Green hydrogen: the zero-carbon seasonal energy storage solution

Bulk storage | One of the planet's most abundant elements, hydrogen has the capacity to be a game-changer in decarbonising the global energy system, writes Janice Lin, founder and president of the Green Hydrogen Coalition

Back in 2016, I was serving as founder and executive director of the California Energy Storage Alliance (CESA). CESA is membership-based trade association and advocacy group that has helped build California into one of the world's most robust energy storage markets. At that time, CESA did not know exactly where California was headed with clean energy, but we did know other jurisdictions, such as Hawaii, were committing to 100% renewable portfolios. The CESA team was curious – if California created a similar clean energy goal, how would that drive California's energy storage needs? To answer this question, we performed a simple exercise. The CESA team took one year's worth of daily loads from CAISO OASIS data and ran a model that increased the wind and solar on the system until total production matched total energy consumption. Then we plotted the results for every day of the year, as show in Figure 1.

The resulting graphic clearly demonstrated that in a very high, 100% renewable scenario, multi-day and seasonal energy storage solutions would be required to balance the grid. At that time, the largest form of energy storage within CESA's membership was pumped hydro, and even that could not offer nearly enough capacity for seasonal energy storage needs.

Driven by curiosity and resolve, I started a search for a technologically and economically feasible seasonal energy storage solution for California and beyond. I spoke to experts far and wide and evaluated solutions from major energy companies to startups. From my explorations, it became clear: of the commercially available solutions, green hydrogen was the only low-carbon, potentially economically viable option to support seasonal, dispatchable, scalable energy storage for the grid.

In my research, I learned that hydrogen was a mature industrial commodity, with approximately 70 million metric tons sold each year around the world – and that virtually all of this hydrogen produced is sourced from fossil fuels. I also learned analysts were predicting that with the increasingly low cost of wind and solar, green hydrogen via electrolysis would become cost competitive with grey hydrogen (hydrogen made from fossil fuels) in coming years.

Even more exciting, my research uncovered the amazing flexibility of hydrogen molecules. For example, hydrogen gas can power the grid via multiple pathways, either through conversion in a fuel cell or by direct combustion in a gas turbine. Indeed, many gas turbines were already able to combust a blend of natural gas and hydrogen, and several leading manufacturers, such as Mitsubishi Hitachi Power Systems and Siemens, were developing new gas turbines that could consume 100% hydrogen gas.

Understanding that green hydrogen could serve as a drop-in fuel replacement for natural gas *and* provide long duration seasonal energy storage using existing infrastructure was my "Eureka!" moment. By repurposing existing energy infrastructure, I knew green hydrogen held the promise of making our clean energy transition affordable, reliable and scalable.

I became very excited about the potential for green hydrogen to accelerate decarbonisation. At CESA, we reformed our definition of energy storage to include hydrogen storage technologies, including in purpose-built storage facilities as well in pipelines. I'm proud of CESA's work for the storage market in California in general, and especially for introducing green hydrogen into the storage conversation.

At this point, I was so infatuated by green hydrogen's potential that in 2019, after a decade of service, I stepped down as executive director of CESA to launch the Green Hydrogen Coalition. The Green Hydrogen Coalition (GHC) is an educational non-profit dedicated to facilitating policies and practices to advance the production and use of green hydrogen in all sectors where it will accelerate the transition to a carbon free energy system.

The GHC defines "green hydrogen" as hydrogen created from renewable energy sources such as solar, wind, hydro power, biomass, biogas, or municipal waste. The GHC is accelerating green hydrogen

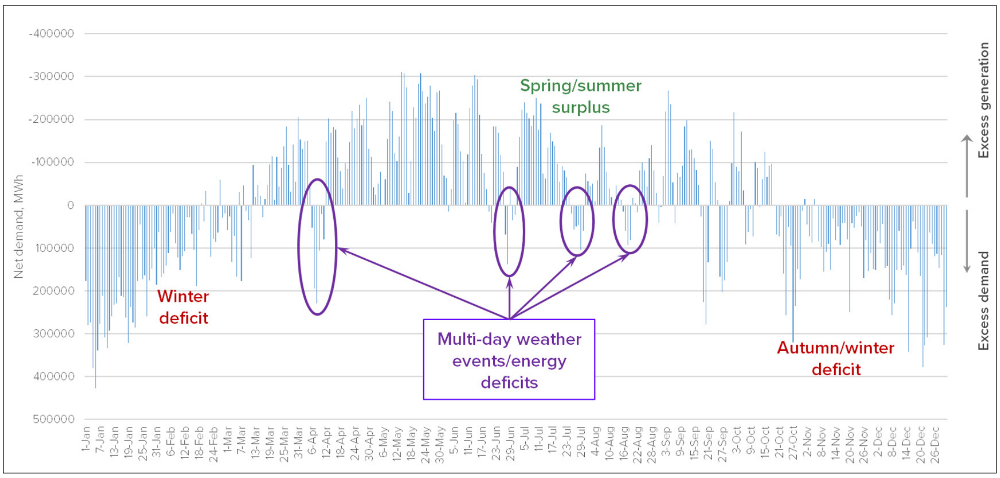

Figure 1. Substantial storage capacity will be needed to support a 100% renewables scenario in California

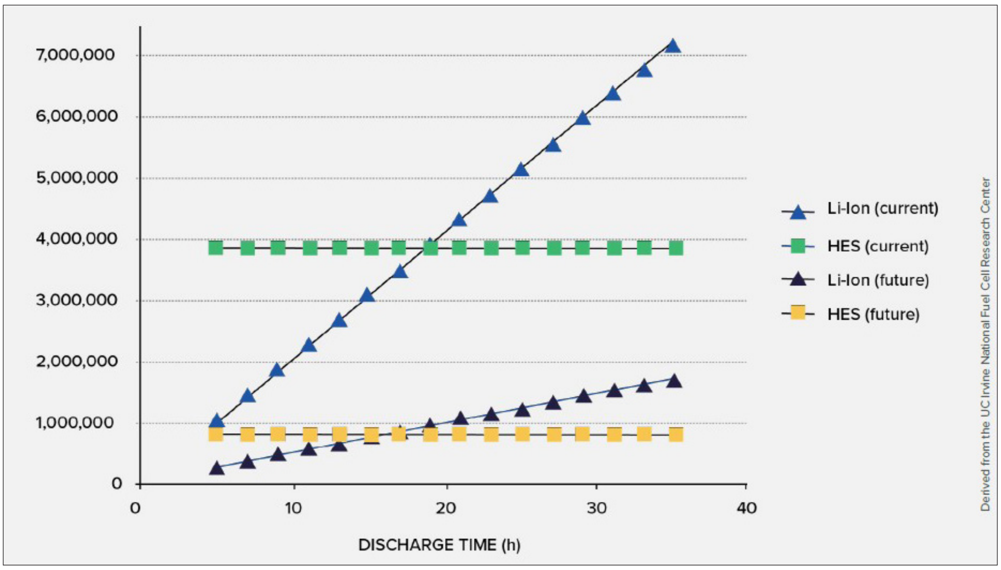

Figure 2. Hydrogen has separate power and energy scaling

infrastructure investment by aggregating demand at scale across sectors and pairing these opportunities with low-cost green hydrogen supply. In this way, our mission covers green hydrogen for seasonal energy storage, but our scope is broader.

Since seasonal energy storage is where my green hydrogen journey started, I wanted to share some reasons I am convinced that green hydrogen is the ideal seasonal energy storage medium:

1. Hydrogen is abundant
2. Green hydrogen offers separate power and energy scaling
3. Green hydrogen can be produced from multiple renewable energy sources
4. Green hydrogen can be stored at scale

Hydrogen is abundant

Lithium-ion battery storage is today's leading and preferred energy storage medium. It is cheap, well understood- why worry about hydrogen? The answer is simple. In a 100% global renewables scenario, it is simply not feasible to solely rely on lithium to meet energy storage needs.

A recent simulation completed by the University of California, Irvine (UCI) showed that global solar and wind dynamic production to meet total world annual energy demand would require the support of nearly 20,000TWh of energy storage.

If all our planet's lithium were dedicated to support grid storage, we would still fall woefully short of the energy storage capacity the grid requires. According to UCI, 20,000TWh of storage would require over 3,000 million tons of lithium, 60 times the amount that exists on Planet Earth. Moreover, that giant lithium-ion battery would only last five to 10 years, after which we would have to build a completely new replacement system to store the energy.

In stark contrast, hydrogen is extremely abundant - the most abundant molecule in the universe. On Earth, hydrogen mainly exists bound into compounds like water, the most abundant compound on the planet. Hydrogen also exists in almost all organic compounds, such as animals and plants that are alive, as well as animals and plants that have long been dead (aka, fossil fuels) – which is why most hydrogen gas is sourced from fossil fuels today. Since hydrogen in one form or another is available almost everywhere on earth, it has great potential to be a locally produced green energy resource for nearly every community.

Simply put, although lithium-ion energy storage is an important part of the toolkit, there is just not enough lithium to support the needs of our clean energy future. Only abundant, available hydrogen can offer the large-scale storage capacity and flexible discharge horizons to support a global clean energy future.

Green hydrogen offers separate power and energy scaling

When a long period of storage, say 10 hours or more, is required to provide power, it may be significantly more cost effective to store energy via hydrogen instead of electrochemical batteries. Hydrogen storage is unique from other storage technologies in that it has separate power (kW) and energy (kWh) scaling, as displayed in Figure 2. This helps save on cost because the size of a fuel cell or generator can be determined independently of the size of the volume of stored hydrogen. A 2019 study by the U.S. National Renewable Laboratory (NREL) found that green hydrogen for energy storage applications of 13 hours or more would make financial sense using today's technology. In the future, it is expected that costs for all energy storage systems will fall, but approaching the 13-15 hour mark, the capital costs for a hydrogen energy storage system are and will be lower than for Li-ion.

Green hydrogen can be produced from multiple renewable energy sources

A promising and scalable method for hydrogen production is electrolysis powered by renewable electricity from low-cost resources like solar and wind. Electrolysis uses renewable electricity to split water molecules into their elemen-

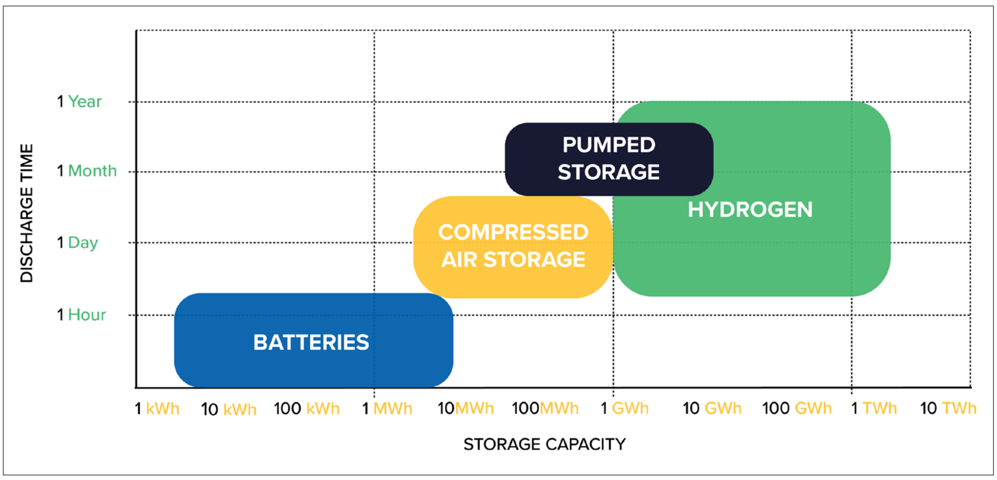

Figure 3. Energy storage capacity vs. discharge time for commercially available seasonal storage solutions

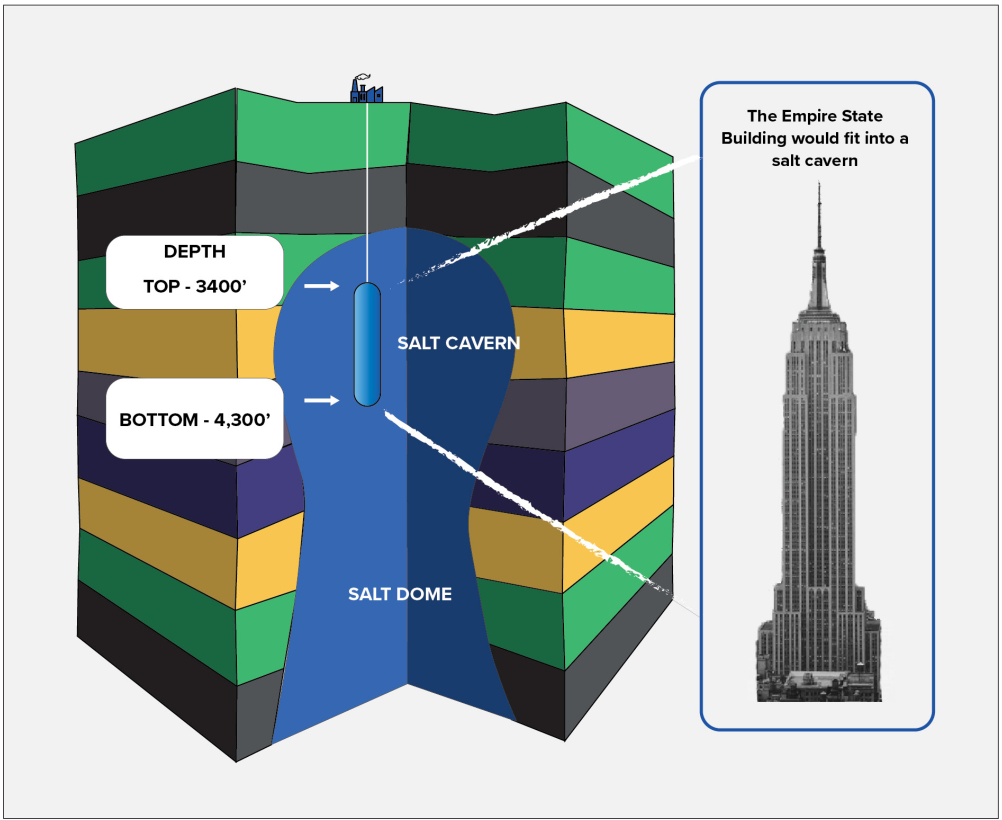

Figure 4. Green hydrogen can be stored in vast salt caverns

tal components: oxygen and hydrogen. The feedstock for green hydrogen is really that simple and abundant: water and clean energy. The process emits no greenhouse gases.

Green hydrogen gas can then be dispatched back to the grid in two ways: it can either pass through a fuel cell, or be combusted as a fuel in a gas turbine. Major turbine manufacturers such as Mitsubishi Hitachi Power Systems are developing hydrogen turbine technology which can replace the combustion units in coal and natural gas fired power plants. The main waste products fuel cells and hydrogen gas turbines are GHG-free: heat, power, and water.

Green hydrogen can also be made from biogas, via steam methane reformation or by thermally converting organic matter such as municipal and agricultural waste into a gaseous form that can be further refined into pure green hydrogen.

Green hydrogen can be stored at scale

Green Hydrogen can be stored via different methods and at different temperatures and pressures depending on the application; each storage method has tradeoffs related to location, scale, duration and cost. For example, hydrogen is already commercially stored in 100% dedicated hydrogen pipelines, as a blend in natural gas pipelines, in above ground stationary and mobile pressurised containers of various sizes, and in underground bulk storage facilities.

In large volumes, it is more cost-effective to use store hydrogen in bulk-storage facilities. Bulk storage can take advantage of natural geological formations such as salt caverns and depleted oil wells. This is a geographically limited opportunity but could bring great financial savings to storing large quantities of hydrogen.

Bulk underground hydrogen storage in salt caverns has been demonstrated as a safe and effective process in the US Since 2016, Liberty County Texas has been home to a very large Praxair underground hydrogen storage cavern. The subsurface Texas facility has a storage capacity of 20 MMCF (566,000 m^3) of hydrogen. Hydrogen is injected into the cavern at pressures over 1,000 psi. The facility is integrated into a 310-mile 100% hydrogen pipeline that serves over 50 refineries and chemical plants.

Bulk storage is an important part of the GHC’s first initiative. The GHC is working to support the successful conversion of Intermountain Power Project (IPP) in Delta, Utah, USA. IPP is an 1,800MW coal-fired power plant that is being converted to a combined cycle gas turbine that will initially run on 30% green hydrogen by volume, and ultimately 100% on or before 2045.

At IPP, electrolytic green hydrogen made from wind and solar will be compressed into a massive nearby salt cavern with a storage capacity for 150,000MWh of electricity (See Figure 4). Here, hydrogen gas can be stored for days, weeks, months, and even seasons to be dispatched on demand as a clean fuel for carbon-free gas turbine power generation. The storage capacity of the salt caverns in this location is tremendous - one cavern can hold 5,512 tons of hydrogen gas, equivalent to the hydrogen needed to fill 200,000 hydrogen powered buses, and over 100 such caverns can be built at this location. The stored hydrogen will be used to power a gas turbine that will support offtakers in the City of Los Angeles, California. The stored hydrogen may also potentially fuel transportation, decarbonise the natural gas pipeline, or support production of green ammonia.

Conclusion

Since I first started my search for the ideal seasonal energy storage solution back in 2016, much has changed in the energy world. I am pleased to see that in the last four years, green hydrogen has emerged as a key solution to seasonal energy storage, and to accelerating our low-carbon energy goals more generally. Almost every week it seems I hear about a significant new green hydrogen project. The frequency and size of new projects such as IPP are an indication of an irreversible and growing momentum for a global green hydrogen future. Green hydrogen will be a key solution in our ongoing energy transition and a great companion to drive and store more renewable energy.

Green hydrogen is the super game-changer that can provide bulk, multi-day and seasonal energy storage, and much more. ■

Author

Janice Lin is the founder and CEO of the Green Hydrogen Coalition and the founder and chief executive officer of Strategen. In 2009 she co-founded the California Energy Storage Alliance (CESA) and served as its executive director until 2019. More information on the Green Hydrogen Coalition’s work is available at www.ghcoalition.org