Geological Storage of Hydrogen

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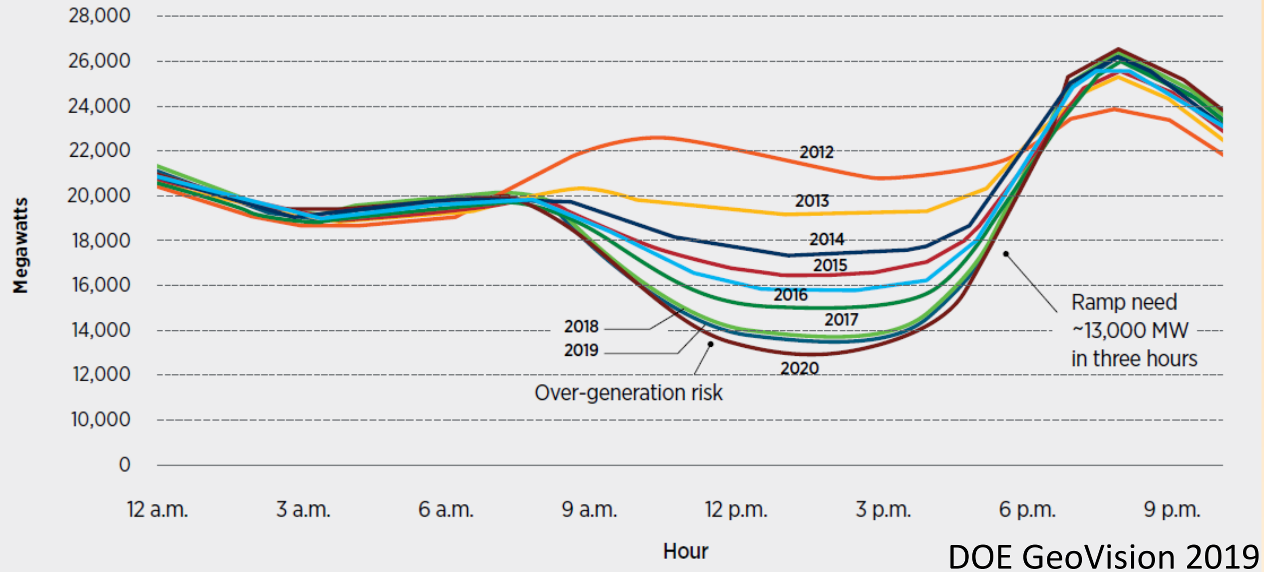
GeoH2

Why hydrogen storage?

- Storage evens out variations and differences in supply and demand

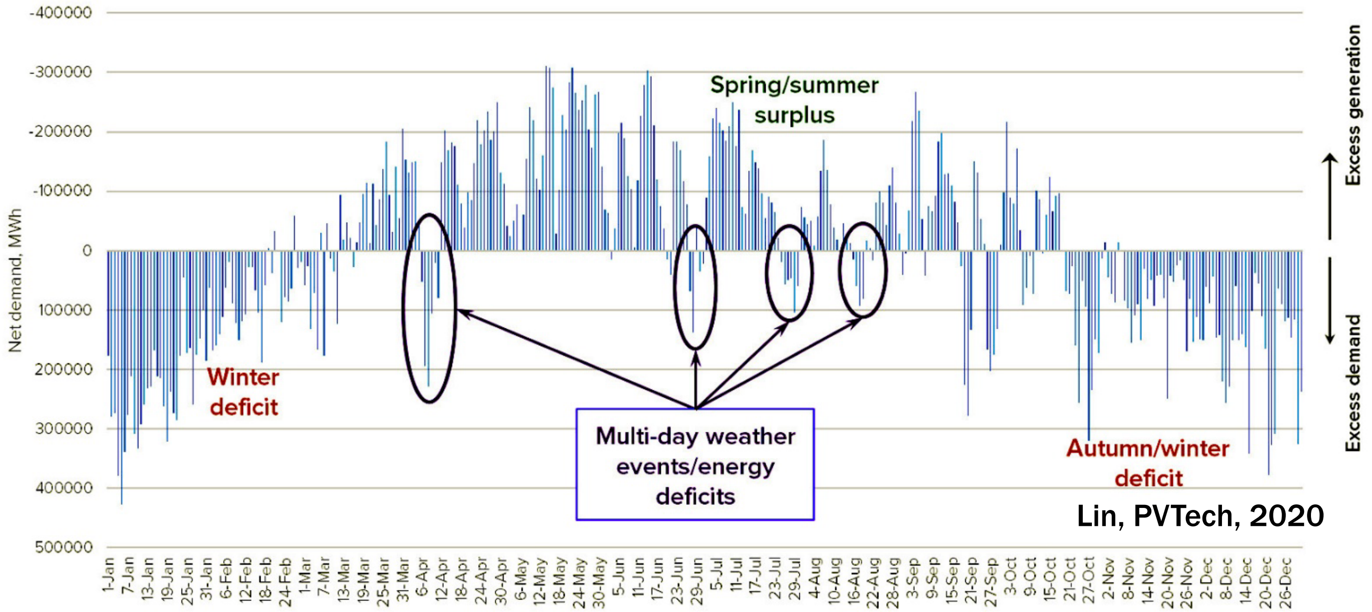
- Hydrogen: Wide range of uses as energy carrier w/o carbon emissions at end user
- H_2 can be transported in pipelines
- H_2 can be stored in tanks and in the subsurface similar to natural gas
- Subsurface for long-term storage

Change in daily net-load profiles with increasing VEG



DOE GeoVision 2019

California excess VEG/demand for assumed 100% renewables



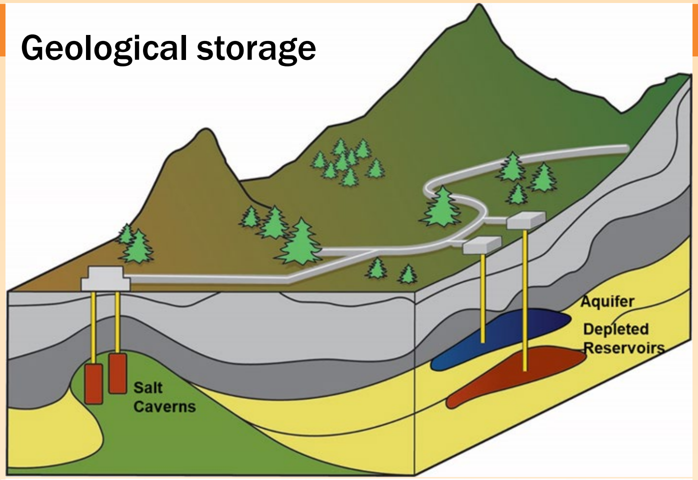
Lin, PVTech, 2020

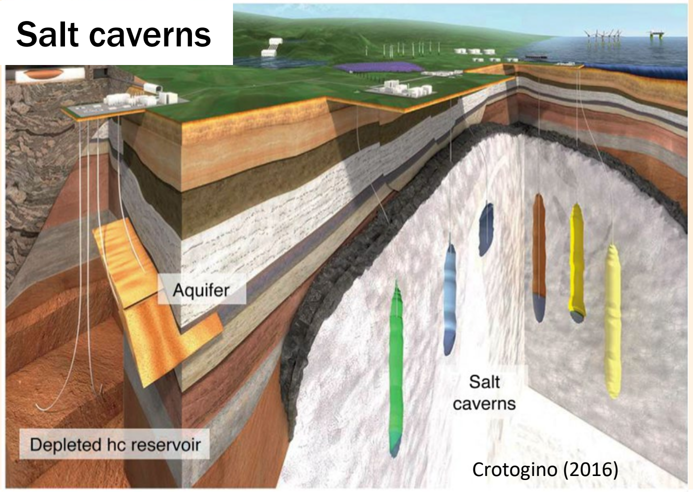
Bulk H_2 storage methods

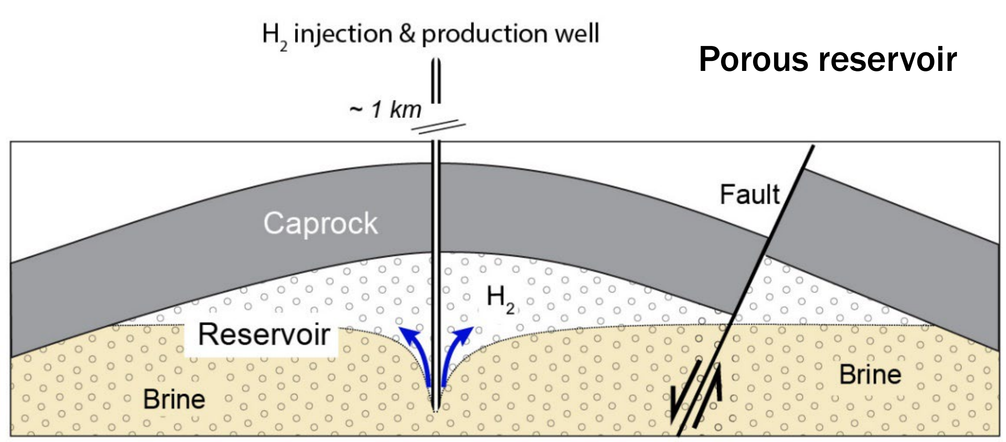
	Pressure [bar]	Stored H_2 [t]	Working capacity [t]
Pressure vessels			
Spherical vessel	1-10	27	25
Pipe storage	7-100	50	45
Pre-stressed concrete	7-875	1	0.9
Cryogenic			
Liquid H_2 @ 20K, -253°C	1		≤245
Cryo-compressed @ 200K, -73°C	350-480		
Geological			
Salt cavern	55-152	6,000	3,720
Lined rock cavern	10-230	672	640
Porous reservoir (saline aquifer, depleted oil/gas reservoir)	150-170	54,000 or more	19,000 or more

modified after Ahluwalia et al. 2019

- **Complementary approaches for different end uses**
- **Geological storage provides best options for large capacity storage**







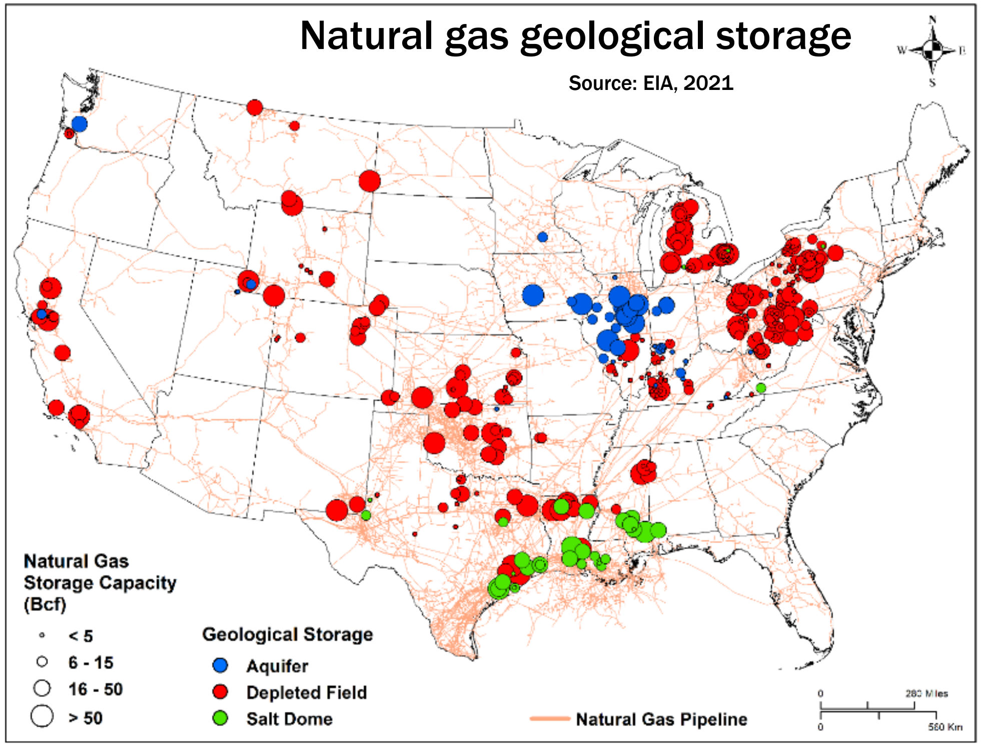
Porous reservoir storage

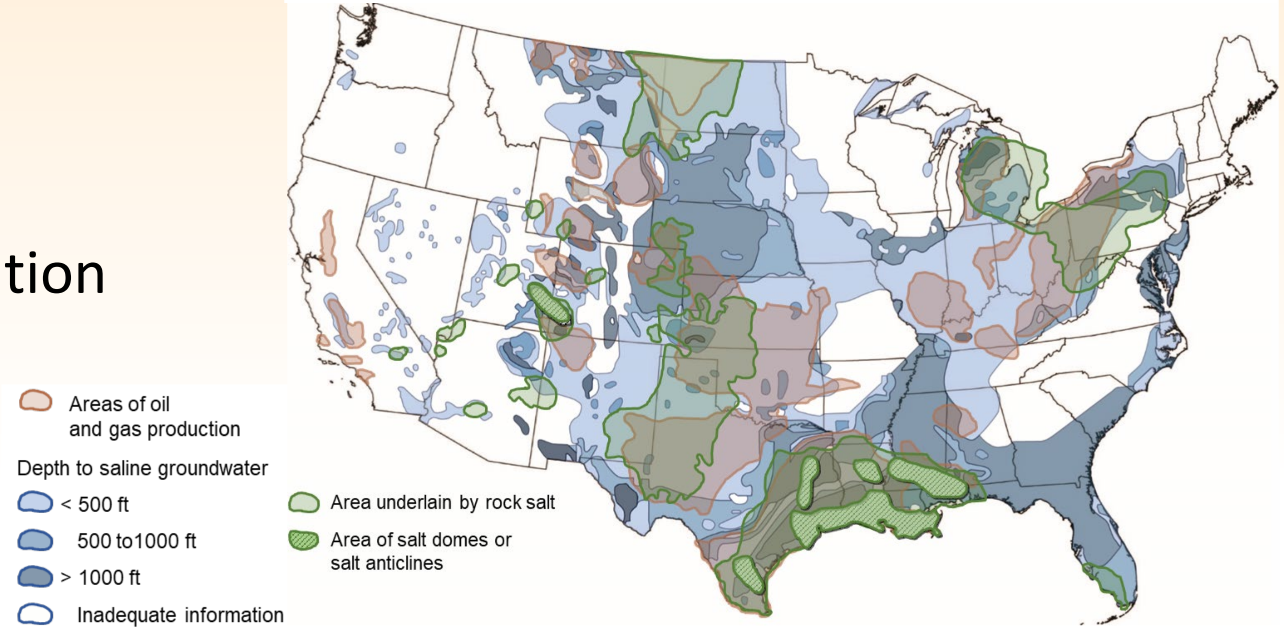
Advantages:

- Unlimited capacity, most cost-effective for long duration
- Widest geographic distribution
- Proven for NG and NG/H_2 blends, untested for H_2 storage
- Possible combination with CO_2 storage

Challenges:

- Location controlled by subsurface geology
- Reduced working capacity, H_2 loss by migration
- Potential for contamination
- Caprock integrity (saline aquifers)
- Integrity of abandoned wells (depleted O&G fields)





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

Extras

Sources of Hydrogen

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)
No direct CO_2 emissions	No direct CO_2 emissions	?	Solid carbon	Low CO_2	CO_2 emissions	CO_2 emissions

*

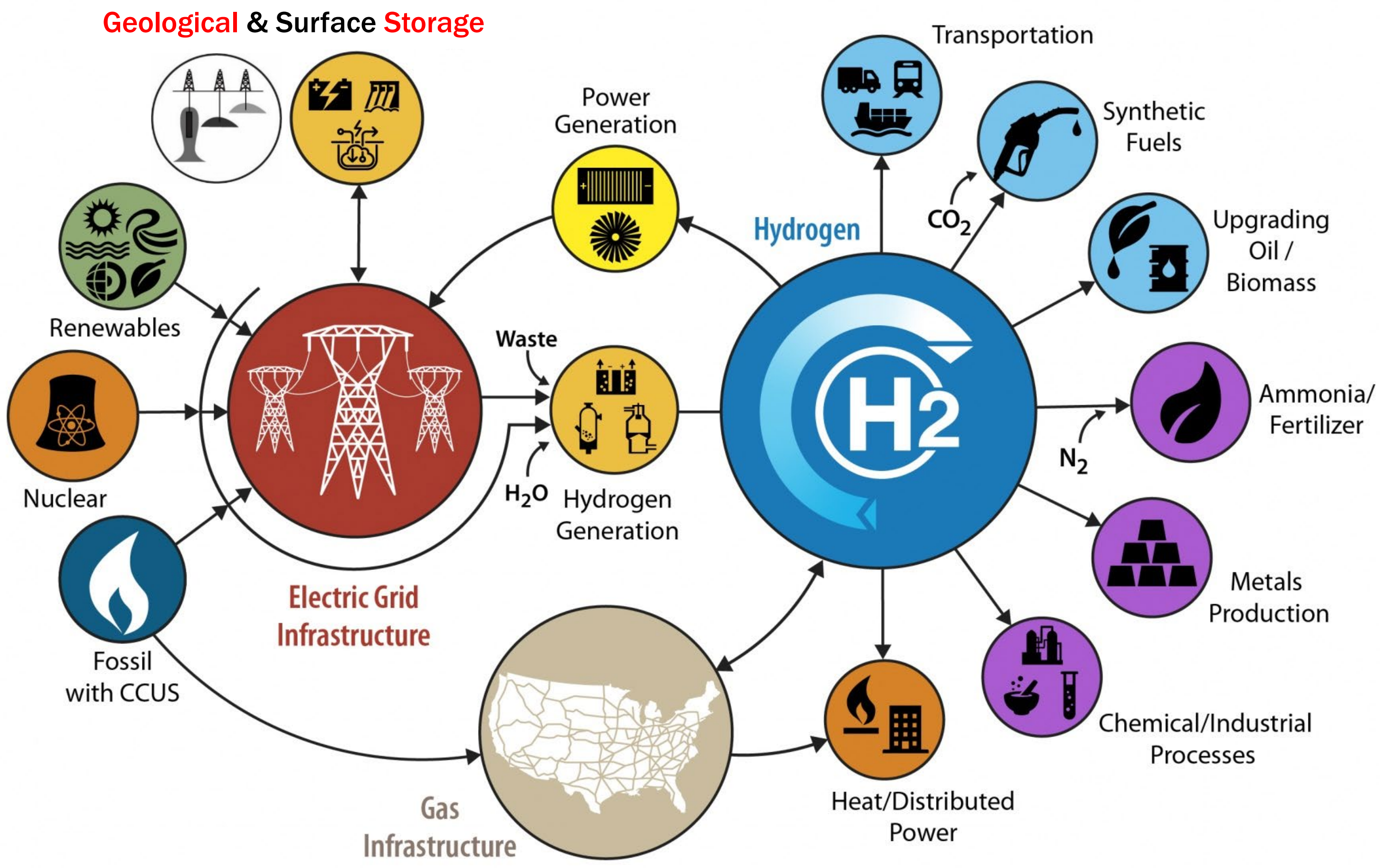
Biomass Gasification ~ $1.90/kg
Nuclear thermolysis ~$2.40/kg

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

Hydrogen as part of Low Carbon Economy

- Low carbon emissions
  - From electrolysis (hydro, solar, wind, nuclear, geothermal) without CO_2
  - From fossil fuels combined with carbon capture and storage (CCS)
  - Electric power generation through fuel cells, turbines without CO_2
- Transportable
  - Pipeline gas
  - Liquified
  - Compounds (e.g. ammonia, NG-H_2 mix)
- Store-able
  - Large capacity (geological)
  - Indefinite storage duration
- Multiple sources
  - Electrolysis
  - Natural gas reforming
  - Coal gasification
- Multiple Uses
  - Transportation
  - Industrial
  - Power

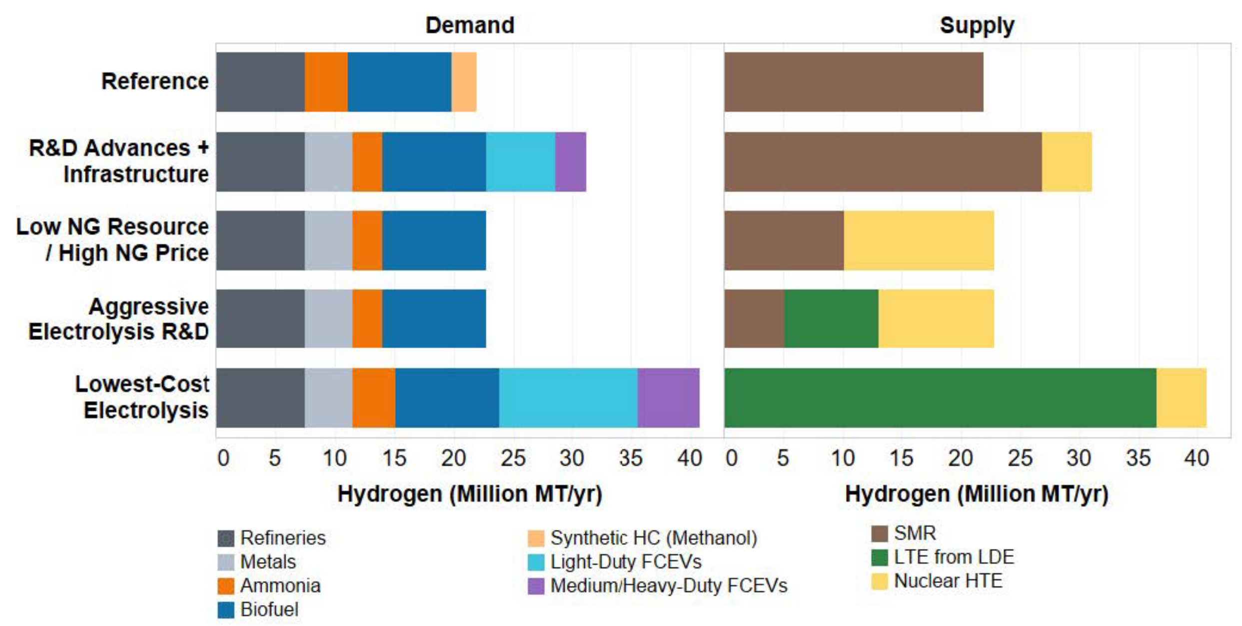


Source: DOE, Office of Fossil Energy, 2020

Increasing H_2 demand will require storage *at scale*

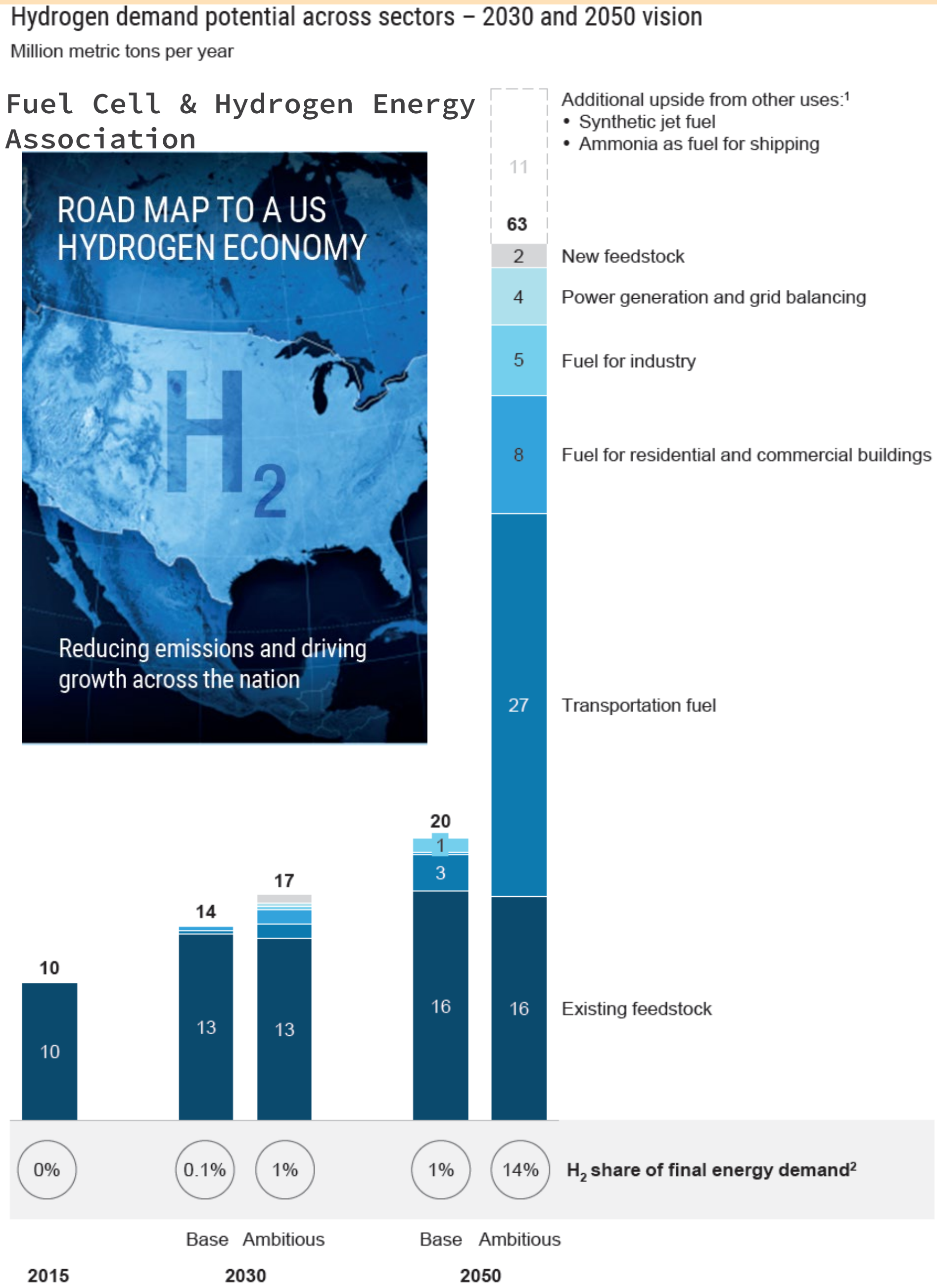
Projected Potential US Hydrogen Demand (MMT/year)

2030		2050	
Base	Ambitious	Base	Ambitious
14	17	20	63



NREL 2020

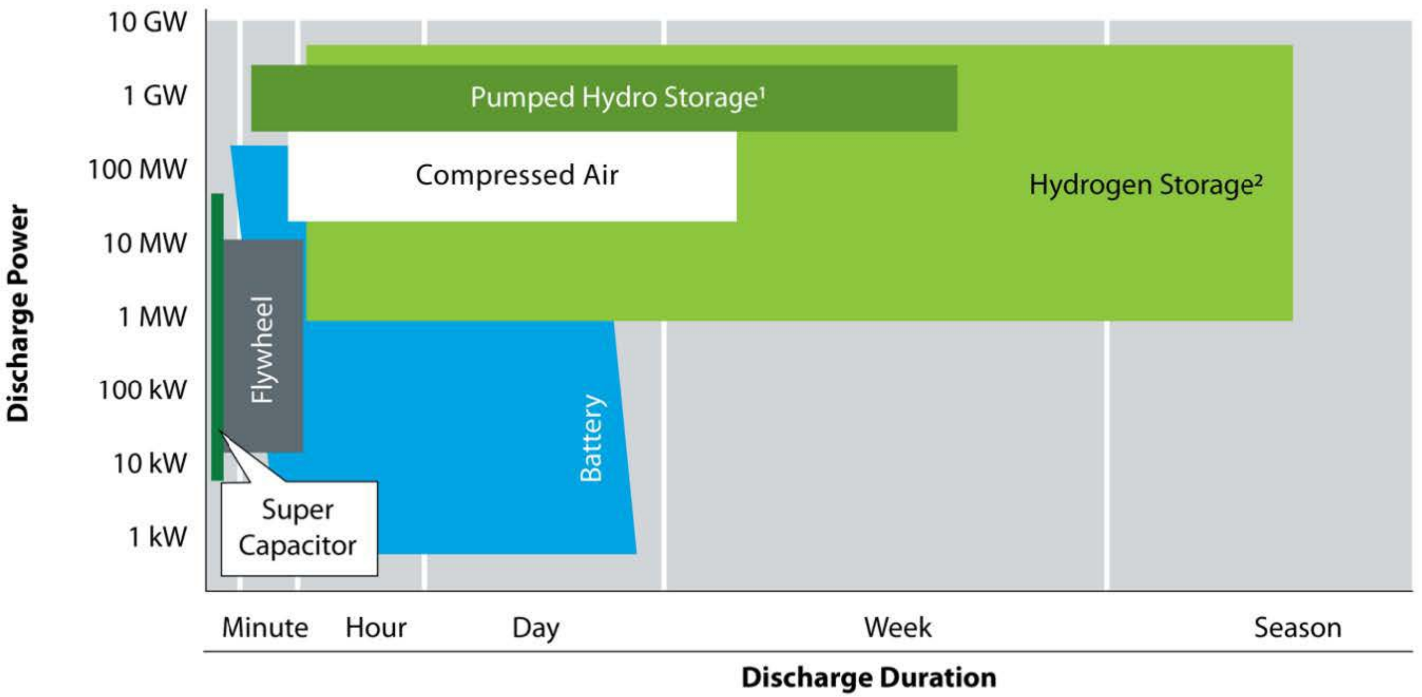
Fuel Cell & Hydrogen Energy Association



1 Assuming that 20% of jet fuel demand would be met by synthetic fuel and 20% of marine bunker fuel by ammonia
2 Demand excluding feedstock, based on IEA final energy demand for the US
Note: Some numbers may not add up due to rounding

https://www.fchea.org/us-hydrogen-study 2019

Hydrogen as Energy Storage Medium

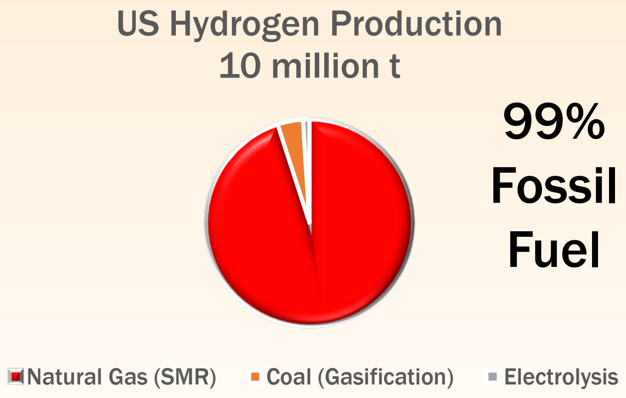


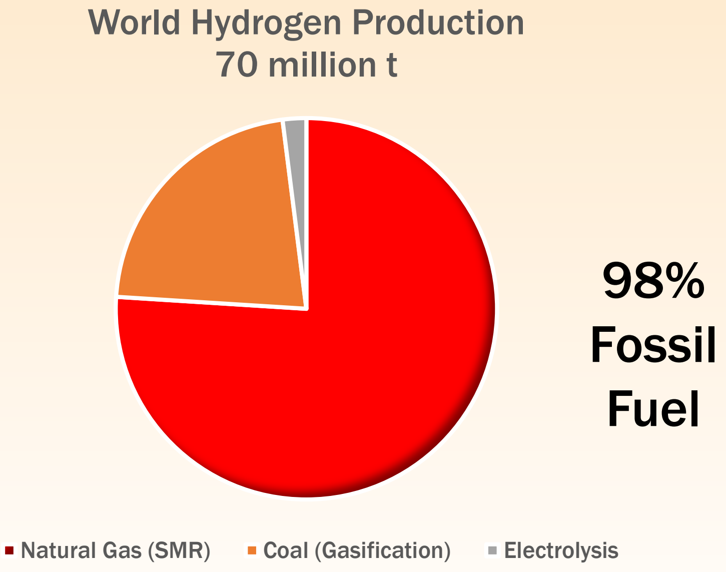
[1] Pumped hydro capacity is limited due to geographic constraints. Estimated maximum potential is <1% of U.S. electrical energy demand
[2] As hydrogen, ammonia, or synthetic natural gas

NREL 2020

Hydrogen Production

- 1 kg H_2 ~ 1 gallon gasoline (energy equivalence)
- 1 t H_2 ~ 1,000 gallons gasoline
- 2.32 t H_2 in 1 million scf H_2 @ 1 Bar; 25° C





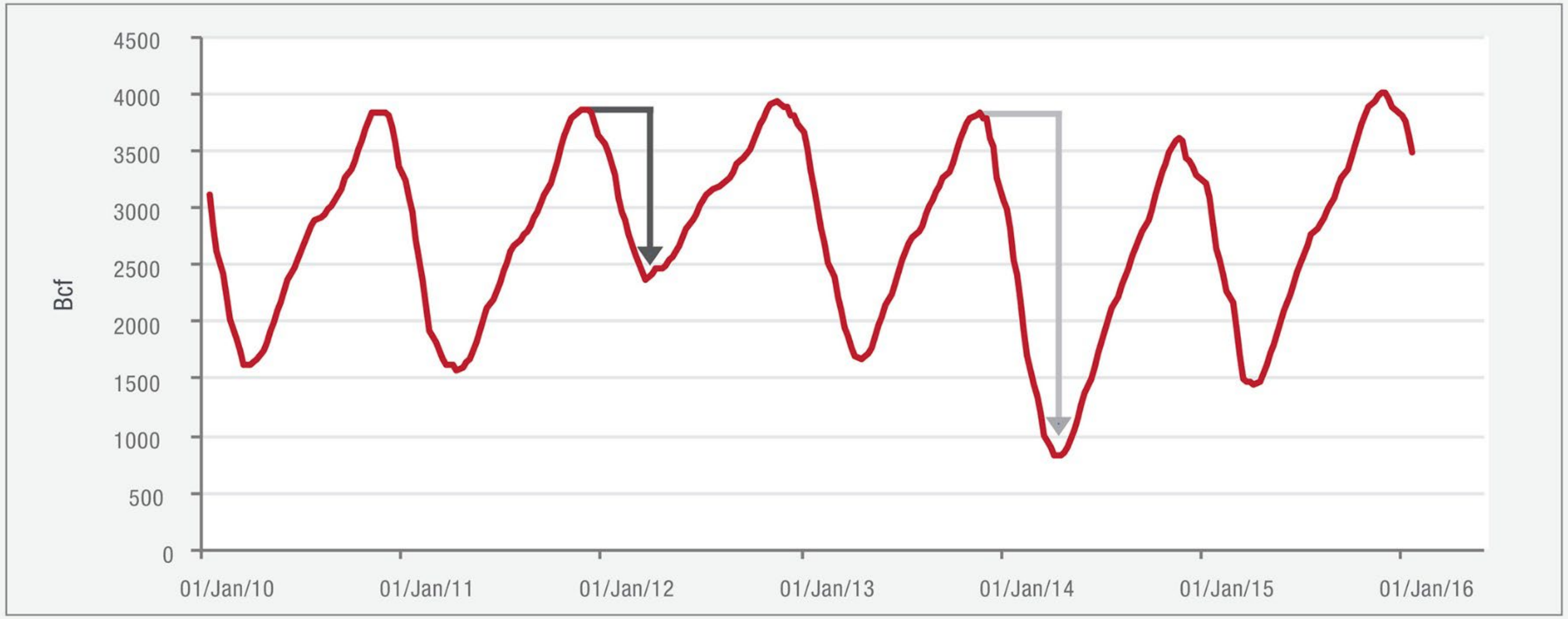
https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

US Natural Gas Storage

- ~400 NG storage sites
- Depleted O&G fields: 80%
- Aquifers: 10%
- Salt caverns: 10%
- Storage capacity ~13% of yearly NG consumption
- About 20% of winter consumption from storage

Natural Gas Working Storage Levels

Energy Information Administration, “Weekly Natural Gas Storage Report, History,” January 8, 2016.



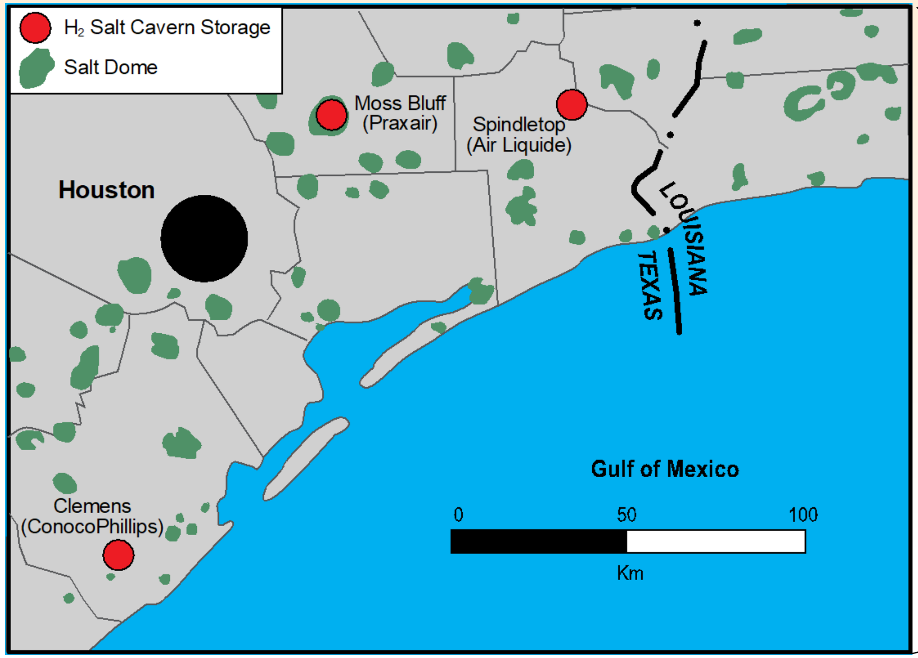
The chart above shows how storage fluctuates with the weather. During the mild winter of 2012, the gas withdrawn from storage was far more moderate (see black arrow). In contrast, in 2014, the year of the Polar Vortex, natural gas storage was “drawn down” sharply (see grey arrow). But even in the mildest of winters, such as 2012, natural gas withdrawals from storage were vital to meeting winter natural gas demand.

Today’s H_2 storage compared to NG storage

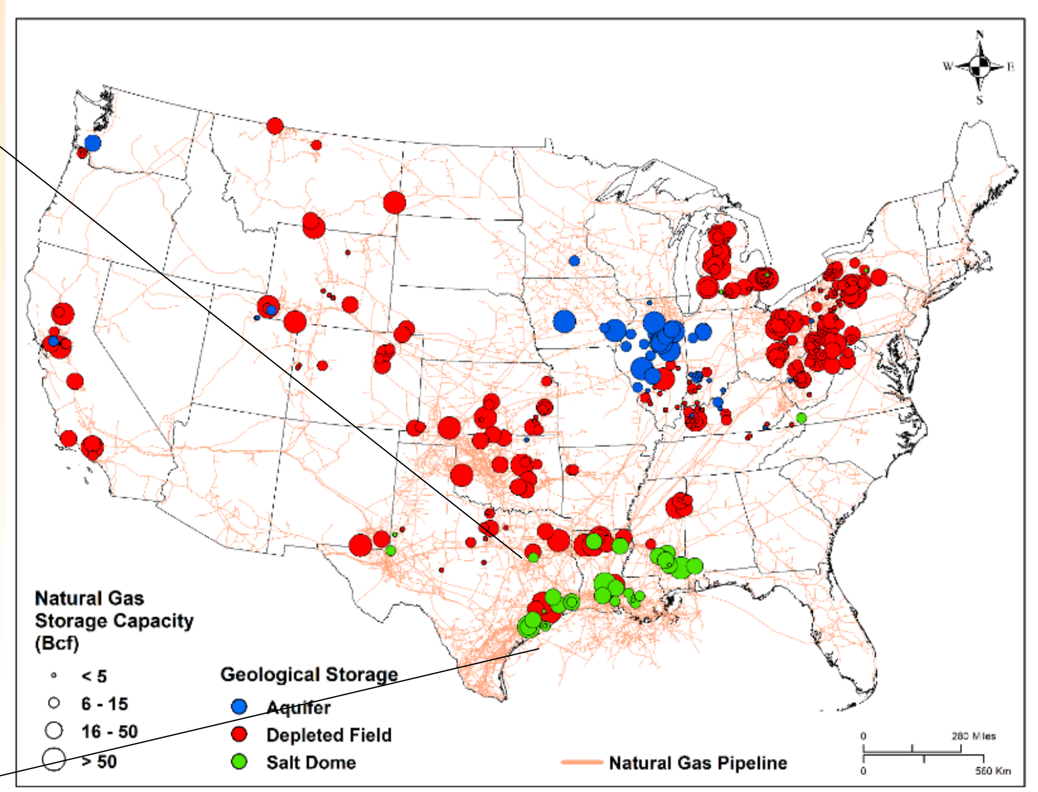
H_2 ~ 1/3 energy per unit gas volume than natural gas

Existing US H_2 storage:
~ 6 billion cf
~14,000 t H_2 Storage

US natural gas storage
30 trillion cf/year consumed (2020)
400 underground storage sites
4 trillion cf storage capacity



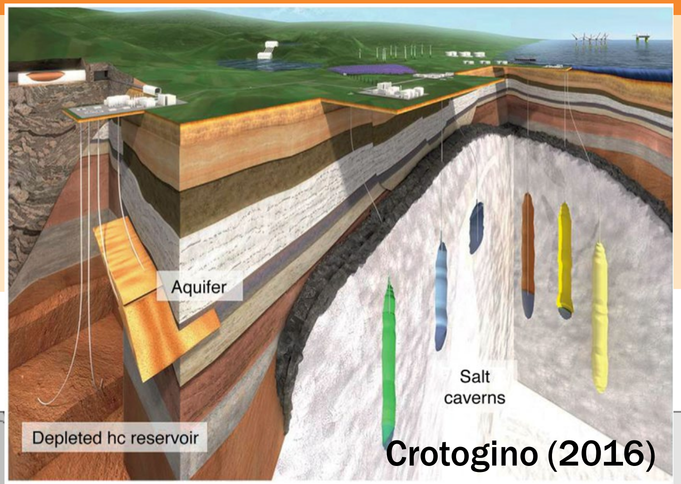
Modified from NEA, 2017

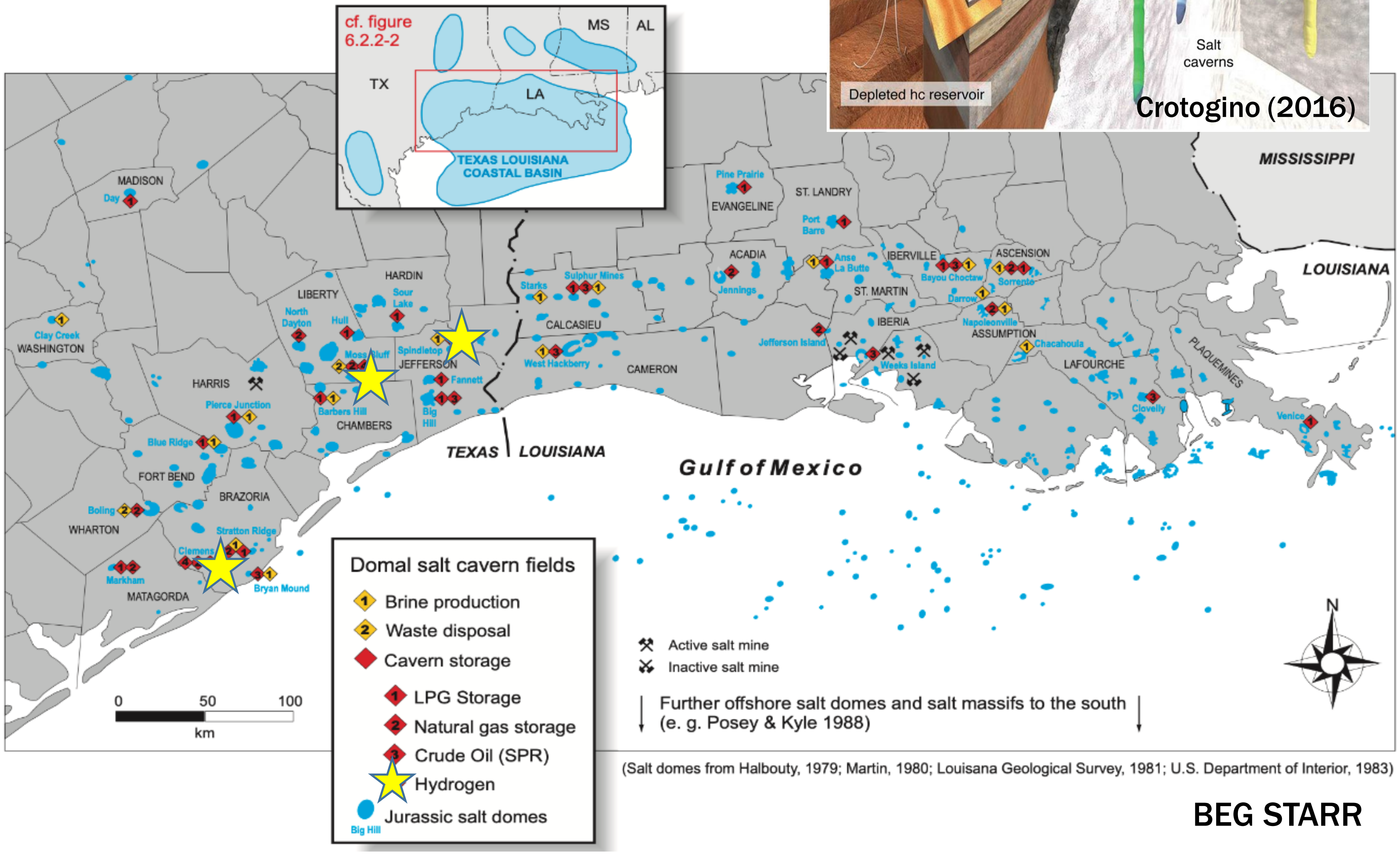


Source: EIA, 2021

Salt cavern storage—proven & operational technology

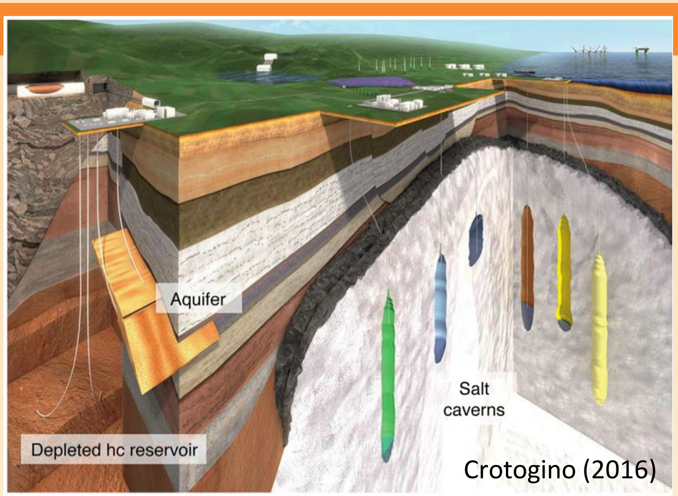
- 3 sites in TX, 1 in Scotland
- Lowest-cost bulk storage
- Proven technology
- Limited geographic distribution of suitable salt deposits
- Brine disposal
- Limited size
  8,000 t operational
  80,000 t proposed, Hystor, MS





BEG STARR

Salt cavern storage—proven & operational technology



Salt domes & cavern storage US Gulf Coast

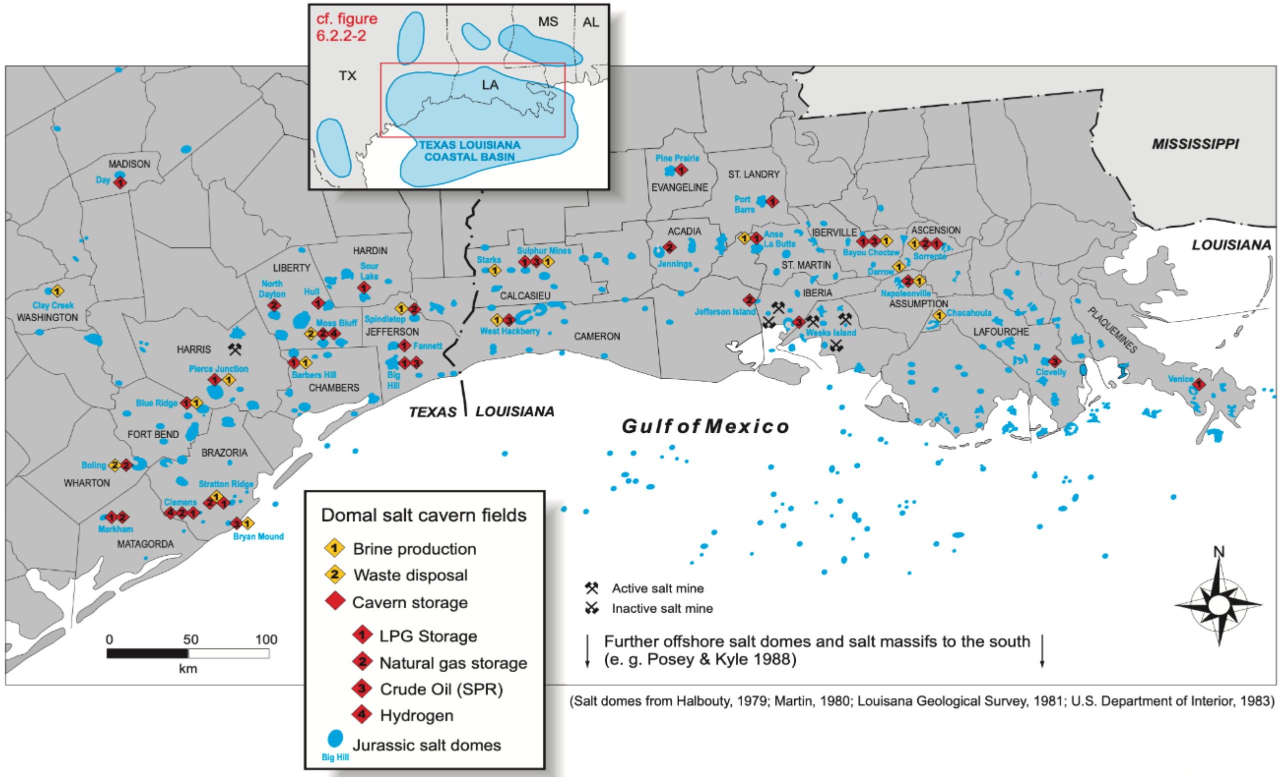


TABLE 20.2 Metrics of Hydrogen Caverns in the United States and the United Kingdom [10]

	Teesside (UK)	Clemens Dome, Texas (USA)	Moss Bluff, Texas (USA)	Spindletop, Texas (USA)
Salt formation	Bedded salt	Salt dome	Salt dome	Salt dome
Operator	Sabic Petrochem.	Chevron Phillips Chemical Comp.	Praxair	Air Liquide
Commissioned	1972	1986	2007	information not available
Geometrical volume/m^3	210 000	580 000	566 000	906 000
Mean cavern depth/m	365	1 000	1 200	1 340
Pressure range/10^5 Pa (bar)	45	70–137	55–152	68–202
Net energy stored/GW h	27	81	123	274
Amount of H_2/t	810	2 400	3 690	8 230
Net volume/m^3 (std)	9.12×10^6	27.3×10^6	41.5×10^6	92.6×10^6

DLR. Plan-DelyKaD (2015)