SAND2022-4375C

Sandia National Laboratories

efficiency exchange

Beyond Batteries: Diverse "Potential" Energy Storage Solutions for Long-Duration Energy Storage

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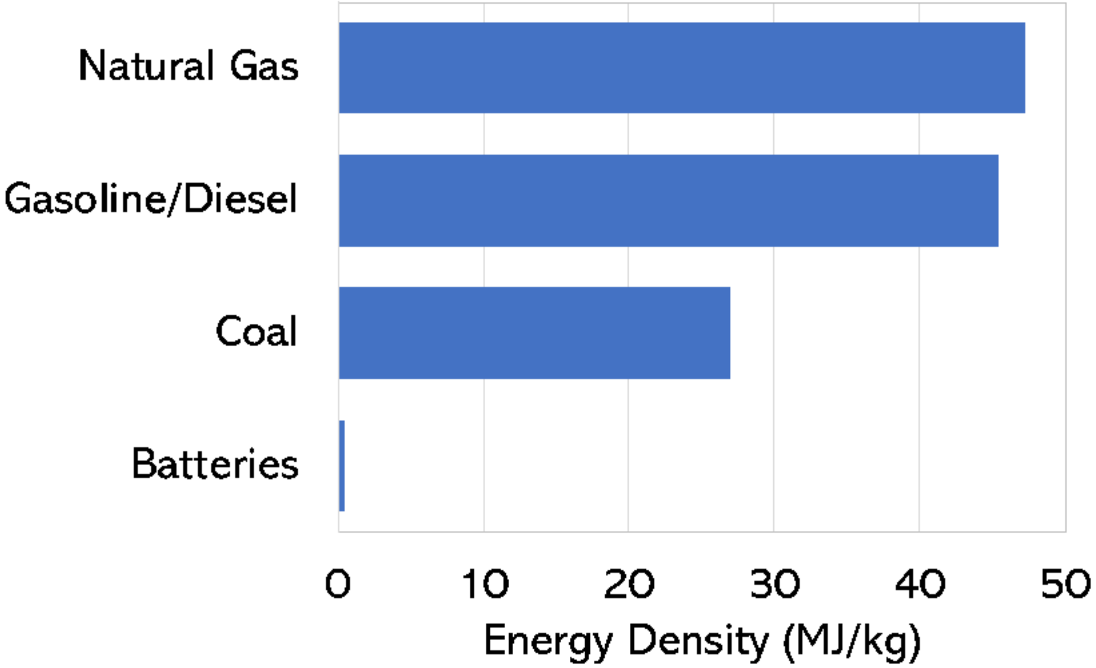
The Challenge of Large Scale Energy Storage

*How can we replace high energy density fossil fuels, not just for generation, but for **storage**?*

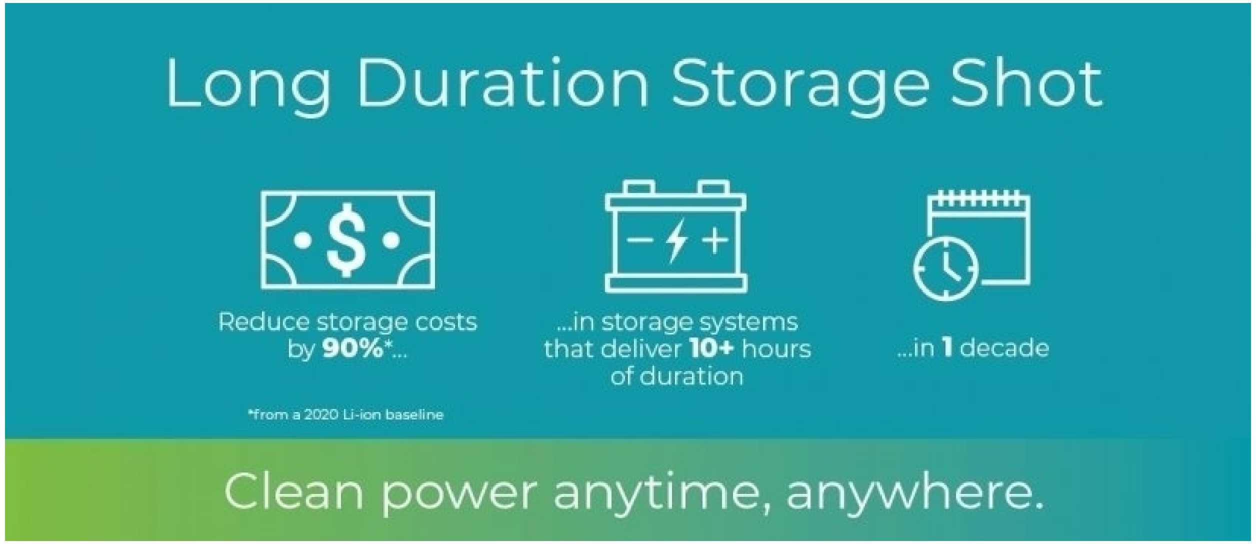
greengroundswell.com

Coal-based energy storage



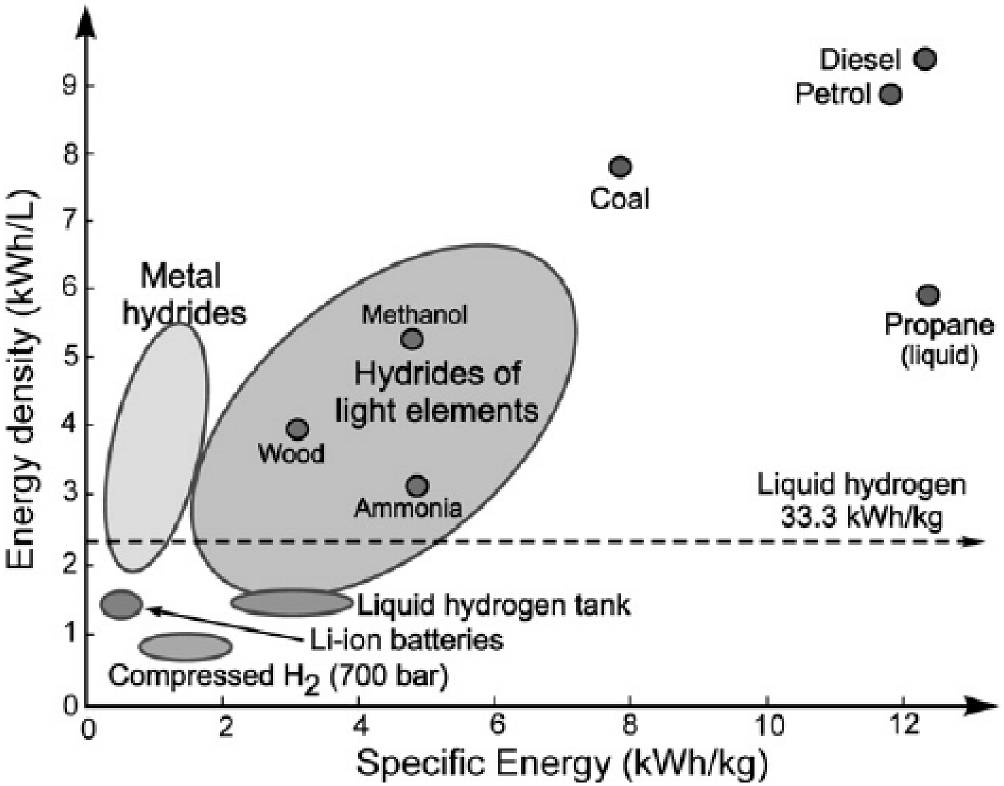
ENERGY earthshots U.S. DEPARTMENT OF ENERGY

Storage™



https://www.energy.gov/eere/long-duration-storage-shot

What Are Our Options?



Adapted from A. Sartbaeva, A, *et al*. "Hydrogen nexus in a sustainable energy future.", (2008) *Energy Environ. Sci.* **1**, 79-85.

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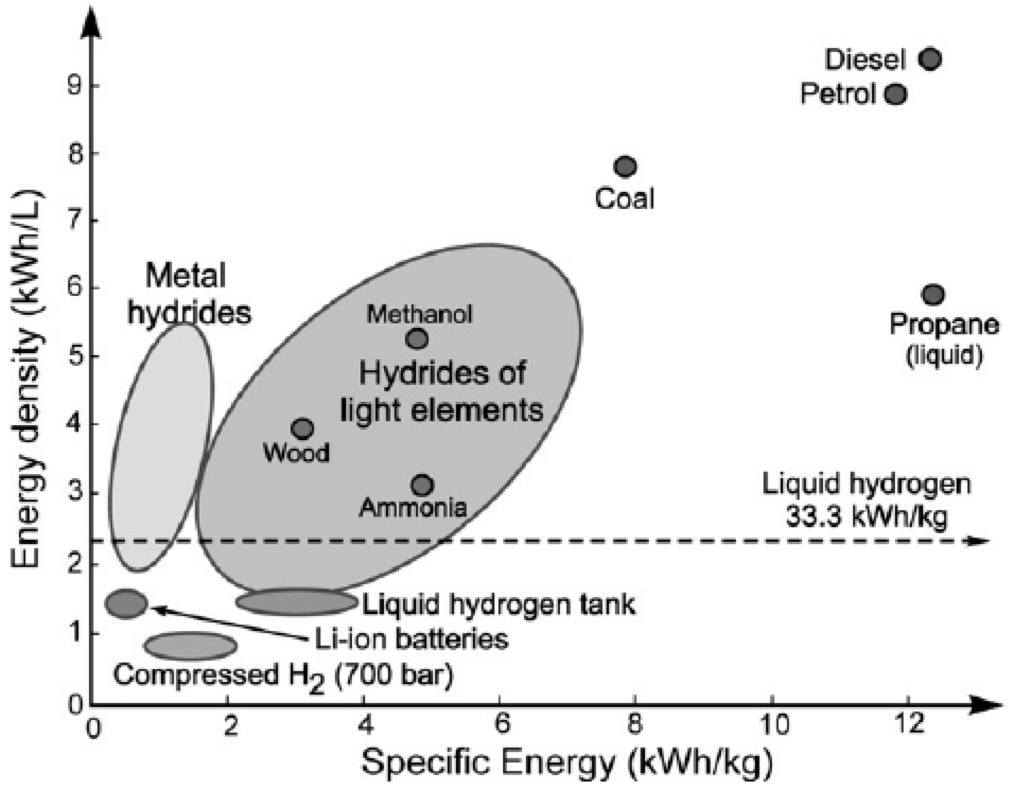

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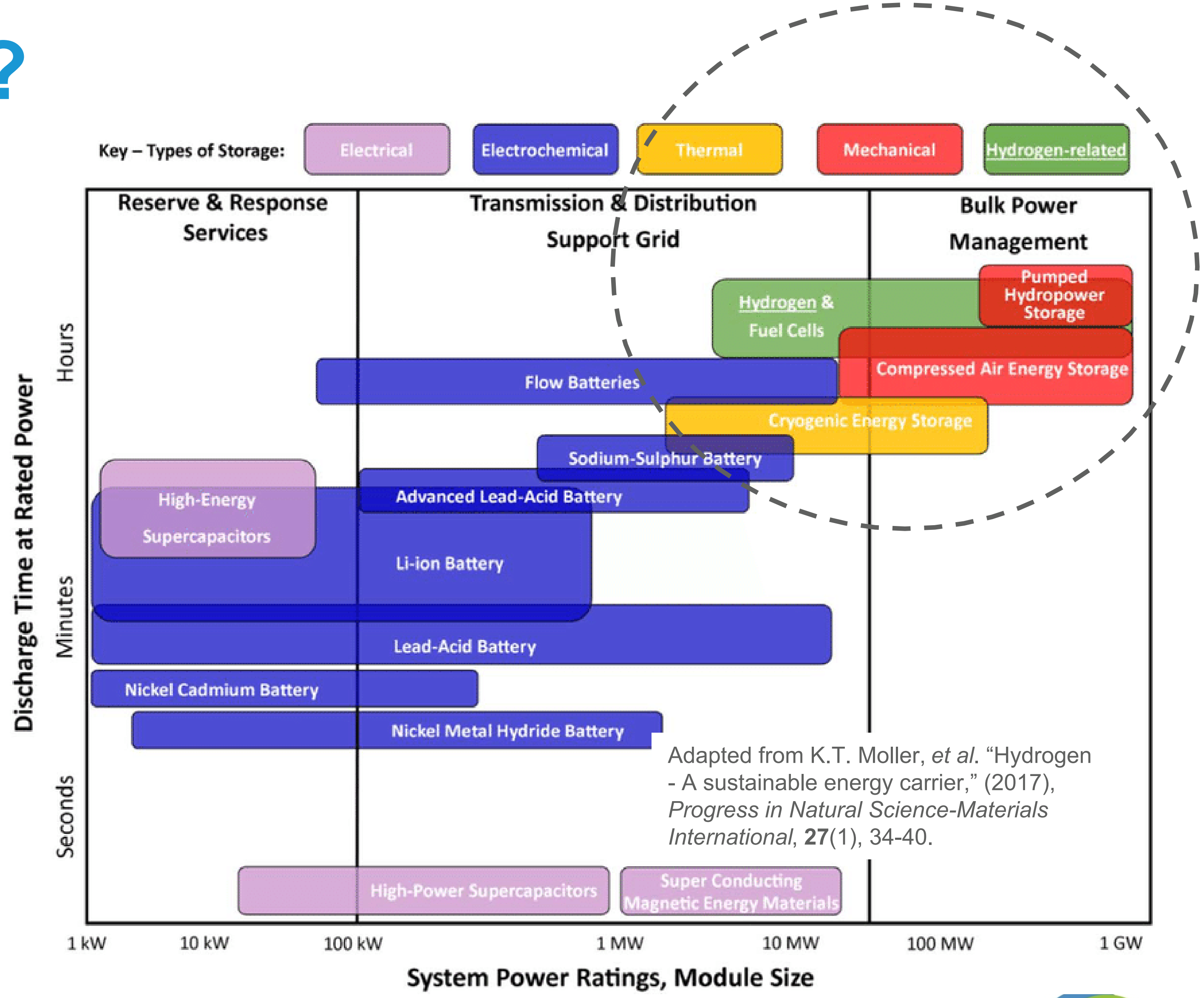
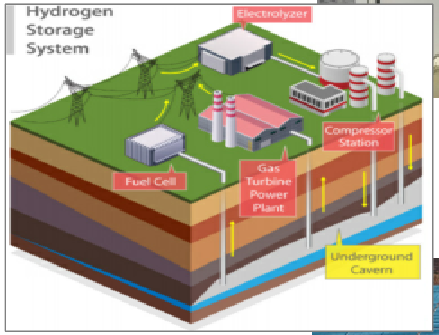
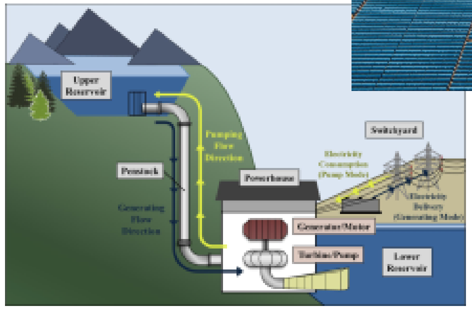


Adapted from K.T. Moller, *et al*. "Hydrogen - A sustainable energy carrier," (2017), *Progress in Natural Science-Materials International*, **27**(1), 34-40.

Technology Menu

- Electrochemical (Batteries) Storage
- Hydrogen and Chemical Storage
- Thermal Storage
- Gravity-Based/Mechanical Storage





Technology Menu

- Electrochemical (Batteries) Storage
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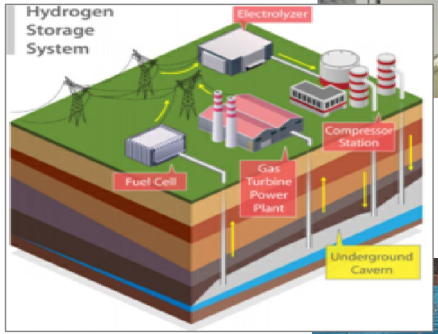
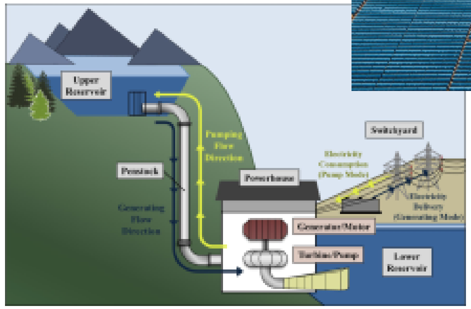
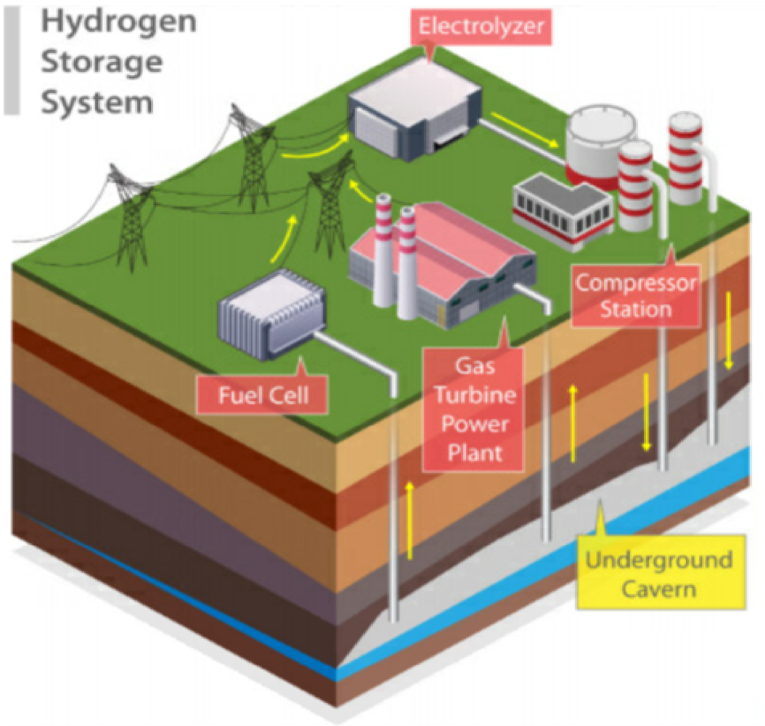
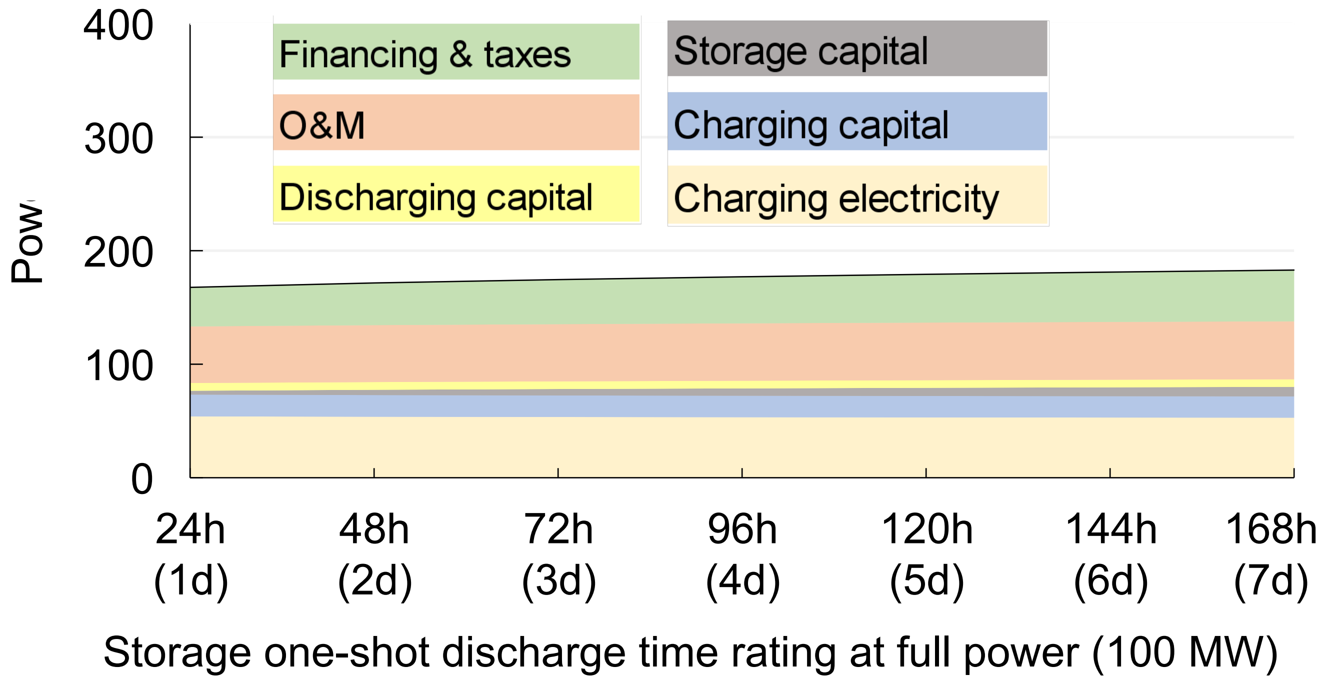




Hydrogen Storage



Hydrogen Energy Storage in Geologic Caverns



Hydrogen energy storage involves use of an electrolyzer, bulk storage (e.g. cavern or underground pipe), and fuel cell or turbine.

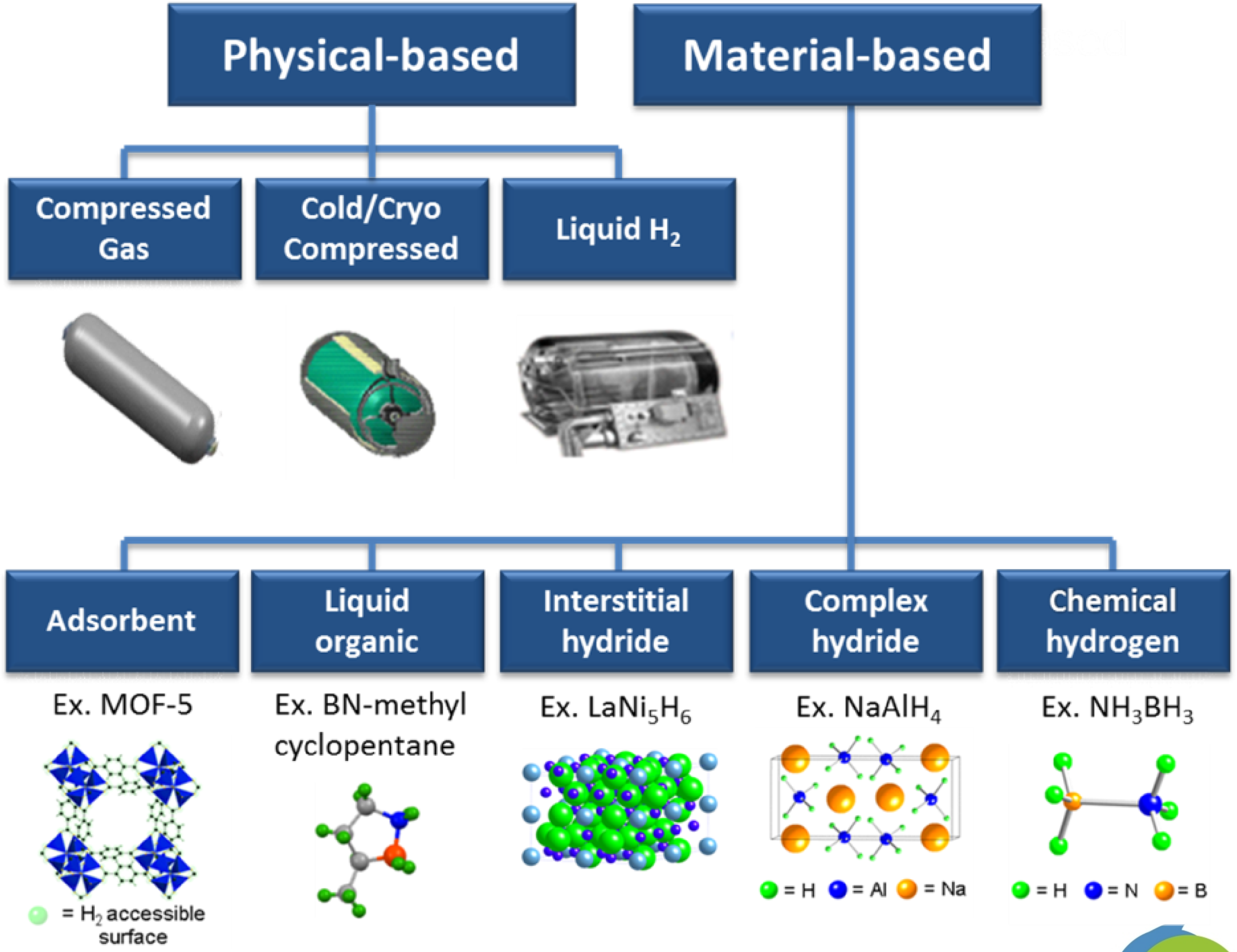
Hydrogen energy storage is competitive at long durations due to the low cost of each additional hour. Value proposition can be enhanced through RD&D that improves efficiency and reduces capital cost.

Source of Images: (Left) “The Four Phases of Storage Deployment: A Framework for the Expanding Role of Storage in the U.S. Power System.”. 2021. NREL. https://www.nrel.gov/docs/fy21osti/77480.pdf, and (right) Hunter, et. al., in press. 2021. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3720769

Slide Content from Neha Rustagi (HFTO)

How Is Hydrogen Stored?

Once generated from electrolysis (or another process), hydrogen can be stored in gaseous, liquid, or “bonded” forms.



Source: https://www.energy.gov/eere/fuelcells/hydrogen-storage#:~:text=On%20a%20volume%20basis%2C%20however,based%20on%20lower%20heating%20values.

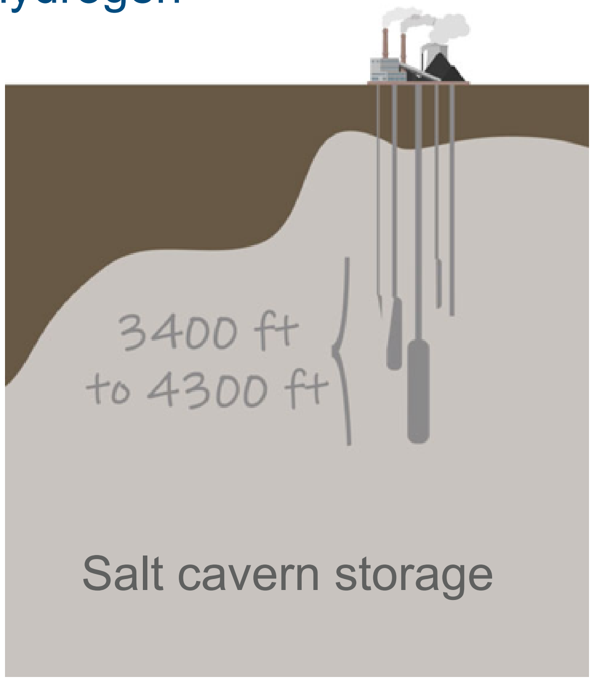
Large-Scale Hydrogen Storage

IPP-Renewed

- **Intermountain Power Project (IPP)** provides regional power, including to Southern California, through the Southern Transmission System

"Renewed" will 'update' IPP for increased transmission of renewables and base load generation via hydrogen

- Gas turbines (840 MW): 30% H_2+NG starting in 2025, 100% H_2 by 2045
- Salt caverns will provide long-term storage (up to 500M kg H_2)



Salt cavern storage

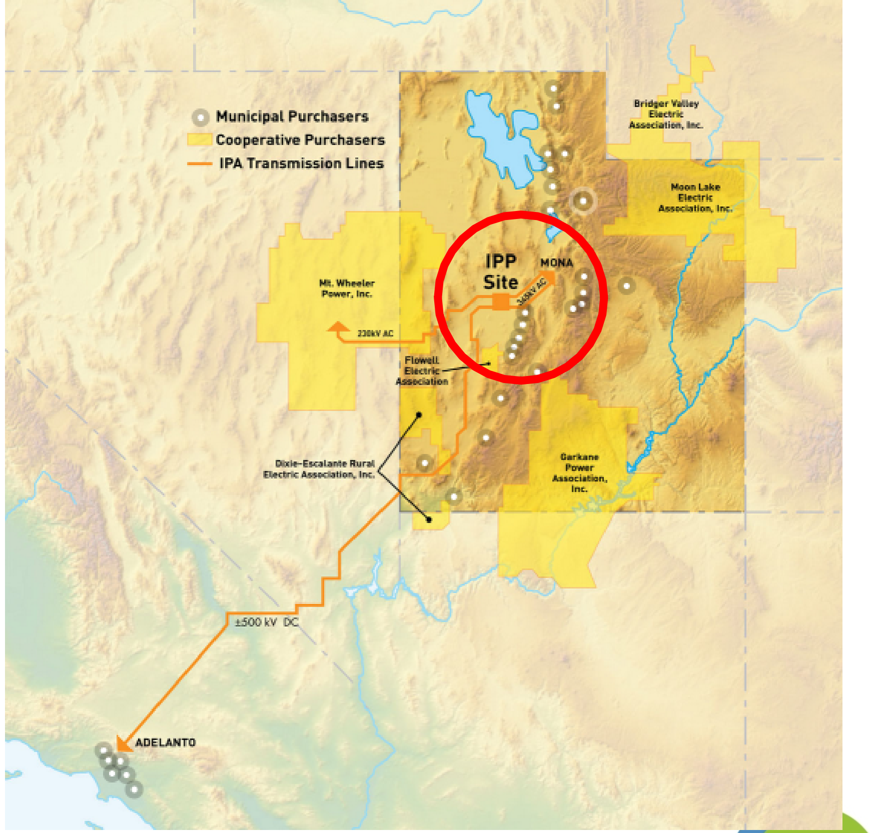
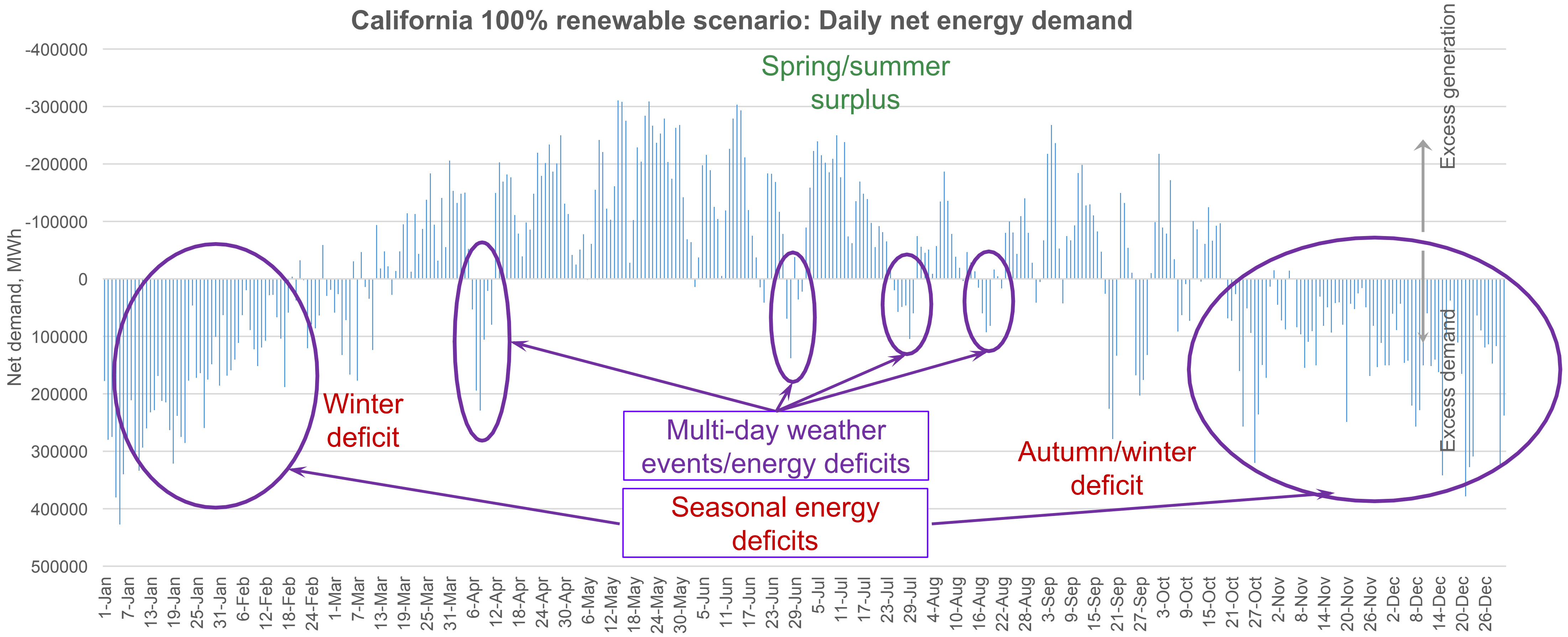


Image from: https://www.ipautah.com/ipp-renewed/

A Large-Scale Challenge for Storage…Today!



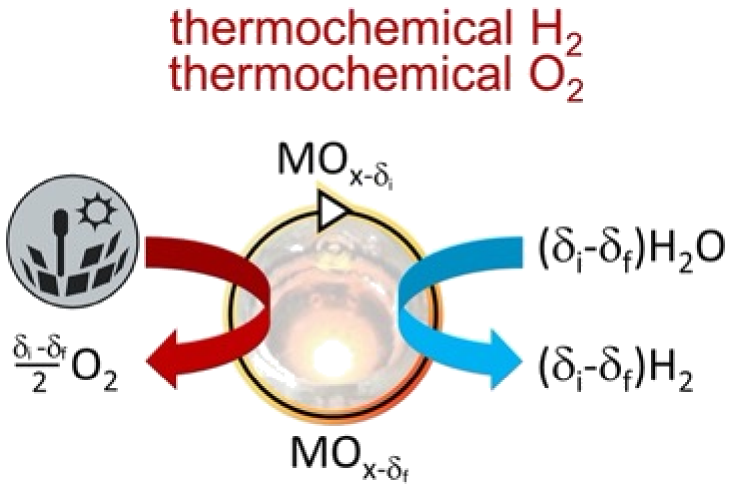
Source: CAISO and Strategen Analysis

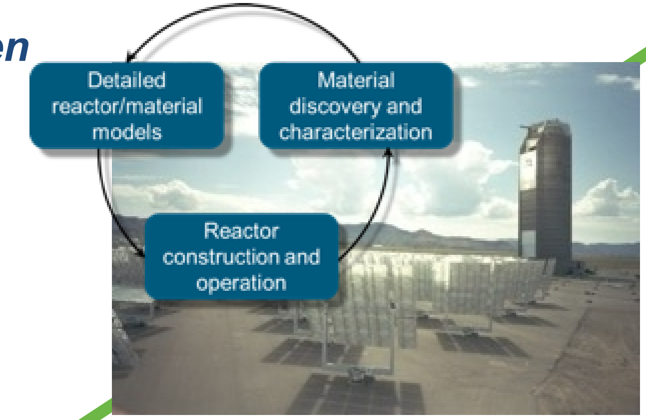
Solar Thermo-Chemical Hydrogen Production

Two-step thermo-chemical water-splitting cycle

MW scale concentrating solar power facilities provide energy for

1. Metal oxide ***thermal*** reduction
2. Oxidation with water ***producing hydrogen***





Hybridized thermochemical water-splitting cycle

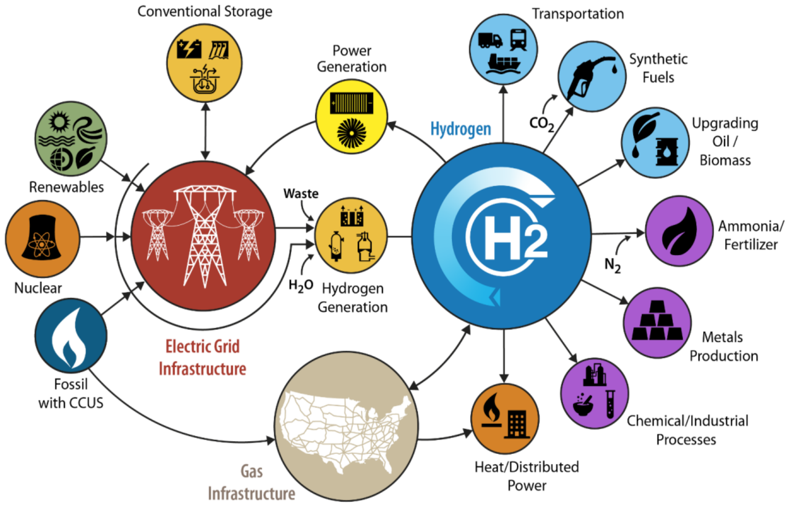
MW scale concentrating solar power facilities provide energy for

1. Metal oxide ***electrolytic*** reduction
2. Oxidation with water ***producing hydrogen***

The challenge: develop efficient and scalable solar-powered reactors up to 100,000 kg/day

Benefits of Hydrogen

- Produced from water and electricity (electrolysis)
  - Many other production schemes in development
- Produces electricity w/ high efficiency (fuel cell)
- Can be produced and consumed on-demand on very short time scales (or stored)
- Can be burned for high-quality heat
- Carbon free
- Excellent reducing agent
  - Replaces carbon in manufacturing
- Highest specific energy of any fuel
- Non-toxic, does not ’pool’ or pollute



1 **H** 1.008	=	• simple • clean • flexible

Challenges for Hydrogen

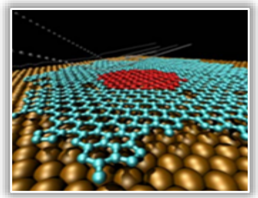
- **Non-industrial (green) hydrogen is too expensive**
  - Supply chain for non-industrial use is nascent
  - Infrastructure at scale cannot be replaced/developed overnight
    - Gas network is estimated to be valued at >$1,000B
    - Over 150,000 gasoline stations in US (value ~$100B)
- **Energy efficiency is a challenge**
  - Energy to get hydrogen in and out of solid state materials
  - Life-cycle energy efficiency is a challenge for chemical hydrides
  - Energy of compression and liquefaction must be considered for bulk storage
- **Durability of storage systems is not adequate or is not well-understood (e.g. leakage, fatigue)**
- **Safety: Hydrogen is managed as chemical, not as energy/fuel**
  - We need '*non-hardhat*' relationship with hydrogen
- **Codes and Standards needed to implement safe commercial storage systems and interface technologies have not been established**
- **Full life-cycle cost and efficiency analyses are lacking**

1
H
1.008

Sandia Research to Provide a Scientific Basis for…

Materials **–** for hydrogen production, storage, delivery and utilization
Safety – risk analysis and the creation of risk-informed standards

Hydrogen Production



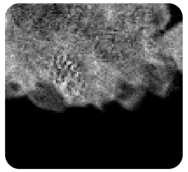
Discovery of advanced water-splitting materials for large-scale H_2 production

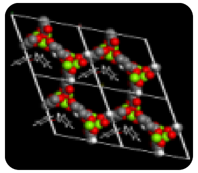
HydroGEN Advanced Water Splitting Materials

Hydrogen Storage

Discovering the behavior and performance of solid storage materials

HyMARC Hydrogen Materials Advanced Research Consortium





Hydrogen Delivery

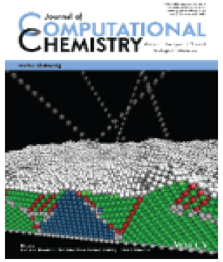
Assessing technology conversion for hydrogen distribution

HyBlend U.S. DEPARTMENT OF ENERGY

Fuel Cells

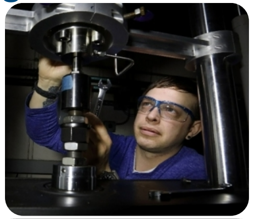
Develop new membrane systems for enhanced electrochemical performance

Materials Compatibility



Elucidation of hydrogen embrittlement phenomena across length scales

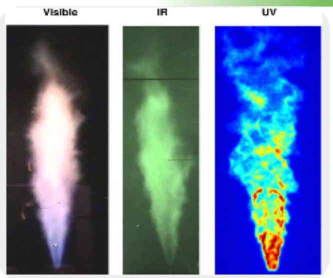
H-Mat Hydrogen Materials Compatibility Consortium SM



Systems Engineering

Hydrogen for marine, rail, and aviation

Safety, Codes & Standards



State-of-the-art characterization of thermophysical & thermochemical behavior of H_2 integrated with Bayesian theory

HYRAM+ Hydrogen Plus Other Alternative Fuels Risk Assessment Models

efficiency exchange

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Hydrogen

1 Dollar 1 Kilogram 1 Decade

Hydrogen Shot Summit Proceedings

Access presentation slides and video recordings from the opening plenary, closing plenary, and breakout panel sessions at the Hydrogen Shot Summit.

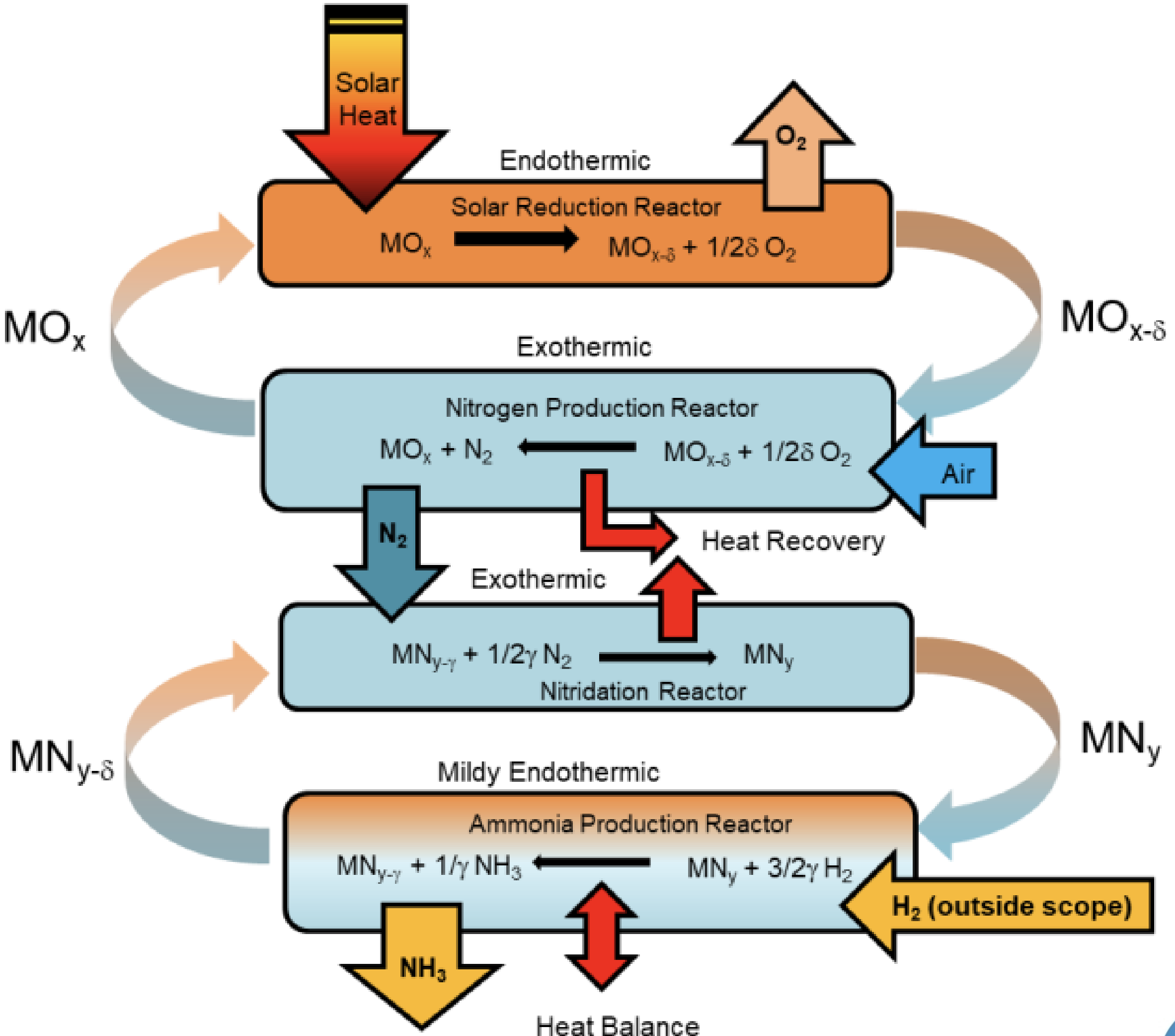
- **Opening Plenary**
- **Breakout Panel Session 1: Electrolysis**
- **Breakout Panel Session 2: Thermal Conversion with Carbon Capture and Storage**
- **Breakout Panel Session 3: Advanced Pathways**
- **Breakout Panel Session 4: Deployment and Financing**
- **Closing Plenary**

https://www.energy.gov/eere/fuelcells/hydrogen-shot-summit

Hydrogen's Cousin: Solar Thermal Ammonia Production

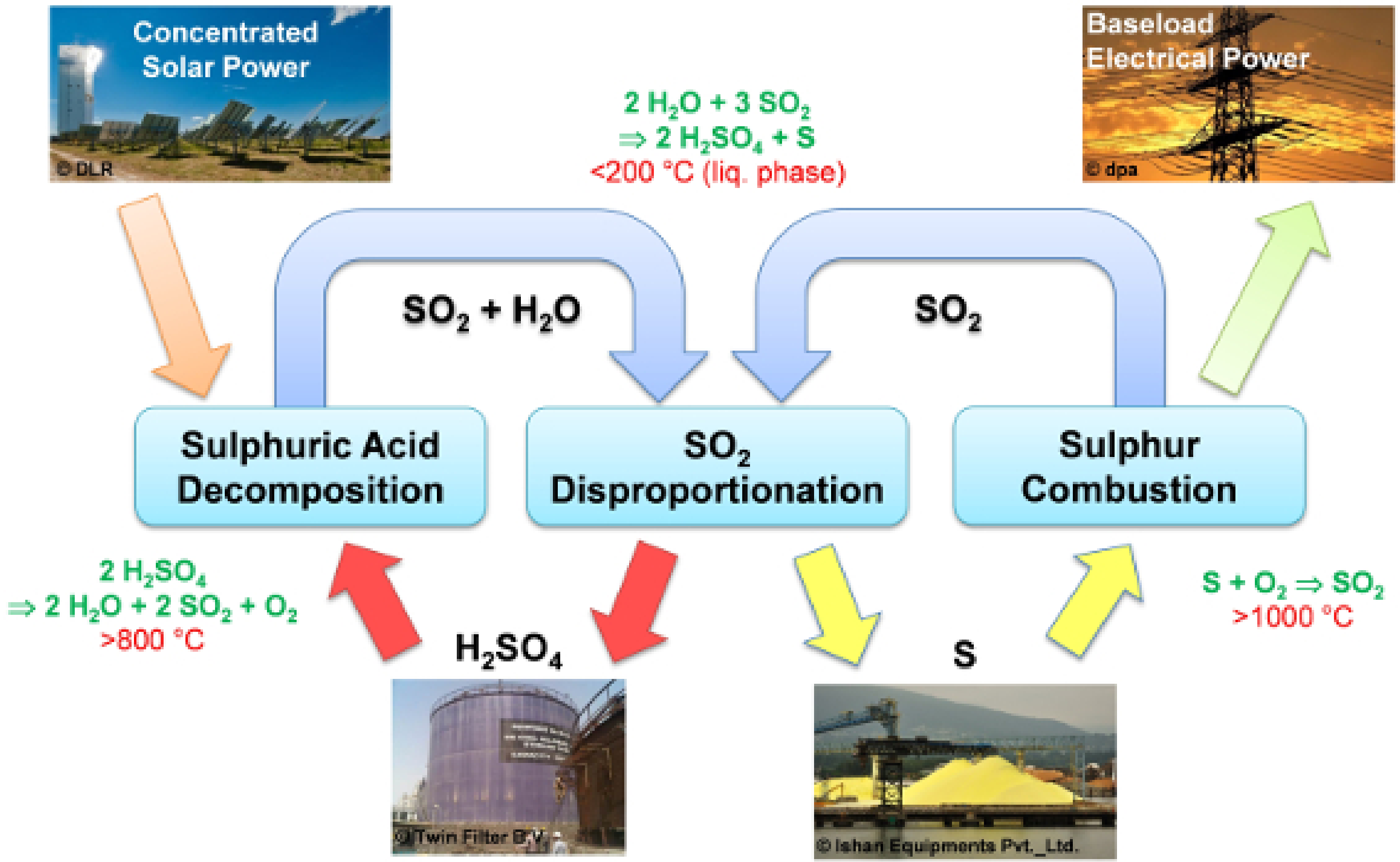
Use solar thermal energy to produce nitrogen feedstock for subsequent ammonia production

- Inputs are sunlight, air, and hydrogen; the output is ammonia
- Significantly lower pressures than Haber-Bosch
- Greatly decreases or eliminates carbon footprint using renewable H2
- The process consumes neither the oxide nor the nitride particles, which actively participate in the reactions, cyclically



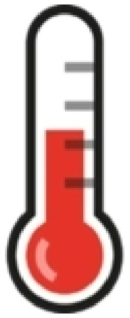
PEGASUS: Sulfur-Based Chemical Storage

Renewable **P**ow**E**r **G**eneration by Solar P**A**rticle Receiver Driven **SU**lphur **S**torage Cycle

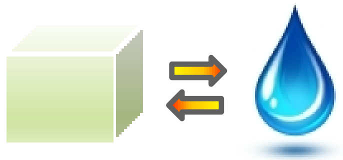


https://www.pegasus-project.eu DLR - Deutsches Zentrum für Luft- und Raumfahrt (Germany)

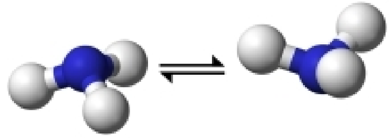
Thermal Energy Storage



- Sensible (single-phase) storage
  - Use temperature difference to store heat
  - Molten salts (nitrates <600 °C; carbonates, chlorides 700 – 900 °C)
  - Solids storage (graphite, concrete, ceramic particles), >1000 °C



- Phase-change materials
  - Use latent heat to store energy (e.g., molten salts, metallic alloys)



- Thermochemical storage
  - Converting thermal energy into chemical bonds (e.g., decomposition/synthesis, redox reactions)

Molten-salt storage tanks at Solana CSP plant in Arizona. Credit: Abengoa

Falling particles for direct solar heating Sandia National Laboratories

Sensible Thermal Energy Storage

Molten Salt Storage

photo credit: Mary Grikas, Wiki commons, 10/9/15

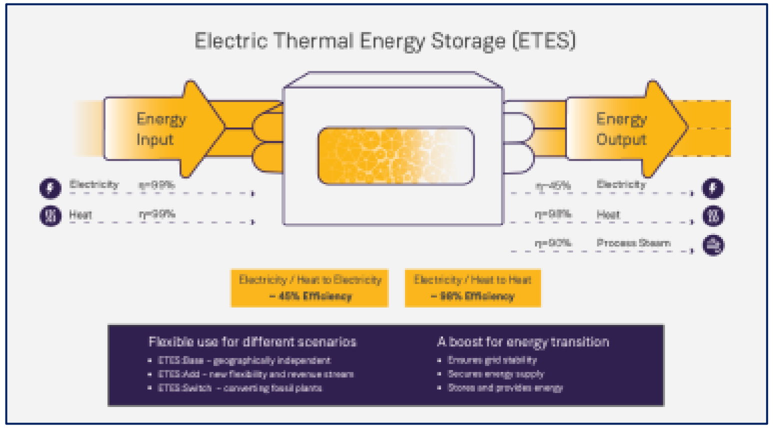
Crescent Dunes CSP, Nevada
100 MW/1 GWh

https://en.wikipedia.org/wiki/Solana_Generating_Station

Solana CSP, Arizona
280 MW/1.7 GWh

Fixed Rock-Bed Thermal Storage

Range from MW to GW scale
Nominal Power: >30MW
Capacity > 130MWh
Storage for discharge up to 24 hours

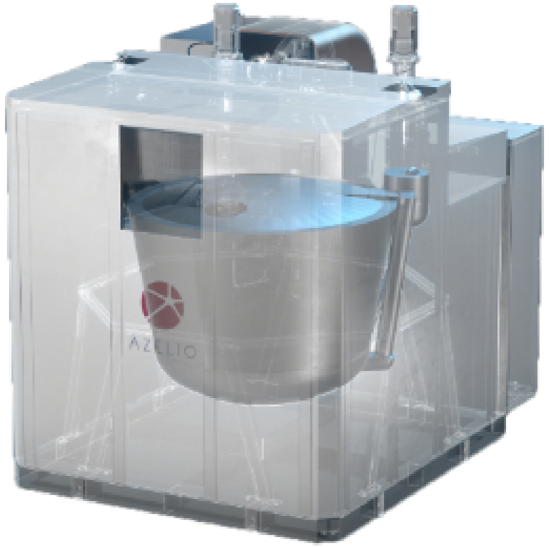


Hamburg, Germany
1000 tons of rock at 750°C
Using steam turbine, generator will produce 24 hour storage at 1.5MW

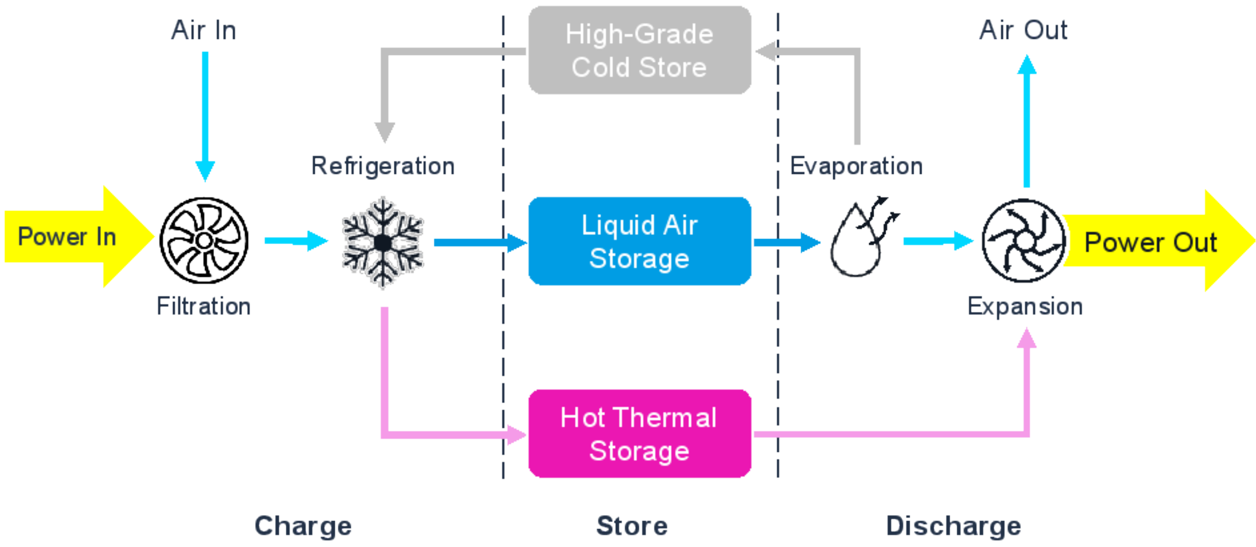
Siemens-Gamesa

Latent Thermal Storage

Azelio TES.POD ®



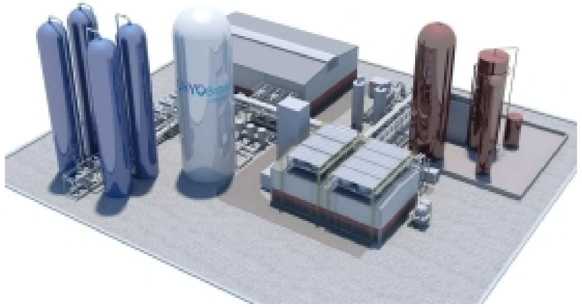
- Electrically-generated heat stored in a recycled aluminium phase change alloy at the melting point of 600°C.
- Heat transferred to stirling engine to provide power.
- Residual heat available (55-65C).
- Each unit has 13kW power for 13 hours
- 0.1MW to 100MW



Images: Highview Power

Highview Power

Highview Power Liquid Air Energy Storage
50 MW/400 MWh
(Vermont - planned)



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Thank you!

Questions?

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Thank you to Drs. Clifford Ho and Chris San Marchi for select presentation content.


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2022
VIRTUAL CONFERENCE
APRIL 14-15, 2022