MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

THERMAL-MECHANICAL-CHEMICAL ENERGY STORAGE WORKSHOP

Updates on Hydrogen as a Means for Long Duration Energy Storage

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Arlington, VA

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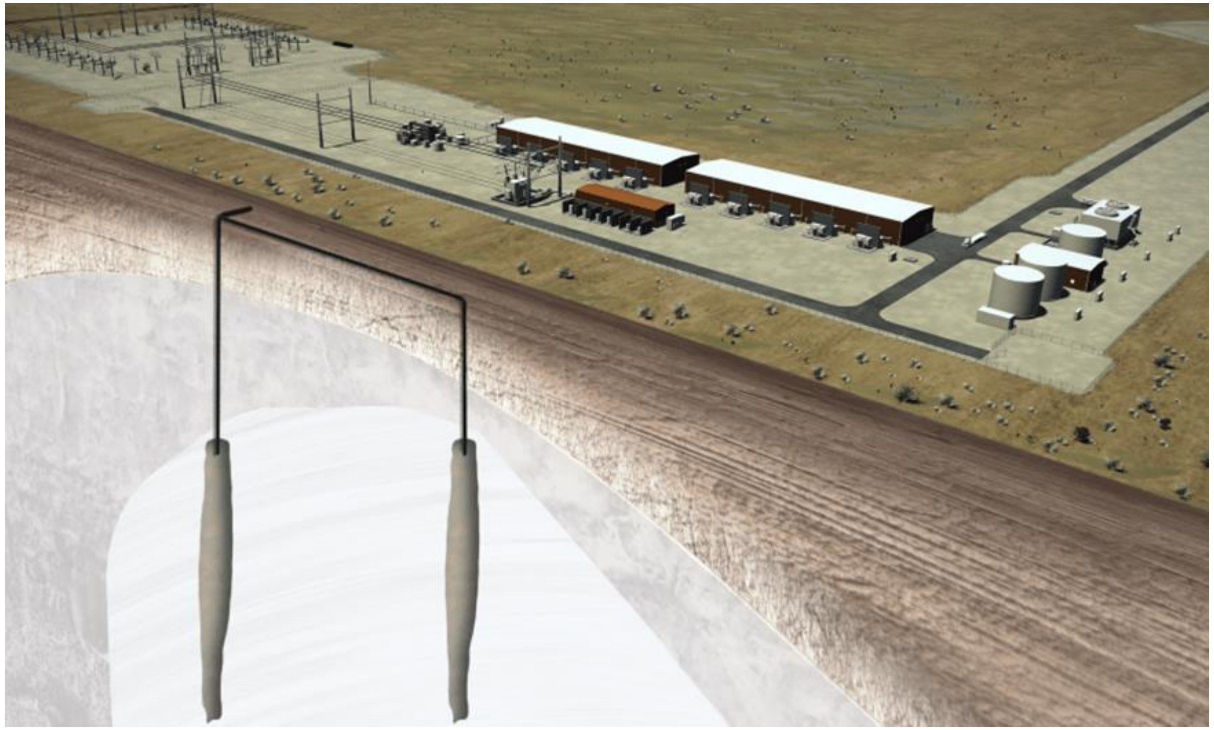
THERMAL-MECHANICAL-CHEMICAL ENERGY STORAGE WORKSHOP



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- Hydaptive
- Electrolyzer Validation
- Hydrogen Storage
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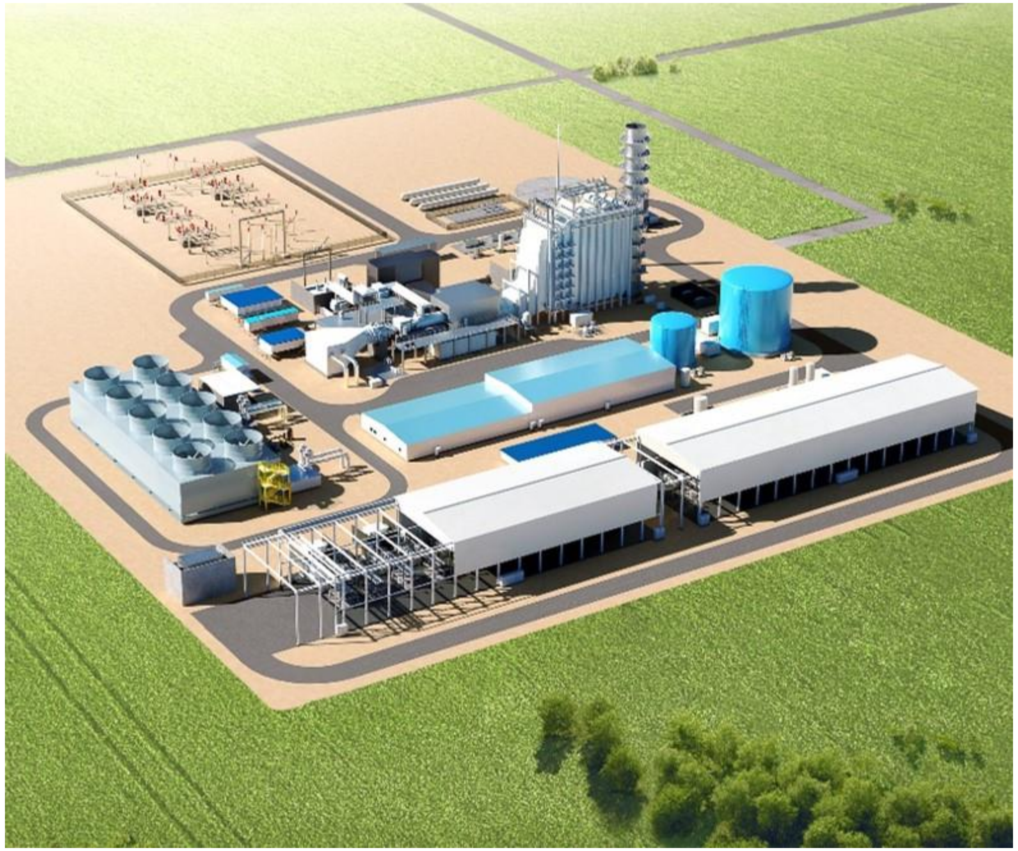
What is Hydaptive? –

Hydaptive is the trade marked name for Mitsubishi Power Americas, Hydrogen product line.

It is comprised of:

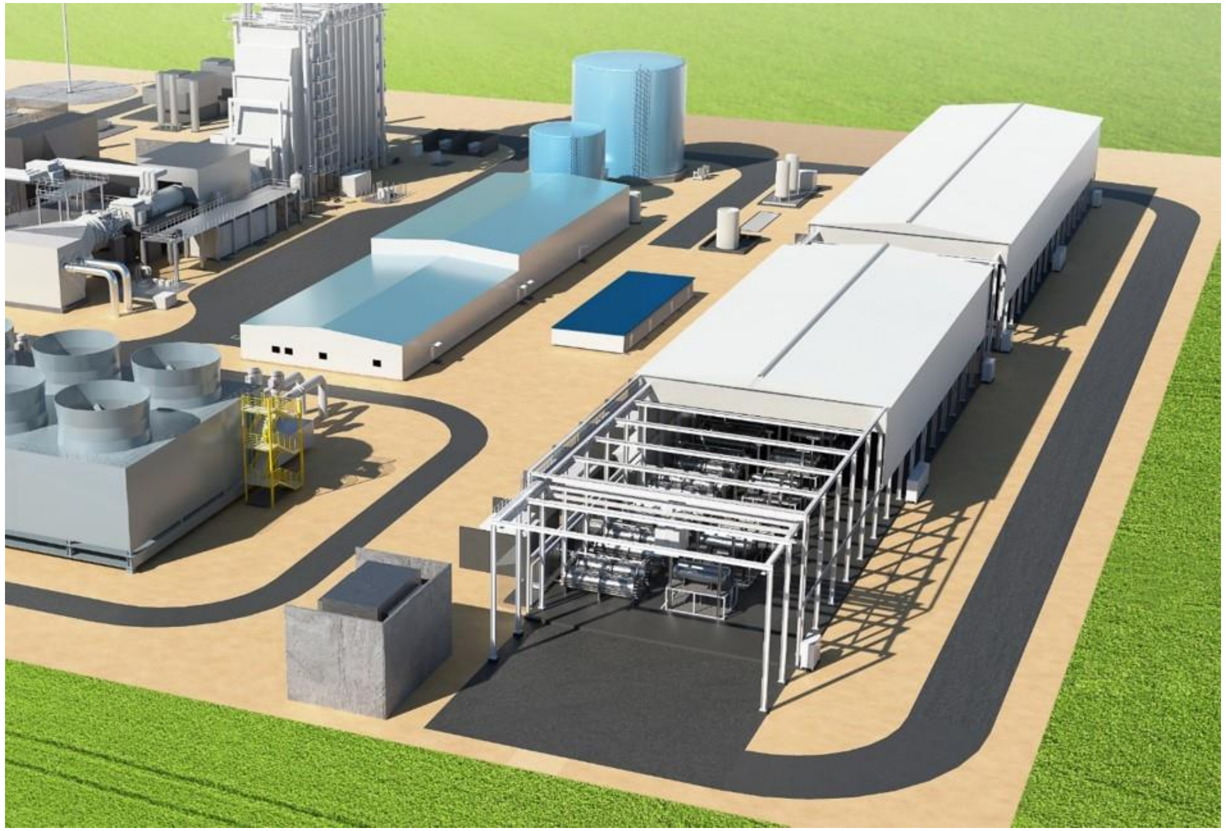
- **Hydaptive™ Hydrogen Production** A stand alone Hydrogen generation facility, (can be used as demand side management flex resource).
- **Hydaptive™ Integrated Package** (Hydaptive™ Package)– integrated with gas turbines, combined cycle, electrolyzers, and Hydrogen storage along with optional reactive power services and battery energy storage.
- **Hydaptive™ Storage** – Hydrogen storage and battery energy storage systems which can be large scale caverns or smaller on site tank storage systems.

Hydaptive™ Integrated Package (Hydaptive™ Package)



- The Hydaptive^{TM} Integrated Package is a full digital and physical integration between a hydrogen-capable generation asset integrated with-an electrolytic-based hydrogen production facility.
- During periods of excess renewable power, the power is converted to Hydrogen for long duration storage.
- During periods of high demand the stored Hydrogen is converted back to power.
- The Hydaptive^{TM} package is available for new gas turbine power plants or as a retrofit to existing plants to improve flexibility and extend asset life.

Hydaptive™ Hydrogen Production



- Hydaptive™ Hydrogen production is a standalone hydrogen facility which is not integrated with a power generation facility. This may be due to location, use case application, or other considerations.
- Hydaptive™ Hydrogen Production benefits from the Hydaptive Integrated package.
- As a standalone facility, the primary function is to produce carbon-free hydrogen to capture excess renewable power for various uses in power, mobility, heavy industrials, or other sectors seeking to utilize optimized hydrogen solutions.

Electrolyzer Validation

Hydrogen Production Technologies

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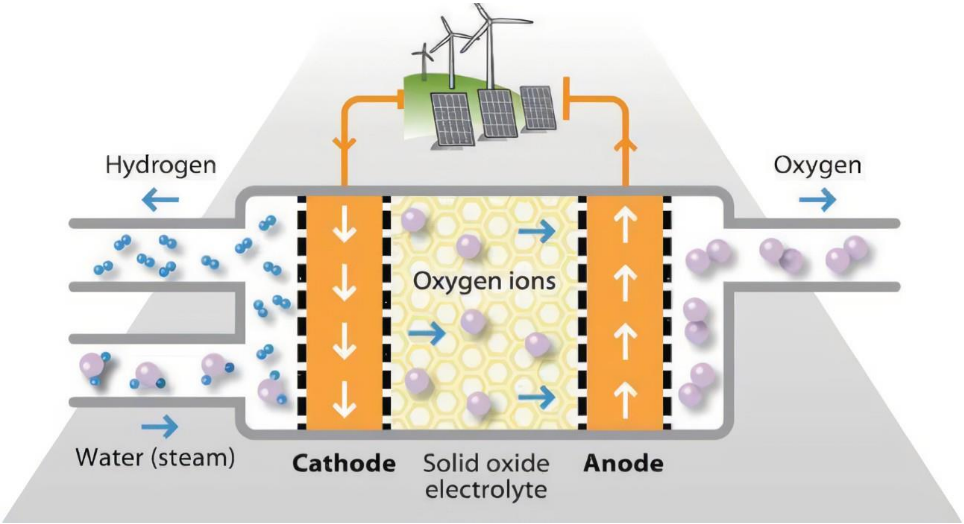
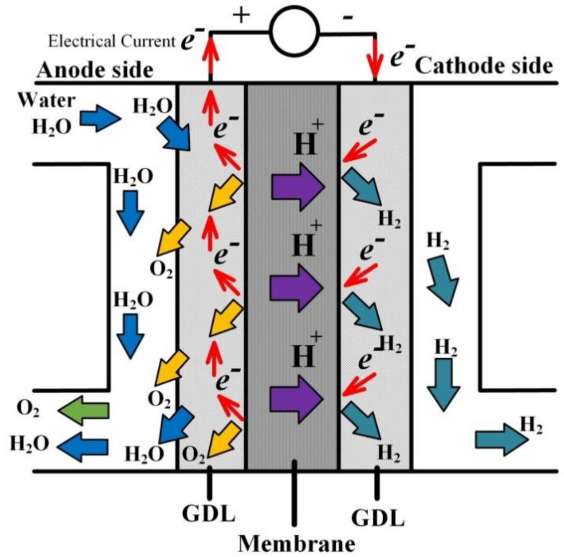
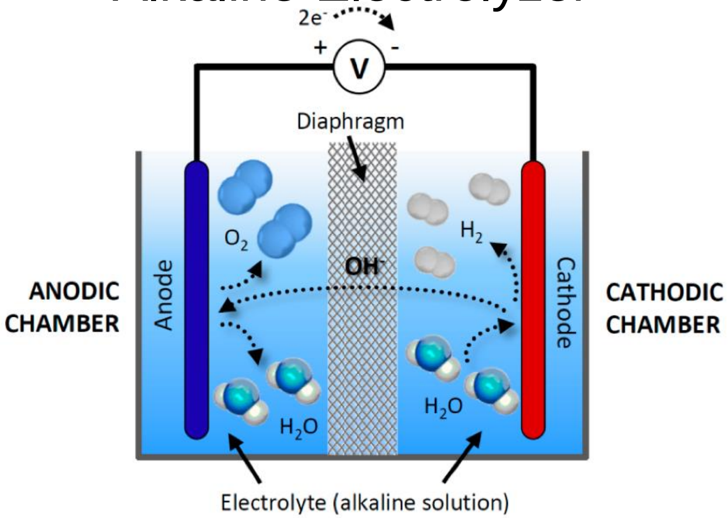
Solid Oxide Electrolyzer Cell



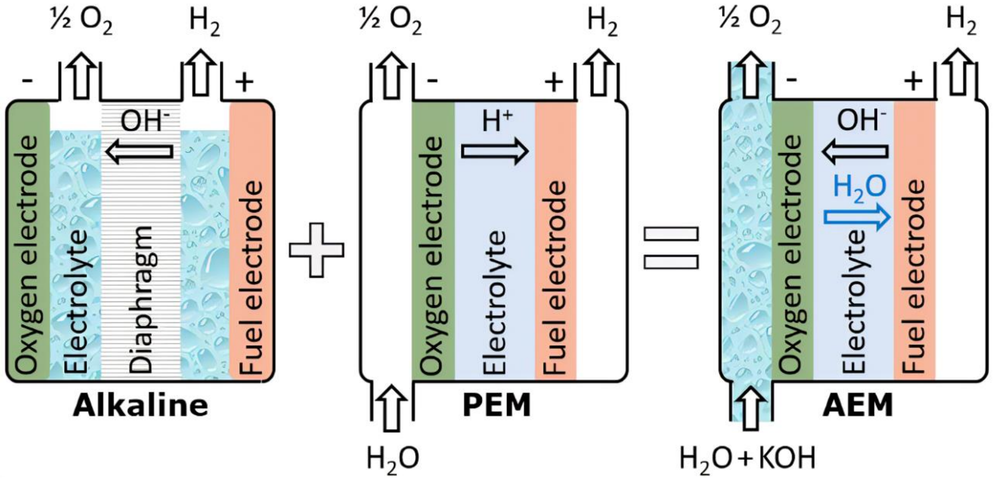
Proton Exchange Electrolyzer



Alkaline Electrolyzer

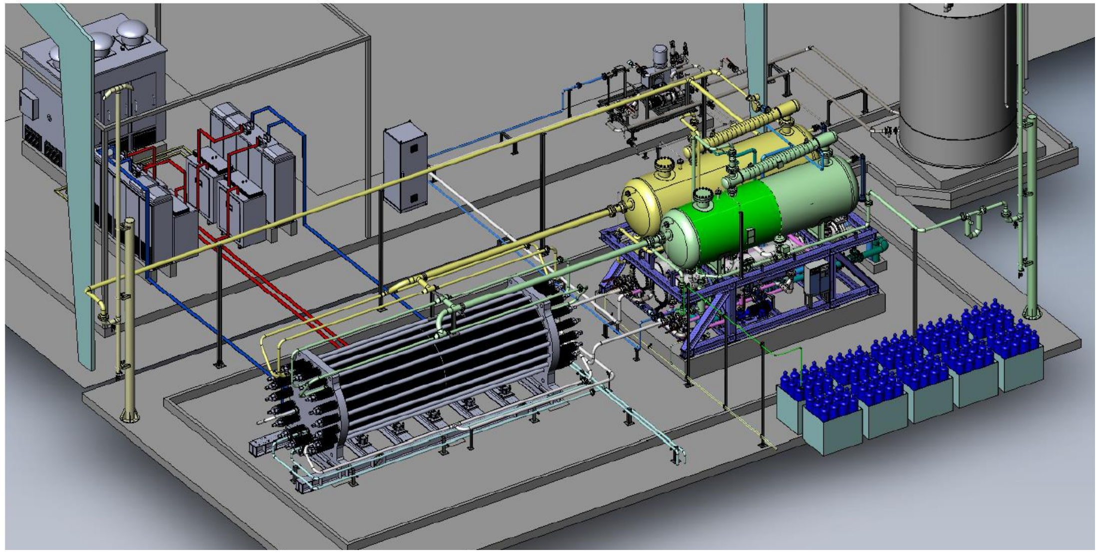


Anion Exchange Electrolyzer



Product Validation

- Full scale alkaline electrolyzer test and validation.
- Electrolyzer and gas separator will validate operability and performance.
- Test site is in Porsgrunn, Norway at the Herøya Industrial Park, AS.
- Electrolyzer stack and gas separator have completed ASME certification, factory tests and will arrive Norway early August.
- Installation is in progress and tests will start in September.



Updates on Hydrogen for Long Duration Energy Storage

Hydrogen Storage

Comparison of Capacities of Energy Storage Technologies

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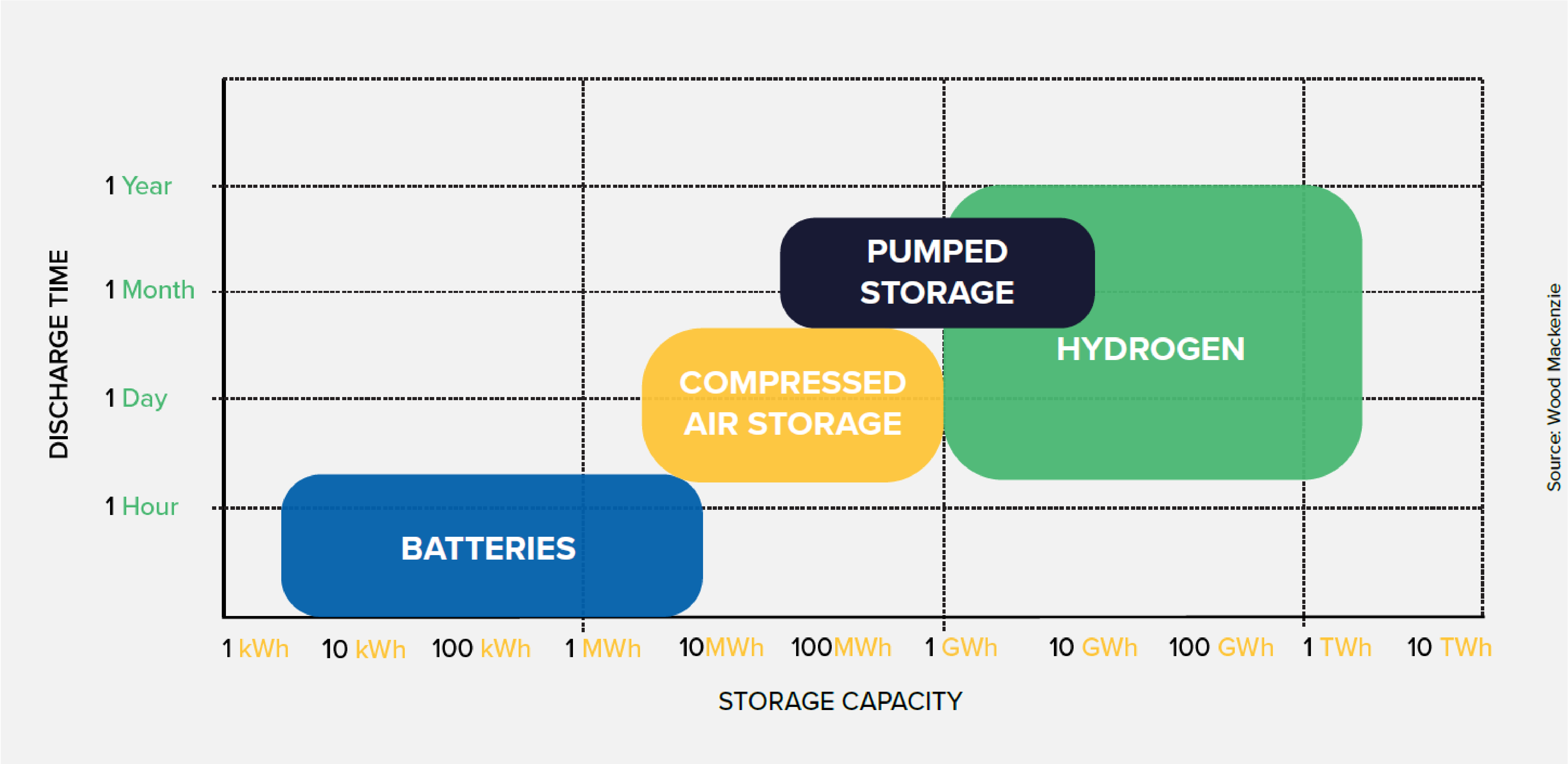
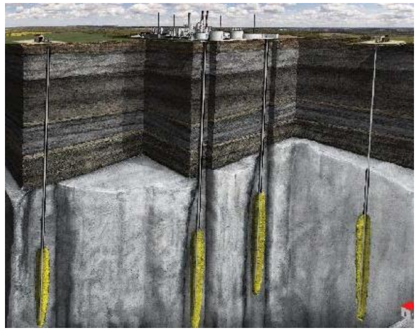


Reference: Green Hydrogen Coalition Handbook

General Storage Methodologies Evaluated

Geological Storage



- ➢ Salt Caverns
- ➢ Hard Rock Caverns

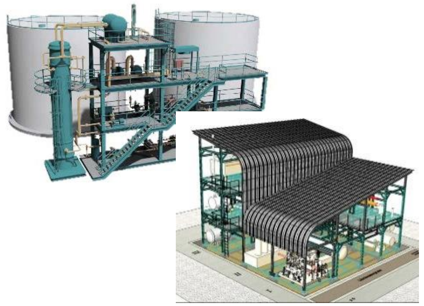
Pipeline Storage

- ➢ Steel Pipeline-24”
- ➢ Horizontal Pipeline Segments
- ➢ Vertical Wells
- ➢ Composite Pipeline (future evaluation)

Pressure Vessel Storage

- ➢ Steel Concrete Composite Vessels
- ➢ Vertical Underground Silos
- ➢ Modular Hydril Tubes
- ➢ Large Diam Horizontal Vessels

Chemical Storage



- ➢ Liquid Organic Hydrogen Carrier (LOHC)

Increasing Cost of H2 Storage on a $/kg Basis

General Storage Methodologies Evaluated

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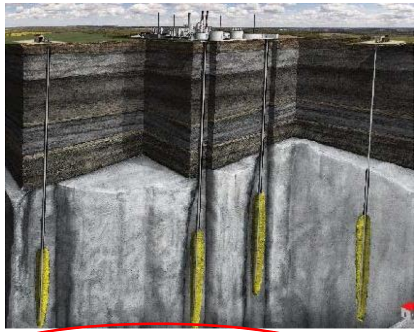
Geological Storage



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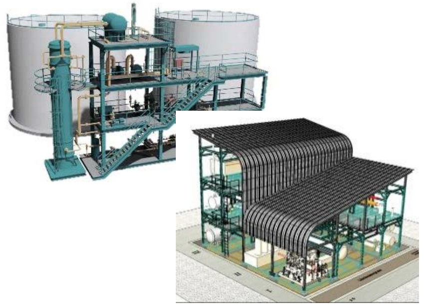
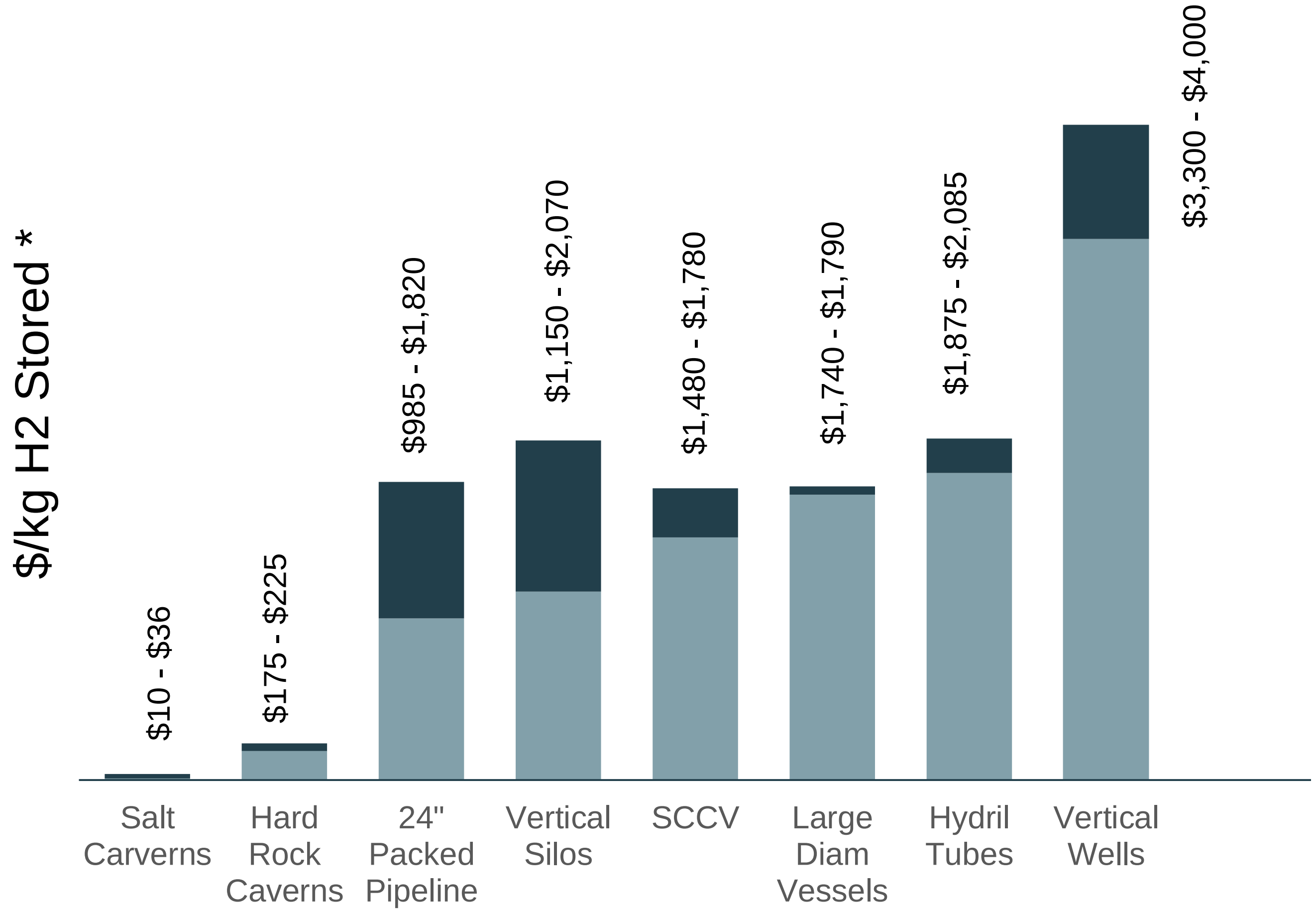


- Liquid Organic Hydrogen Carrier (LOHC)

Increasing Cost of H2 Storage on a $/kg Basis

Storage Economics Comparison



* Excludes Compression Costs

Observations

- Caverns most economical solution
- Pipeline extremely site/distance sensitive
- UG Vertical silos ideal for 20 MT storage volume and multiples thereof
- Steel Concrete vessels may be most economical above-ground storage option
- Vertical wells not a viable solution
- LOHC cost off the chart

Broad Range of H2 Storage Costs

Salt Caverns

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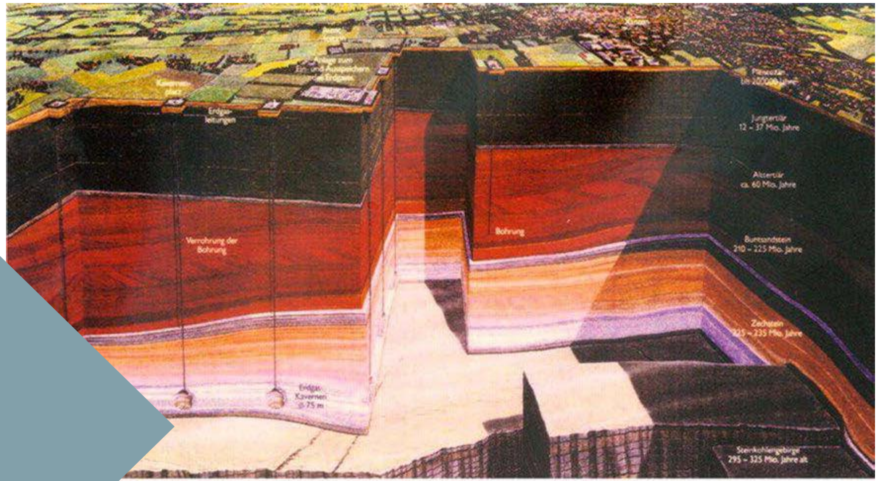
Cost	Application Range	Advantages & Disadvantages
❑ $10-$36/kg H2	❑ 110-550+ MW Facility ❑ Up to 6,600 tons H2 storage per cavern	+ Most cost-effective means of storing large H2 volumes + Proven technology - Geographically limited



Access to injection wells further reduce cost compared to brine ponds

Appalachia salt caverns represent high end of cost range. Gulf coast salt caverns in middle range.

Ideal storage methodology for regional H2 Hubs

Packed Steel Pipeline

Cost	Application Range	Advantages & Disadvantages
❑ $985-$1,820/kg H2 ❑ Based on estimates for ¾ mile to 11 mile pipeline runs	❑ 22+ MW Facility ❑ 4.07 metric Tons H2 storage per mile of 24" pipeline	+ Universal storage solution for short and long distances + Shared storage solution for multiple connected sites - Lengthy schedule driven by permitting requirements

Packed H2 24" pipeline concept at 3,000 psig has not been practiced on an industrial scale. Critical to develop a comprehensive pipeline & weld spec meeting all code and industrial standard requirements.

Pipeline solution critical to Overall H2 Strategy

Tube Vessels

Hydril Tube Vessels

Cost	Application Range	Advantages & Disadvantages
❑ $1,875-$2,085/kg H2	❑ 22 MW Facility ❑ ~220 tubes required for 4.8 tons H2 storage	+ Proven technology + modular/leasable - Maintenance challenge- significant number of valves/PSVs

Large Diameter Vessels

Cost	Application Range	Advantages & Disadvantages
❑ $1,875-$2,085/kg H2	❑ 22 MW Facility ❑ (7) 6'x100' vessels required for 4.8 tons H2 storage	+ Proven technology + High transportation costs depending upon proximity to fabrication facility

Only feasible for demonstration facility

Hydrogen Storage – In Summary

[1] "Discharge" capability based on hydrogen GTCC
[2] Assumes ~3,000 psig to 1,000 psig working gas
[3] Assumes 500+MW H2-GTCC @ 100% H2 operation
[4] Assumes 500+MW H2-GTCC @ 30% H2 operation

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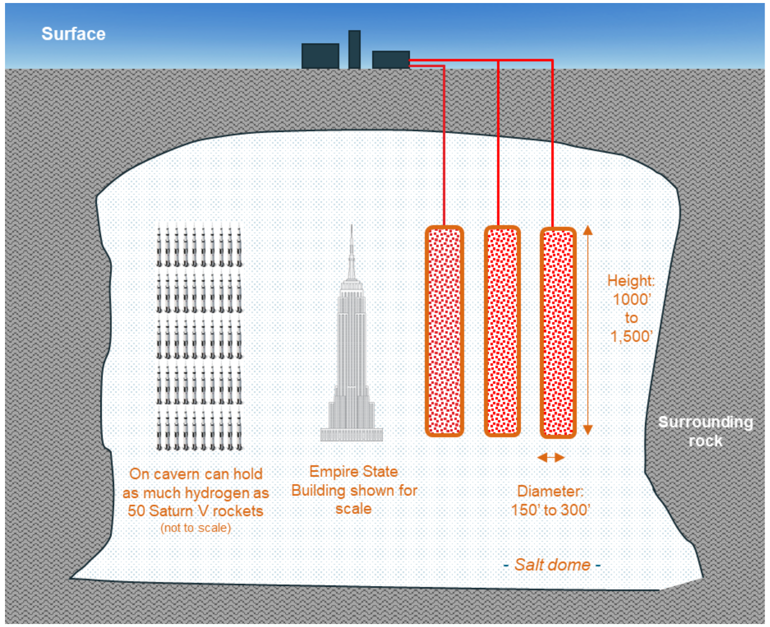
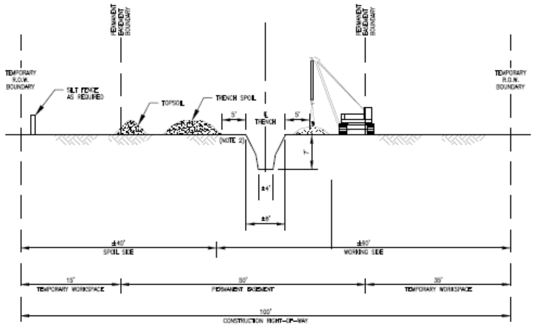
Salt Cavern



Per 1 Cavern Stats

- >100,000 MWh[1]
- 5,500 tonnes[2] H_2
- 10 days[3] to 1 month[4]

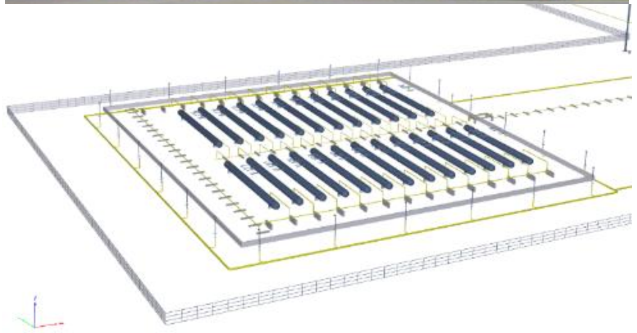
Hydrogen Pipeline Pack



Per 10-mile Stats

- >1,000 MWh[1]
- 45 tonnes[2] H_2
- 2 hours[3] to 16 hours[4]

Pressurized Vessels

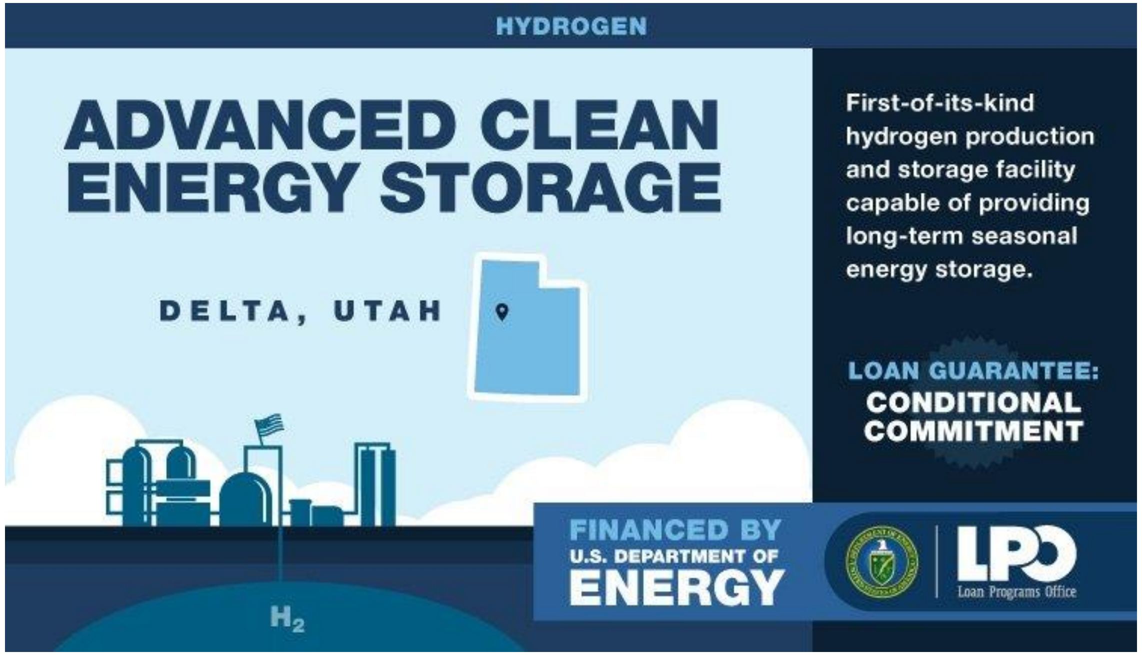


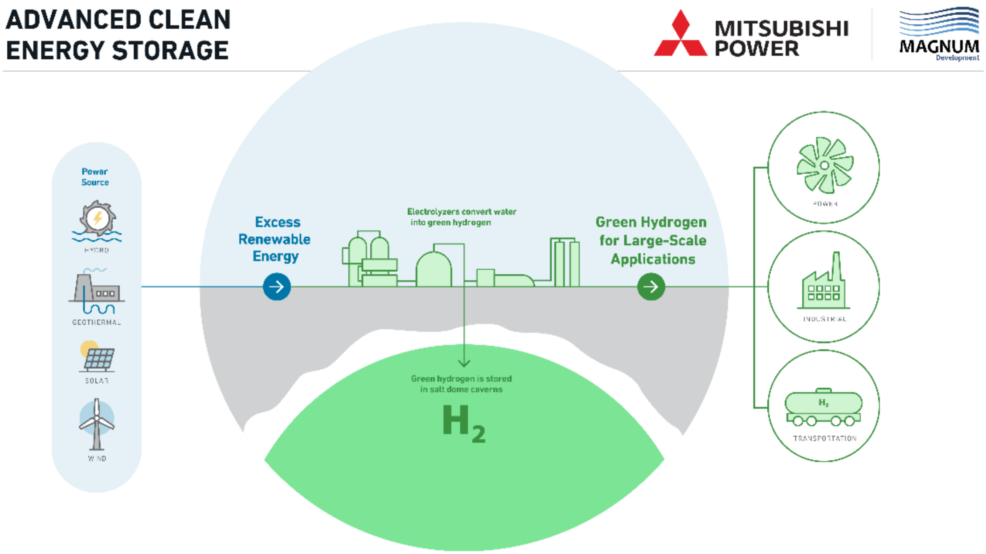
Per 10-Bullet Stats

- >200 MWh[1]
- 10 tonnes[2] H_2
- 0.5 hours[3] to 4 hours[4]

Project Updates

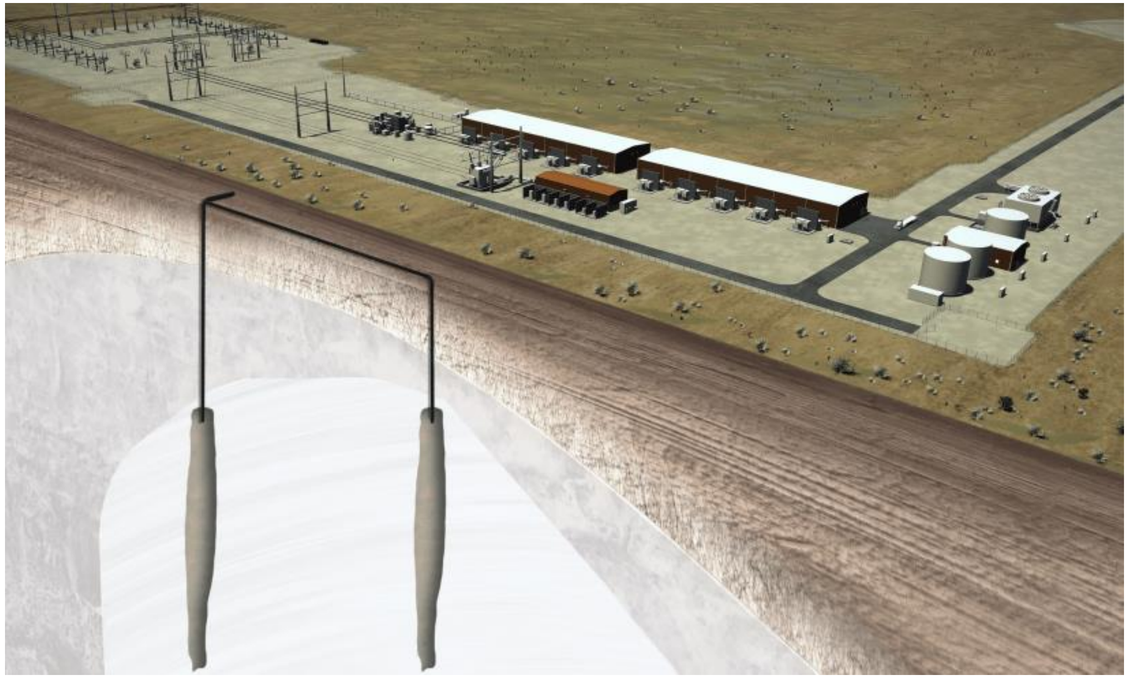
Advanced Clean Energy Storage Update





In June 2022, the Department of Energy issued a $504.4 million loan guarantee to finance Advanced Clean Energy Storage, a clean hydrogen and energy storage facility capable of providing long-term, seasonal energy storage. The facility in Delta, Utah, will combine 220 megawatts of alkaline electrolysis with two massive 4.5 million barrel salt caverns to store clean hydrogen.

Advanced Clean Energy Storage Update



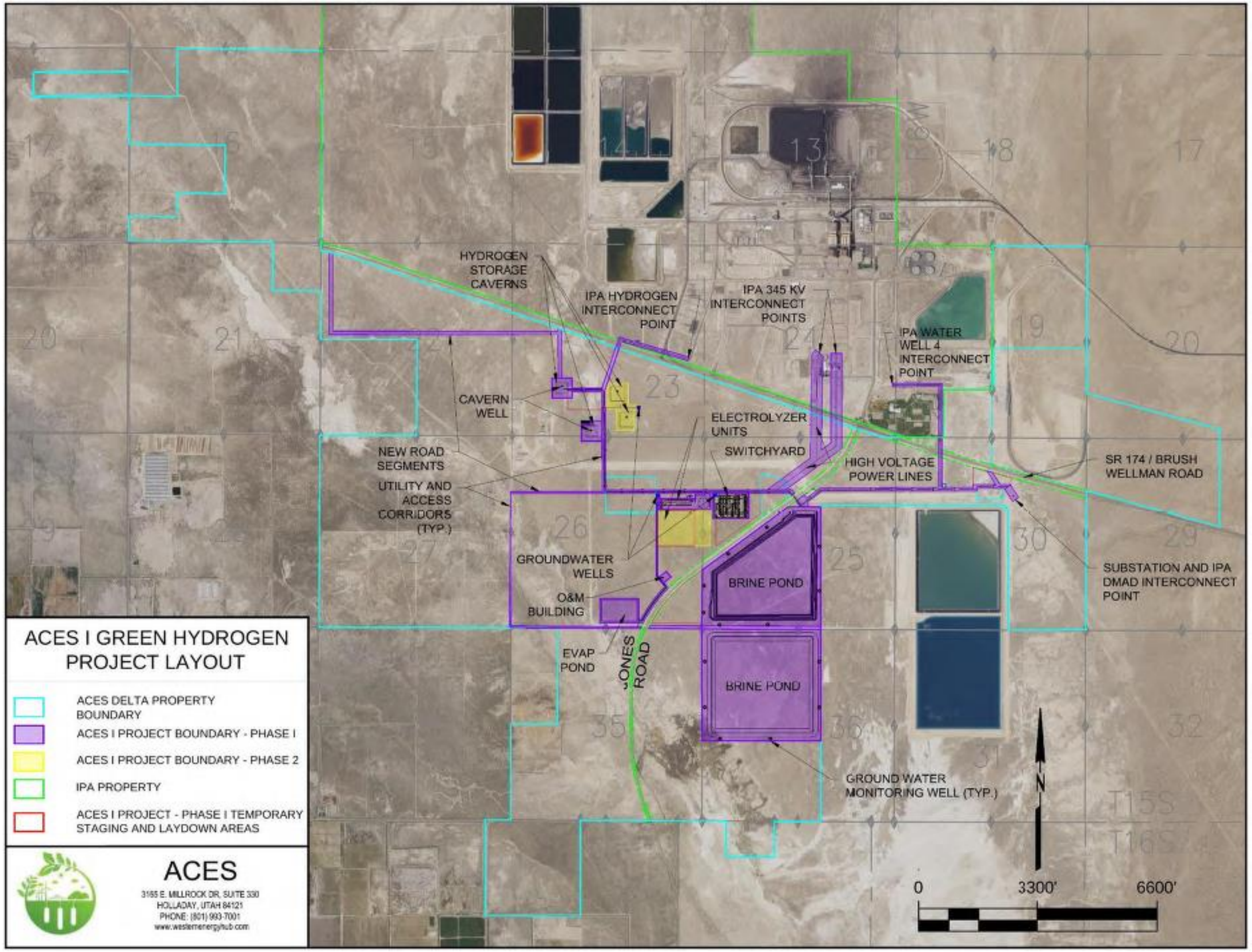
TECHNOLOGY INNOVATION

Advanced Clean Energy Storage uses a 220-megawatt bank of electrolyzers and intermittent renewable energy to produce hydrogen, store it in salt caverns, and deliver that hydrogen for future dispatchable generation. The scale of deployed electrolyzers as well as the use of salt caverns to store hydrogen are both significant innovations.

CLIMATE BENEFIT

Advanced Clean Energy Storage may contribute to grid stabilization and reduction of curtailment of renewable energy by using hydrogen to provide long-term storage. The stored hydrogen is expected to be used as fuel for a hybrid 840 MW combined cycle gas turbine (CCGT) power plant that will be built to replace a retiring 1,800 MW coal-fired power plant. The project is estimated to help prevent 126,517 metric tons of carbon dioxide emissions annually based on the difference in the emission profiles of the IPP turbines between 100 percent natural gas fuel to a 70 percent natural gas and 30 percent hydrogen fuel blend.

Advanced Clean Energy Storage Update



Energy Storage Summary

ENERGY STORAGE FUNDAMENTALS

1. Coal-fired and oil-fired power generation are now virtually eliminated in some parts of the US
2. To continue to decarbonize power, we need to reduce the use of natural gas. This will require energy storage.
3. Li-ion batteries will be used to store energy for short durations. Green hydrogen for longer durations.
4. Green hydrogen will also eventually be used as a fuel to decarbonize “hard to electrify” parts of our economy.
5. Green hydrogen will eliminate emissions of CO_2, CO, VOC, etc. NOx emissions will be extremely low.

GREEN HYDROGEN KEY CONSIDERATIONS

Green Hydrogen enables cost effective achievement of climate goals as an energy storage resource (power industry) and as a decarbonized fuel (“hard to electrify” verticals)

Green Hydrogen value chain – including electrolysis, storage, transport, and use in power plants – is commercially mature

Sector Coupling of green hydrogen infrastructure enables even more cost effective achievement of economy-wide decarbonization goals

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