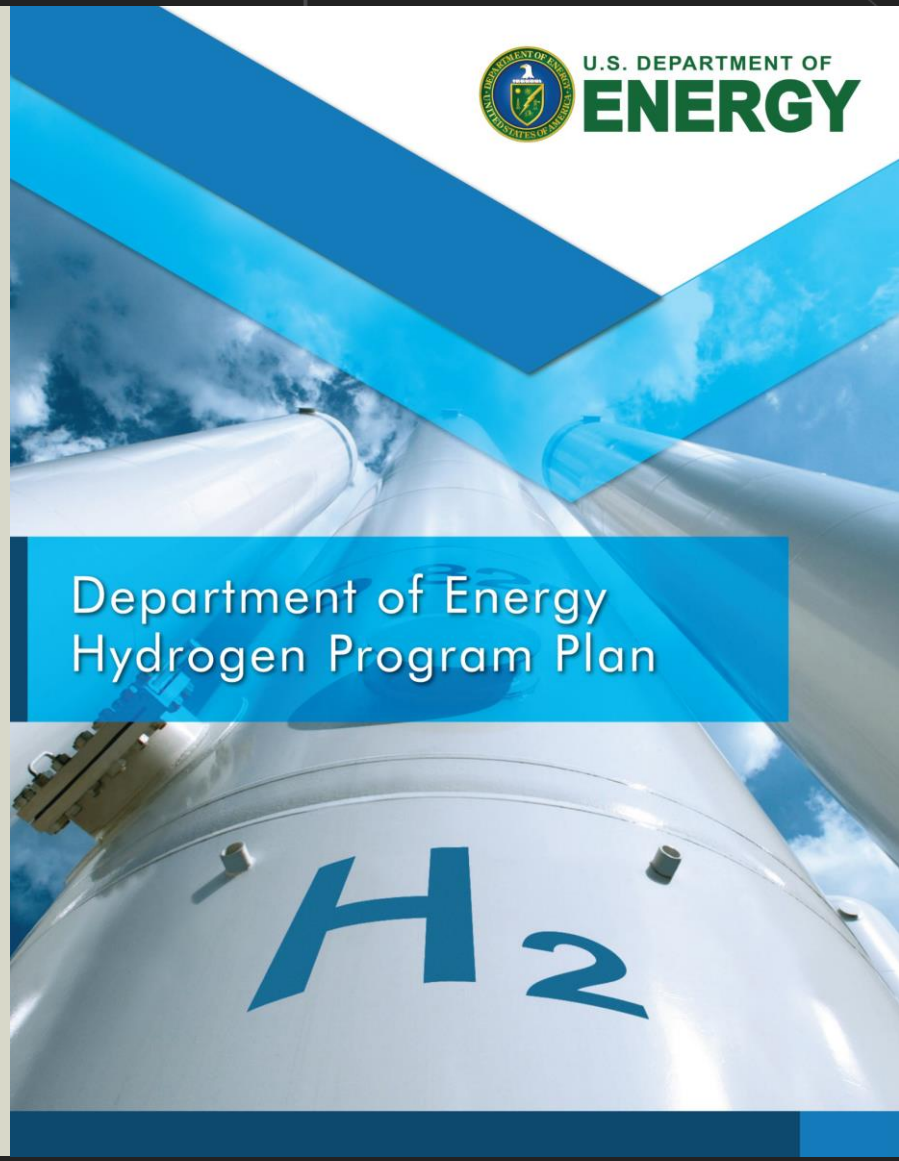
DOE Hydrogen Program Plan

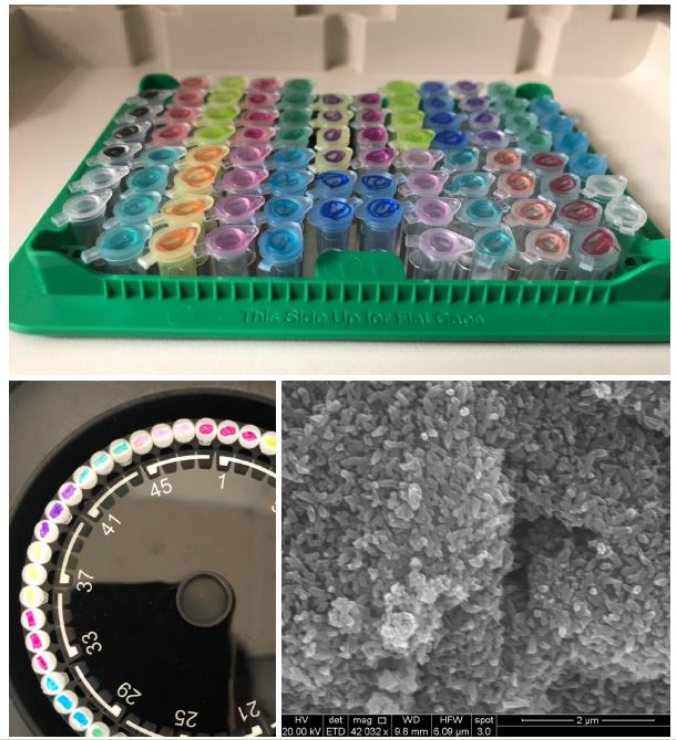
- Infrastructure Bill includes $9.5b for hydrogen research
  - $8.0b to Office of Clean Energy Demonstrations
  - Develop four regional hydrogen hubs to be located in different geographic regions across the U.S.
  - Goal of demonstration projects and end-use diversity… aimed at private industry

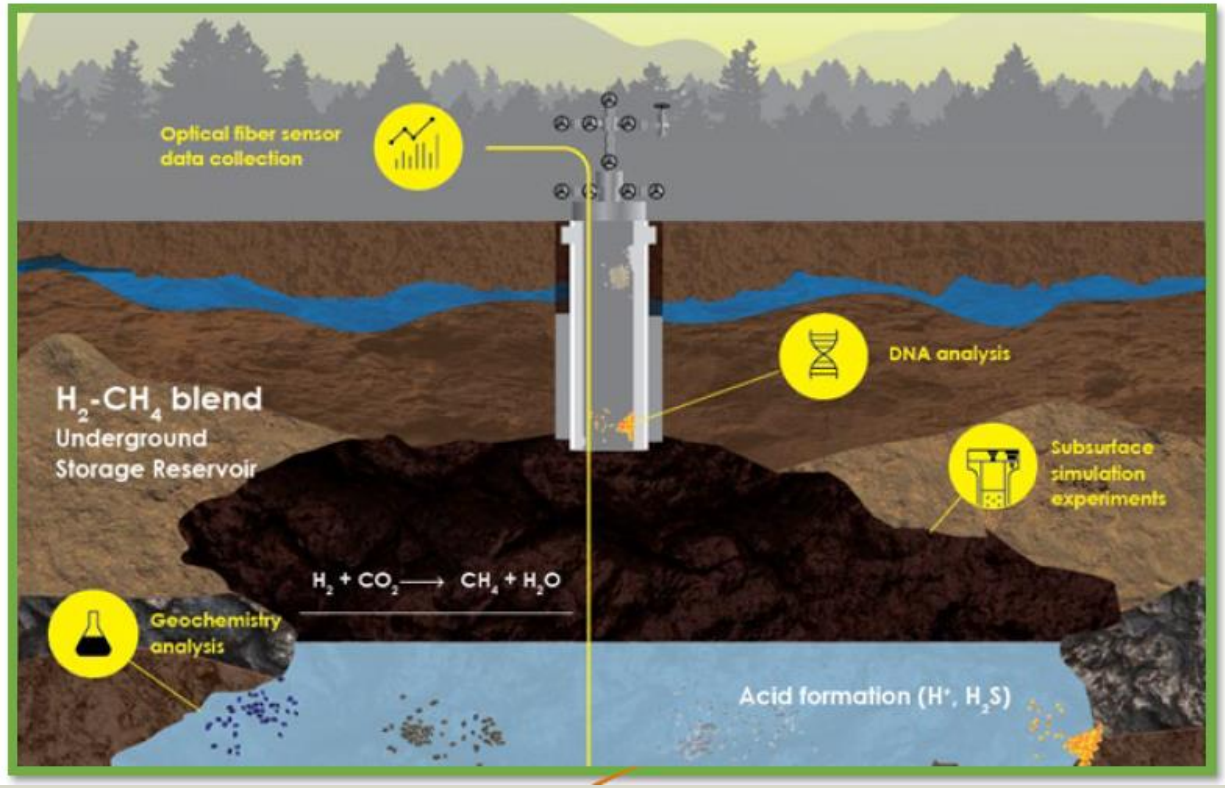


RESEARCH AND DEVELOPMENT

- Partnership between three national labs: NETL, PNNL, LLNL

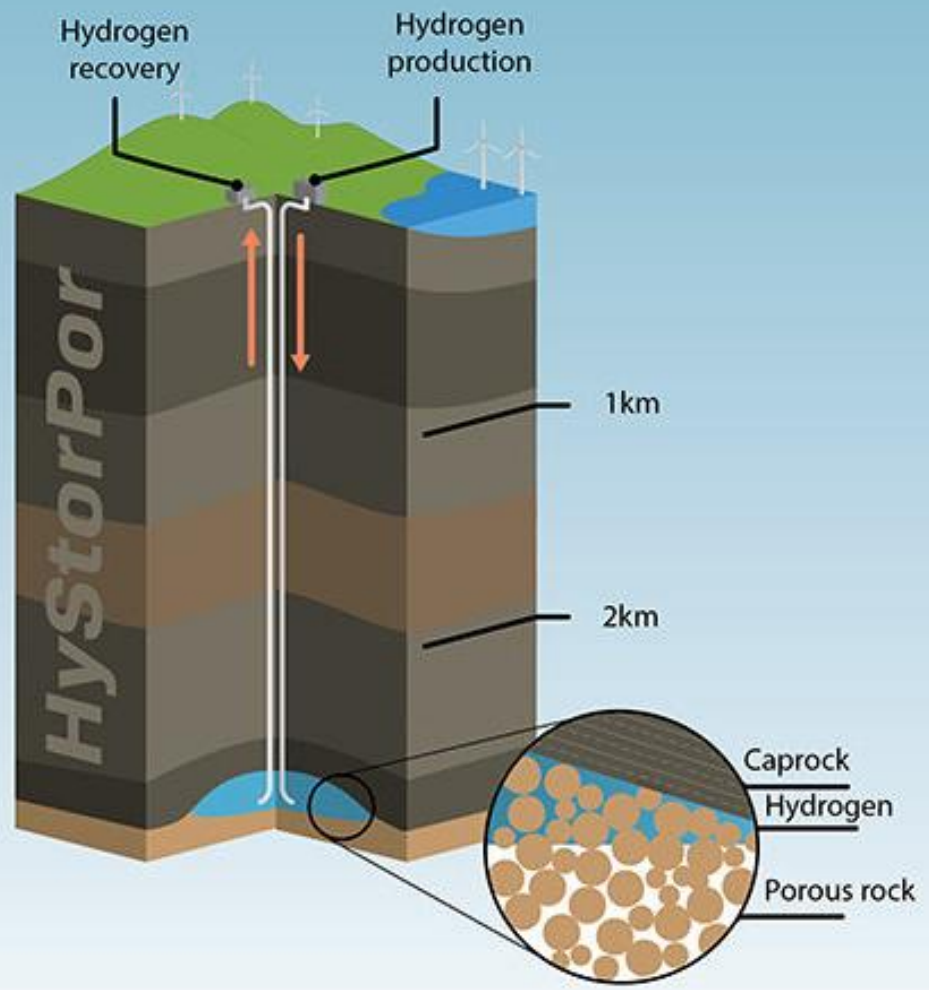
SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration





HyStorPor - Porous Reservoir Storage

- UK Research into porous hydrogen storage
  - Need temperatures >250°F or >30% salinity to avoid microbial growth
  - "Normal" sandstone doesn't cause geochemical concerns
  - Caprock can hold hydrogen pressure
  - Continuing to investigate permeability and pressure cycling



Source: HyStorPor

RESEARCH AND DEVELOPMENT

PRCI Pipeline Research Council International
LEADING PIPELINE RESEARCH

External Outreach
15 organizations
30 experts

Core Team
17 organizations
50 experts

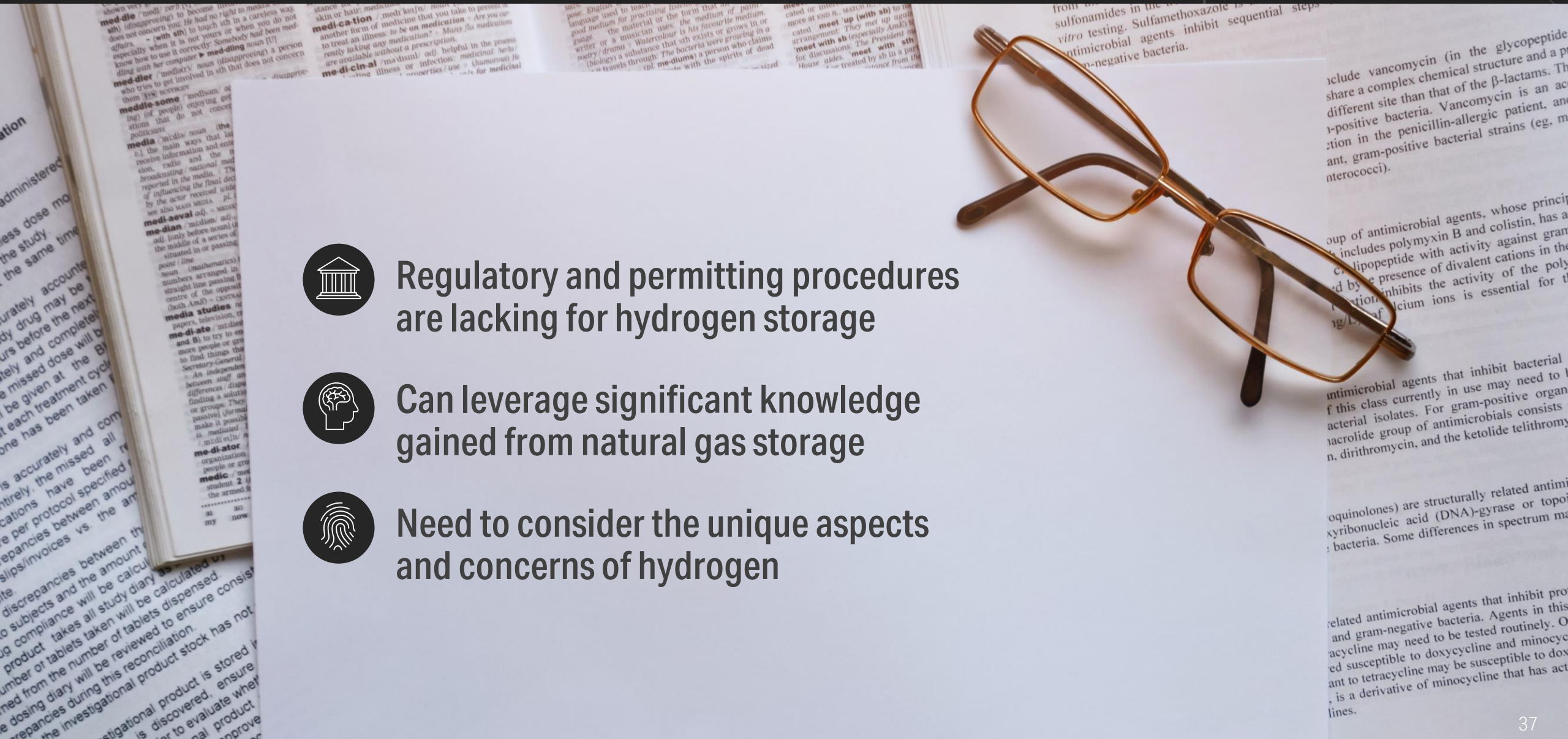
RESEARCH AND DEVELOPMENT

RESPEC

NH_3

- Ammonia is an alternative form of hydrogen energy
- Easily liquified
- Water soluble
- Less energy density
- NOx

HYDROGEN STORAGE



- Regulatory and permitting procedures are lacking for hydrogen storage
- Can leverage significant knowledge gained from natural gas storage
- Need to consider the unique aspects and concerns of hydrogen

SUMMARY

THERMODYNAMICS

Hydrogen has 1/3 the energy content as natural gas and is less efficient to store = 1/4 the energy in the ground!

GEOLOGY

Domal salt caverns are proven

Bedded salt caverns and reservoirs are not proven

MATERIALS

Need to consider materials that are compatible with hydrogen

Casing, seals, and cement.

THANK YOU

QUESTIONS?

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605.394.6400

Sources:
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https://www.rechargenews.com/transition/worlds-first-liquefied-hydrogen-carrier-launched-in-japan/2-1-722155
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