CARNEGIE SCIENCE

RESEARCH BRIEF

JULY 2024

KEY POINTS FOR DECISION-MAKING

- **Curtailed power may provide opportunities for low-efficiency hydrogen storage systems.** In electricity systems that feature abundant zero-cost electricity, such as when wind and solar generation exceed mean demand, costs related to hydrogen storage are not highly sensitive to an efficient use of otherwise-curtailed power, but they are sensitive to capital cost reductions.

- **Underground hydrogen storage may provide value in deeply decarbonized (>85%) systems.** Underground hydrogen storage ($2/kWh) can reduce electricity costs in wind and solar systems with natural gas dispatch limited to 15%.

- **Existing underground gas storage facilities may provide ample hydrogen energy storage at national scale.** If about half the U.S. underground storage capacity for natural gas were repurposed for pure hydrogen, that half (175 of 327 TWh available) could provide national-scale seasonal energy storage in a 100% reliable wind-solar-hydrogen electricity system.

Underground gas storage facilities may be repurposed for hydrogen

Hydrogen energy stored underground can reduce system costs despite low efficiency

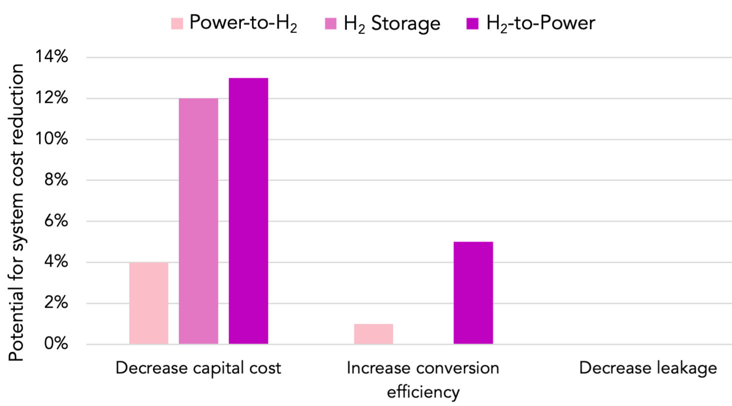
To build least-cost electricity systems, it's key to understand the value of capital cost reductions relative to round-trip efficiency improvements in systems with abundant curtailed power. In contrast to battery storage systems, power-to-hydrogen-to-power (P-H_2-P) storage systems provide opportunities to separately optimize the costs and efficiency of the system's charging, storage, and discharging components.

We used a macro-energy model to evaluate the sensitivity of system costs to techno-economic characteristics of P-H_2-P systems in stylized wind-solar-battery electricity systems with restricted natural gas generation. Assuming current costs and current round-trip P-H_2-P efficiencies, the least-cost wind and solar electricity systems have large amounts of excess renewable generation capacity. These systems included P-H_2-P in the least-cost solution, despite its low round-trip efficiency and relatively high P-H_2-P power discharge costs. These electricity system costs are not highly sensitive to the efficient use of otherwise-curtailed power, but are sensitive to the capital cost of the P-H_2-P power discharge component. If the capital costs of the charging and discharging components were decreased relative to generation costs, curtailment would decrease, and electricity system costs would become increasingly sensitive to improvements in the P-H_2-P round-trip efficiency.

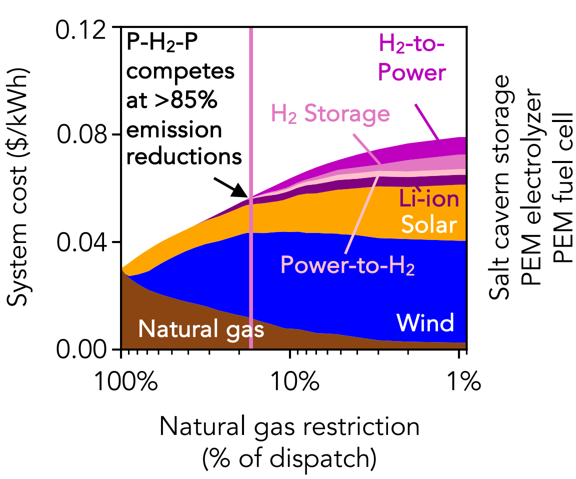
These results suggest that capital cost reductions, especially in the discharge component such as in fuel cells, should be a key priority for innovation in P-H_2-P systems for applications in electricity systems dominated by wind and solar generation.

Summary

Our results suggest that hydrogen storage systems can decrease the costs of reliable wind and solar electricity systems, despite very low round-trip efficiencies. Reducing capital costs of hydrogen energy storage and conversion would reduce wind- and solar-based electricity-system costs more than would round-trip efficiency improvements. We find that ample U.S. hydrogen storage capacity could be obtained by repurposing depleted natural gas reservoirs currently used for seasonal storage. We conclude that capital cost reductions can allow hydrogen storage systems to cost-effectively complement electricity systems reliant on wind power and solar power.



Greater opportunity for P-H_2-P capital cost improvements than efficiency improvements in reducing system costs. Percentages show the wind and solar system cost reduction (value of innovation) from current commercially available hydrogen conversion and storage technologies to theoretical zero capital cost technologies or theoretical 100% efficient technologies.



Underground hydrogen storage may provide value in least-cost wind- and solar- based systems in cases with deep (>85%) emission reductions. Salt cavern storage ($2/kWh) competes with natural gas at >85% decarbonization. For comparison, hydrogen storage in tanks ($15/kWh) is cost-effective in only >95% carbon-free systems.

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This brief is based on the paper "**Opportunities and constraints of hydrogen energy storage systems**" published in *Environmental Research: Energy* (2024).

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