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NREL

H2 and AI: Lessons from the World's Most Energy Efficient Data Center

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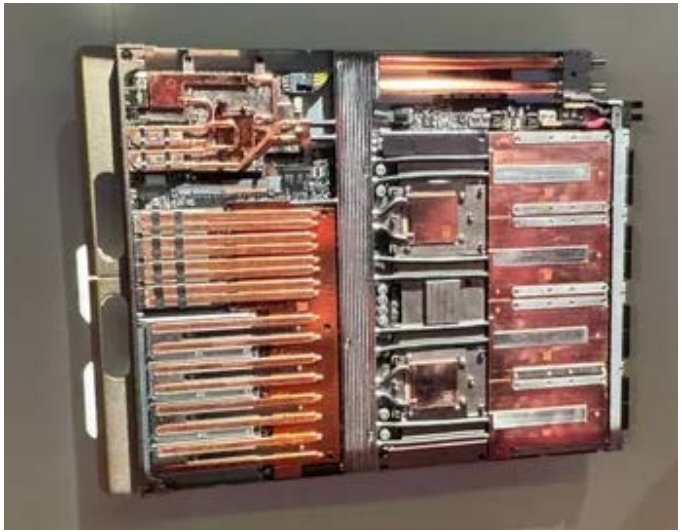
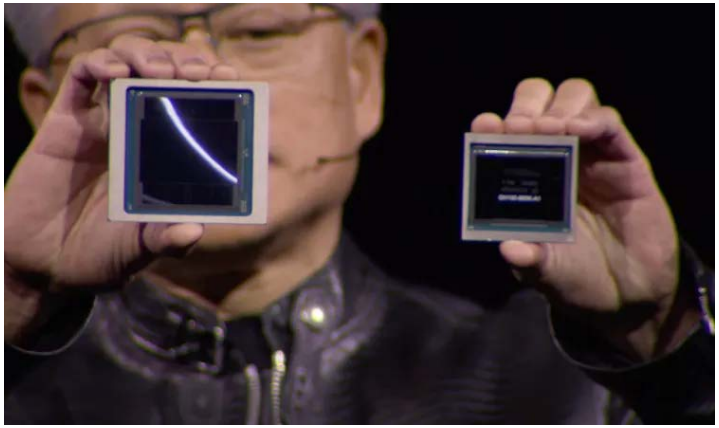
Photo by Josh Bauer, NREL 61725

Artificial Intelligence

- Artificial intelligence (AI) is the ability for computers to mimic human intelligence—or at least do things that can seem intelligent.
- AI's applications fall into three categories: classifications, forecasting, and generation, which is the new kid on the block.





- Web services traditionally have ~10 kW racks and *loosely coupled* CPUs.
- Newer "AI" GPU chips consume dramatically more power than traditional Intel CPUs.
- Rising power densities require component-level liquid cooling.
- Traditional "supercomputer" HPC has 60–70 kW racks.
- Nvidia roadmap for 600 kW racks in ~2027.
- A large "hyperscalar" data center used to be 100 MW; AI data centers are in the range of 1–5 GW.

Cooling Consideration - Safe Temperature Limits

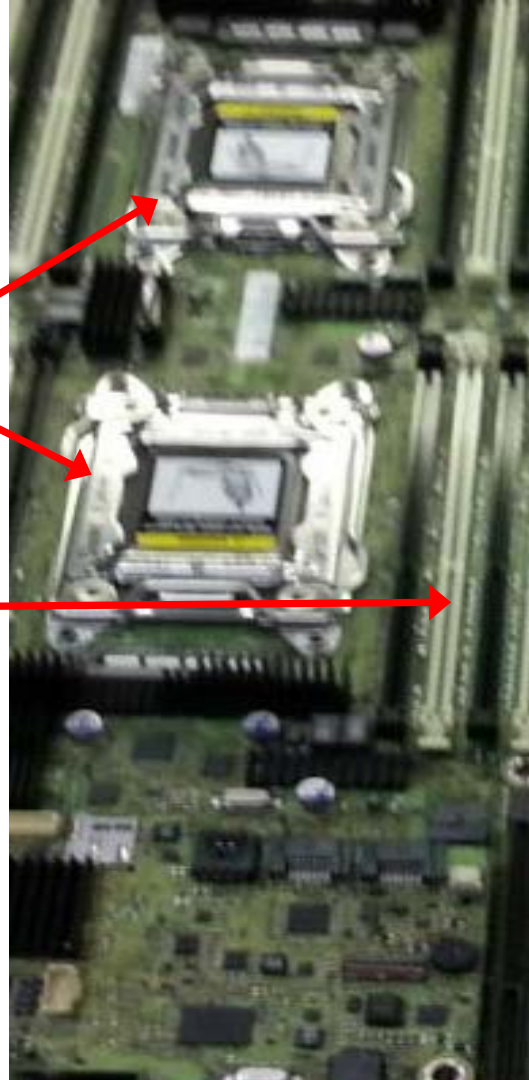
CPU, GPU, and memory represent ~75%–90% of heat load …

Each of these have “TCase” limits.

CPUs
~65˚C
(149˚F)

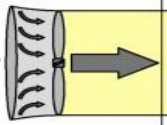
Memory
~85˚C
(185˚F)

GPUs
~75˚C
(167˚F)



Cooling Efficiency – Air vs Liquids

Air is a better insulator than heat exchange media

Heat Transfer		Resultant Energy Requirements			
Rate	ΔT	Heat Transfer Medium	Fluid Flow Rate	Conduit Size	Theoretical Horsepower
10 Tons	12°F	Forced Air 	9217 cfm	34" Ø	3.63 Hp
		Water	20 gpm	2" Ø	.25 Hp

- Heat exchange: liquids are ~1,000x more efficient than air.
- Transport energy: liquids require ~10x less energy. (14.36 air to water horsepower ratio, see figure).
- Liquid-to-liquid heat exchangers have closer approach temps than liquid-to-air (coils), yielding increased economizer hours.

What Have We Accomplished
at NREL?

NREL ESIF Data Center

Utilize the bytes and the Btus!

Showcase Facility, built 2012

- ESIF 182,000 s.f. research facility
- Includes 10-MW, 10,000 s.f. data center
- LEED Platinum Facility, PUE 1.03
- NO mechanical cooling (eliminates expensive and inefficient chillers)
- Uses evaporative cooling only.

Data Center Features

- Direct, component-level liquid cooling (25°C cooling water supply).
- 35°–40°C return water (waste heat), captured and used to heat offices and lab space.
- High voltage 480 VAC power distribution directly to high power density 70–80 KW compute racks.

Compared to a typical data center:

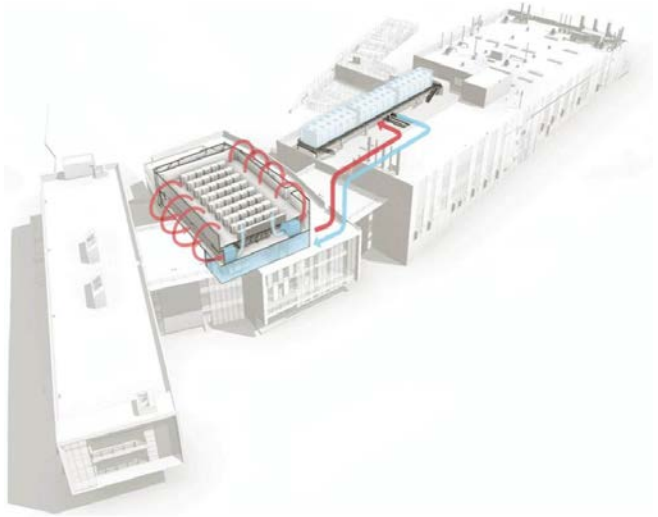
- **Lower CapEx – cost less to build**
- **Lower OpEx – efficiencies save ~$1M per year in operational expenses.**

Integrated “chips to bricks” approach.

Evaporative Cooling & Heat Re-Use

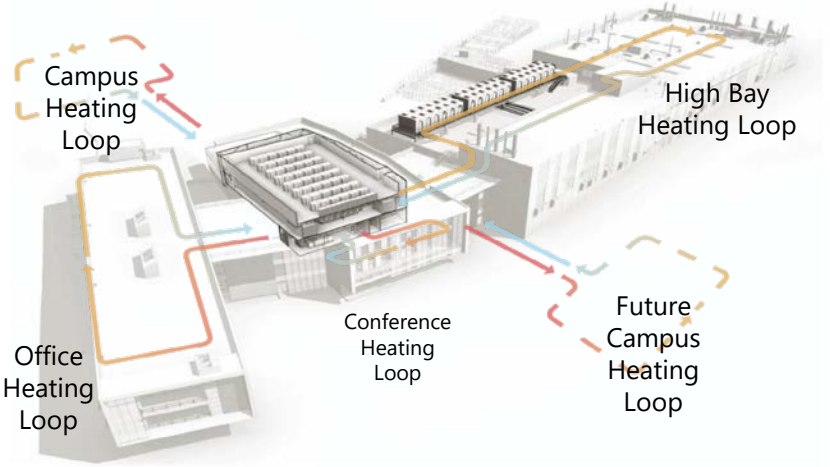
EVAPORATIVE COOLING

- Cooling Towers Provide Efficient Cooling
- Plate & Frame Heat Exchangers Provide Isolation to the Data Center Energy Recovery System

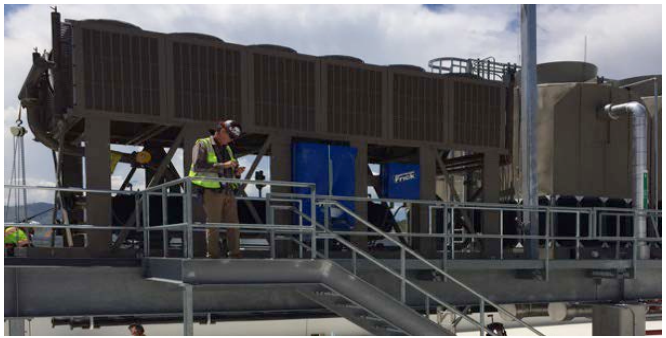


HEAT – ENERGY REUSE

- Goal - **Minimize Cooling** Energy in the Data Center While **Reducing Heating** Loads in Other Areas
- ESIF Utilizes 30% of the Data Center "Waste" Heat on an Annual Basis*
- Utilization to Increase with the Addition of Future Campus Heating Loops, new EMAPS facility.



Data Center Water Reduction



- Data center water usage is a big concern
- Evap. cooling water demand ~2 MG/year
- In collaboration with JCI and Sandia, installed **prototype Johnson Controls** thermosyphon dry cooler
- Compare and contrast JCI dry cooler performance w/ evaporative towers

- Paper released: available at https://www.nrel.gov/docs/fy17osti/66690.pdf
- Cut water usage in half without sacrificing efficiency
- JCI press release: http://contractingbusiness.com/commercial-hvac/ahr-expo-exhibitor-news-johnson-controls-display-bluestream-hybrid-cooling-system

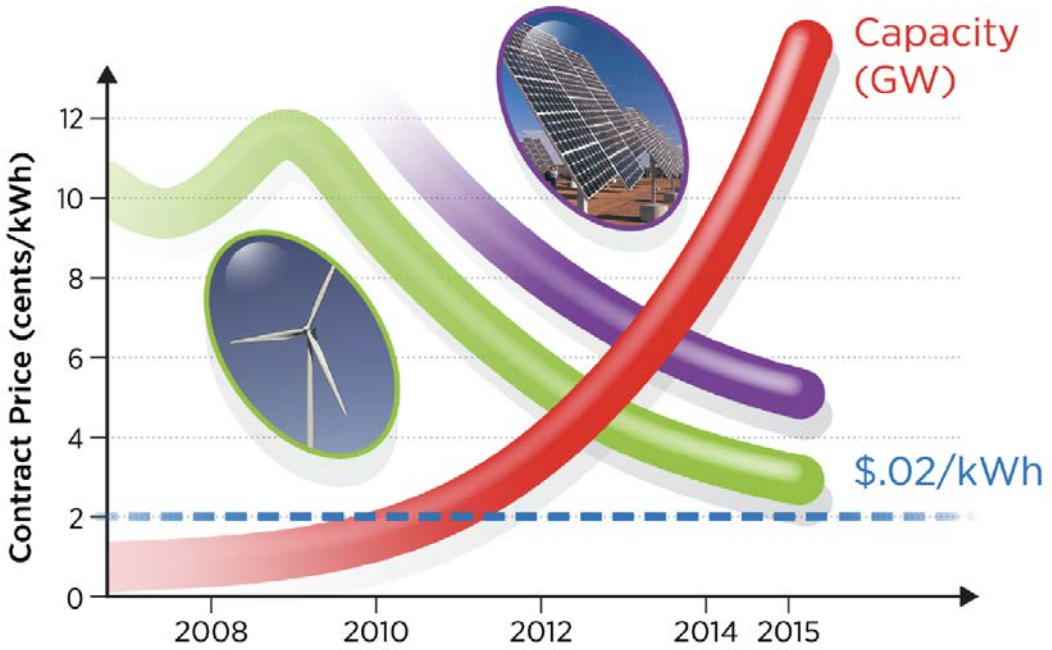
Renewable Hydrogen for
a Carbon-Free Data Center

Potential Role for H2 in Data Centers

- Rethink the power delivery to and power distribution within data centers.
- At NREL, developed a novel proof-of-concept “hydrogen-based” data center utilizing renewable energy sources, electrolyzers, hydrogen storage, and hydrogen fuel cells as key building blocks.

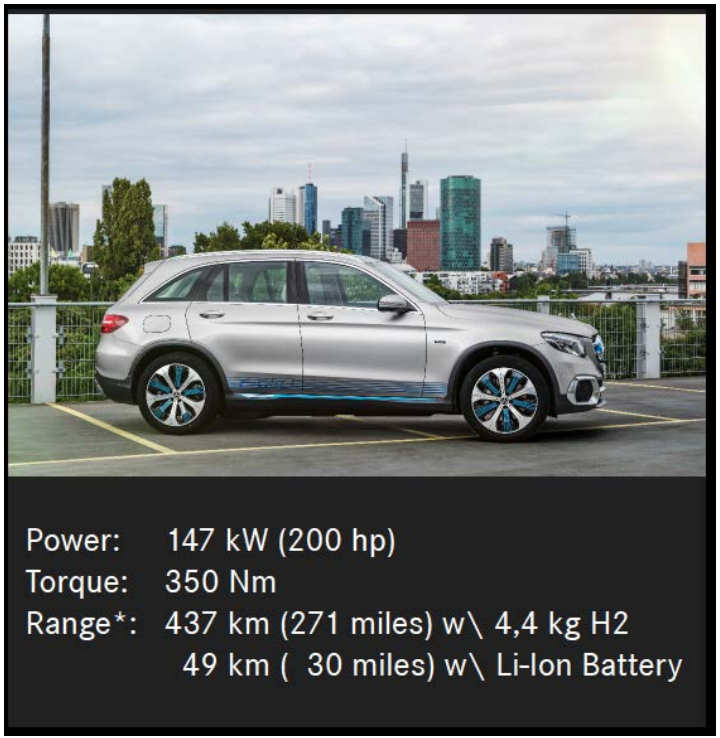
Technology Trends / Electricity Prices

Future Energy Systems are Emerging



Source: (Arun Majumdar) 1. DOE EERE Sunshot Q1'15 Report, 2. DOE EERE Wind Report, 2015

Automotive Fuel Cells and Data Centers



Mercedes Benz GLC F-CELL (IAA Sept 2017)

Hydrogen Fuel Cell Backup Power:

- Robust and modular system, 65 kW building block.
- Leverage volume production of automotive industry, GLC F-Cell available 2020.
- Polymer electrolyte membrane (PEM) fuel cell process allows **fast dynamic response** (smaller UPS).
- Low temperature for **long life**.
- **Silent** operation, **zero** local **emissions** (no CO_2).
- Depending on utility rates, could use for load shedding, demand response, and grid services.

Why Hydrogen?

- Hydrogen is already a critical industrial feedstock.
- Annual U.S. production exceeds 10MMT per year.
- Primary use is for oil refining and ammonia production.

Source: Pivovar, Rustagi, and Satyapal, “Hydrogen at Scale Key to a Clean, Economic, and Sustainable Energy System,” Electrochemical Society, 2018.

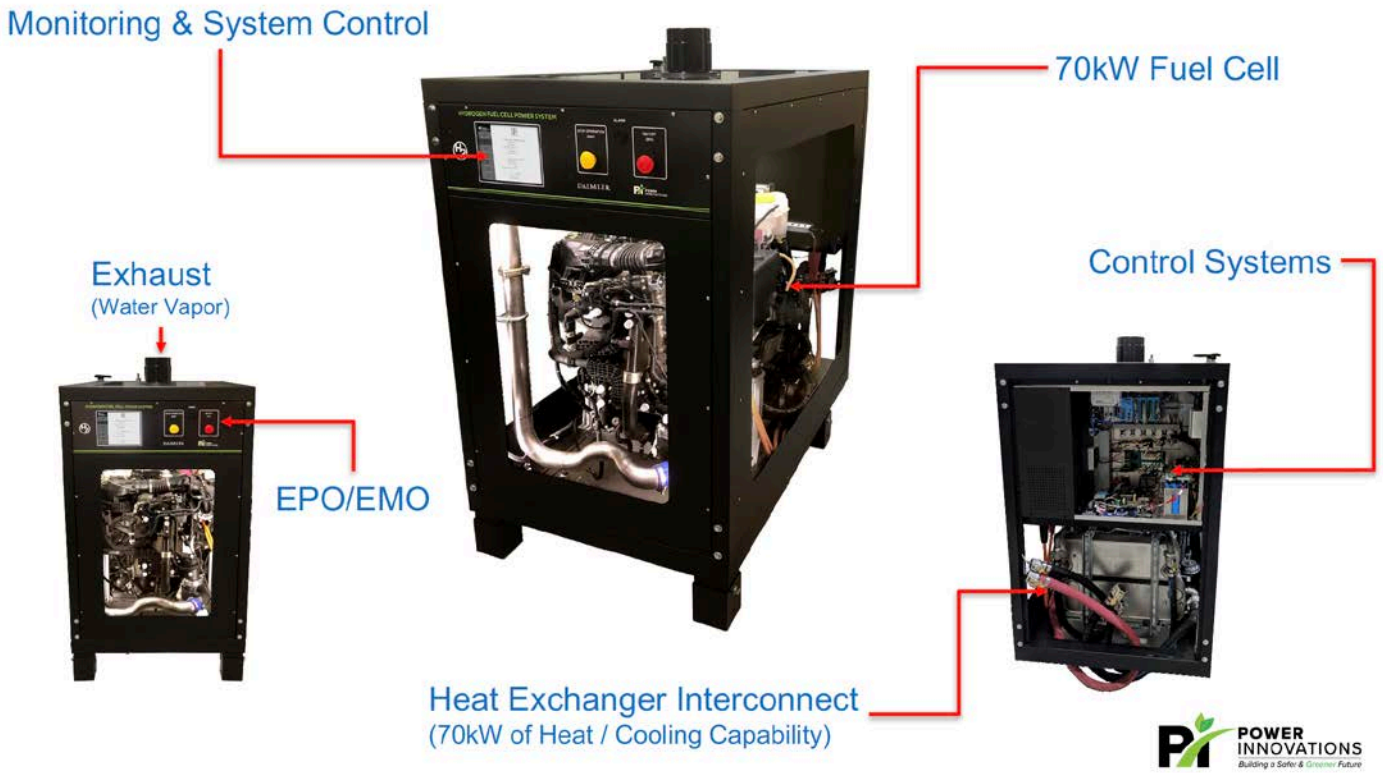
- Diesel generators are noisy, and emissions limit their usage.
- H_2 has advantages over batteries for many applications (seasonal energy storage, heavy-duty long-haul transportation, and industrial processes).
- In H_2-based systems, the energy carrier (H_2) is distinct from the energy conversion (fuel cell) offering advantages in refueling rate, footprint, and geographic distribution.

NREL's Unique Role

At NREL, we have PV, electrolyzers, H_2 storage, the data center, and H_2 technical expertise to:

- Establish codes and standards necessary to safely use H_2 in a data center.
- Support industry partners interested in hydrogen fuel cells for data center and other stationary applications (backup power, grid services, defense, disaster recovery, remote villages, etc.)
- Identify additional H_2 applications to accelerate fuel cells to scale faster
- Determine trade-offs for large scale 100% renewable hydrogen systems
  - Realistic capacity factors, storage, cost, etc.
  - Understand cross-over point for batteries vs. fuel cells as f(MW)
- Demonstrate H_2 in use in highly visible HPC at NREL to further promote the flexibility/resiliency of hydrogen to a broad audience of visitors.

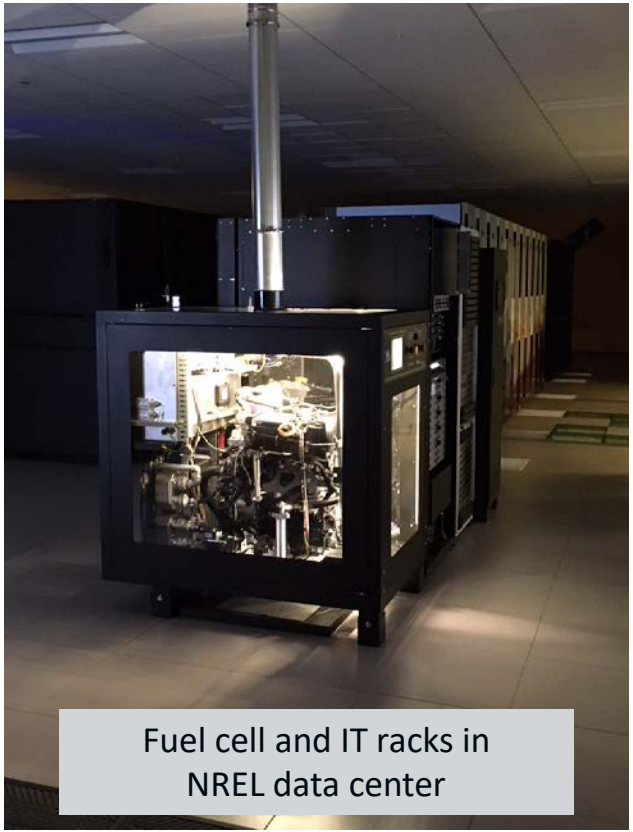
Fuel Cell System Components



H2 Fuel Cell Data Center Proof-of-Concept at NREL

Fuel Cell Demonstration

- Provided continuous H_2 to fuel cell.
- Fuel cell provided 380 VDC to two IT racks.
- Demonstrated load following for variety of typical workloads.
- Captured 65°C heat from H_2 fuel cell in “CHP” approach.
- Possible future H_2 data center:
  - Short runs of DC
  - N+1 fuel cell row-level redundancy
  - *Eliminate UPS and backup generators*.



Fuel cell and IT racks in NREL data center

Data Center Industry Interest in H2

Backup Power

- **Microsoft**, **Caterpillar**, and **Ballard** successfully demonstrated using H2 fuel cells to supply reliable and sustainable backup power to a Cheyenne, WY data center for 48 hours.
- Microsoft looking to build data center consortium supporting H2 fuel cell backup solutions.

Primary Power

- Data center startup **ECL** plans first 1GW AI data center on a 600-acre site east of Houston, Texas, powered by hydrogen.
- Initially using H2 from steam methane reformed natural gas.
- Transition to low carbon H2 pending technology advances and pricing.
- **Bloom Energy** proprietary solid oxide technology converts natural gas, biogas, or hydrogen to electricity …

H2 Data Centers - Final Thoughts

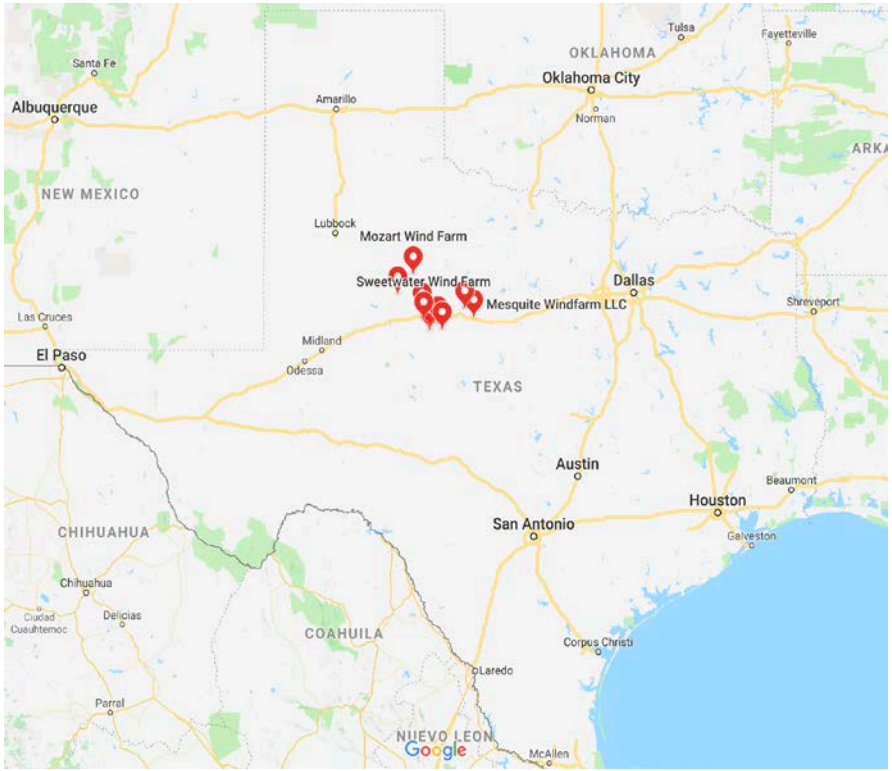
- Less concerned about the “color” of the H2 than getting started with what ever flavor is available.
- Potential link to H2 Hubs as an off-taker.
- The Microsoft data center consortium supporting H2 fuel cell backup solutions is a great first step.
  - Could simplify/streamline data center permitting process.
  - Could provide grid services and contribute to data centers as good neighbors on the grid, avoiding NIMBY.
- H2 for data center primary power
  - Will be limited by access to and availability of H2 pipelines.
  - Pipelines eliminate the need for on site storage
  - Lots of advantages
    - Reliability- modular row-oriented design and power redundancy
    - Simplified data center design and power distribution
    - Eliminates need for separate backup power and UPS

This work was authored by NREL for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from Getty-181838438

Hydrogen Pipeline

- Three of the world's 10 largest wind farms are situated in central Texas*.
- This is about 725 km from a 2,250 km long hydrogen pipeline along the U.S. Gulf of Mexico coastline.



Source: https://www.worldatlas.com/articles/the-10-largest-wind-farms.html