Hydrogen at Scale in the United States

Why geology matters

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Bureau of Economic Geology Hydrogen Working Group:

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- *Large-scale geological storage, in situ H_2 generation, and economics*

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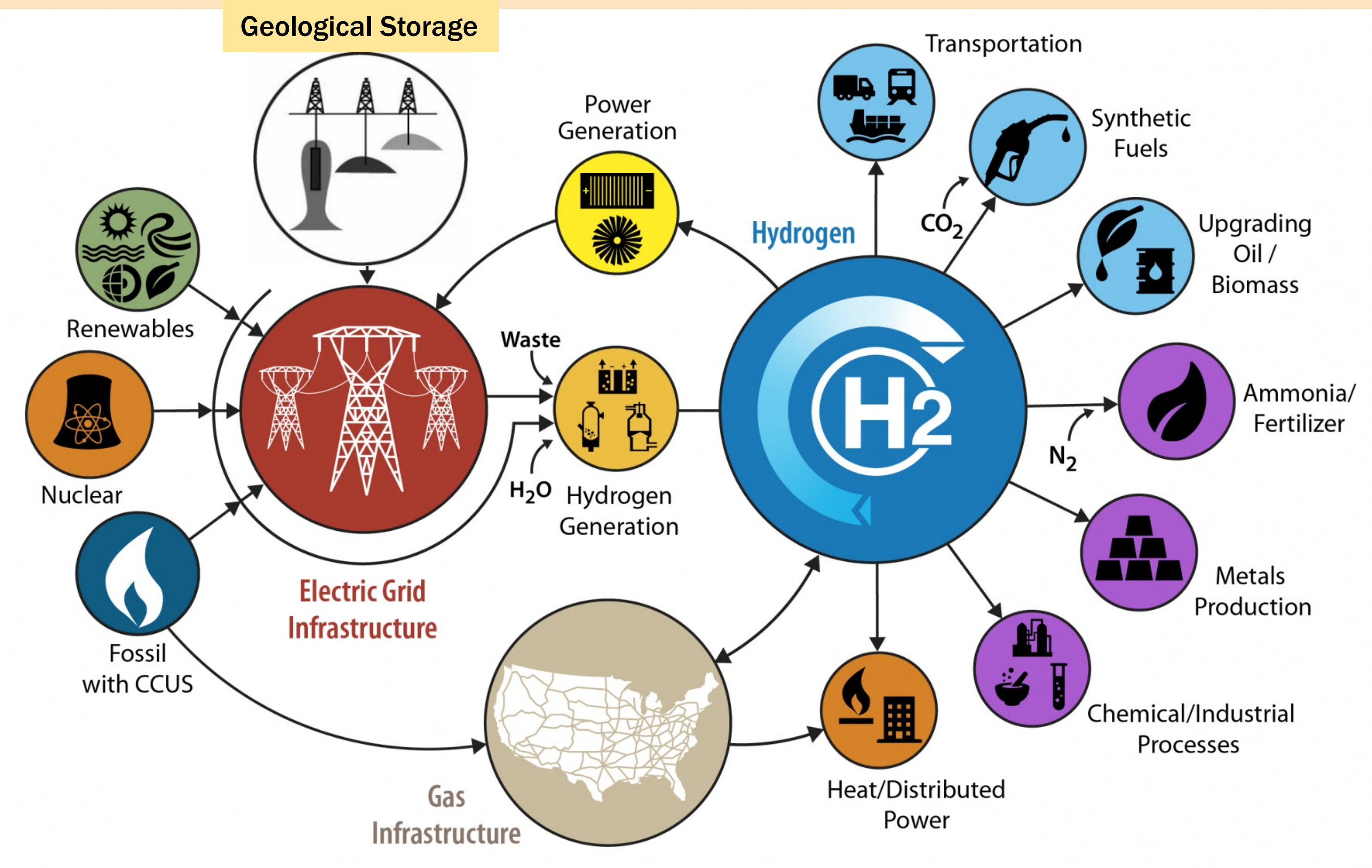
Hydrogen as Part of a Low Carbon Economy in the US

- Transportable
  - Pipeline gas
  - Liquified
  - Compounds (e.g. ammonia)
- Store-able
  - Large capacity (geological)
  - Indefinite storage duration
- Multiple sources
  - Electrolysis
  - Natural gas reforming
  - Coal gasification
- Low carbon emissions
  - From fossil fuels combined with carbon capture and storage (CCS)
  - From electrolysis (hydro, solar, wind, nuclear, geothermal) without CO_2



Source: DOE, Office of Fossil Energy, 2020

The Color Spectrum of Hydrogen Supply

Higher H_2 Production Cost

$5.60 – 13.00/kg H_2

Lower H_2 Production Cost

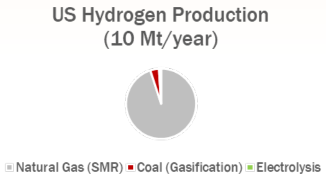
$1.35 – 2.30/kg H_2

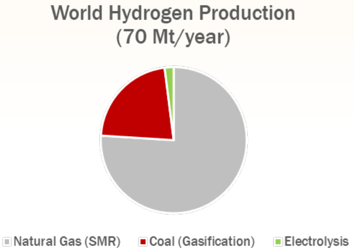
Renewable* (electrolysis)	Nuclear* (electrolysis)	"Grid" (electrolysis)	Natural Gas (pyrolysis)	Fossil Fuels/ Natural Gas (w/ CCS)	Natural Gas (steam reforming w/o CCS)	Coal (coal gasification w/o CCS)
Green	Pink	Yellow	Turquoise	Blue	Grey	Brown
No direct CO_2 emissions	No direct CO_2 emissions	?	Solid carbon	Low CO_2	CO_2 emissions	CO_2 emissions

*

Biomass Gasification ~ $1.90/kg

Nuclear thermolysis ~$2.40/kg





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Source: Production & cost data from DOE, Office of Fossil Energy, 2020

https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

Why Geological Storage ?

- *H_2 ~ 1/3 energy of natural gas by volume*
- *Current H_2 storage in US is ~6 Bcf*
- *Potential H_2 Growth*

H_2 Future Share of Natural Gas Market	Equivalent H_2 Storage Needed*
1 %	~100 Bcf
10 %	~1000 Bcf

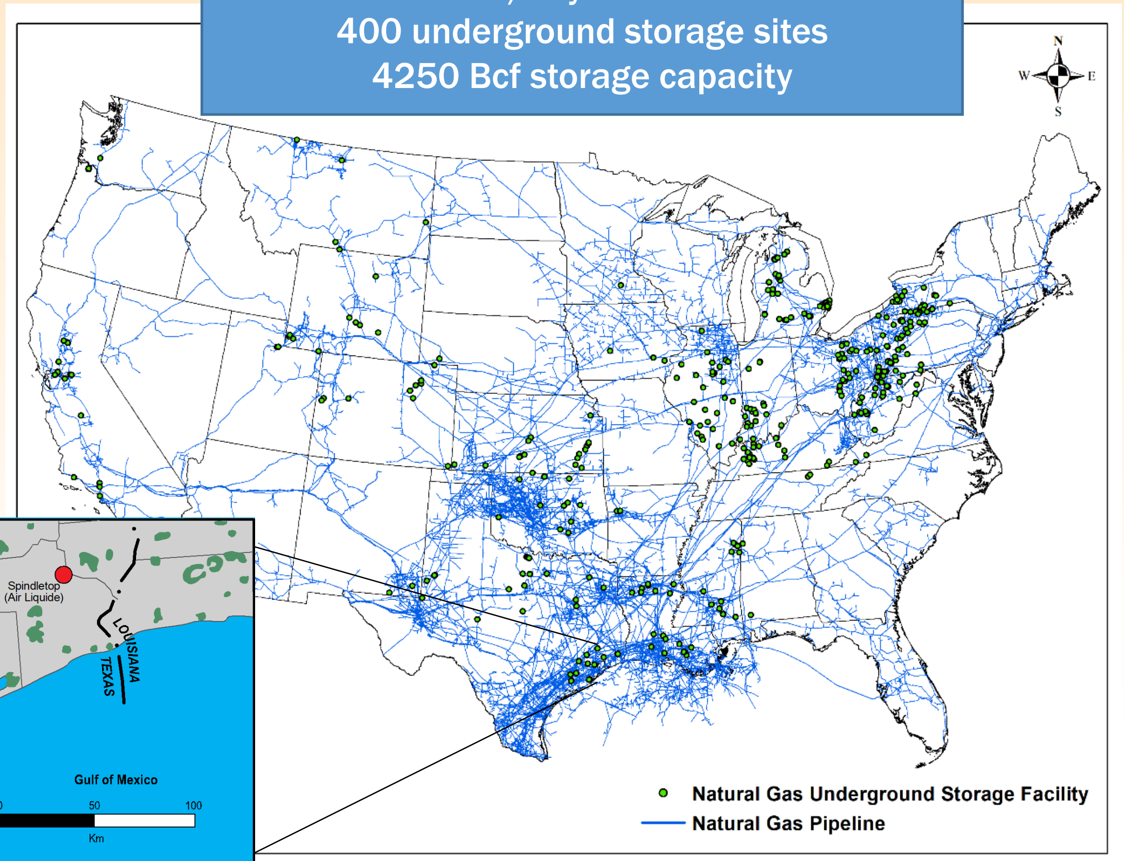
* Assumes 10 % storage/consumption requirement; 2019 NG market reference

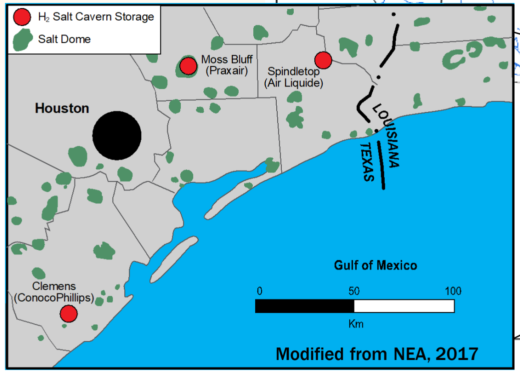
Main envisioned application categories of H_2

- Industrial
- Power backup and balancing
- Heavy transportation

United States Natural Gas Storage & Pipeline Infrastructure

US Natural Gas
85 Bcf/day consumed
400 underground storage sites
4250 Bcf storage capacity





Source: EIA, 2021

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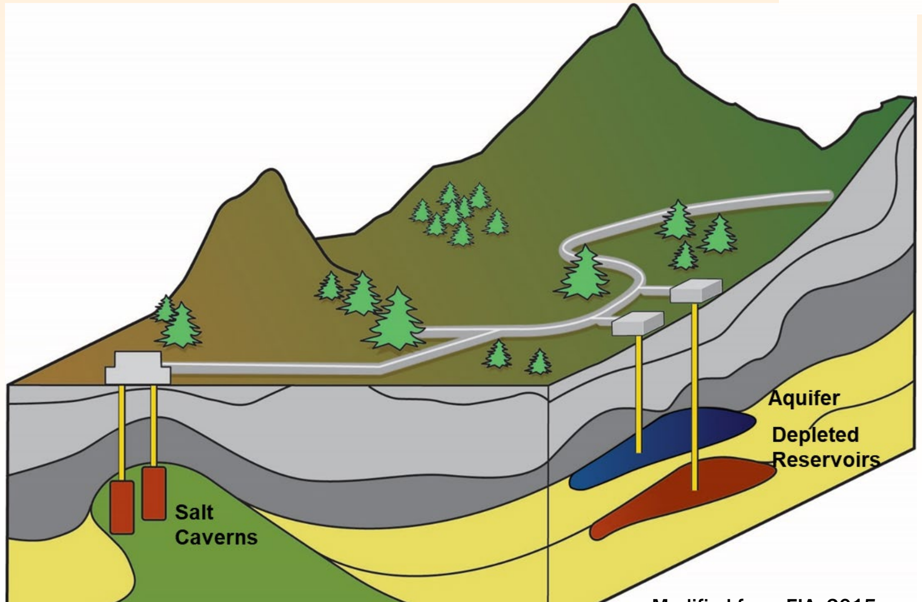
Geological Storage

- Geological storage provides options for large (> 1000 tonne H_2) storage sites
- Viable geological storage options include:
  - Dissolution caverns in salt domes
  - Depleted oil & gas fields
  - Saline aquifers

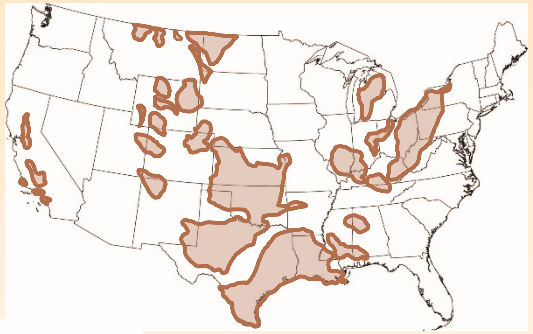
  (Depleted oil & gas fields and saline aquifers: Porous media)
- Geographic coverage important
  - Generation sites
  - End use sites
  - Infrastructure

Geological Storage

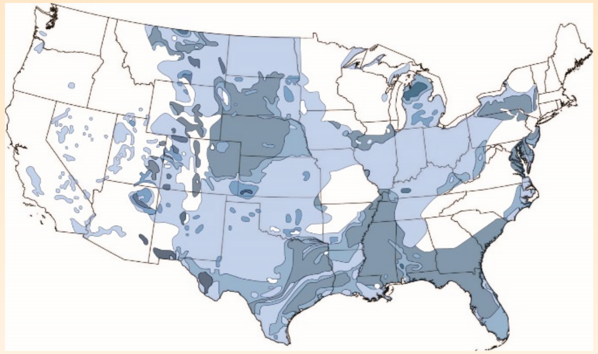


Modified from EIA, 2015

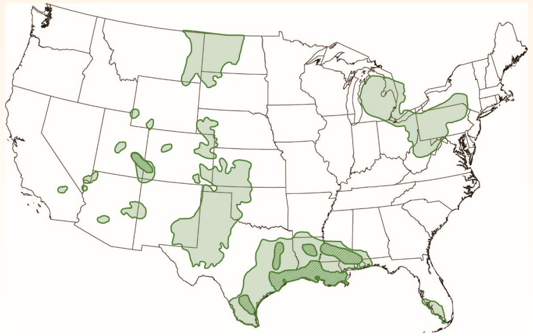
Oil & Gas Producing Areas



Saline Aquifers

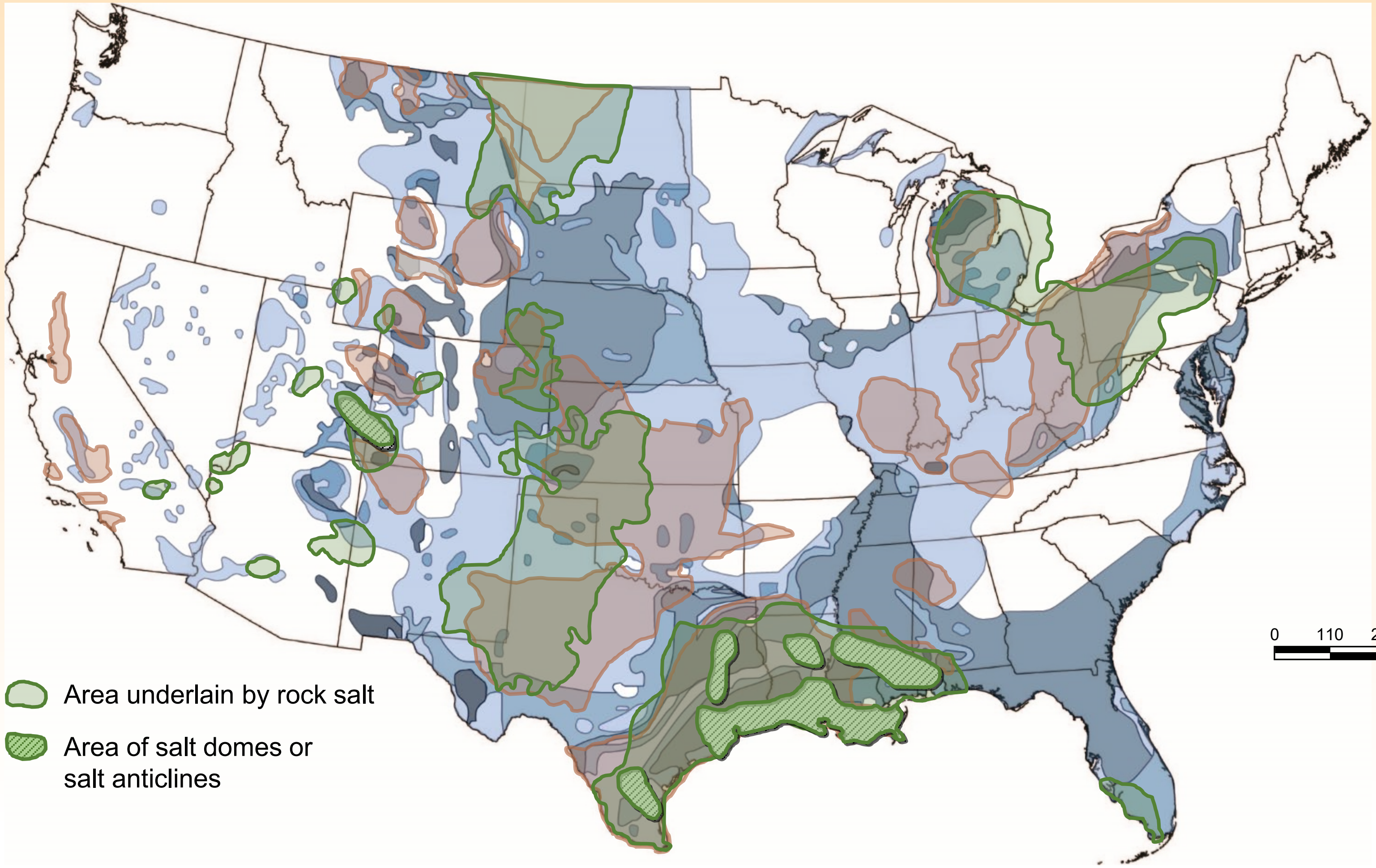


Major Salt Deposits



Modified from Lord et al, 2014; Johnson and Gonzales, 1978

Aquifers, Salt Domes and Oil and Gas



Sources: Alley, 2003; Johnson and Gonzales, 1978, Lord et al, 2014

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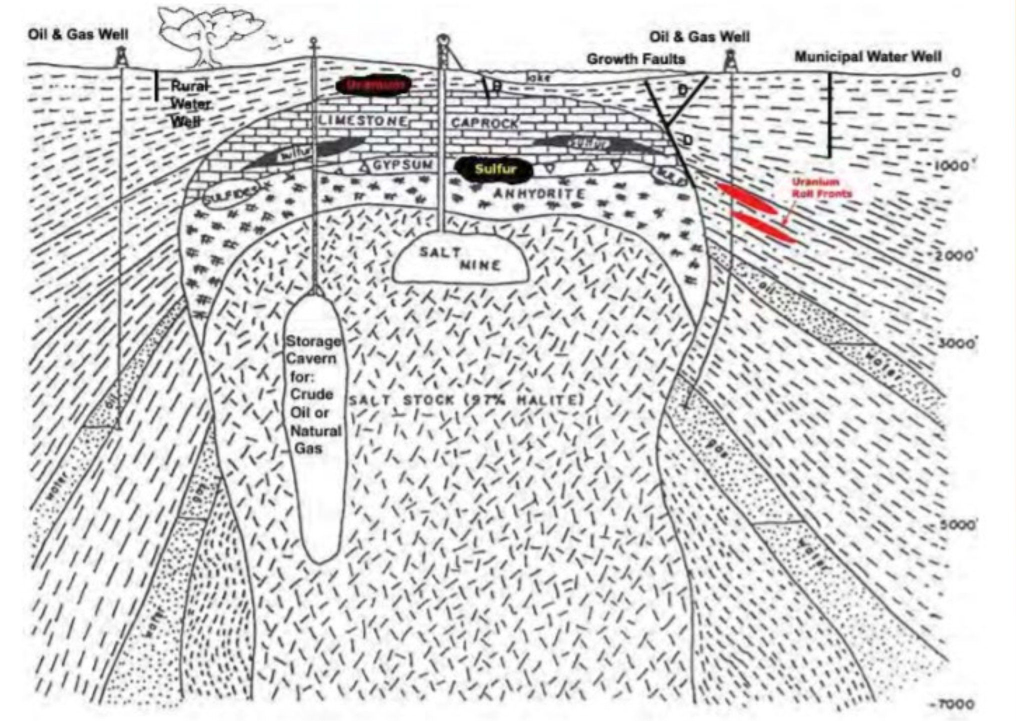
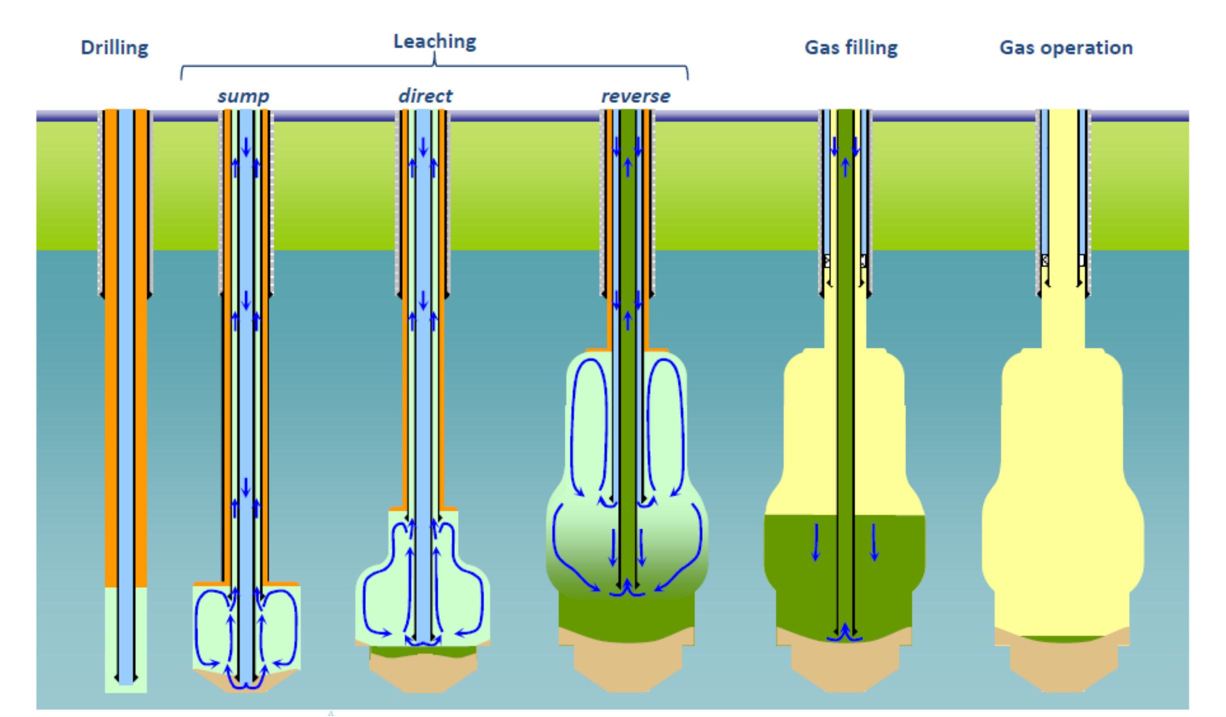
Hydrogen Storage in Salt

- Storage in salt (dissolution) caverns



Schematic Salt Stock & Uses

Source: Campbel et al, 2018, J Geol Geosci

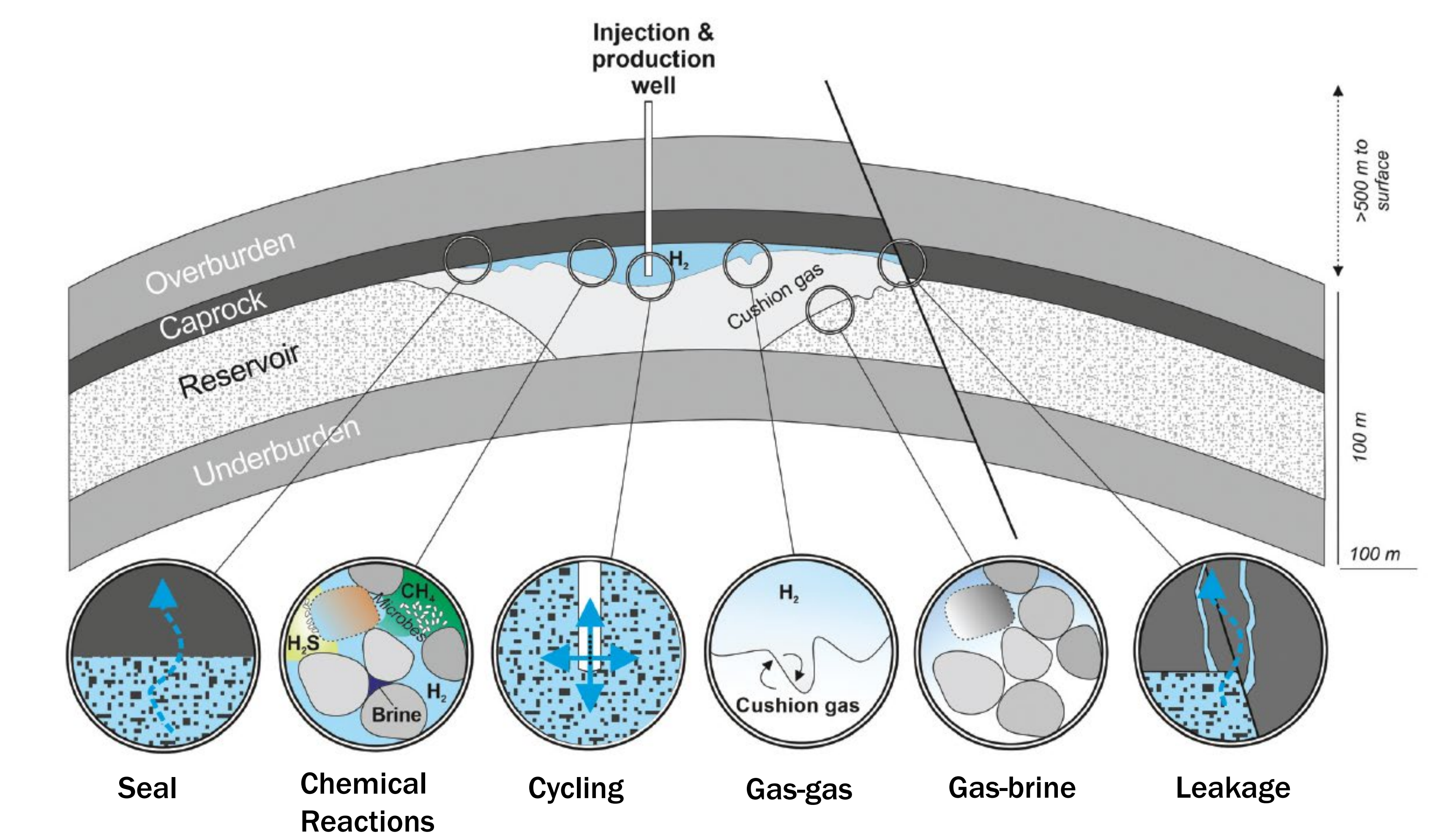


Steps in Creating Salt Cavern

Source: Hevin, Storenergy, 2019, European Workshop on Underground Energy Storage

Hydrogen Storage in Porous-media Reservoirs (Depleted Fields and Saline Aquifers)

- Leakage
- Fluid-rock interactions
- Injection/production
- Gas-gas and gas-brine



Source: Heinemann et al, 2021 Energy Environ. Sci., 2021,14, 853

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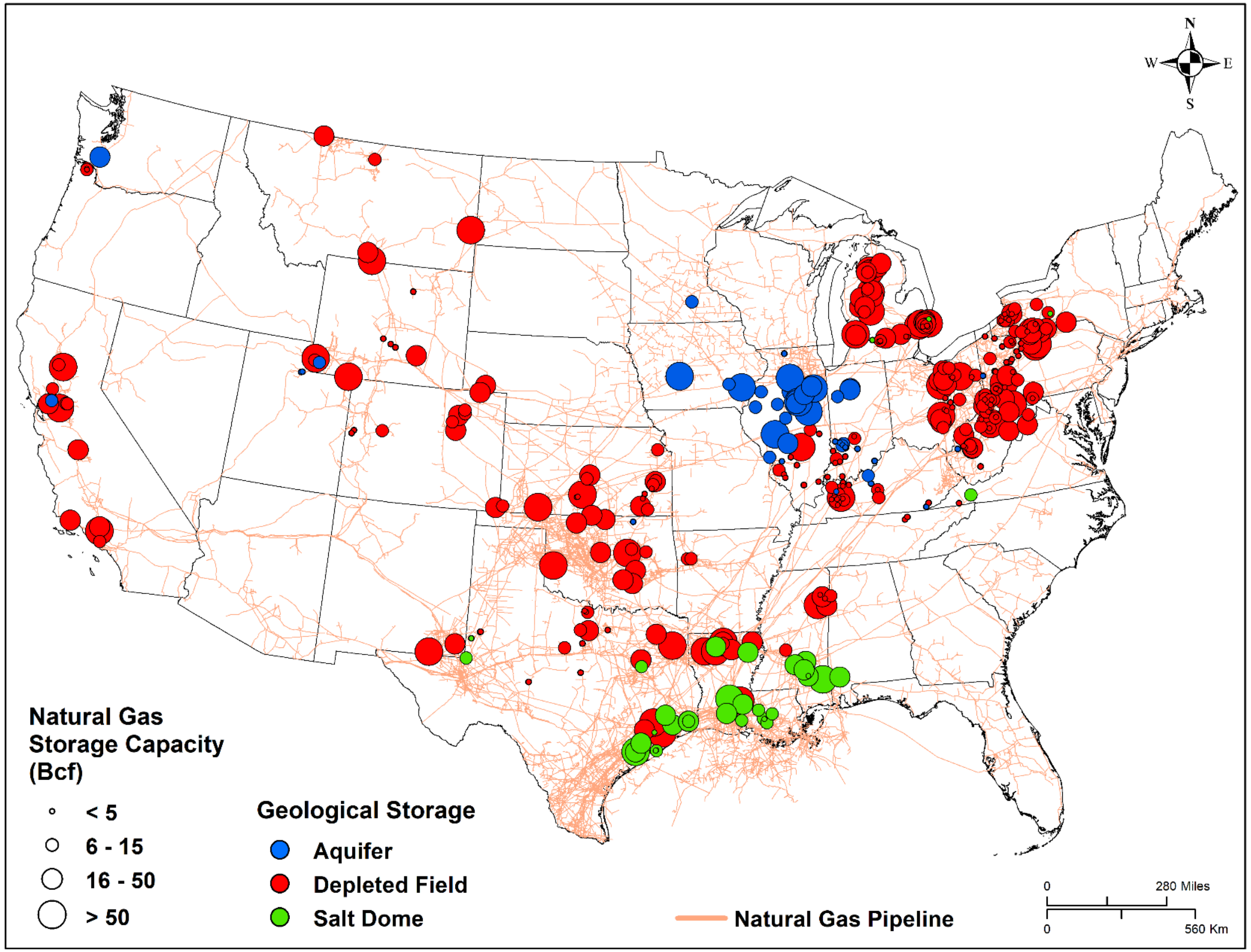
Natural Gas Infrastructure and Geological Storage



Source: EIA, 2021

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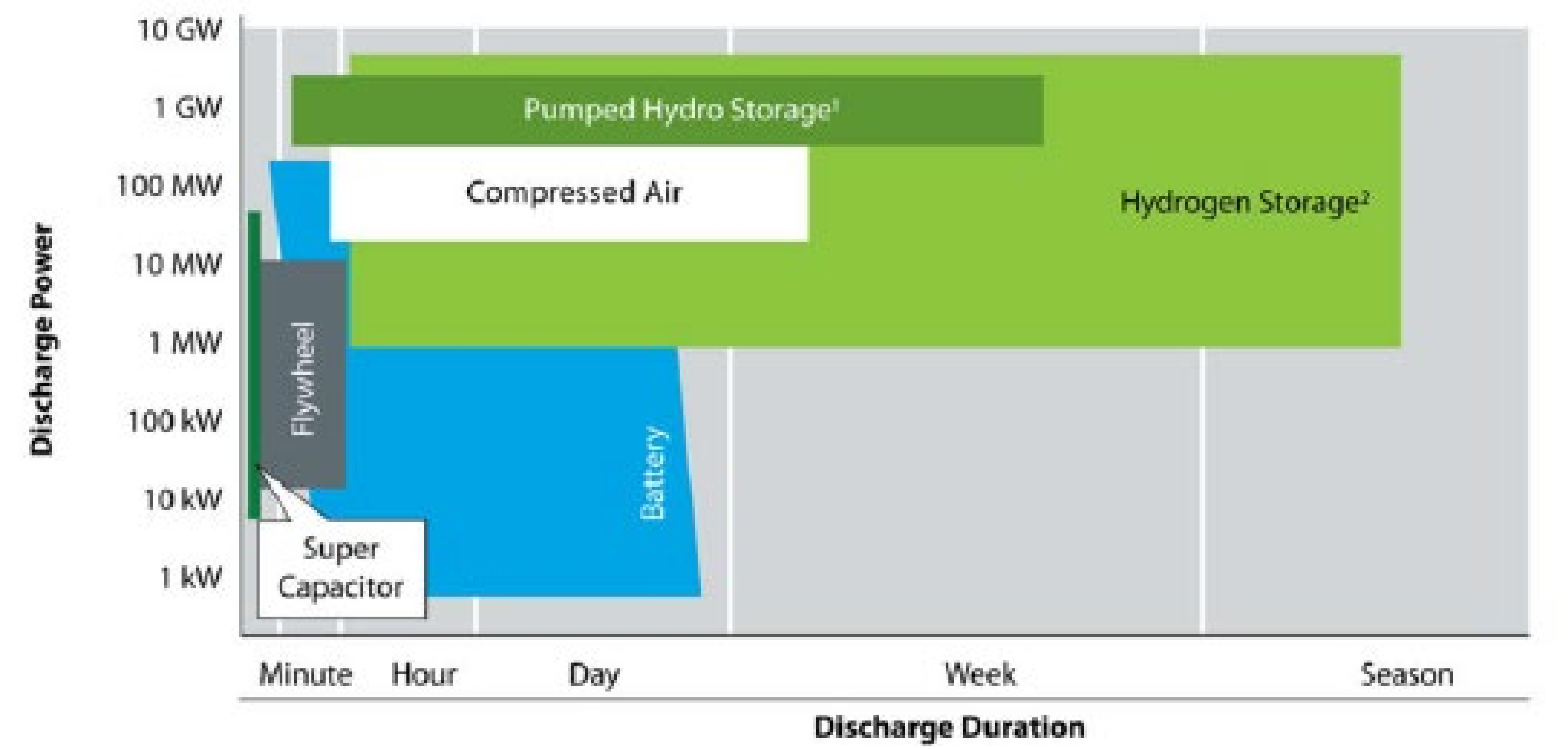
Large-scale Geological Storage of H_2 in US

Type	Status	Comments	Research
Salt (dissolution) caverns	3 active H_2 storage sites in Texas for industrial use	• Limited geographic distribution of suitable salt deposits	• Cost/life-cycle analysis • Catalog areas for expanded storage
Depleted oil & gas fields	Untested for H_2 storage (proven for Natural Gas)	• Wide geographic distribution • H_2-reservoir interaction is not well understood	• Cost/life-cycle analysis of storage in reservoirs • Chemical reactions • Geomechanics • Pilot field tests of H_2 • Catalog suitable sites
Saline aquifers	Untested for H_2 storage (proven for Natural Gas)	• Wide geographic distribution • H_2-reservoir interaction is not well understood • Suitability of sealing caprocks	• Cost/life-cycle analysis of storage in reservoirs • Chemical reactions • Geomechanics • Pilot field tests of H_2 • Catalog suitable sites

Need research to develop expanded inventory of suitable storage sites across the US

Comparative Energy Storage

Energy reliability and resilience is paramount for US energy infrastructure



Source: 2020 U.S. DOE Energy Storage Handbook, Ch.11, Headley & Schoenung

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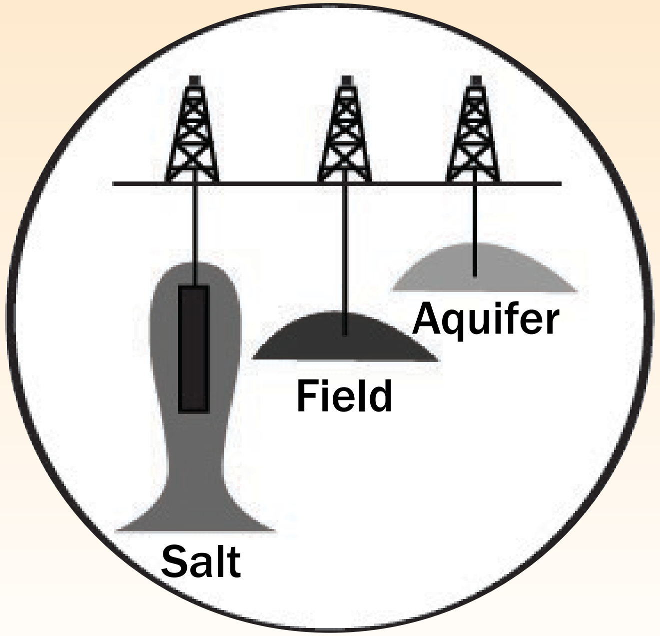
Better (More Energy & Longer Lasting) "Batteries" ?

Vistra Energy's Lithium-ion battery system Moss Landing, CA

1.2 GWh (300 MW);
4 hour storage duration

One (small) Geological Hydrogen Site (~1 Bcf)



100 GWh
Seasonal (months) storage duration

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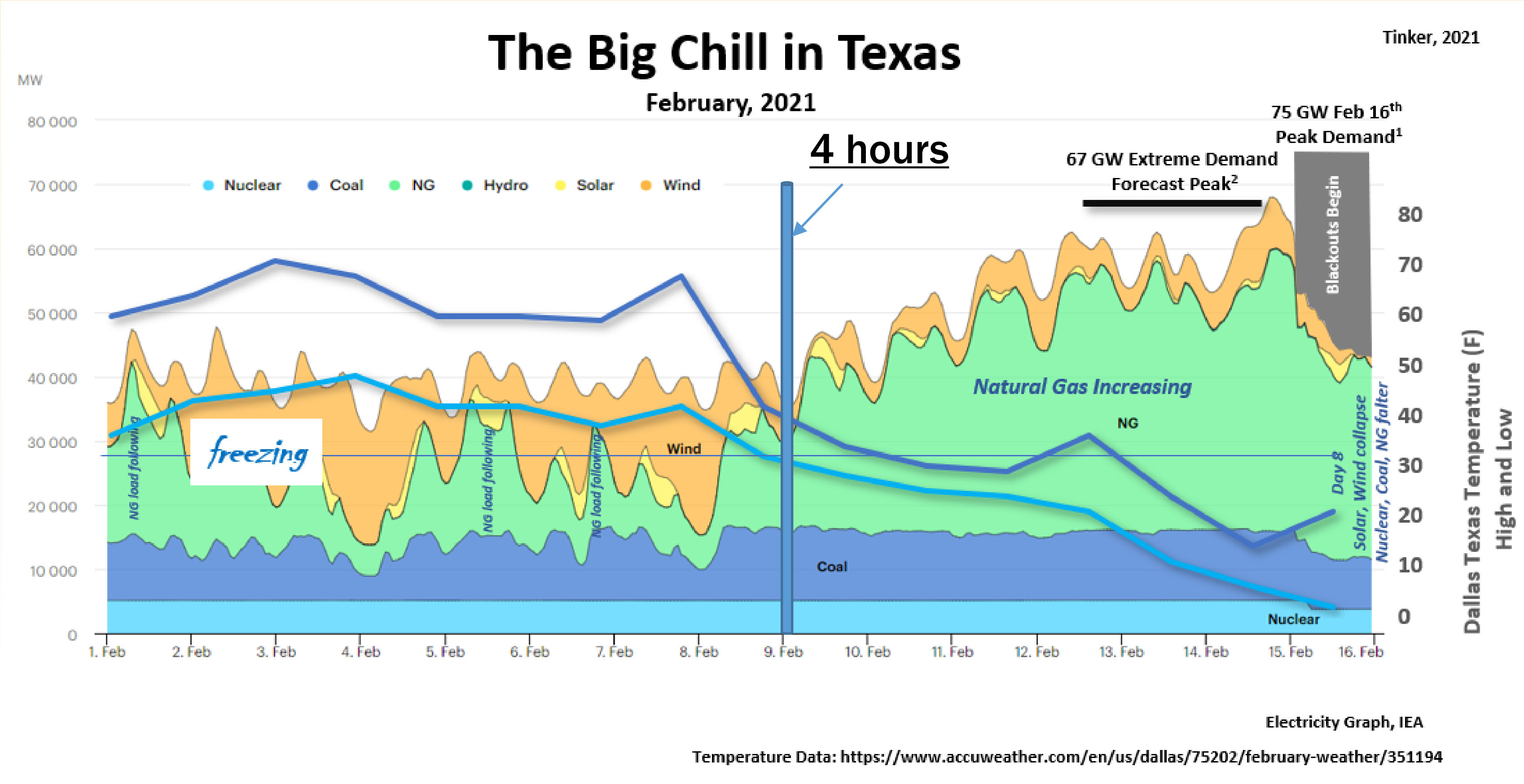
Need Energy Storage for Extended Periods



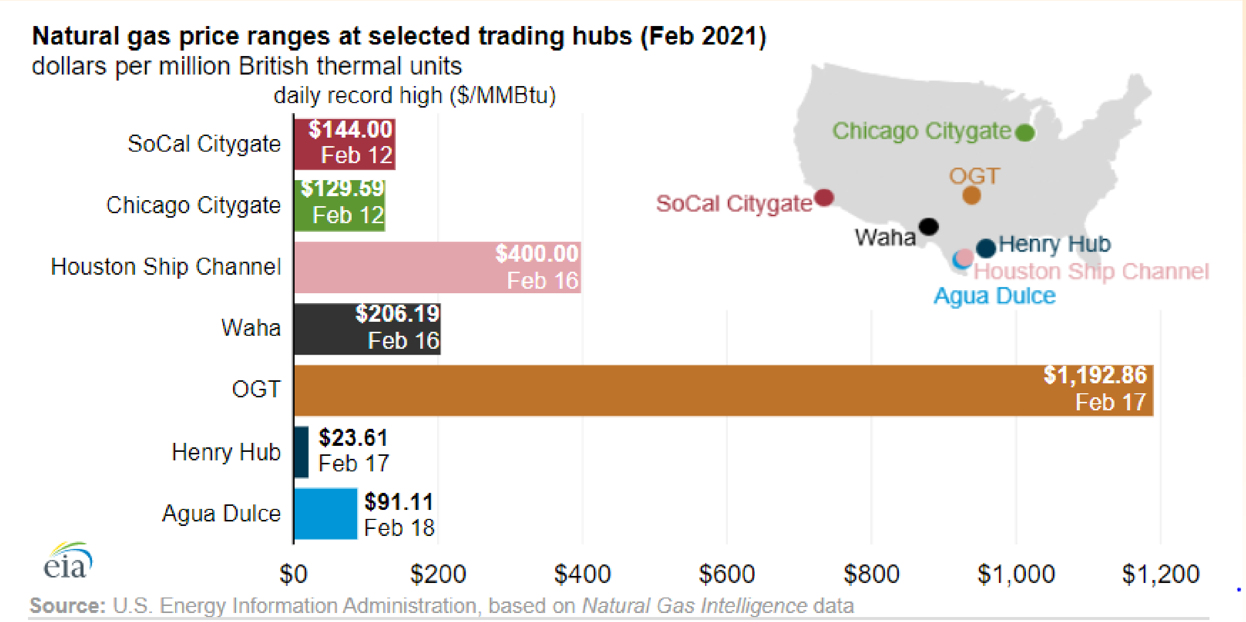
[1] U.S. Energy Information Administration ERCOT demand forecast peak of 75 GW

[2] North American Electric Reliability Corp. predicted winter extreme weather event demand peak in ERCOT

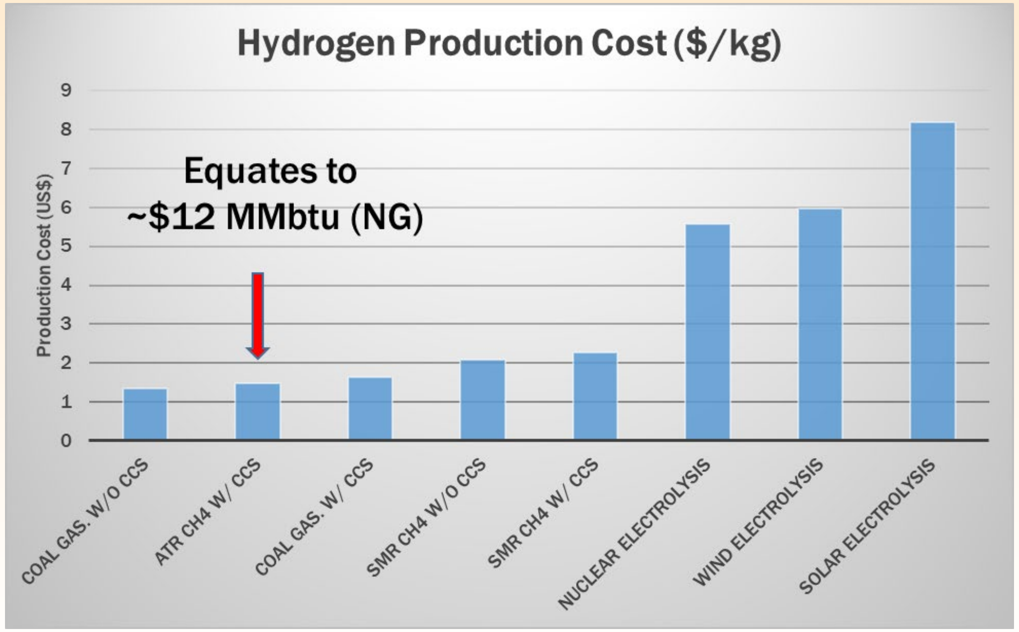
Source: Tinker 2021 (unpublished)

Recent Short-term NG Price Spikes

Incentivized hydrogen storage and supply could be used as alternative strategic energy reserve



Source: EIA, March 5, 2021



Source: 2020 U.S. DOE Hydrogen Strategy

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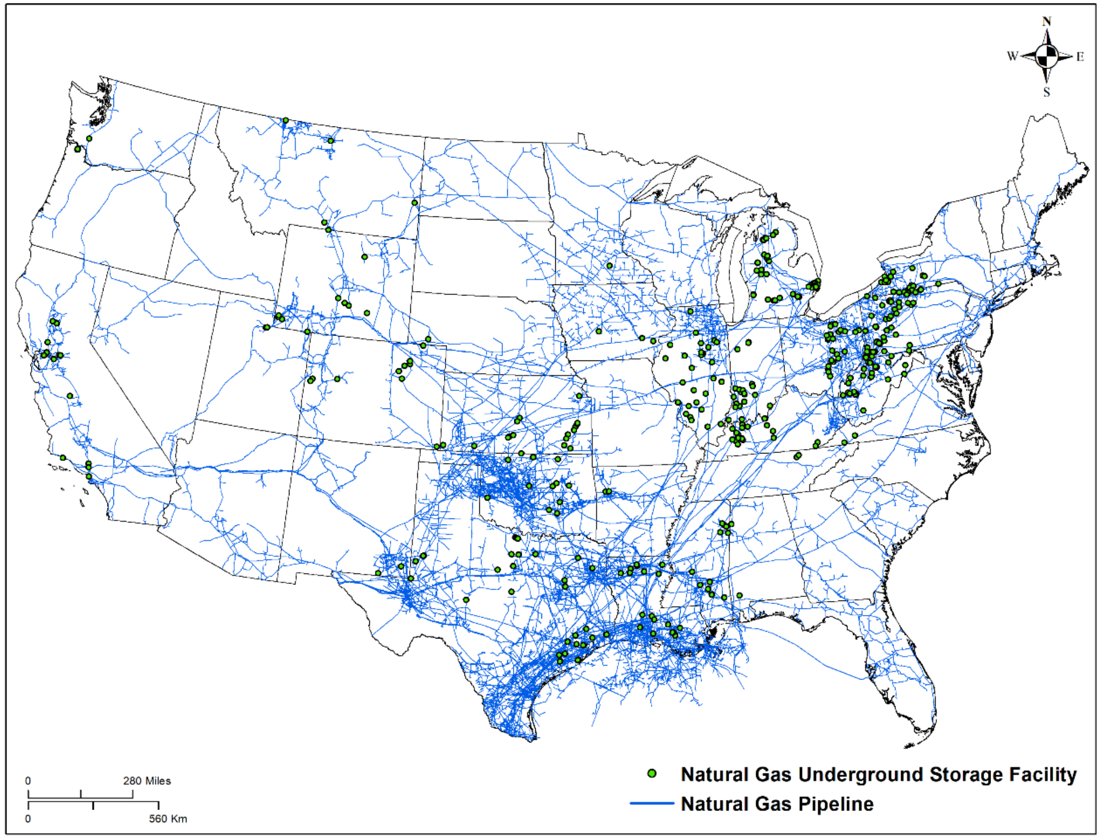
Some Ideas to Help Build H_2 Markets

- Develop market development scenarios of regional markets in the U.S. leveraging local value chains and industries
- Develop policies and incentives for H_2 (e.g.) that make sense within the spectrum of energy transition options and local value chains
  - Low % hydrogen blend in U.S. natural gas system
  - Strategic hydrogen supply and storage
- Support research for integrated pilot systems to test and optimize technologies and supply chains
  - Supply/Generations – Geological Storage (including CCS for fossil fuel-based systems) – Transportation - Usage

Market and System-scale Modeling Research

- Develop and assess scenarios for large-scale hydrogen market and infrastructure development in the U.S.
- Use U.S. natural gas system as baseline to inform scenarios
- Identify and match industry usages and potential supply sources considering demand characteristics and locations



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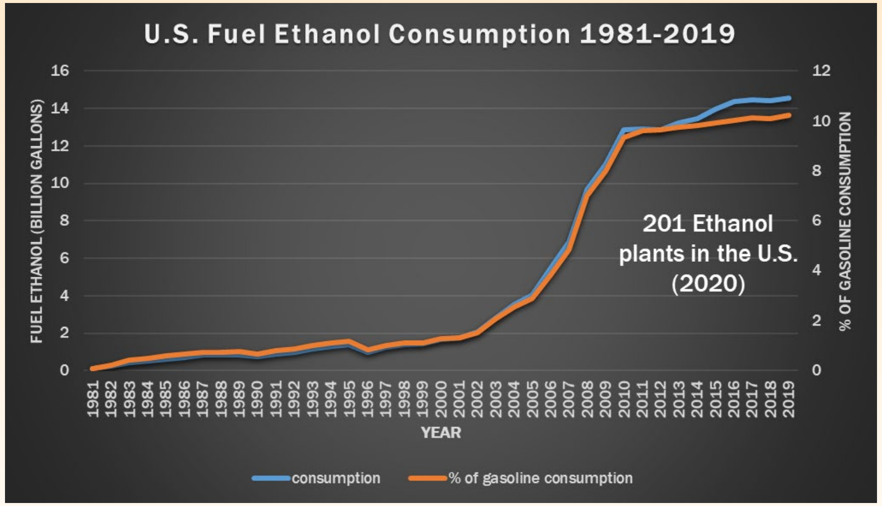
"10 %"

- Blend low % (e.g. 10 %) hydrogen into US natural gas system
- Reduce US GHG emissions AND develop market opportunities
  - 10 % NG (8.5 Bcf/day) equates to US CO_2 emissions of 165 Mt/year
  - Develop markets (supply, storage, transportation, demand)
  - *Understand that not all NG usages may be able to accommodate H2*
- Stepping stone approach – paves way for hydrogen economy

Ethanol Policy Example



https://www.nrel.gov/docs/fy13osti/51995.pdf
Melaina, M W, Antonia, O, and Penev,
M., 2013, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*.
United States: Web. doi:10.2172/1068610

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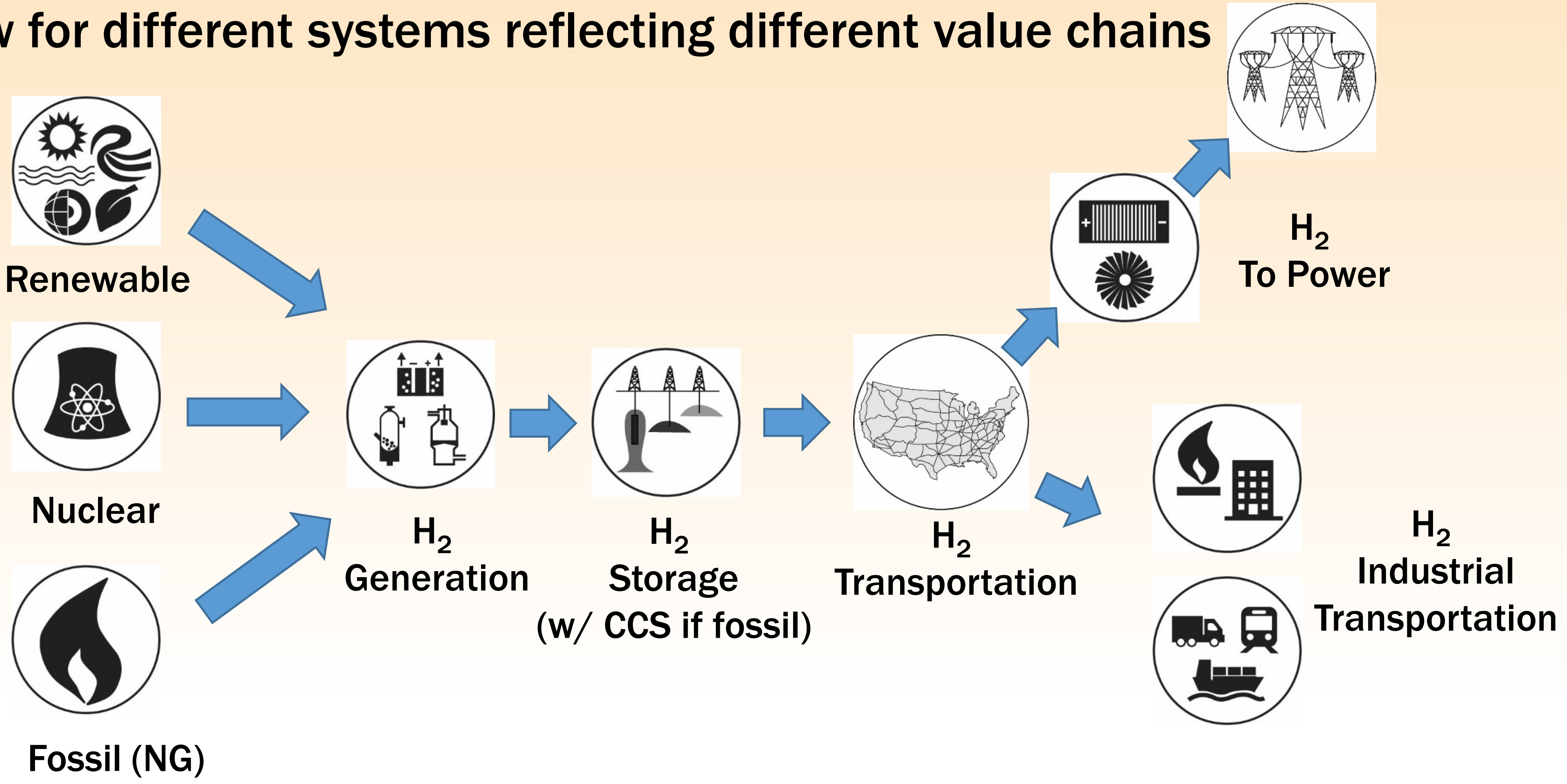
Integrated Full-Cycle Pilot Systems Research

- Supply – Storage – Transportation – End Use
- Allow for different systems reflecting different value chains



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Comments on Hydrogen Policy, Regulations, & Strategy

- Main guiding U.S. policies Energy Policy Act (2005) and Energy Independence and Security Act (2007)
  - Support R&D ; focus on H_2 as alternative fuel for transportation
- No cohesive H_2 framework; regulations within OSHA, EPA (GHG), and PHMSA for H_2 hazards and transportation
  - FERC: new rule for use of thermal energy to produce H_2 for fuel cell electric power generation; FERC may have jurisdiction for interstate pipeline transportation of H_2/Natural gas blends
- Geological storage of “natural gas and other gaseous materials” - including H_2 regulated in Texas by TX Railroad Commission
- DOE released U.S. Hydrogen Strategy and Hydrogen Program Plan in 2020
  - Emphasis on Research, Design & Development from 2020 – 2030
  - Increasing private sector role to scale up market deployment from 2030 onward
- EU Hydrogen strategy released in 2020
  - Sets renewable hydrogen generation capacity and production targets for 2020 – 2030
  - Estimates Euro 55 – 90/tonne CO_2 pricing to make blue and green hydrogen competitive

Conclusions

- Geological storage of hydrogen with broad geographic coverage will be important for large-scale hydrogen utilization in the U.S.
- Characterization of suitable storage sites including testing of depleted fields and saline aquifers is viewed as critical.
- Integrated market-chain pilot systems (supply, storage, transportation, and usage) could function as full-system test sites.
- Regulatory policy framework functions for current hydrogen production, storage, transportation and usage but will need to be revised/updated for large-scale hydrogen energy systems.

Thank you – Questions ?

U.S. Policies

- Support R&D
- Main focus on H_2 as alternative fuel for transportation

Act/Incentive	Purpose
Energy Independence and Security Act (2007)	Increase energy independence & security; increase renewable fuel production; support GHG capture research – Indirect support of green hydrogen
Energy Policy Act (2005)	Directive for R&D (Title VIII) on technologies related to hydrogen production, storage, and use
Alternative Fuel Excise Tax Credit	Tax credit of $0.50/gallon of liquified H2, NG, biofuels….
Alternative Fuel Infrastructure Tax Credit	Tax credit for fueling equipment including liquified H2
Alternative Fuel Tax Exemption	Exemptions for alternative fuels for farm equipment, city buses…
Fuel Cell Motor Vehicle Tax Credit	Up to $8,000 for purchase of Fuel Cell light-vehicle

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U.S. Codes and Regulations

- Lack of cohesive regulations for H_2 in Code of Federal Regulations
- Most extensive H_2 regulations are w/in OSHA, EPA, & PHSMA

Agency	Purpose
OSHA (Department of Labor - Occupational Safety and Health Administration)	- Addresses hazardous materials; installation of H2 systems, locations, containers, piping etc.
EPA (Environmental Protection Agency)	- Indirect reference through GHG Reporting: any H2 production source emitting 25,000 tonnes of CO2 must comply with GHG Reporting - Chemical Action Prevention scheme addresses storage of hydrogen > 10,000 pounds
PHMSA (Department of Transportation - Pipeline and Hazardous Materials Safety Administration)	- Regulate 700 miles of H2 pipelines (as Flammable Gas) - Research on H2 effects on steel pipelines - Regulate H2 in transportation - Design, filling & marking Fuel Cells - Transportation of compressed gases incl. H2
FERC (Federal Energy Regulatory Commission)	- Regulate interstate natural gas pipeline transmission; jurisdiction could cover hydrogen blends but likely need new regulatory considerations - New PURPA* (RM21-2) include thermal energy from cogeneration to produce hydrogen for electricity generation using fuel cells * PURPA (Public Utility Regulatory Policies Act 1978)

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Source: Parfomak (CRS), 2021

U.S. and EU Strategies and Plans

- Both U.S. and EU have strategies and plans for Hydrogen

U.S.	EU
DOE Hydrogen Strategy (July, 2020) DOE Hydrogen Program Plan (November, 2020)	EU Hydrogen Strategy (July, 2020)

Focus on Research, Design & Development
2020 Enabling activities by Government
- H2 production to meet $1-$2/kg cost metrics
- H2 delivery to enable low-cost safe & reliable delivery/distribution
- H2 storage to enable low cost, high capacity storage
- H2 Conversion: fuel cell and combustion technologies
- H2 End-use: develop multiple applications; optimize hydrid and integrated energy systems
- H2 Cross cutting: address safety, codes and standards; develop best practices
 	
2030
Increasing private sector role to scale up market deployment
	- Estimates Euro 55 – 90/tonne CO2 to make H2 with CCS competitive with 'grey' H2
	- Roadmap to develop H2 in Europe
	    - 2024: 6 GW of H2 electolysers (1 mln tonnes H2)
	    - 2030: 40 GW of H2 electrolysers (10 mln tonnes H2)
	    - 2030 +: dedicate 25 % of renewable power for H2 generation
	- Promote research and innovation:
	    - H2 electrolysers
	    - Infrastructure
	    - Expanded end-use applications
	    - Improved & harmonized safety standards
	    - Large-scale projects across value-chain

https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

https://www.energy.gov/articles/energy-department-releases-its-hydrogen-program-plan

Undergound Storage Regulations

- FERC has jurisdiction for approximately 223 underground natural gas storage facilities that are part of the interstate natural gas network
- Federal regulators deferred to States in 1997 to have oversight of underground natural gas storage
- Geological hydrogen storage in Texas is regulated by the Texas Railroad Commission
  - Texas Title 16: Part 1, Chapter 3
    - 3.96: Underground Storage of Gas in Productive or Depleted Reservoirs
    - “Storage of natural gas or other gaseous material…”
    - 3.97: Underground Storage of Gas in Salt Formations
- Hydrogen injection <u>is not</u> under EPA Underground Injection Control (UIC) regulations for CO_2 storage
  - States can assume primacy for UIC

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