HYDROGEN FOR SEASONAL ELECTRICITY STORAGE

Prospects

UNCERTAIN

This fact sheet is part of an Energy Innovation paper assessing clean hydrogen's value for cutting climate pollution from 12 end uses. The full report includes context, analysis, policy recommendations, and citations—see QR code or link at bottom.

Hydrogen can serve long-duration energy storage needs but carries public health risks.

NOTE: *This should be compared with the "Day-to-Day Power Generation" overview.*

CONTEXT: Achieving a fully clean electricity system with a high share of variable renewable energy resources will require complementary long-duration energy storage (LDES) services. In particular, the grid will need seasonal to multi-annual energy storage capacity, with the former primarily shifting wind and solar generation from high- to low-output months, and the latter primarily shifting hydro generation from wet to dry years. Electrolyzers can use excess clean energy to make hydrogen, which can then be stored at large volumes over long periods.

INFRASTRUCTURE NEEDS: Combustion turbines can burn hydrogen for power, but a core challenge is controlling emissions of nitrogen oxide (NOx)—a pollutant that harms the respiratory system. Today, new or modified turbines can burn 100 percent hydrogen with high NOx emissions (conventional "diffusion" combustion) or co-fire up to 50 percent hydrogen with natural gas with lower NOx emissions (newer "lean premix" combustion). However, it will be critical to achieve 100 percent hydrogen use with near-zero NOx emissions.

Hydrogen for LDES implies the use of "peaker" power plants that run infrequently but can quickly adjust their operations. Facilities predicated on running more often (e.g., combined cycles) don't make sense for hydrogen, as their frequent use would imply electrolyzing hydrogen in many of the same hours that it's being burned for power. Only LDES services justify hydrogen's inefficiencies for power.

Fuel cells can also use hydrogen to generate power, notably more efficiently than combustion and with no harmful emissions. Cost and performance obstacles at scale currently make them better suited for distributed than centralized power, though the latter may improve with time. Fuel cells can provide backup power for critical facilities (e.g., hospitals) where batteries might be too expensive for keeping large complexes online for long periods, but these cases are rare enough to refuel on-site hydrogen storage tanks via trucks rather than build pipelines.

In general, power plants are unlikely to someday gain access to readily available hydrogen via pipeline—instead, utilities should have clear plans for how hydrogen will be electrolyzed and stored, as they will likely need to provide or procure the clean power for electrolysis. Such plans may include new or repurposed hydrogen pipelines where they allow power plants to access underground storage sites like salt dome caverns, which have very large capacities and lower costs but are geographically limited. Pipelines can also connect other high-value hydrogen users in tight industrial clusters. This allows for "sector coupling," where power plants can use more hydrogen in some periods and put more hydrogen into the pool in others. Flexibility by other customers in their hydrogen use can then reduce storage costs for the whole cluster.

SOCIAL IMPACTS: Hydrogen for LDES faces two main risks. First, developers may pursue "hydrogen-ready" peakers without a clear plan for switching to 100 percent clean hydrogen. Falling short can drive overinvestment in natural gas on the premise of these plants someday being clean. Second, developers may fail to adequately control NOx emissions. Peakers are disproportionately located in low-income neighborhoods and communities of color, where they considerably worsen health outcomes even when emitting at permitted rates.

COMPETING TECHS: Two types of competing technologies exist for this end use—other storage resources that can act as LDES, and energy resources that shrink the need for storage.

There are four classes of technologies that can provide LDES: (1) **mechanical storage** like pumped hydro or compressed air energy storage; (2) **electrochemical storage** like iron-air or flow batteries; (3) **thermal storage**; and (4) **chemical storage** like hydrogen and its derivatives (e.g., ammonia). Many hold an edge over hydrogen in higher round-trip efficiency or having no risk of harmful emissions. However, hydrogen's relative competitiveness improves at seasonal and multi-annual durations and when it can take advantage of sector coupling.

Other technologies can cut the need for LDES by complementing variable renewable energy. Emerging options include **enhanced geothermal** and **advanced nuclear**, which can run around the clock or follow changes in electricity demand. **Carbon capture** may also play a role, particularly if it can fully eliminate on-site emissions (e.g., Allam Cycle plants) and use biofuels. However, any use of natural gas would suffer from upstream methane leakage, and biofuel combustion or gasification brings its own health-harming emissions challenges.

TAKEAWAY: Regulators should require a very high burden of proof of hydrogen power plants' value on cost, feasibility, public health, and equity metrics relative to competing technologies. Proposals should be limited to seasonal storage applications, include detailed plans for how and from where utilities will procure clean hydrogen, and ensure that power plants will be capable of using 100 percent hydrogen with ultra-low to zero NOx emissions. This will require sites with high variable renewable energy penetration (to justify the need for LDES) and low-cost geologic storage; it will also depend on the successful development of cost-effective fuel cells or low-NOx hydrogen combustion systems. In most U.S. jurisdictions, LDES needs are still many years away, meaning regulators need not make big bets on hydrogen today—especially since doing so could lock in fossil fuel infrastructure if it fails to pan out.

FURTHER READING:

- Ann Collier, Dan Esposito, Trevor Gibson, and Lakin Garth, "Insight Brief: Clean Hydrogen for the Electric System," Smart Electric Power Alliance and Energy Innovation, April 2024, https://energyinnovation.org/publication/insight-brief-clean-hydrogen-for-the-electric-system/
- Long Duration Energy Storage Council, "The journey to net-zero: An action plan to unlock a secure, net-zero power system," June 2022, https://www.ldescouncil.com/assets/pdf/journey-to-net-zero-june2022.pdf
- Ghassan Wakim and Kasparas Spokas, "Hydrogen in the Power Sector: Limited Prospects in a Decarbonized Electric Grid," Clean Air Task Force, June 2024, https://www.catf.us/resource/hydrogen-power-sector/
- **Featured story:** Sammy Roth, "This tiny Utah town could shape the West's energy future," *Los Angeles Times*, May 19, 2022, https://www.latimes.com/environment/newsletter/2022-05-19/this-tiny-utah-town-could-shape-the-wests-energy-future-boiling-point
- **Full report:** https://energyinnovation.org/publication/hydrogen-policys-narrow-path-delusions-and-solutions