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Invited Talk

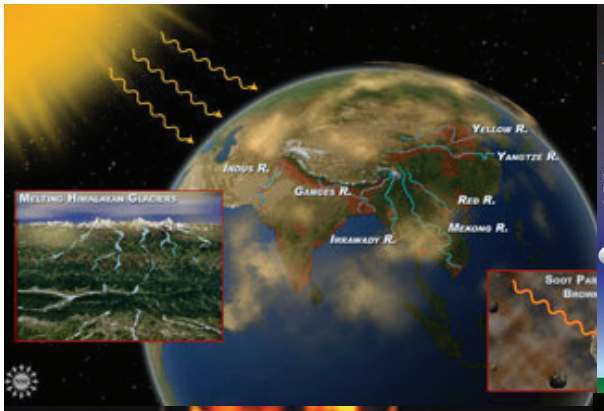
Role of Energy Storage and Hydrogen in Decarbonization

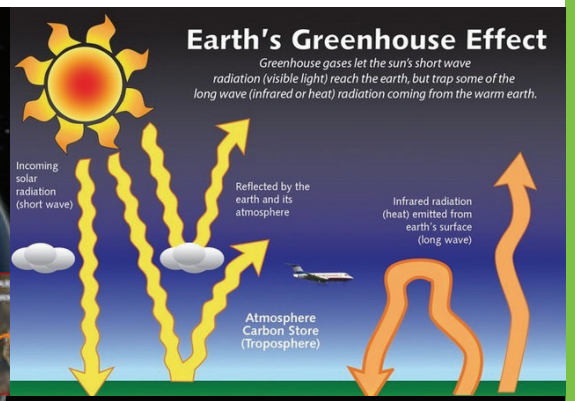
CSEE JPES Forum, China
11 October 2022

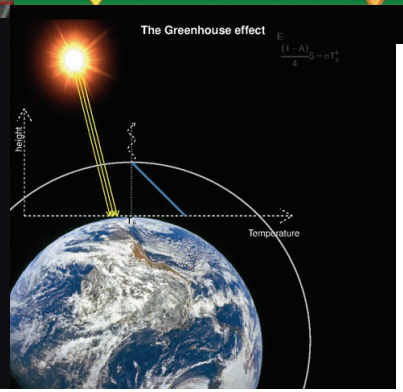
Virginia Tech

ARI

Global Warming Potential (GWP) of Greenhouse Gases







GLOBAL WARMING

- ✓ **Carbon dioxide (CO_2): 1**
- ✓ **Methane (CH_4): 28**
- ✓ **Nitrous oxide (N_2O): 265**
- ✓ **Hydro fluorocarbons (HFCs): 138**
- ✓ **Per fluorocarbons (PFCs): 6,630**
- ✓ **Sulphur hexafluoride (SF_6): 23,500**

(over 100-year time scale)

GHG Emissions Reduction/ Decarbonization Targets

Country	50% by	100% by
US	2030 (Power Sector)	2050
EU	2035 (All Sectors)	2050
China	2030 (Power Sector)	2060
India	----	2070

The Decarbonization Debate

- Industrialized countries want emerging countries to cut carbon emissions.
- Emerging economies want to continue using fossil fuel for electricity production
- There is a third way – Use a diverse portfolio of solutions

Six Priorities for Decarbonization in Industrialized and Emerging Economies

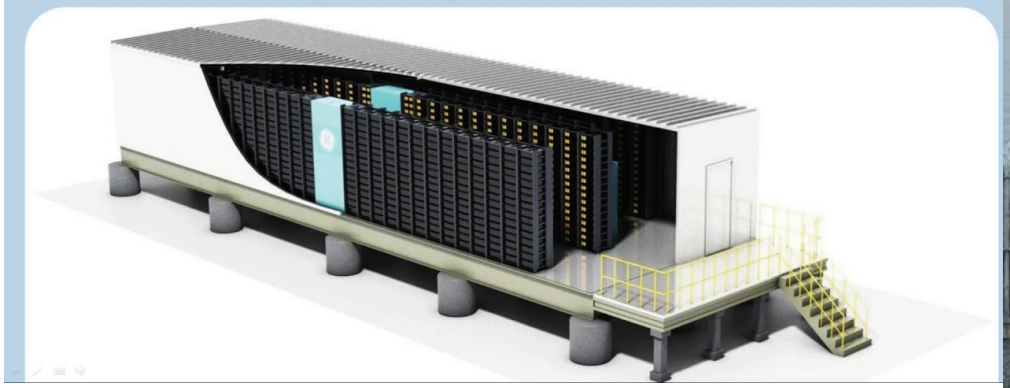
IEEE Spectrum, Sep 2022

Reduce Carbon Emissions

1. Energy Efficiency Applications
2. Carbon Capture Systems
3. Renewable Energy Integration
4. **Hydrogen and Storage Solutions**
5. Cross-Border Energy Transfer
6. Advanced Nuclear Technologies

Electrochemical Energy Storage Technologies

Battery Energy Storage System - BESS



- **Batteries.** Very large batteries can store electricity until it is needed. These systems can use lithium ion, lead acid, lithium iron or other battery technologies.

Mechanical Energy Storage Technologies

Mechanical Energy Storage Technologies

- Table compares a few of these mechanical systems along with key operating characteristics.

Table Comparison of Mechanical Storage Technologies				
Technology	**Duration**	**Reaction Time**	**Round-Trip Efficiency**	**Unique Geographic Requirements**
PSH	Several hours to days	Several seconds to minutes (depends on technology choice)	80+%	Separate reservoirs with adequate differences in elevation
CAES	Several hours to days	Several minutes	52%*	Typically requires unique impermeable underground caverns
Flywheels	Seconds to a few minutes	Subsecond	93%–96% (high)	None
Gravity Energy Storage (GES)	Several hours	Several minutes	Insufficient data	None

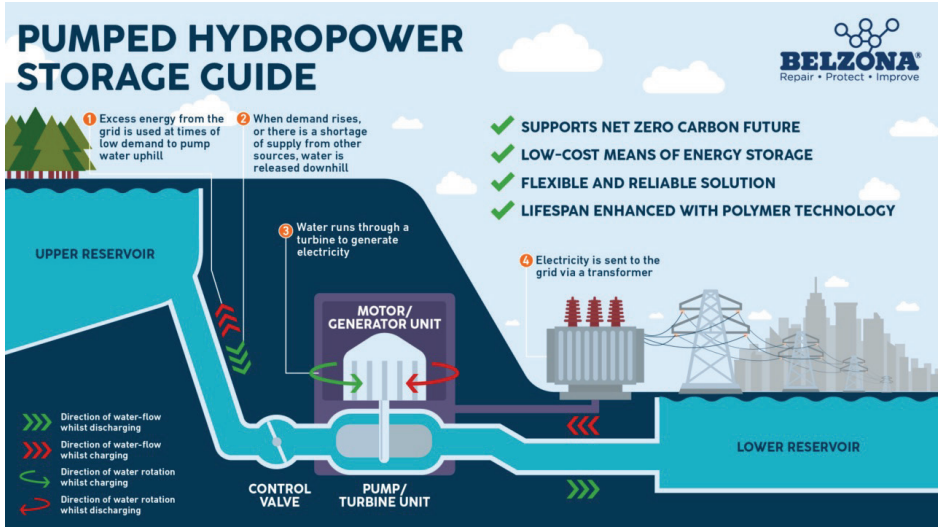
*: As CAES relies on both electricity to compress air and a fuel (typically natural gas) to expand the air, its efficiency cannot be readily compared to other storage technologies. The value used in this report represents the ratio of the output of electrical energy to the combined input of electrical energy for the compressor and the natural gas input for expansion, using the heating value of natural gas to convert its energy to how much electricity it could have produced (Mongird et al. 2019).

https://www.nrel.gov/docs/fy21osti/76097.pdf

Pumped Storage Hydropower

- **Pumped Storage Hydropower (PSH)**

Electricity is used to pump water up to a reservoir. When water is released from the reservoir, it flows down through a turbine to generate electricity.



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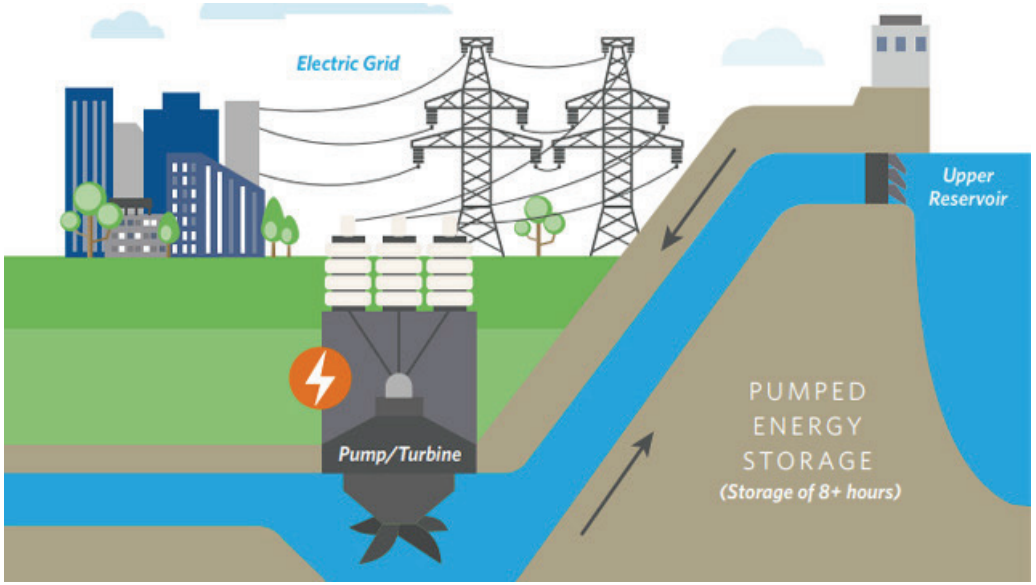
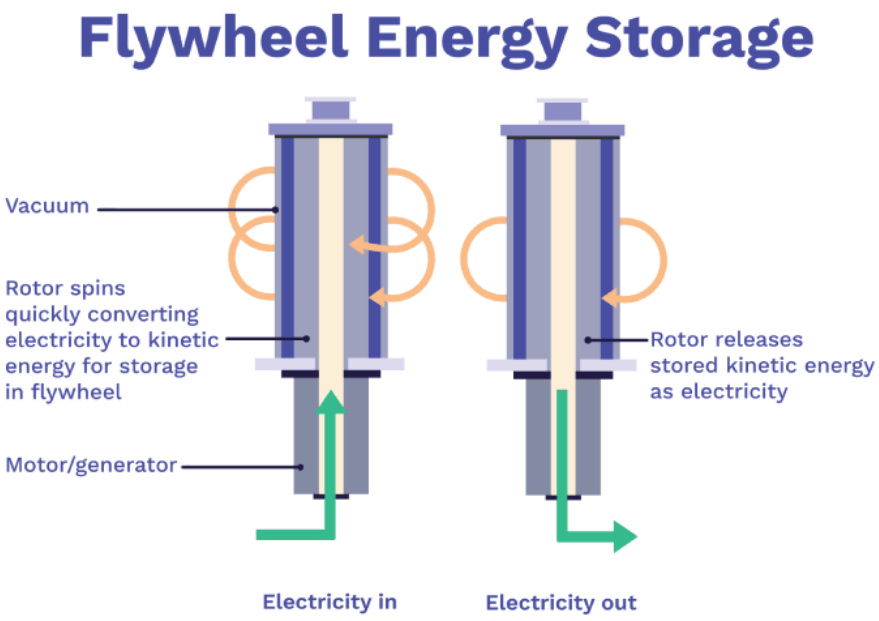


https://www.bv.com/industries/hydropower-hydraulic-structures/pumped-storage-hydropower

PSH is the most developed and widely commercialized energy storage technology for power sector applications globally. Despite its well-developed status, PSH is limited by its geographic requirements and high upfront capital cost, which may be a strong barrier to its continued deployment in certain contexts.

Flywheel

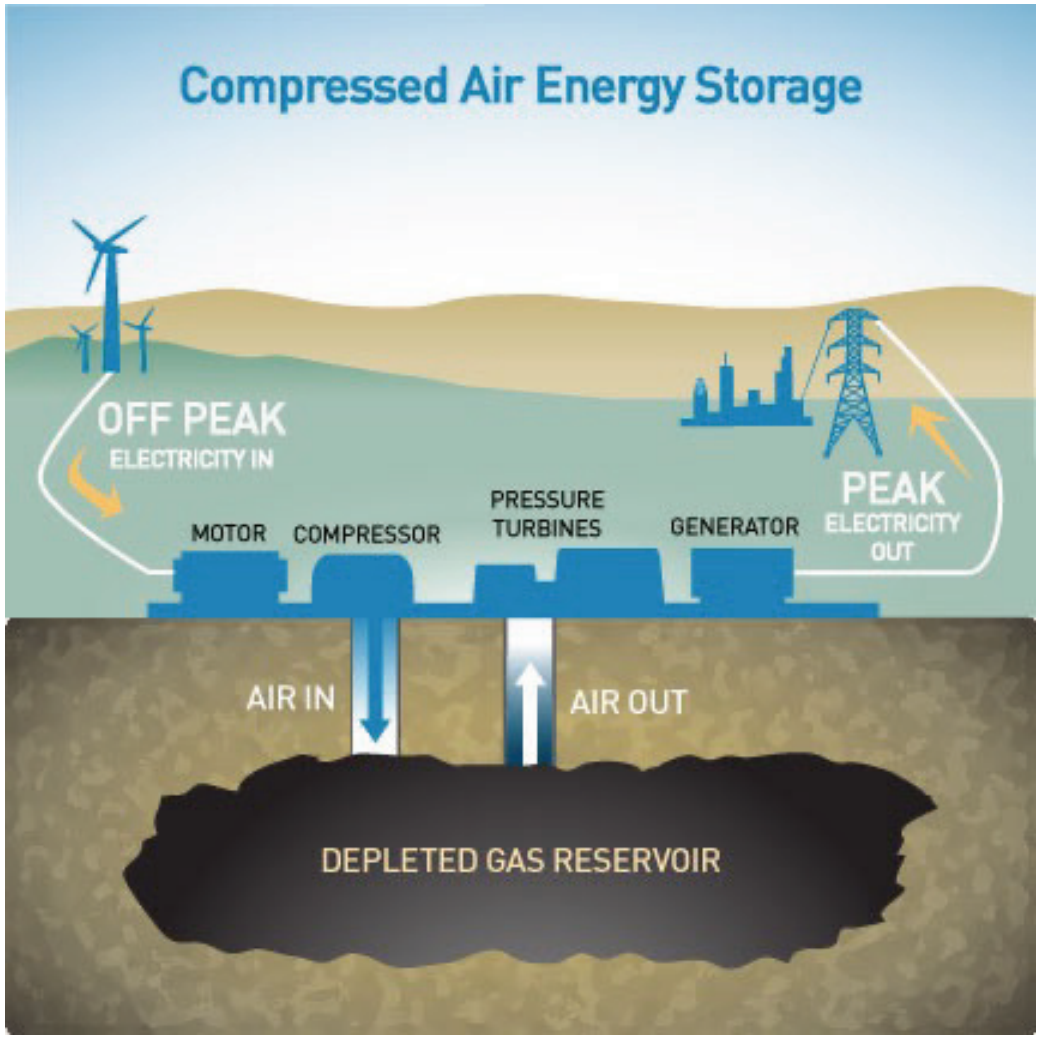
- **Flywheels**. Electricity is used to accelerate a flywheel (a type of rotor) through which the energy is conserved as kinetic rotational energy. When the energy is needed, the spinning force of the flywheel is used to turn a generator. Some flywheels use magnetic bearings, operate in a vacuum to reduce drag, and can attain rotational speeds up to 60,000 revolutions per minute.



https://www.epa.gov/energy/electricity-storage

Compressed Air Energy Storage (CAES)

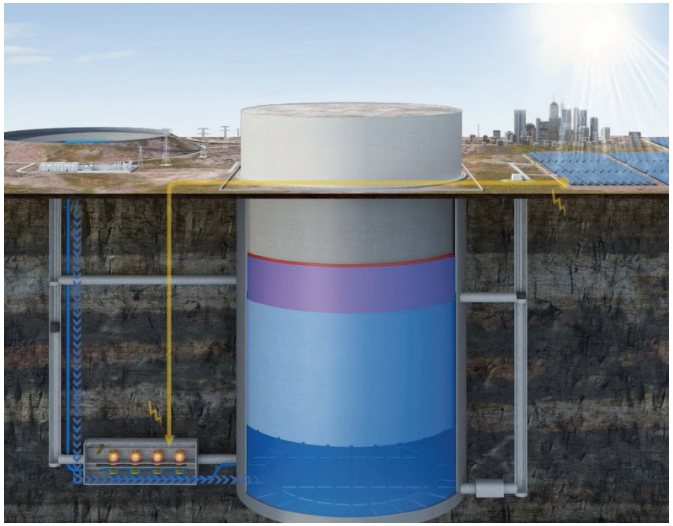
- **Compressed Air Energy Storage (CAES)**. Electricity is used to compress air at up to 1,000 pounds per square inch and store it, often in underground caverns.
- When electricity demand is high, the pressurized air is released to generate electricity through an expansion turbine generator.



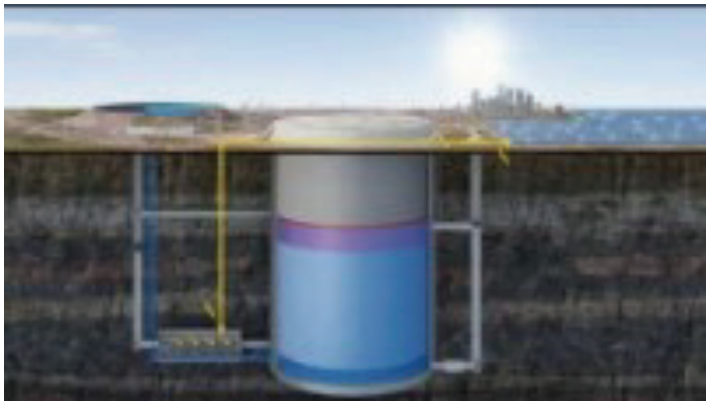
https://www.pge.com/en_US/about-pge/environment/what-we-are-doing/compressed-air-energy-storage/compressed-air-energy-storage.page

Gravity Energy Storage (GES)

- **GES** is an immature technology with the potential to provide long-term energy storage similar to CAES or PSH.
- The general concept involves lifting the storage medium (sand, concrete, gravel, or rock) from the ground (or from underground in places with abandoned mine shafts) to a higher elevation.
- The kinetic energy of the heavy weight held at high elevation can be extracted using an electric induction generator, similar to the concept that enables regenerative braking in electric vehicles.



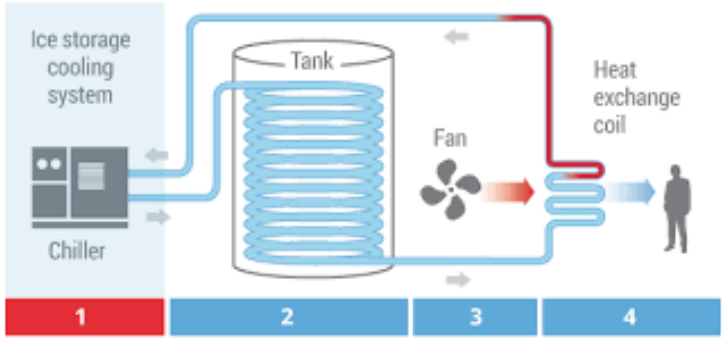
https://www.youtube.com/watch?v=ObvQFX6noDw



Additional Energy Storage Technologies

Thermal Energy Storage (TES)

- **Thermal Energy Storage (TES):** Electricity can be used to produce thermal energy, which can be stored until it is needed.



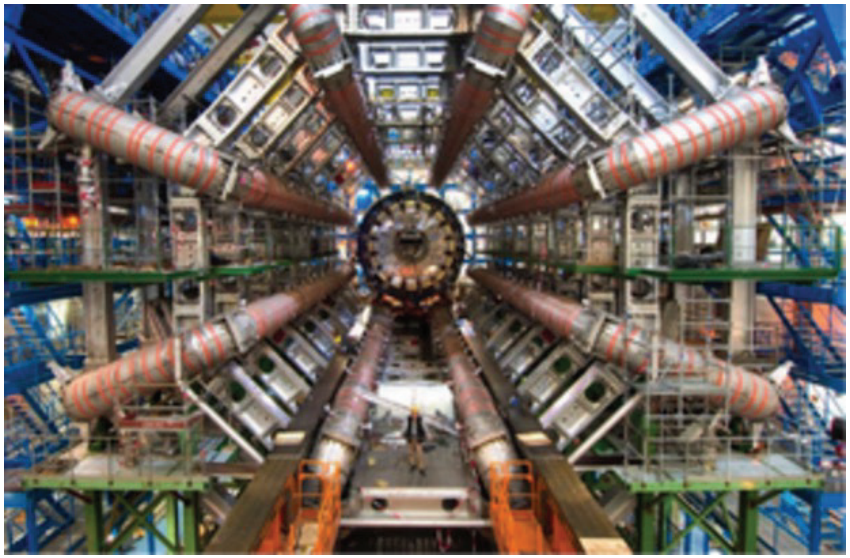
- TES is marked by long durations of several hours and is therefore a good fit for peaking capacity needs. TES is often combined with CSP, which needs high levels of direct solar radiation that can only be found in select geographies.

Supercapacitors

- **Supercapacitors:** supercapacitor, also known as an ultracapacitor, is a device that stores energy by static charge.
- These systems have high power and low energy capacities.
- Supercapacitors are useful for power quality applications, as they can frequently charge and discharge at high currents for short durations.
- When paired with electrochemical devices, they have been shown to improve the efficiency and lifetime of the battery components.

Superconducting Magnetic Energy Storage (SMES)

- SMES systems store energy in the electrical charge of a coil of superconducting material, which exhibits zero resistance below certain temperatures.
- These devices require external cooling infrastructure to maintain extremely low temperatures.
- SMES systems are marked by high power densities, low energy densities, very fast reaction times, and long cycle lives.



https://www.nrel.gov/docs/fy21osti/76097.pdf

Hydrogen decarbonization pathways

Hydrogen Energy Storage Systems

- The large-scale production of hydrogen from electricity and its efficient conversion back to electricity is still in the pilot-phase of development, although a few large-scale projects have been completed around the world, with more planned.
- Hydrogen is currently unable to compete with electrochemical energy storage like lithium-ion batteries for shorter duration services on a cost-basis;
- Very high potential in the transportation sector.

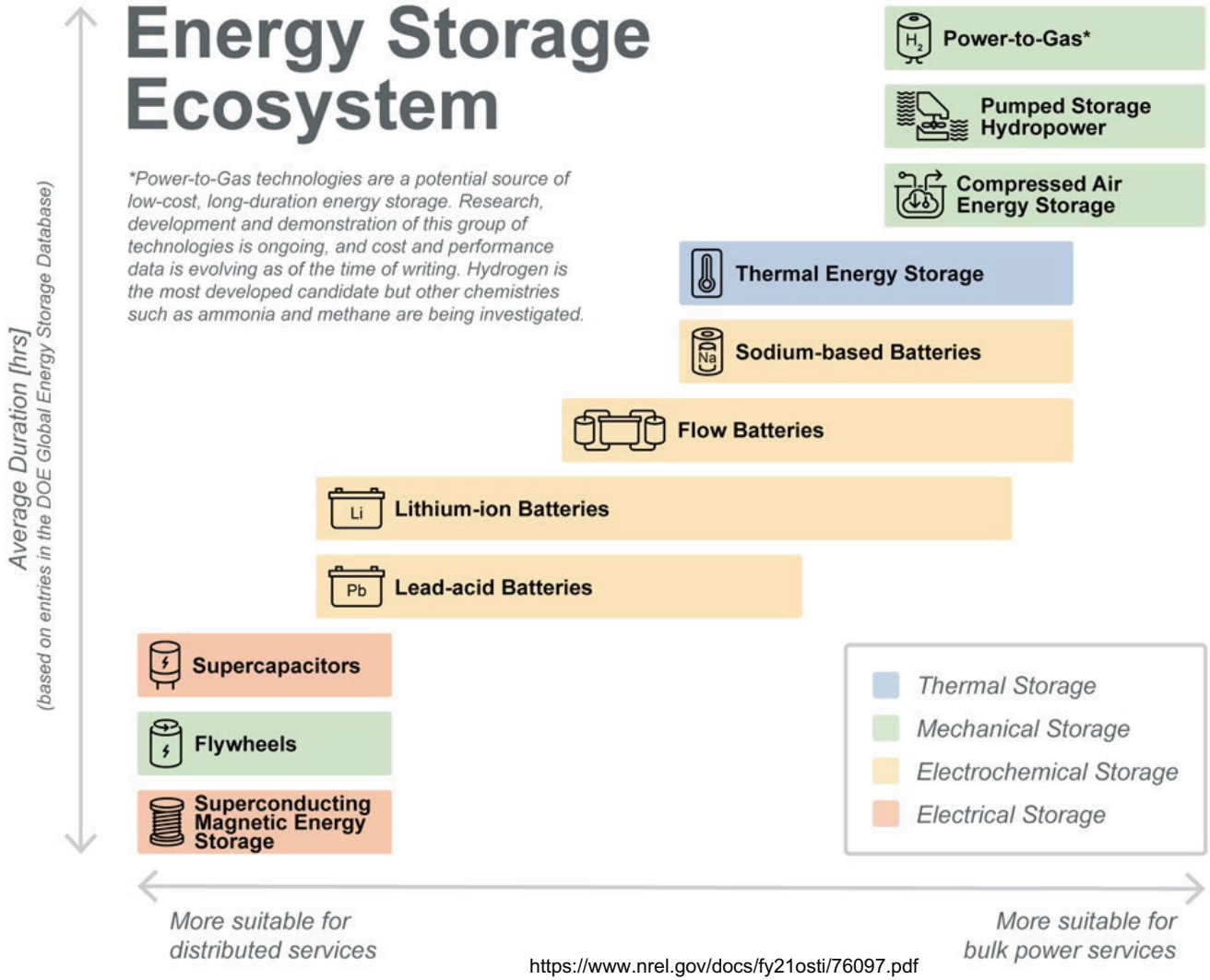
https://www.nrel.gov/docs/fy21osti/76097.pdf

Hydrogen Energy Storage Systems (Example Deployments or Pilot Projects)

- In 2015, the municipal utility of Mainz, Germany, in collaboration with several industrial, university, and government partners developed a 6-MW photon-exchange membrane-electrolyzer hydrogen production facility that will be able to produce 89.8 kg of hydrogen gas per hour.
- The electrolyzer is connected to an adjacent 8-MW wind power plant and seeks to store excess renewable energy as well as supply ancillary services to the wholesale market.
- In Linz, Austria, the world's largest hydrogen production facility powered solely with renewable energy commenced operation in late 2019.
- This 6-MW capacity pilot plant will use clean energy from renewable energy resources to create 'green hydrogen' that will be used at a neighboring steel manufacturer.

https://www.nrel.gov/docs/fy21osti/76097.pdf

Ecosystem of Energy Storage Technologies and Services



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Thank You

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