HEC Hydrogen Sessions

Long Duration Energy Storage with Hydrogen

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Agenda

- Hydrogen Energy Center
- Velerity
- Hydrogen Drivers
- Long Duration Energy Storage
- Hydrogen Storage
- Existing Geologic Hydrogen Storage
- Proposed Hydrogen Energy Storage Projects

Hydrogen Energy Center

HEC is a nonprofit professional society focused on accelerating the hydrogen as an enabling solution for renewable energy

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

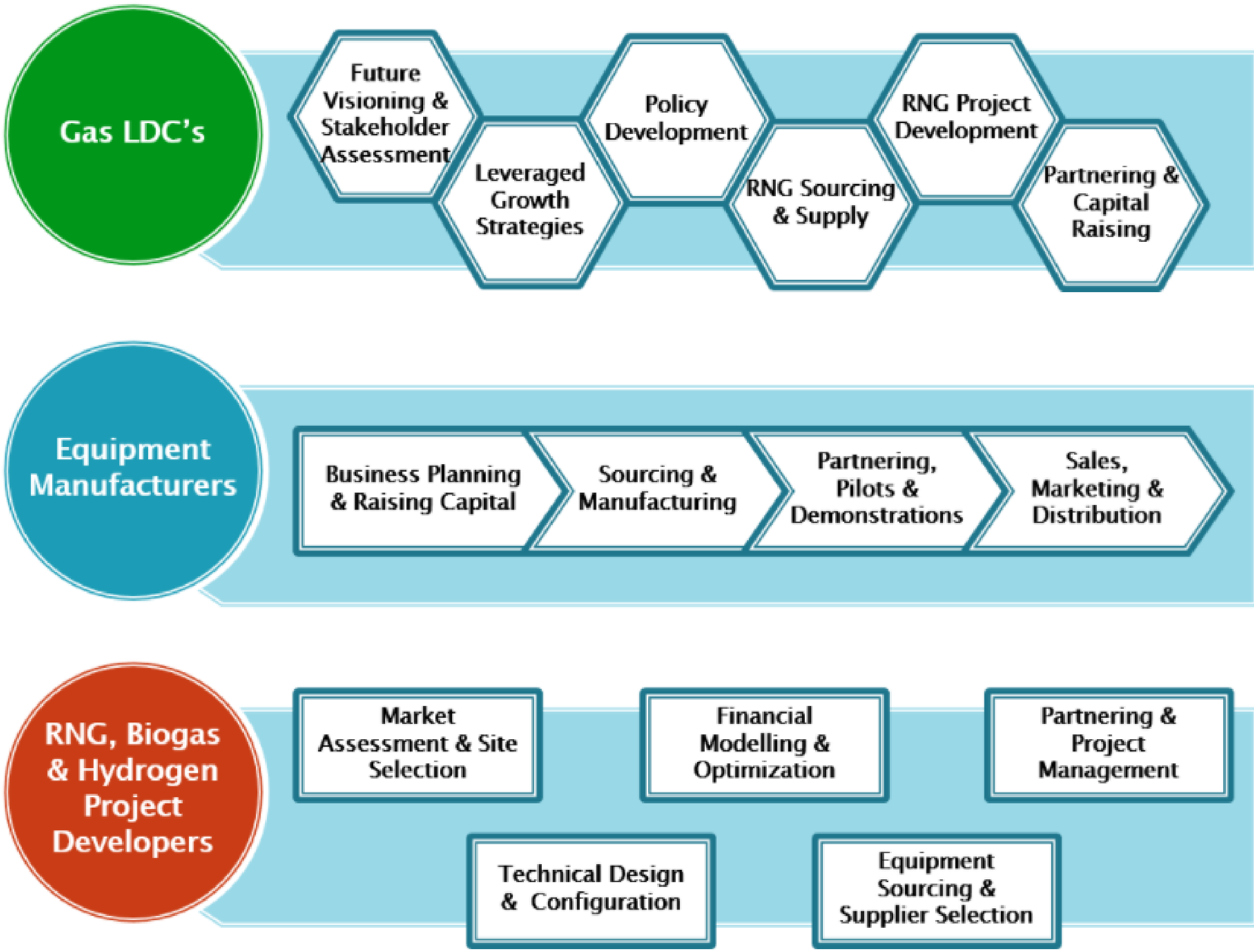
Consider supporting this important effort by becoming a member:

- Influence the course of renewable hydrogen energy technology and policy.
- Be a part of projects that really build hydrogen solutions.
- Have full access to white papers, technical reports, and meeting minutes from our projects and from other organizations.
- Immerse yourself in the hydrogen "goings-on" by connecting with developments & networking with people who are collectively driving the hydrogen "bus".

Upcoming Hydrogen Sessions

May 7, 2021	Decarbonizing Long Haul Trucking with Hydrogen
May 14, 2021	100% Hydrogen Pipelines
May 21, 2021	Power Production with Hydrogen
May 28, 2021	Building a Global Trade in Hydrogen
June 4, 2021	Electrolysis and Water Splitting
June 11, 2021	Hydrogen Production with Carbon Separation
June 18, 2021	Wind to Hydrogen

Velerity Services



Velerity – Illustrative Clients

CINERGY ABB Sierra Pacific RESOURCES National Grid

conEdison, inc. CONOCO NSTAR elpaso

TransCanada *In business to deliver* ™ conectiv Duke Energy Dominion

Reliant Energy Promigas Allegheny FPL

Beacon POWER DQE Colonial Pipeline Company NOVA SCOTIA POWER An Emera Company

TOKYO ELECTRIC POWER COMPANY SafeHydrogen, LLC *Shh... Its quiet power* SUNOCO

Overview

Variable Renewable Energy Expanding Globally

- Grid economics are changing with must run zero marginal cost renewables displacing coal and gas plants
- Increasing VRE creating challenges for grid operators to maintain a reliable grid

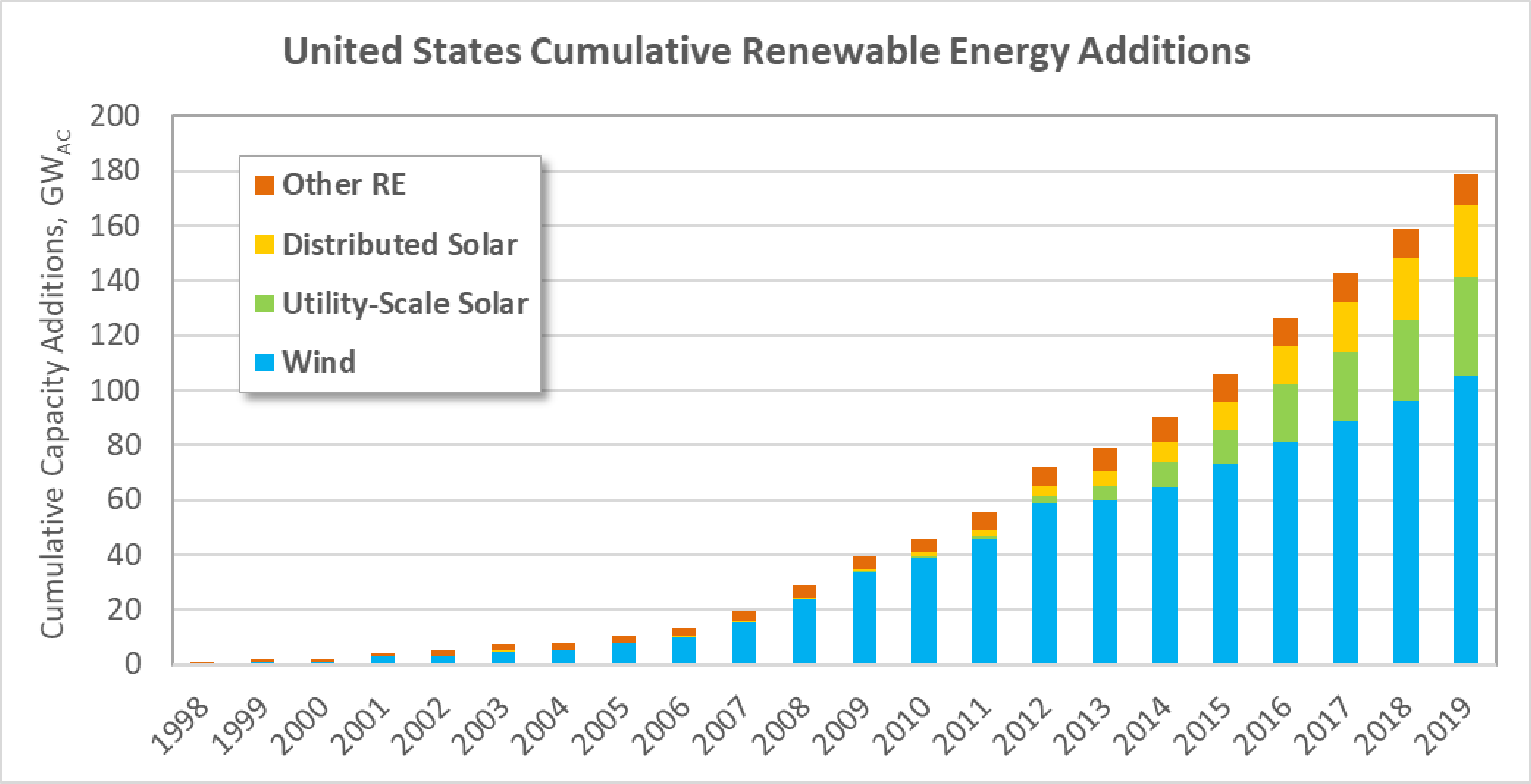
Zero Carbon Targets Requiring New Approaches

- End game zero carbon objectives resulting in future visions with renewables plus storage
- System planners evaluating options for long duration and seasonal storage, considering a wide range of stored energy solutions

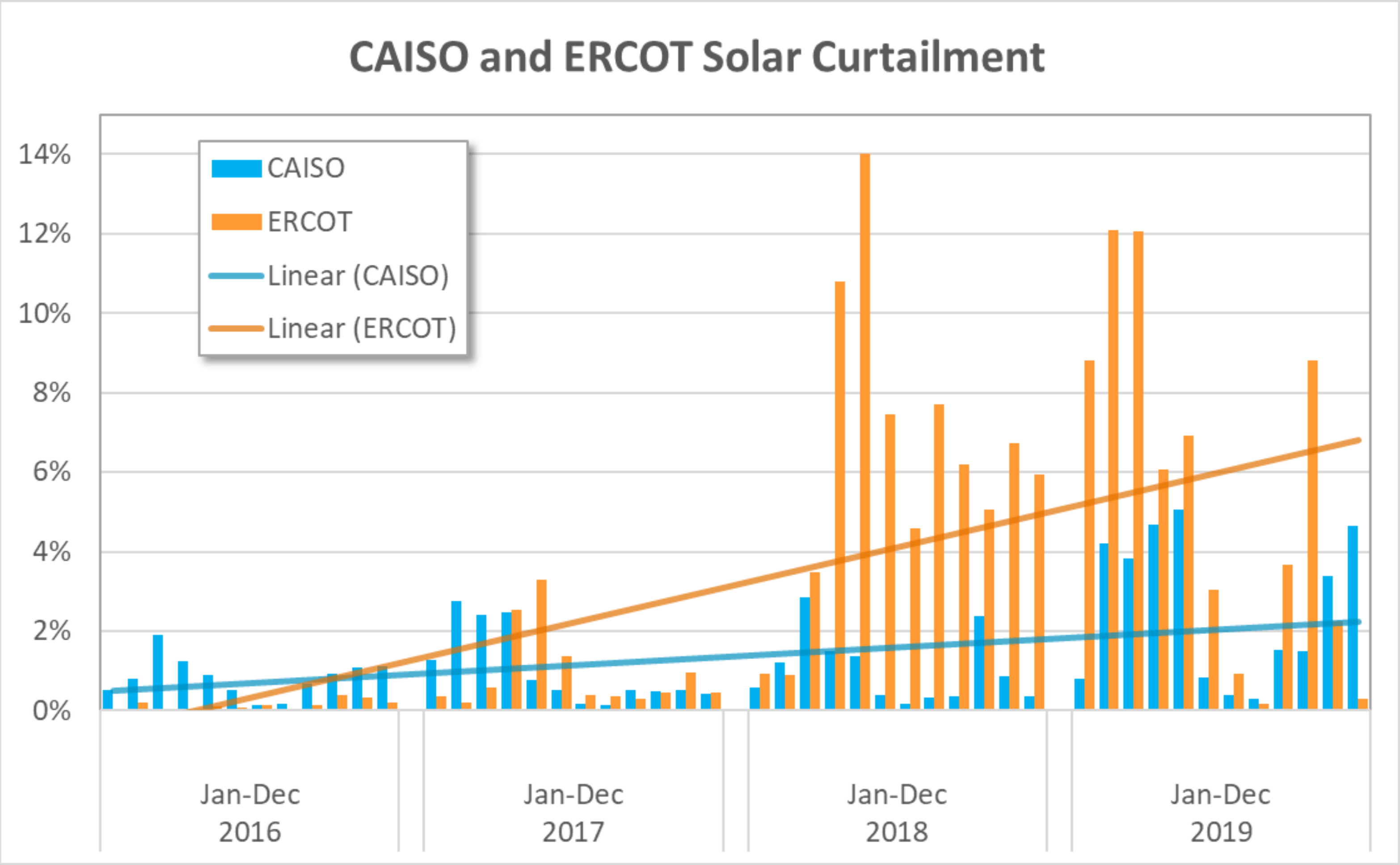
Hydrogen Has Emerged as a Candidate for Long Duration Storage

- Hydrogen production costs have cratered with VRE curtailment & over supply
- Hydrogen can be used to generate power in CCGT's either mixed with methane or at 100%
- Large volume geologic storage of hydrogen is a low cost

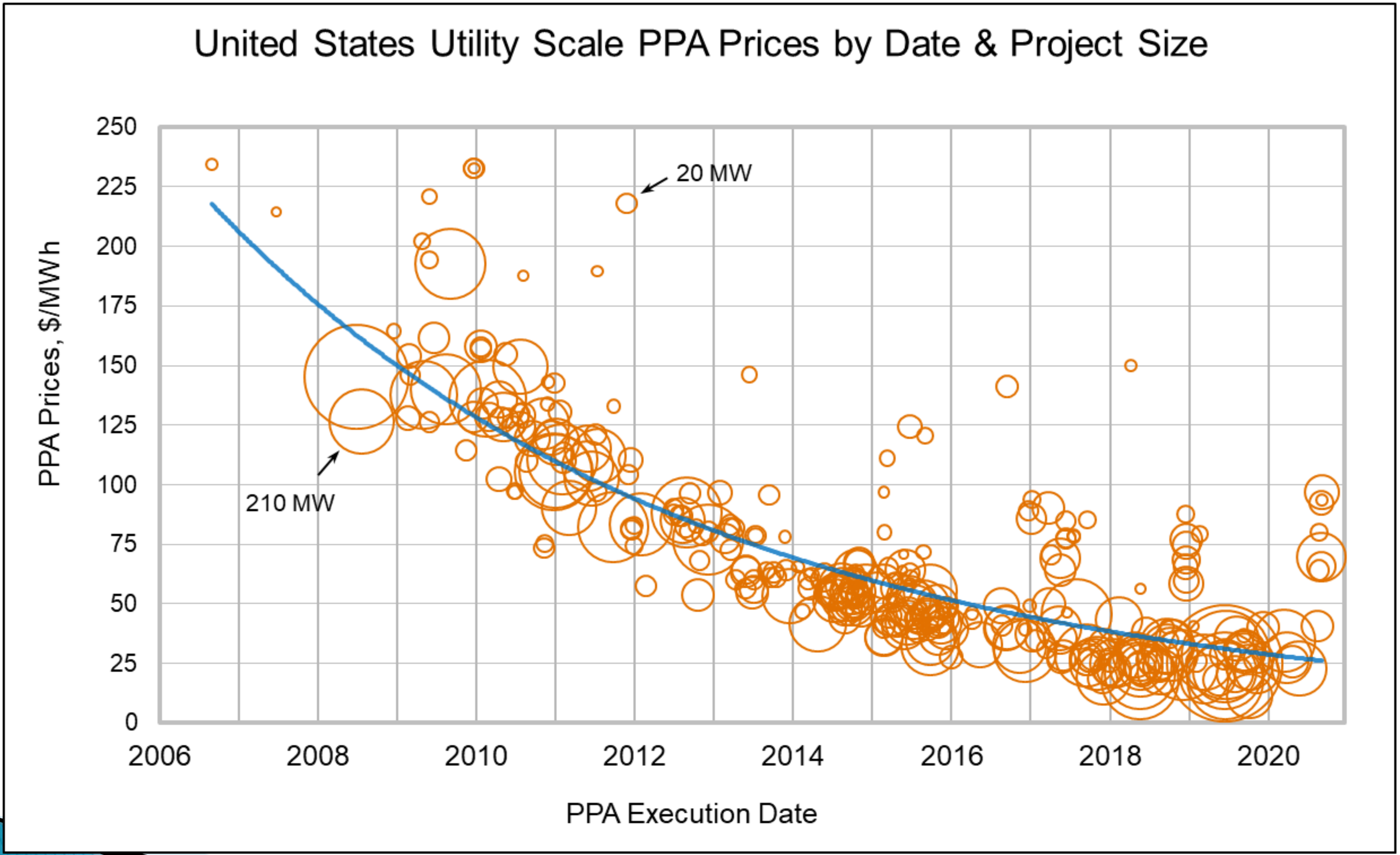
Variable renewable energy continues to climb, with calls for accelerating deployment



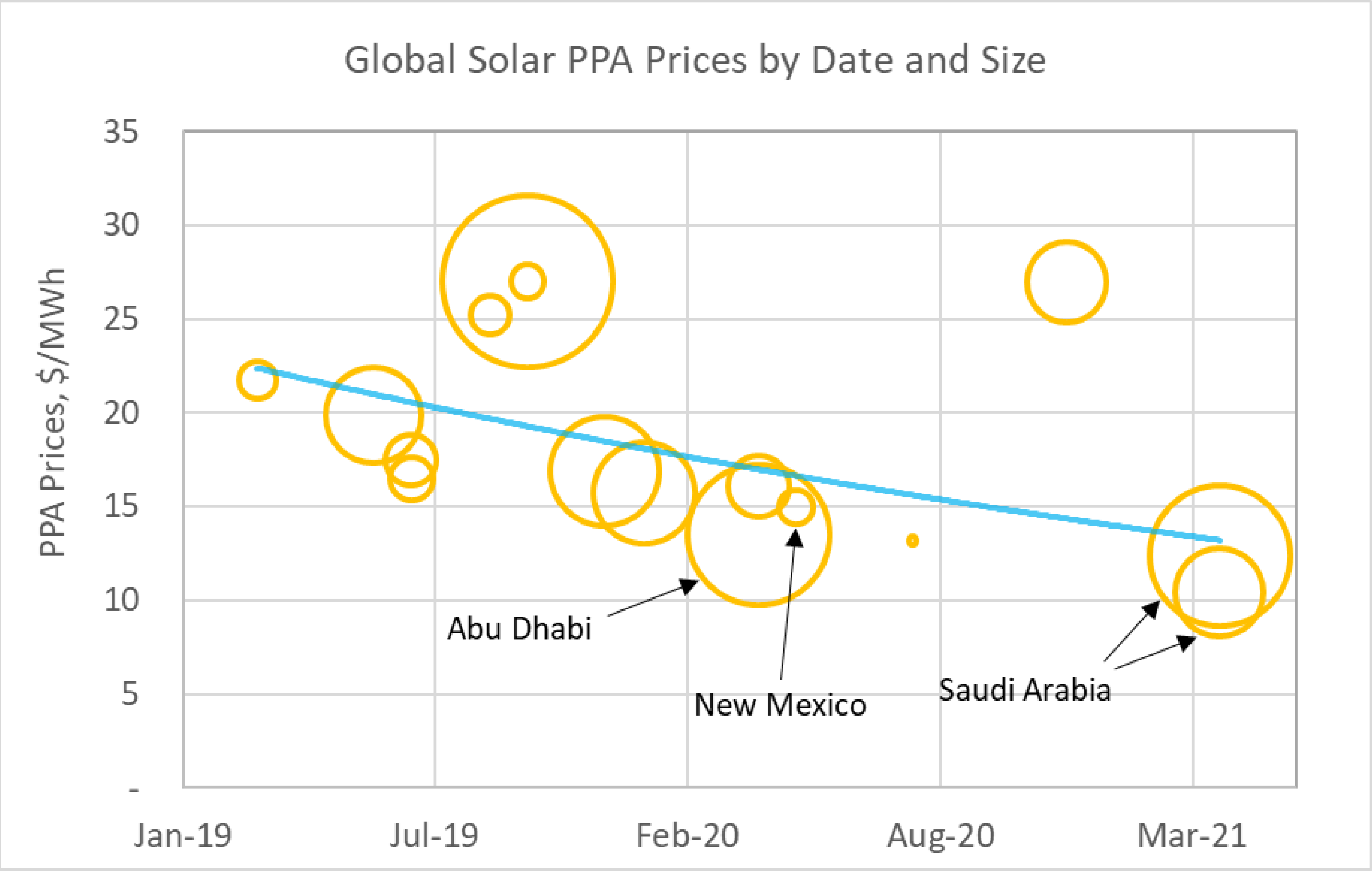
The issue of growing curtailment is impacting RE project economics and creating an opportunity for electrolytic hydrogen production



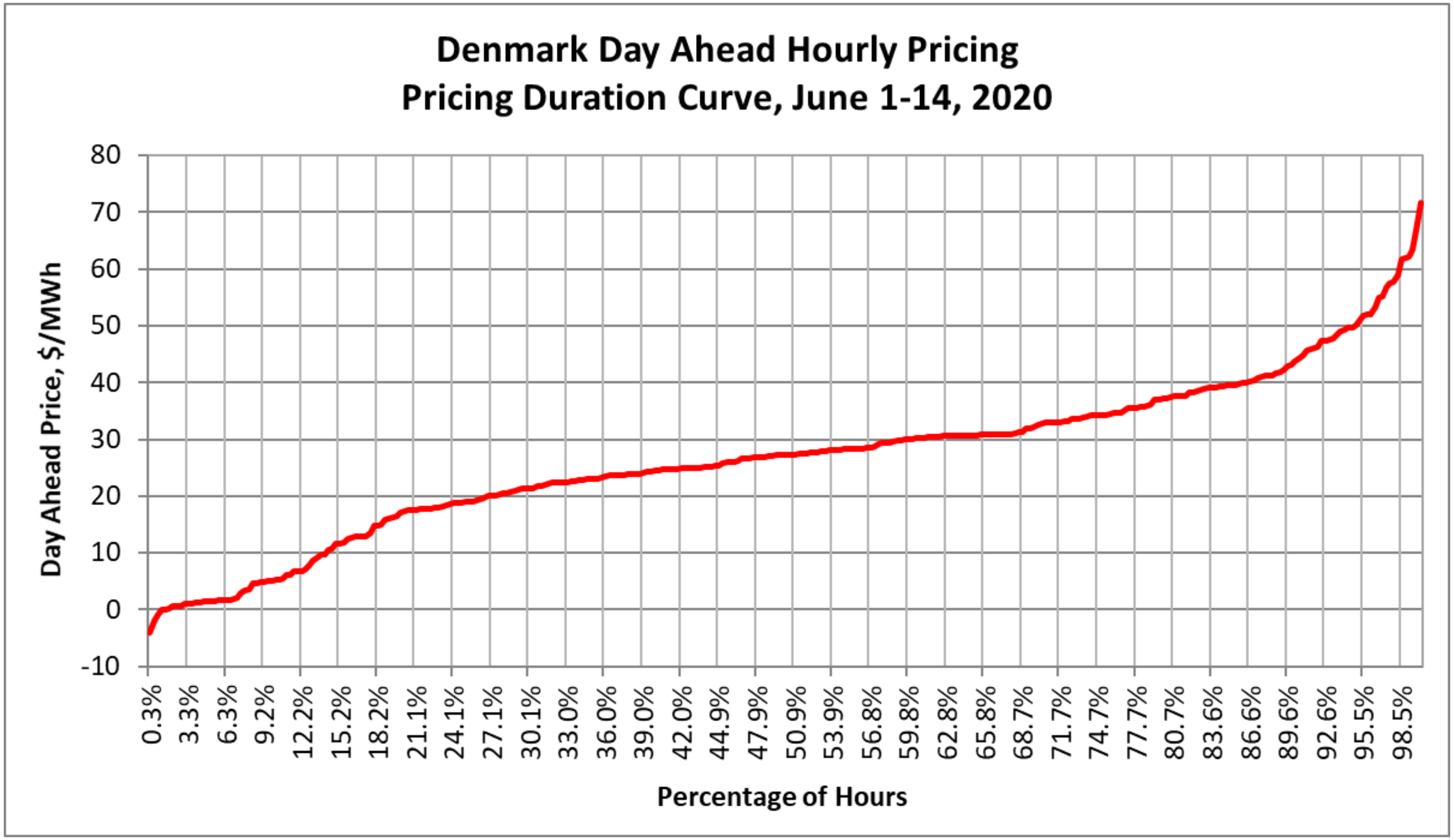
A fundamental driver creating an opportunity for hydrogen is the extraordinary drop in PPA prices



Globally, PPA prices for solar are nearing 1 cent per kWh, implying marginal cost of hydrogen production at 50 cents per kilogram



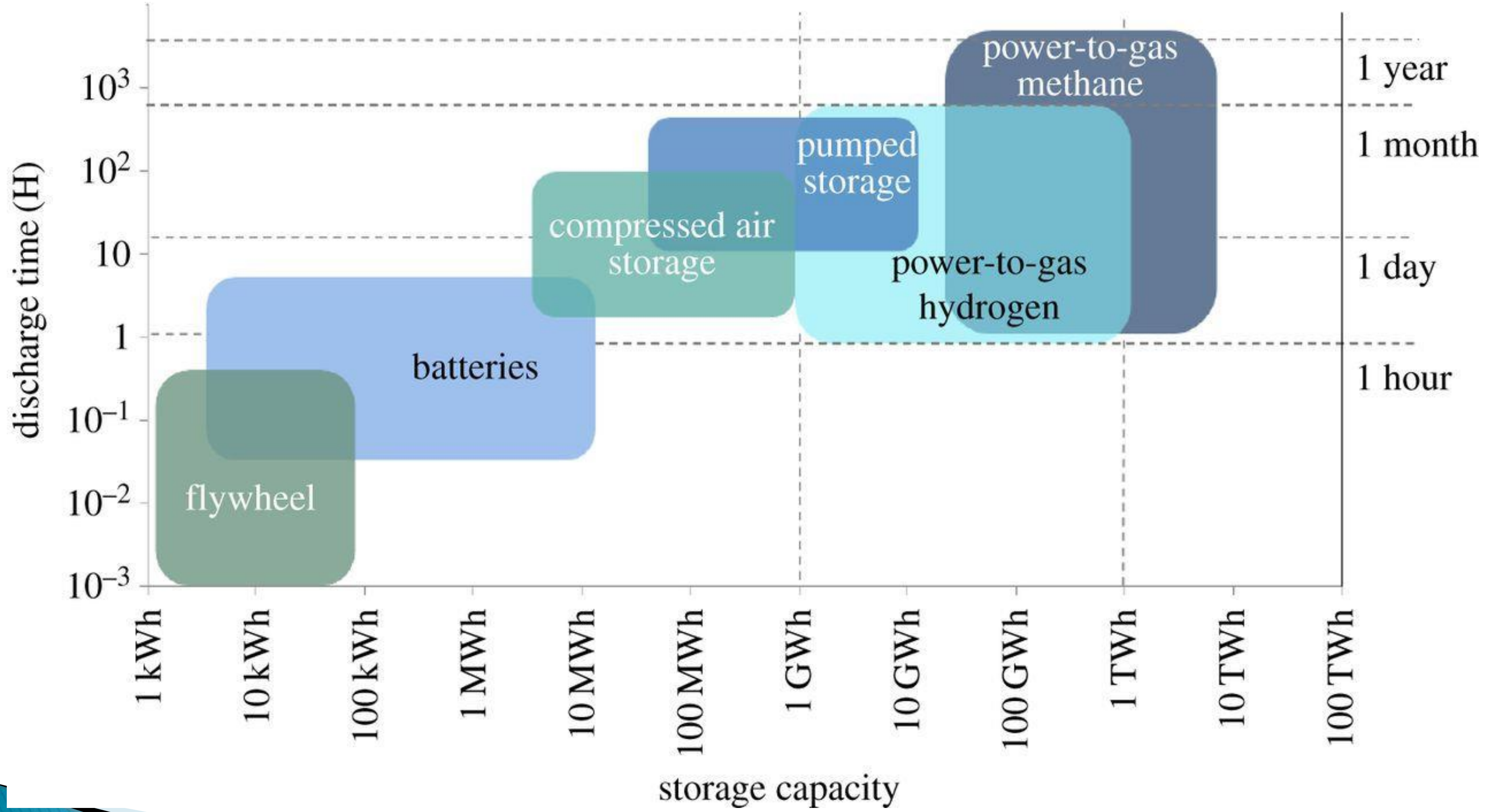
The opportunity for electricity price arbitrage is increasing, with the spread only to increase over time



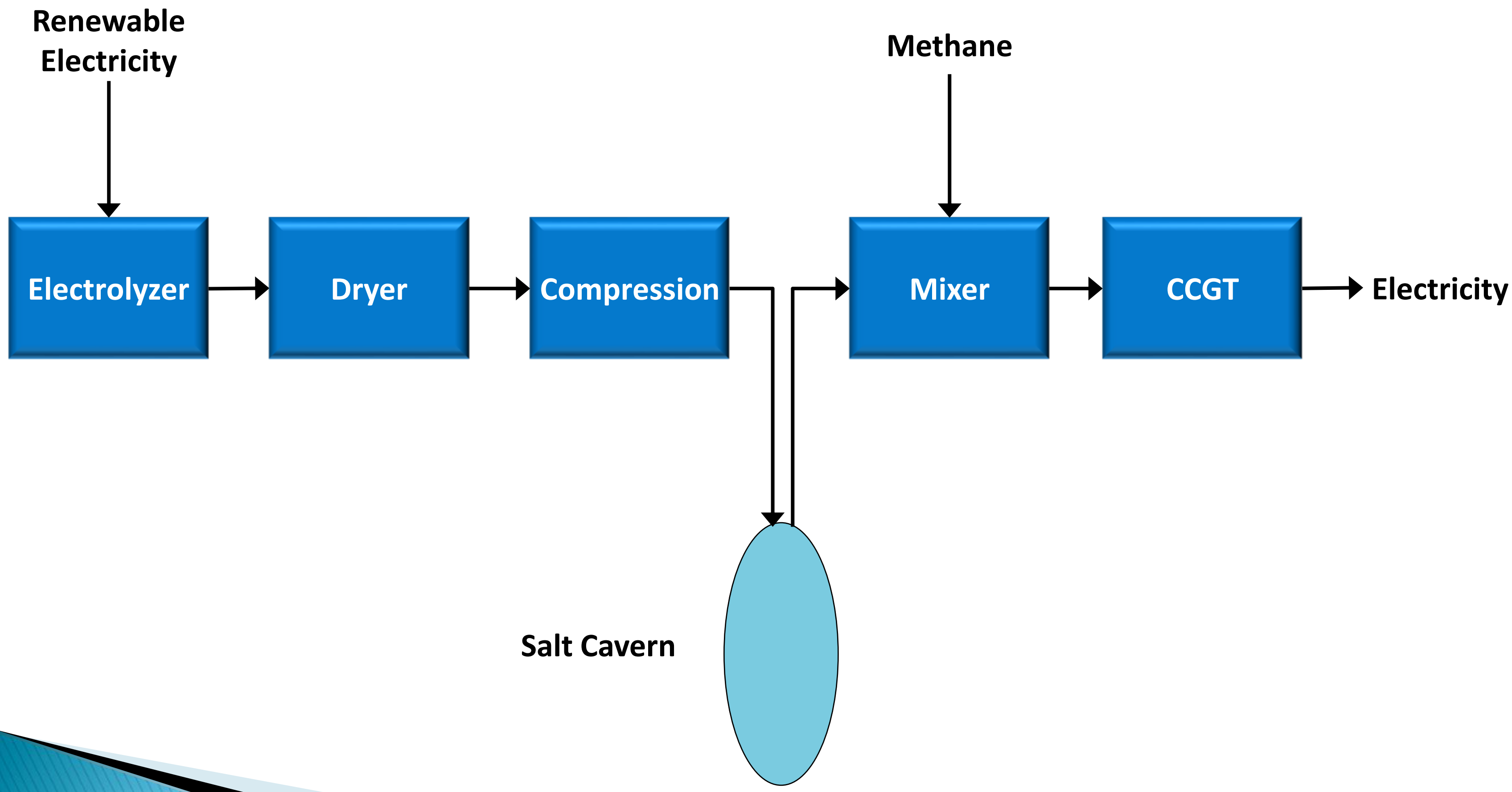
The competition for long duration energy storage is heating up, with many competing technologies and configurations in development

- Long Duration Storage
  - Flow Batteries
  - Pumped Hydro
  - Hydrogen
  - Stacked Blocks
  - Liquid Air
  - CAES
  - Thermal Energy Storage
  - Others

To simplify differentiating technologies, energy storage technologies can be graphed based on storage capacity and storage duration



One approach to long duration energy storage with hydrogen is to use electrolyzers and combined cycle gas turbines with salt caverns



Worldwide electrolyzer manufacturing is ramping up to meet demand, while turbine manufacturers have already introduced hydrogen ready turbines

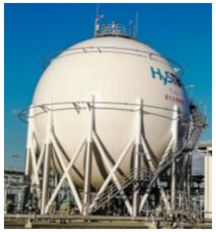
Electrolyzers	Turbines
Nel	GE
ITM Power	Siemens
Cummins	Mitsubishi Power
Plug Power	

The major bulk hydrogen storage approaches include pressure vessels, cryogenic and geologic hydrogen storage

Spherical Pressure Vessel

- McDermott Hortonsphere
- 10.4 bar
- 120' diameter
- 25,365 kg total
- 23,082 kg net

Spherical Cryogenic Vessel



- Kobe, Japan
- 2,500 cubic meters
- 177,500 kg

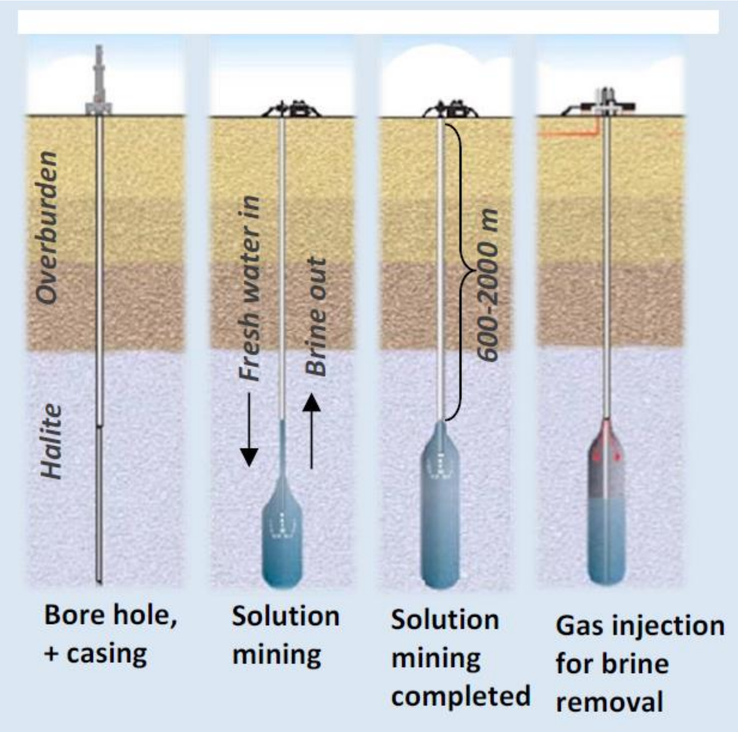
Lined Rock Cavern

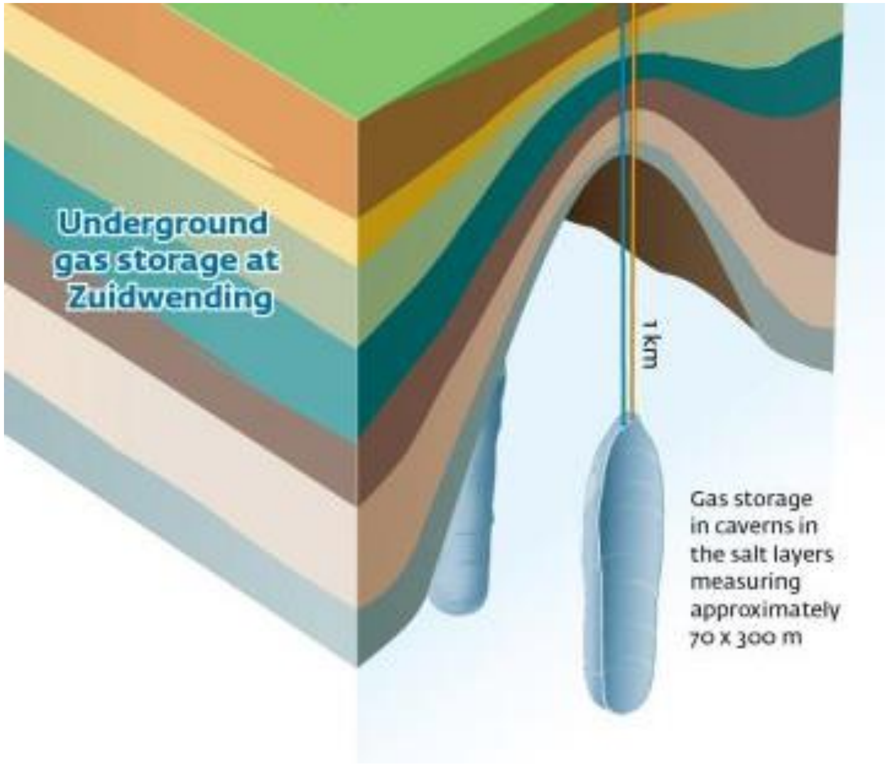
- Skallen, Sweden
- 40,000 cubic meters
- 10 – 230 bar
- 688,010 kg total
- 650,536 kg net

Salt Dome

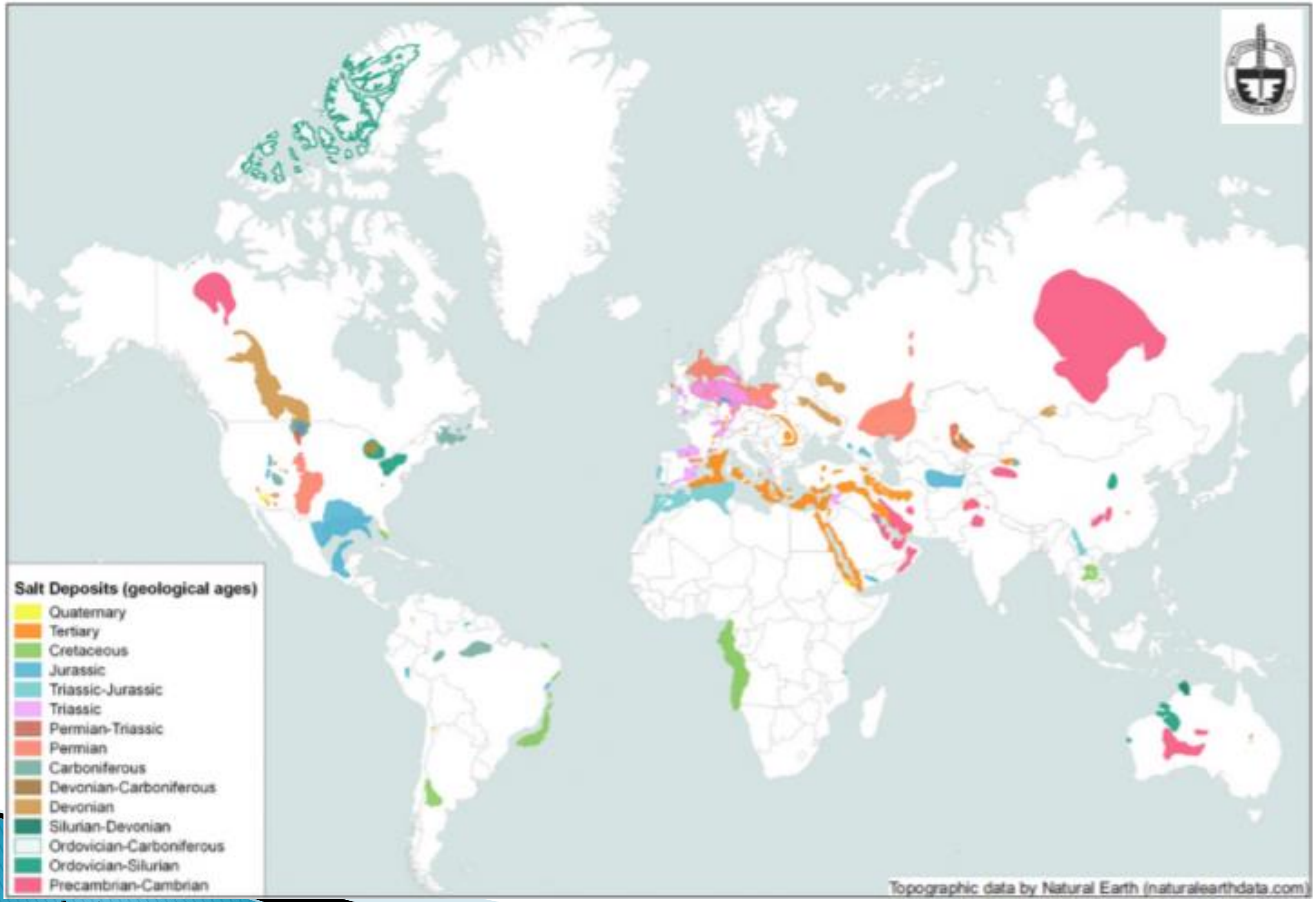
- Praxair, Texas
- 566,000 cubic meters
- 55 – 152 bar
- 6,755,730 total
- 4,131,161 kg net

It takes several years to prepare salt caverns for gas storage, with technology and process well understood through natural gas storage

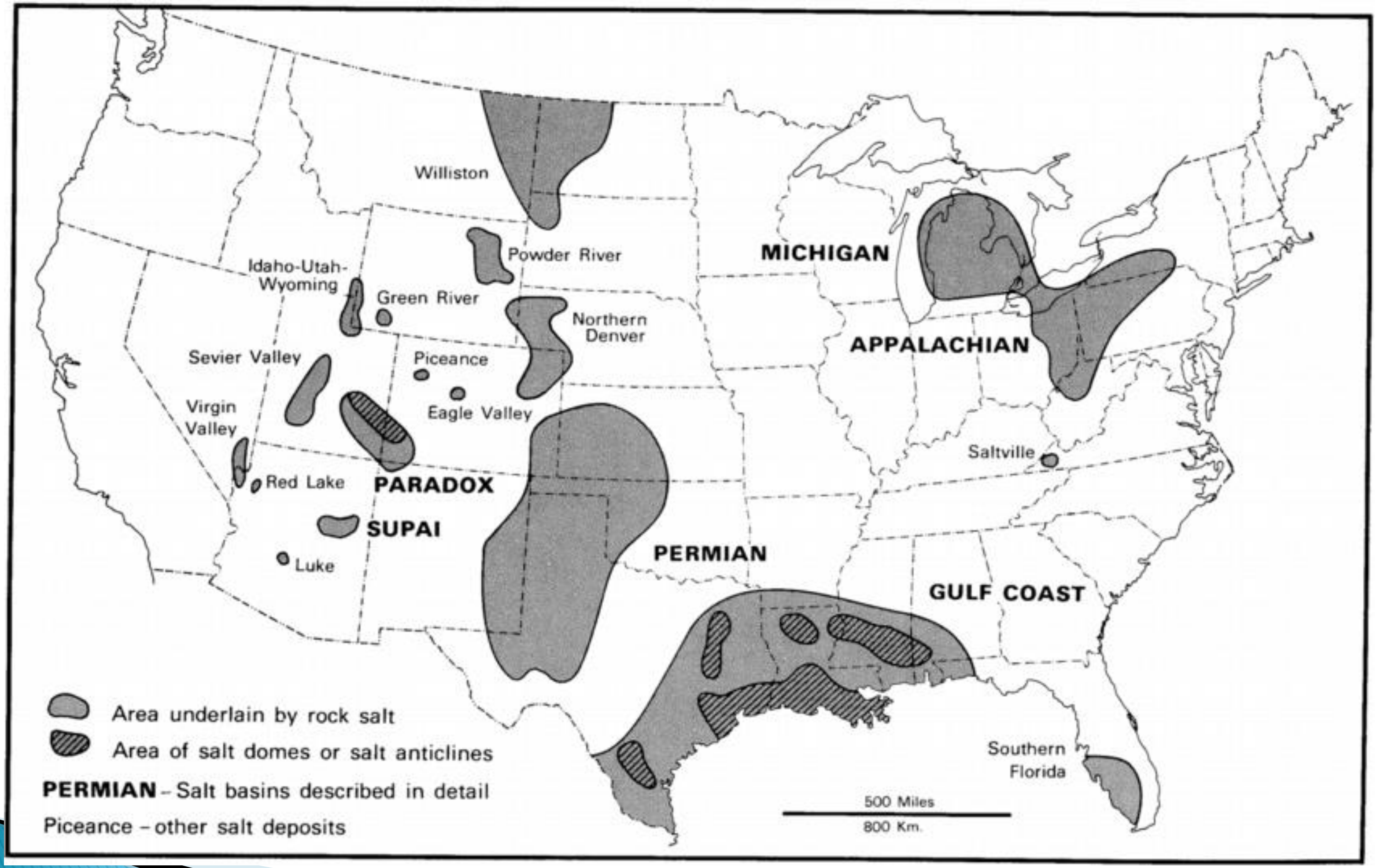




Salt deposits are in many locations around the world.



The United States has multiple candidate locations for hydrogen storage sites



Source: Salt Deposits in the United States and Regional Geologic Characteristics Important for Storage of Radioactive Waste, Mar 1978

The United Kingdom already has 27 storage sites being used for natural gas and mixed gas applications

- There are already twenty-seven salt caverns being used for natural gas or hydrogen storage in the UK with three more storing nitrogen (Evans & Holloway 2009). These are located in Cheshire, Stafford, Yorkshire and on Teesside

The are four pre-existing geologic hydrogen storage sites, with three in the United States and one in the United Kingdom

	Teeside (UK)	**Clemens Dome** (Texas)	**Moss Bluff** (Texas)	**Spindletop** (Texas)
Salt formation	Bedded Salt	Salt dome	Salt dome	Salt dome
Operator	Sabic Petrochem.	Chevron Phillips Chem. 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 [bar]	45	70-135	55-152	68-202
Net energy stored [GWh]	27	81	123	274
H_2 **mass** [ton]	810	2 400	3 690	8230
Net volume [m^3] (std)	9.12×10^6	27.3×10^6	41.5×10^6	92.6×10^6

Table 2.4: Metrics of Hydrogen caverns in the USA and the UK

Source: Maarten Pieter Laban

There are quite a few proposed hydrogen energy storage projects around the world

- Intermountain Power Project
- Terega and Hydrogeine de France
- Centrica
- Hypos Alliance
- Mitsubishi Power and Entergy in Texas
- HyPSTER – Hydrogen Pilot STorage for large Ecosystem Replication
- Hystock – Gasunie

The most significant hydrogen energy storage project in development is the $1.9 billion Intermountain Power Project in Delta, Utah

VELERITY

Current Coal System

- 1,800 MW
- 2 coal units
- Commissioned in 1986
- To be retired in 2025
- 8 million tons/year CO_2 emissions in 2018

Natural Gas

- 840m MW natural gas combined cycle power plant
- 68% capacity factor
- Hydrogen ready turbine up to 20%
- Commission date July 1, 2025

Hydrogen and CAES

- 160 MW Compressed Air Energy Storage
- Mix in hydrogen up to 20%
- Build out salt cavern storage for compressed air and hydrogen
- 100% hydrogen by 2040

IPP Salt Dome Storage – Review

- Estimated cavern size at IPP = 4,000,000 barrels
- 1 cavern = net usable 4,642,081 kilograms of hydrogen or 5,118 tons (2,949,163 kilogram cushion)
- Over 100 caverns can be constructed in the salt dome at IPP
- For the 840 MW combined cycle combustion turbines at 68% capacity factor, annual power production is 5,003,712 MWh/year
- For 61% efficiency power production, this would require 53 caverns of hydrogen, or 246,030,293 kilograms of stored hydrogen (note: number of caverns would be less as storage is not required for 100% annual usage)
- Producing hydrogen with electrolysis with 2 cent power and 50 kWh/kg efficiency results in marginal cost of $1/kg hydrogen
- Converting that hydrogen back into electricity, with an efficiency 20.31 kWh produced per kilogram, results in a marginal cost of power at $0.0492/kWh