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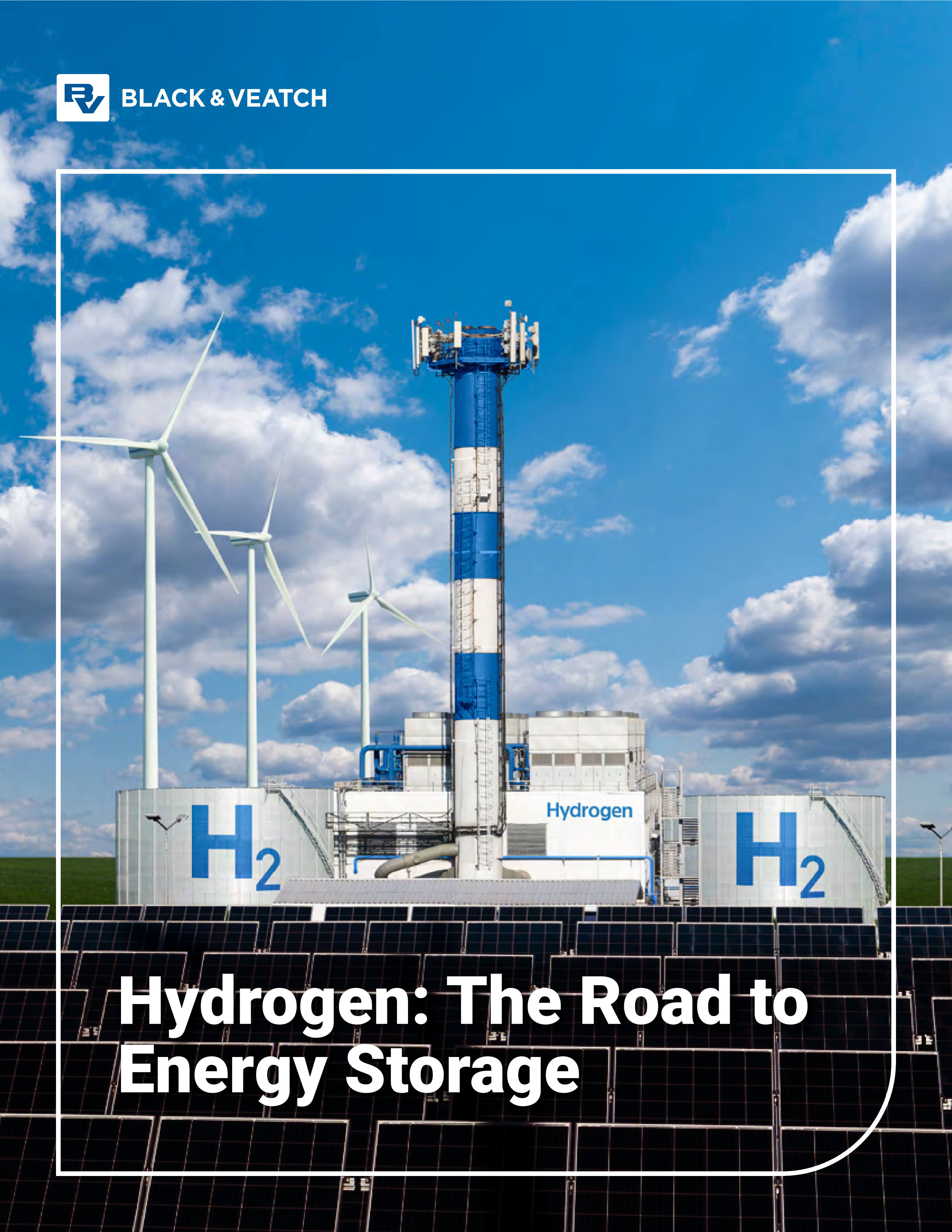

Hydrogen: The Road to Energy Storage

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Realizing the Potential of Hydrogen

Aggressive decarbonization and sustainability goals are driving unprecedented amounts of renewable energy onto the grid as the world scrambles to move towards low- and zero-carbon generation – with negative-carbon not too far behind. The International Energy Agency (IEA) claims that countries are shifting to renewable energy sources like solar and wind to minimize their dependency on imported fossil fuels, whose costs have skyrocketed, due to fears about energy security driven by geopolitical tensions. According to the agency, the capacity of renewable energy worldwide is predicted to increase by 2,400 gigawatts (GW) between 2022 and 2027, which is comparable to the existing power capacity of China.

Full-scale adoption of carbon-free electricity still hinges on successfully overcoming the notorious “v” word: variability. Variability issues remain a constant threat because nature doesn’t align with electricity needs.

Simply put, wind and solar produce energy on a schedule that is out of sync with consumer demand: Solar supply peaks at noon and onshore wind turbines peak in the middle of the night, but consumers tend to use electricity in the morning and evening as they start and end their day. Enter energy storage.

Lithium-ion batteries represent the primary focus for most consumer-level battery storage solutions such as portable electronics, automobiles and residential storage. Lithium-ion batteries support the day-shifting of energy, charging and discharging rapidly following variable renewable generation to offer four to eight hours of grid deployable power.

But the physical limitations of lithium-ion chemistry cannot extend past eight hours of storage discharging at rated power — not particularly helpful when the power cuts out and consumers are left without electricity for days — or when market economics encourage seasonal shifting, i.e., the Holy Grail of energy storage, which would allow us to use the electricity generated in warm, sunny July during the cold, dark months of February.

To unlock the full potential of renewable energy to cut carbon emissions, we need (cost-effective, utility-scale) long-duration energy storage, which is commonly defined as anything more than 10 hours of storage, but which consumers know can experience the need for days' worth of capacity.

There are few commercially feasible, economically viable, technically scalable [long-duration energy storage technologies] on the market. Pumped-hydroelectric storage (PHS) is one option. PHS is a safe, efficient, long-life and proven technology that facilitates the shift to renewables. Its advantages are compelling, especially for countries like Vietnam, Thailand and the Philippines, which have access to hydro capacities. PHS balances power generation and demand by storing energy for more than eight hours and dispatching it as needed. An additional benefit is it can utilize existing transmission lines for distribution thereby improving transmission efficiency.

When faced with insecure supply scenarios during recent decades, power providers have turned to natural gas as the stand-by/backup-fuel of choice. However, as the present energy crisis continues to impede global natural gas availability, the IEA suggests that Asia and other geographies reliant on importing natural gas address energy security issues alongside decarbonization targets by significantly increasing clean energy investment.

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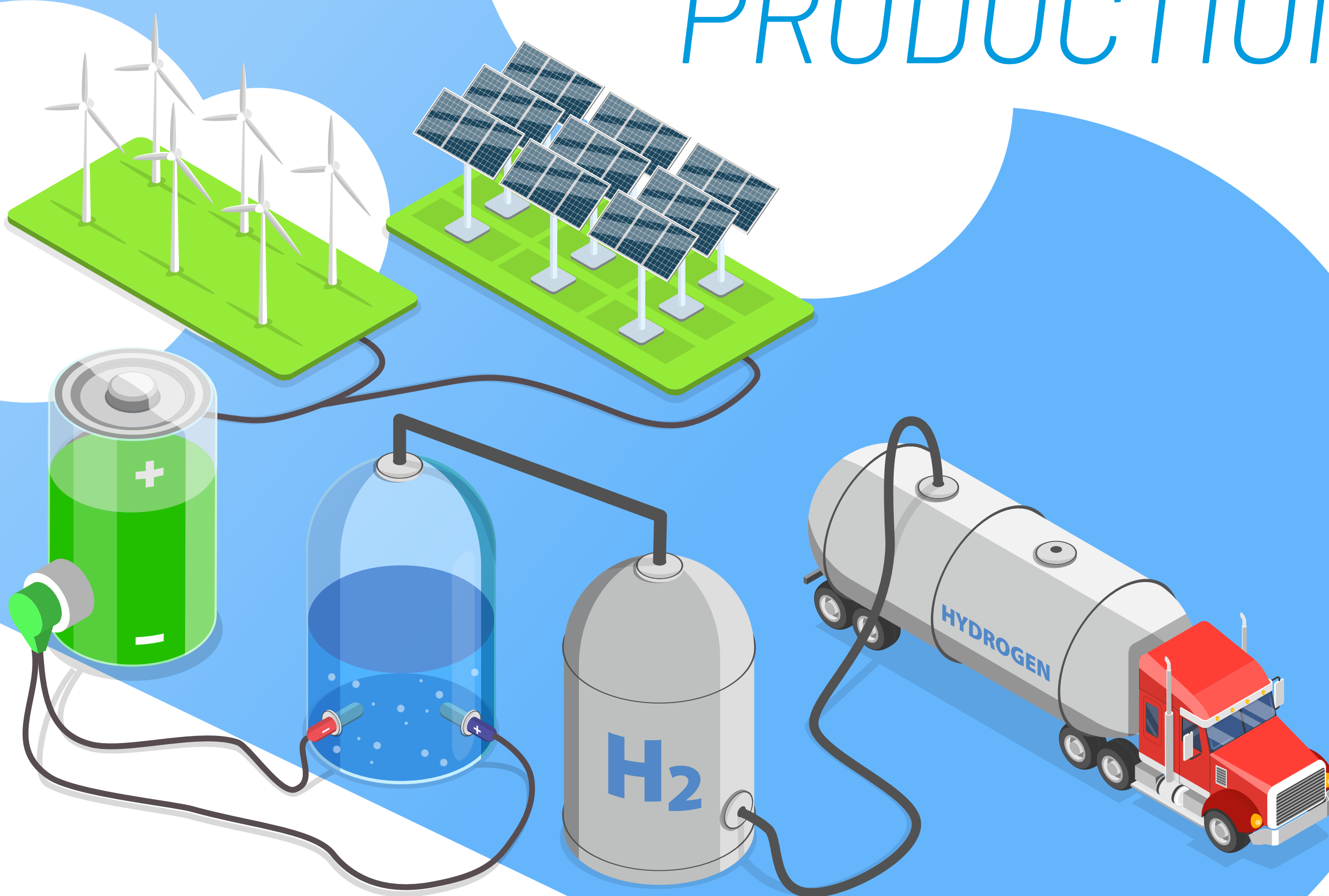
HYDROGEN PRODUCTION



In the zero-carbon future, a zero-carbon fuel is a solution. That fuel is hydrogen. Hydrogen does not occur by itself on earth the way natural gas (methane) does. Hydrogen has to be manufactured from either hydrocarbon fuels (CxHy) as is current practice, but this emits carbon dioxide, or alternatively hydrogen can be extracted from a very abundant resource, water (H20) as will be future practice, involving no carbon at all.

Thus the process power-to-gas (PtG or P2G) uses renewable electricity to decompose water into its elemental constituents that can be stored, transported and combusted to produce power, as either compressed gas or liquified – by combining hydrogen with the abundant nitrogen in the air to produce, of all things, ammonia (NH3). Hydrogen, either as a compressed gas or as liquid ammonia can be used to bridge the future gaps between supply and demand, with a zero carbon footprint.

Decarbonization targets aside, S&P Global reports that the economics around natural gas aren't necessarily working out anymore: "At an all-in electricity production cost of $132/MWh, a four-hour utility-scale battery is now priced below the global gas-peaker plant average at $173/MWh." Also, it is important to note "levelized cost of electricity" is typically $/MWh of electricity produced over the life of a facility. This makes natural gas far less attractive than it used to be, particularly as accessibility and duration aren't factored into the cost comparison.

Advanced Battery Technologies

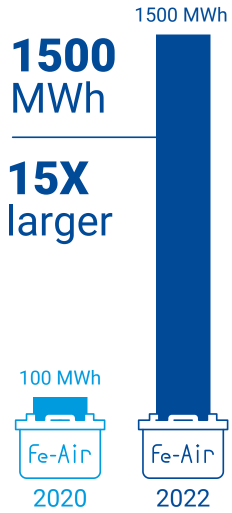
Lithium-ion batteries are the most popular energy storage option today, [controlling more than 90 percent of the global grid battery storage market], but other battery technologies — particularly those built on low-cost abundant materials like iron, zinc and sodium — are coming onto the market.

In early 2022, U.S.-based startup [Form Energy announced it would collaborate with Georgia Power] to deploy an energy storage project of up to 15 megawatts/1500 megawatt-hours using an iron-air battery that it says can offer up to 100 hours of electricity storage. This is [15x larger than the first pilot], announced in 2020 by Minnesota utility Great River Energy, which promised 1 MW/100 MWh.

This marks a tremendous leap forward from current storage projects and would provide backup power to cover more than 99 percent of all localized grid outages. But 100 hours is only about one week, and it isn't nearly enough to enable monthly or seasonal energy shifting.

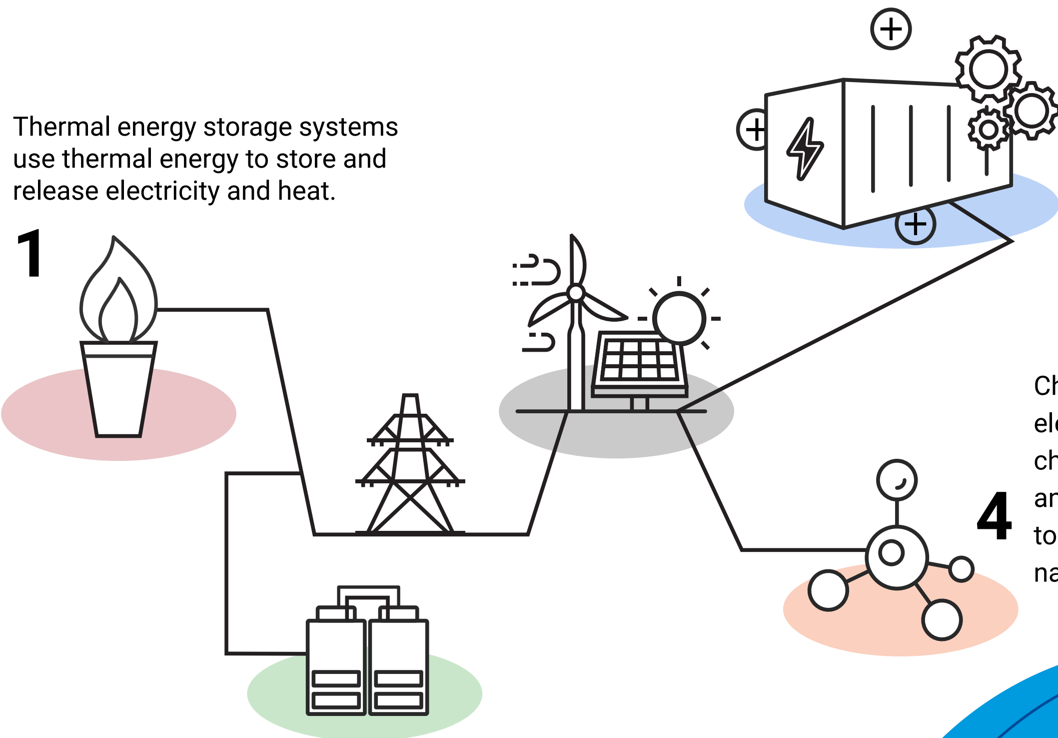
These batteries promise to store multiple days' worth of energy, won't degrade or catch on fire, and are more attractive against the rising raw material cost of lithium-ion battery cells (There is even a battery chemistry based on antimony, another low-cost element.)

A surge in funding for research and development has helped overcome many stubborn hurdles around iron and zinc batteries, and now we're seeing promising advancements. For example, [ZAF Energy Systems] is exploring nickel zinc batteries to support data centers — one of the fastest growing markets for energy storage — pushing beyond what was traditionally driven by lead-acid and lithium-ion energy storage.



Iron-air batteries derive their power from the interaction of iron and oxygen, which causes oxidation. AZO Materials reports that [iron-air batteries save more energy] than lithium-ion – 1,200 Wh/kg compared to 600 Wh/kg. Plus, they are extremely durable, capable of withstanding more than 10,000 full cycles from fully charged to completely discharged and back again (the charge life of lithium-ion is only 3,000 to 5,000 cycles).

There are four major categories of technologies to store energy:



Zinc batteries rely on a water-based electrolyte to charge and discharge, making them safer than potentially flammable lithium-ion, and [according to a 2020 scientific paper](), offer an energy density of up to 1,350 Wh/kg. Plus, the costs are much lower than lithium-ion; [Canadian-based start-up Zinc8]() reports that the capital cost of its eight-hour storage product is about \$250/kWh, declining to \$100/kWh for a 32-hour system and \$60/kWh for 100 hours. By contrast, lithium-ion projects cost about \$300/kWh for any duration over eight hours.

But the downside is that these iron and zinc batteries still don't achieve very long-duration energy storage – 100 hours is a huge improvement over lithium-ion's eight hours, but it is still not enough to enable that oh-so-critical seasonal shifting. Plus, the amount of storage capacity is directly tied to the size of the unit – increasing storage capacity would require increasing the size of the unit, making it more site constrained.

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Plus, it would be remiss to not mention that traditional battery energy storage is extremely mineral-intensive. According to [Canary Media](), batteries require the mining of 11 different mineral ores, from which everything from aluminum to zinc are refined. The article states: "Of all the clean-energy technologies set to boom in coming decades, none will put a strain on minerals supply like batteries. They account for about half of the projected growth in minerals demand over the next two decades in a rapid decarbonization scenario."

Hydrogen: A Step Towards Storage

This is where hydrogen steps in. Bringing batteries and hydrogen together can solve the energy storage issue in a fast, potentially economical manner. Hydrogen, as a form of chemical energy storage, can both complement and serve as a reliable alternative to batteries, particularly when considering that hydrogen prices will become more competitive going forward. And “green” hydrogen — produced through electrolysis of water powered by renewable energy — takes it one step further by offering a carbon-free solution.

To be economical, batteries need to be charged and discharged on a daily basis, discharging for a few hours. Hydrogen, on the other hand, can be produced continuously and stored, providing essentially very long duration storage, seasonal storage that can be used for backup power, limited only by storage volume capacity.

In tandem with batteries, hydrogen can be deployed when it’s needed, much like the natural gas or diesel backups in use today. This flexibility, and its feature as a carbon-free, mineral-free electricity generator provides premium benefits that offset the conversion losses as hydrogen is extracted from water, stored, then used in backup-up turbines or engines that are the conventional power equipment sources that produce electricity.

Small amounts of hydrogen (up to a few megawatt-hours) can be compressed and stored in pressure vessels or — with new technology — absorbed or adsorbed by solid metal hydrides or even advanced nanotubes. Very large amounts of hydrogen can be stored in underground salt caverns of up to 500,000 cubic meters at 2,900 psi, which would mean about 100 gigawatt-hours of stored electricity, says the Energy Storage Association.

Hydrogen can also be turned into “green ammonia” (ammonia, a liquid chemical consisting of nitrogen and hydrogen, can be produced using 100-percent carbon-free renewable energy). Liquid makes it easier to transport and store, especially when using existing liquified natural gas infrastructure. That ammonia can then serve as an energy storage medium, it can even be burned directly as a carbon-free, emissions-free energy source, or — being comprised of one nitrogen and three hydrogen atoms — “cracked” to convert it back into hydrogen, then used as described previously.

The hydrogen can then produce electricity used in engines, or in combined-cycle gas power plants, and even in devices called “fuel cells” that would use the hydrogen directly with the oxygen in air to produce electricity and heat, emitting only water vapor.

Hydrogen, on the other hand, can provide essentially infinite duration storage and backup power limited only by storage capacity

After touching on the mineral-intensity of traditional battery energy storage, it must be said that while hydrogen energy storage would still require minerals to build the electrolyzers that split water into hydrogen, that capital is a sunk cost; once the electrolyzer is built, it can process huge amounts of hydrogen for long periods of time (decades), unlike lithium and iron and zinc batteries, which will require an ongoing feed of minerals considering their shorter lifetimes.

Cost does remain an issue for hydrogen today. Although hydrogen offers several benefits above traditional battery energy storage, iron and zinc do win out when it comes to the number of dollars of capital cost required. Hydrogen hasn't yet reached the economies of scale that will bring costs down.

Further, there is an impact on energy efficiency at every stage of hydrogen's journey from conversion from H2O to H2 gasification and storage, and back to H20 when burned to produce power. But this is not uncommon for "energy carriers:" gasoline, diesel and jet fuel, batteries, and now elemental hydrogen. In each case, energy must be expended to produce an end product, even if the end product is an energy or fuel source. Even solar PV, today roughly 20 percent efficient, required advances in technology, engineering and manufacturing to get to a price point in the 2010s that would make them cost-competitive with fossil resources. That is the path for hydrogen to follow.

Another capability hydrogen offers that is unique to other storage technologies is its potential for direct uses, e.g., as a feedstock in the hard-to-carbon-abate cement, steel, chemical and petrochemical industries; as a zero-carbon fuel in fuel-cell vehicles; and to create synthetic fuels (i.e., "e-fuels") ranging from methanol to gasoline to sustainable aviation fuel. This makes hydrogen even more valuable by enabling multiple revenue streams. It could be that by mid-century hydrogen will be as ubiquitous in our society as potable water, electricity and the internet.

Intermountain Power Project

Intermountain Power Agency's (IPA) Intermountain Power Project (IPP) Renewal Project stands as a potential case study for a long-duration hydrogen energy storage project.

In 2020, IPA selected Black & Veatch to serve as Owner's Engineer on the project, which stands as one of the earliest installations of combustion-turbine technology designed to use a high percentage of green hydrogen.

The IPP Renewal Project involves retiring IPA's original coal-fueled facility, which Black & Veatch designed in the early 1980s, and replacing it with an 840-megawatt natural gas-fueled combined cycle power plant in 2025.

The two single-shaft advanced-class combustion turbine combined cycle units will be commercially guaranteed capable of blending 30-percent green hydrogen at start-up, with plans to increase hydrogen utilization to 100-percent hydrogen by 2045.

Perhaps more intriguing is that the IPP Renewal Project envisions development of long-duration hydrogen storage in geologic salt caverns that are adjacent to the power plant, which would result in a fully dispatchable resource capable of providing highly reliable and resilient power on demand.

Making Hydrogen Energy Storage a Reality

So, now that we've determined that iron and zinc batteries offer terrific medium-duration energy storage (up to 100 hours) and that hydrogen can offer the potential for unlimited amounts of long-duration energy storage, the question comes down to: What needs to happen to move hydrogen energy storage technologies forward?

First and foremost, hydrogen energy storage projects need to be demonstrated and then scaled, ultimately with the support of power utilities and power generation providers. Demonstrating that hydrogen technology can scale will help move it forward, lowering the cost. The green hydrogen hub at the Advanced Clean Energy Storage Project in Delta, Utah will be a true test of this in the marketplace. The project would interconnect green hydrogen production, storage and distribution in the West, helping to decarbonize multiple industries including power, transportation and manufacturing.

True adoption will also require regulatory changes and government incentives. The more that the government can incentivize utilities to start a clean transition to long-duration energy storage, the more successful we will be. It's already happening with renewable energy – according to Black & Veatch's *2021 Electric Report*, which is backed by a survey of nearly 500 U.S. power sector stakeholders, 56 percent of respondents say that government incentives or policies are driving renewable energy investments in their region. The same, we expect, will hold true for long-duration energy storage.

Effort is underway; the DOE is actively working move long-duration energy storage technologies forward. Last year, the agency launched its Energy Earthshots Initiative, designed to "accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade."

The first two Energy Earthshots seek to lower the costs of two promising clean energy technologies within the next decade: Hydrogen Shot seeks to lower the cost of clean hydrogen by 80 percent to $1 per kilogram, while Long-Duration Storage Shot aims to cut the cost of grid-scale, long-duration energy storage by 90 percent. Programs such as these will be absolutely critical in helping to move long-duration energy storage forward.

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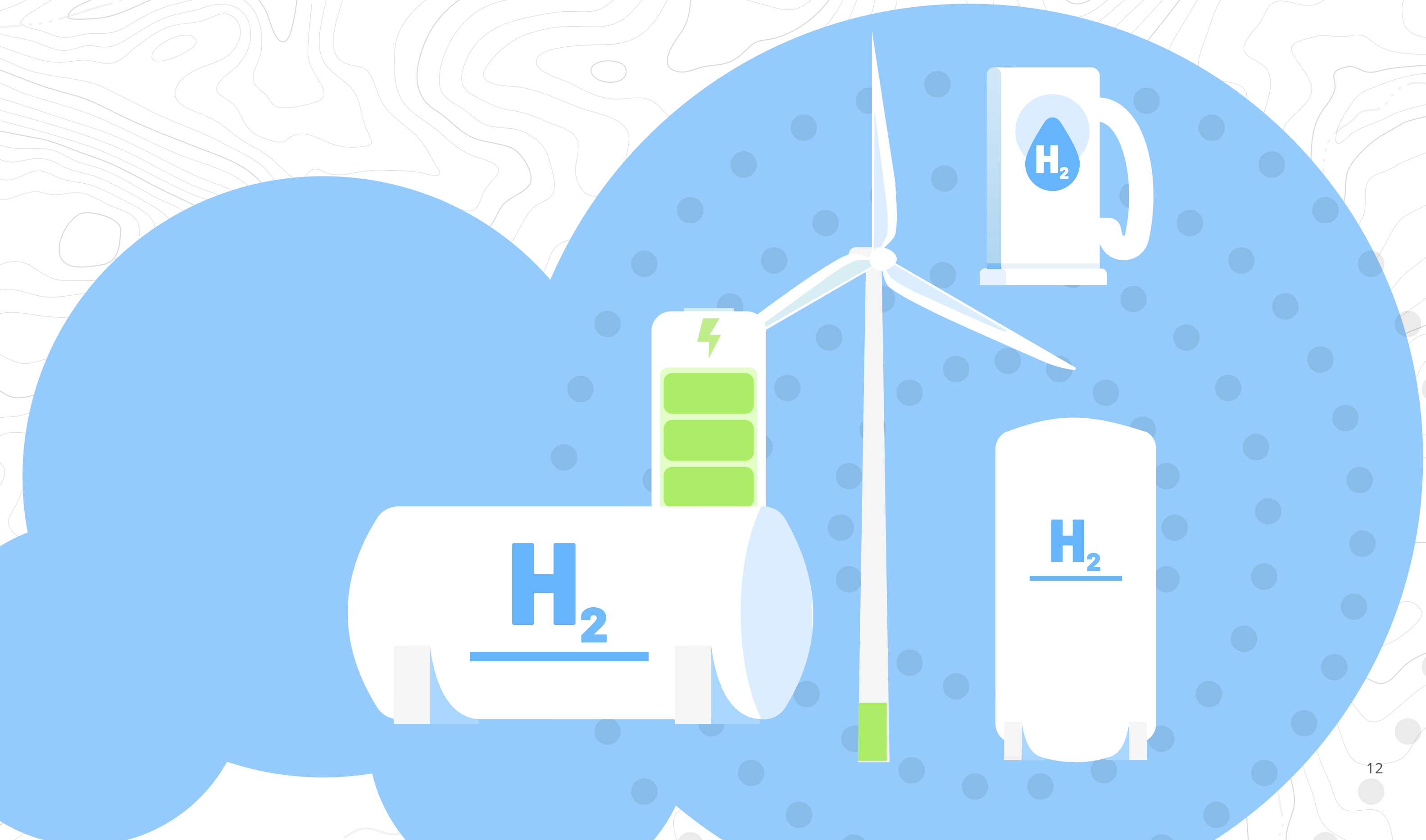
The Path Forward

The global energy marketplace is hungry for long-duration energy storage technologies as renewables continue to grow and become the leading contributor to electricity generation. While the headlines make it sound as though these technologies are ready to go tomorrow, we're still in a period of exploration and development as the market tries to understand where the technology stands right now, it is also working to corral the rollercoaster of expectations around energy storage options, which are many.

Hydrogen isn't a "today" technology, but it is coming down the pike, and when it does, the entire energy game will change. With viable medium-duration energy storage options such as iron and zinc batteries on the table right now, stakeholders would be wise to be looking at methods to create flexible, complementary systems that can evolve as technologies advance.

In the next five to seven years, expect to see a rapid increase in the viability, scalability and availability of medium- and then long-duration storage solutions … as long as the market remembers to avoid the worst mistake possible: getting enamored by one technology and not considering the alternatives and successors (have you used your Blackberry lately?).

Long-duration energy storage is a key that will help unlock global decarbonization. And with traditional and emerging battery energy storage and with hydrogen energy storage both on the table, we'll soon arrive a future where electricity can be generated and stored, then balanced and managed according to demand, thus enabling tomorrow's net-zero future.



To Learn More

To talk to a decarbonization planner, connect with us at bv.com/hydrogen.

Black & Veatch is an active industry advocate for the hydrogen economy including membership of the Hydrogen Council, Fuel Cell Hydrogen & Energy Association, California Hydrogen Business Council, Center for Hydrogen Safety, and Ammonia Energy Association.

Invisible. **Invaluable.**

You can't see hydrogen, a zero-carbon fuel that emits only water, but you can't look past its potential as the world confronts its energy challenges. Black & Veatch is developing the first U.S. hydrogen power generation conversion project, having already developed the first major hydrogen fueling station network.

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