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WHITE PAPER

Comparing the Advantages of Lithium-Ion Batteries and Hydrogen

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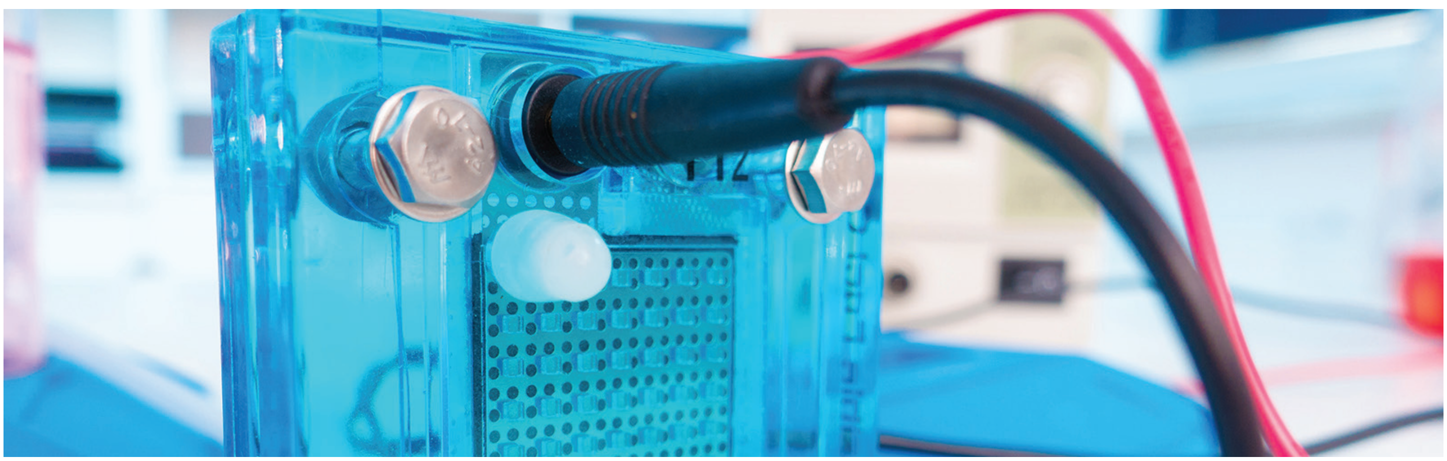
The future of energy storage will depend on being able to store energy practically and economically for months at a time, as opposed to hours. While batteries are clear leaders in current storage applications, hydrogen is increasingly gaining appeal as the efficiency and cost of hydrogen based power has improved significantly.



Renewable energy production potential and energy demand do not often match up geographically or temporally, and no amount of flexible load or demand response can overcome this completely. For example, on a winter night in a polar vortex, there is no sunlight to produce electricity from photovoltaic panels. Asking people in the Upper Midwest to turn off their heat and risk frozen pipes isn't a great solution. Fortunately, energy storage can solve this and similar issues.

When looking at future storage needs, the issue is not short-term energy storage, measured in hours; rather, it is saving energy from late March until it is needed in November. In the first nine months of 2020, California had curtailed more than 1 terawatt-hour (1 million kilowatt-hours) of energy. And in May 2020 alone it was 318 gigawatt-hours, according to California ISO. On May 20 alone, over 2 GW of solar was curtailed from 9 in the morning until 5 in the afternoon, a massive amount of renewable power potential lost. Solar today is 20% of California's power supply and is scheduled to become 50% of total energy used in the state by 2045. The marginal value of solar — and the curtailment of solar — will increase as the percentage of intermittent supply increases in a nonlinear fashion. This means that by the time solar reaches 50% on some days, curtailment could be as much as 80% of possible production. Storage, rather than curtailment, is needed. And extended periods of storage would be even more valuable.

There are many types of energy storage, from pumped hydro and hot sand to ice-based thermal storage. Among the many types of storage, two that are very different from each other stand out as having the potential to have a massive impact on how the energy infrastructure evolves. One, lithium-ion batteries, is all the rage for vehicle propulsion and now is being touted as a way to store energy for everything else. The other is hydrogen.

Until 2018, batteries appeared to have a clear field for future transportation and electrification, storing excess renewable energy until it was needed. In the past few years, something has happened that may shift the tide. Hydrogen, dismissed by most parties in 2018, has seen investment in research and development that has increased the efficiency and lowered the cost of hydrogen-based energy significantly.
The leading hydrogen production processes today are on par with some other battery round-trip efficiencies, and the cost per kilowatt-hour stored is much less for the production of hydrogen than for other batteries. The capital investment for capacity in kilowatts is still higher for hydrogen than batteries, but it too is being reduced. Holding hydrogen in existing underground storage is cheaper than batteries, and the life of an underground storage facility is decades longer than most batteries. Some salt caverns have been in use for underground gas storage since the 1940s.

A number of barriers exist both for battery technologies and hydrogen. This paper examines the barriers for each technology and compares them with the state-of-the-art answers for both technologies. At this time, neither technology is a clear winner or loser, but the scale is tipping from batteries clearly having the upper hand to hydrogen becoming a viable alternative.

There are hundreds of types of batteries and at least 16 ways to produce hydrogen. Some of the batteries and the methods of making hydrogen are "greener" than others. All of the methods and batteries differ in detail, so the comparison has been generalized here, though detailed comparisons have been made by the author to develop this generalization.

To illustrate the two options, green hydrogen from renewable power — specifically polymer electrolyte membrane (PEM) electrolysis — and lithium-ion batteries with a 811 nickel- manganese-cobalt (NMC) cathode composition (80% nickel, 10% manganese, 10% cobalt) were selected as the generic technologies in Figure 1.

BARRIER	BATTERIES	HYDROGEN
Delivery infrastructure	Batteries rely on the electric grid. They are placed at the point of generation, the point of delivery, or somewhere in between, and may offer better delivery of energy over the infrastructure.	Hydrogen can take advantage of natural gas infrastructure, even if demand for natural gas wanes. This infrastructure includes trillions of cubic feet of underground storage, which will have to be evaluated for permeability for hydrogen on a case-by-case basis.
Infrastructure capacity to support using this technology	This infrastructure is at or above capacity on peak days in much of the U.S., and especially in many neighborhoods. Putting two to three times the energy on the grid will require the distribution system to be largely rebuilt. Most distribution circuits are sized to support approximately 20% of residences having an electric vehicle charger. This estimate is based on modeling and using the time from arrival home from work until time to return to work the next day. The transmission system was designed to support current central plant locations, and it suffers capacity losses when those plants are decommissioned. Much of the system will require technology like synchronous condensers to retain current capacity, and could require doubling or tripling capacity in the transition to all-electric loads.	Pipelines are being shut down to minimize fossil fuel use, and utilities are being denied permits to build new or replacement lines. New England has been cut off from the rest of the U.S. by New York's aggressive stance in opposition to new pipelines. Liquids pipelines can be converted to hydrogen in a similar fashion to converting natural gas pipelines. The distribution system in communities is undersized to fuel vehicles at home, but with hydrogen's short refuel times, gas stations could be converted to hydrogen. Additionally, some local hydrogen could be produced from excess local electricity when available.

BARRIER	BATTERIES	HYDROGEN
Typical cycle to upgrade the infrastructure	Substation and distribution systems typically receive upgrades or rebuilds every 40-80 years. Based on 2019 FERC Form-1 analysis, if you use current allocated funding levels, the rebuild rate for substations would be once every 200 years while distribution circuits would be once every 150 years. All of the infrastructure is continuously maintained, but major capacity upgrades only happen when the load has already increased and the circuit is over capacity. Typical upgrade time from start to finish is two to five years for distribution, up to 20 years for transmission, and three to seven years for substations.	Most of the natural gas infrastructure in the U.S. is too new — built after World War II, generally less than 75 years old — to have a good understanding of the actual systemwide rebuild requirements.
Time to upgrade the infrastructure using this storage mechanism to support the demand	Assuming regulators are onboard with the upgrades to transmission and distribution, an optimistic time frame is 30-50 years to remove the larger barriers to electrification.	Given that natural gas infrastructure can be repurposed, few barriers exist that would require major rebuilds. Initially hydrogen can be mixed with natural gas without issue, but as the blend shifts progressively closer to pure hydrogen, there will be a need to find a sealant for the system to prevent embrittlement in harder steels, as well as in some of the plastics used. Weldments and joints are also areas where work may be needed.
Storage time	Most batteries today are being built for four to eight hours of storage, representing typical day/night cycling. Most batteries must be cycled 100-1,000 times a year to make back the capital investment. Flow batteries promise longer storage times with a lower cost of energy the more hours they operate, provided the cycle count stays the same.	Hydrogen can be held indefinitely in storage until needed. Natural gas storage can be repurposed to store hydrogen after evaluation for porosity.
Regulatory hurdles	Regulators require the electric grid to be "used and useful," so building capacity into current projects to support future electrification is rarely allowed.	There are myths about hydrogen that pose issues with some regulatory bodies. Current regulations that prohibit new buildings from connecting to the natural gas system and anti-pipeline laws and regulations prevent the system from being able to serve all needs.
Safety	Batteries can fail in a spectacular fashion. NFPA 855 and other standards mandate upgrades to minimize the impacts of these failures.	Unlike natural gas, which will fill a basement first, hydrogen is lighter than air and moves upward. Fires can occur, similar to natural gas. Because of the small size of its molecules, hydrogen can escape through sealants, pipe walls and other materials. Hydrogen embrittlement is an issue that must be addressed.

BARRIER	BATTERIES	HYDROGEN
Waste and recycling	Lithium-ion batteries are not recyclable presently. They are smelted for the metals, but 40% or more of the chemicals are lost when the smelter burns the battery. In some batteries, this results in toxic gases, while in others no toxic compounds are formed. For lead-acid batteries (the largest segment of the category), 99% of the battery can be recovered through recycling and reuse.	Depending on the process, hydrogen production has little or no waste to speak of. Most of the waste is polymers, which can be recycled, similar to soda bottles, if the right processes are used.
Losses in holding energy for 90-270 days	Lithium-ion batteries lose energy at 0.5% per 30-day period if kept below 20° C. Air conditioning is necessary to keep the batteries cool or higher losses will occur (up to 2% over 40° C), according to *Applied Energy.*	Losses in salt caverns are less than 1% over this time period, according to ScienceDirect.
Vehicle concerns	Batteries are heavy in comparison to gasoline, which could particularly impact electrification of heavy-duty, long-range transportation. Batteries also have caught on fire in accidents in the past.	Hydrogen stored in metal hydrides is similar in weight to gasoline per BTU and is not a fire hazard.
Environmental issues	Battery materials are in some cases rare, and mining methods can have serious environmental impacts.	Hydrogen returns to water vapor when used. The production equipment is durable, mostly made of steel and other industrial metals.
Storing efficiency	Lithium-ion batteries are up to 95% efficient in charging.	Green hydrogen production can be as much as 85% efficient, according to research from Strategic Analysis Inc. and in *Materials Science for Energy Technologies.*
Who is backing this path?	Backers include some automotive companies, electric utilities, renewable developers, and manufacturing companies with products that would gain from the use of batteries.	Backers include large energy producers, some automotive companies, construction and agricultural equipment producers, truck manufacturers, gas station franchisors, gas utilities, and manufacturing companies with products that would gain from the use of hydrogen.

***Figure 1:** Comparison of use barriers for batteries and hydrogen.*

Batteries face tough regulations imposed on the grid by electric utilities and the long timelines those create for electric transportation. Once a circuit reaches capacity and no more electric vehicles can charge in a zone, customers may look for alternatives. The second issue is the lack of recycling for lithium-ion batteries, combined with the environmental issues created from mining component materials. These issues will need to be addressed if batteries — at least lithium-ion batteries — are going to have a long-term future in electrification.

It is up to the battery technology stakeholders to decide if they will address these issues and maintain their advantage or see the use of batteries in energy storage lose ground to hydrogen in the future. At the same time, hydrogen research must continue to address issues of materials and efficiency, or use of hydrogen for energy storage will never achieve mainstream success.

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