Clean Energy Group

The Drawbacks of Liquid Hydrogen

Interest in hydrogen for energy generation and energy storage is increasing across the country, fueled in part by the past promises of federal funding and the potential to reuse existing fossil fuel infrastructure and supply frameworks. However, hydrogen—the lightest and least dense element—is notoriously difficult to transport and store as a gas. While hydrogen is touted for its high energy density by weight, its energy density by volume is extremely low. To deliver the same amount of energy as natural gas, three times the volume of hydrogen gas is needed.

Liquid hydrogen is denser than hydrogen gas, theoretically making its storage and transportation easier. However, there are efficiency, cost, and safety issues associated with liquid hydrogen production and use that may introduce more problems than it solves.

Liquefying hydrogen exacerbates existing high costs and low efficiency

The process of converting hydrogen gas to a liquid, called liquefaction, compounds the existing costs and inefficiencies of gaseous hydrogen production. Due to the extremely low temperature necessary for hydrogen to change from gas to liquid, huge amounts of energy are needed for cooling and maintaining the temperature to keep the hydrogen in a liquid state for an extended period of time. Costs related to production and the specialized materials needed for storage and transport make hydrogen liquefaction a very expensive process.

- Hydrogen liquefaction requires cooling gaseous hydrogen to −253°C (−423°F) where it becomes liquid. This process more than triples the volumetric energy density of hydrogen from 0.69 kWh per liter to 2.36 kWh per liter (source).
- Cooling hydrogen down to −253°C consumes a sizable amount of energy. The average amount of energy needed by large hydrogen liquefaction plants in service today is 13.8 kWh per kilogram of liquid hydrogen, over 35 percent of the stored energy in the fuel itself (source 1, source 2). For comparison, natural gas liquefies at −164°C, requiring less energy for liquefaction. Significant energy is also needed to keep hydrogen below its vaporization point, the temperature above which it becomes a gas again.
- The liquefaction process is inefficient. In operational liquefaction facilities, over two-thirds of the energy input is wasted throughout the process (source 1, source 2).
- The cost of liquefaction is around \$2.5-\$3 per kilogram of hydrogen (source). This is in addition to the high cost of hydrogen production, which, if produced with electrolyzers powered by renewable energy, can cost up to \$7.39 per kilogram of hydrogen (source), resulting in a combined cost of around \$10 per kilogram.
- The storage and transport of liquid hydrogen require highly specialized materials that are resistant to both cryogenic temperatures and hydrogen's tendency to create cracks in steel and iron. Double walled vessels have proven to be the most insulating, requiring even more material for hydrogen storage (source).

Liquid hydrogen evaporates rapidly throughout storage and transport

Around 1-5 percent of stored liquid hydrogen is lost per day due to evaporation. When liquid hydrogen reaches temperatures above −253°C it turns back into a gas, expanding by a factor of around 848 (source). This expansion rate rapidly increases pressure within the tank, raising the risk of an explosion and requiring the gas to be vented out of the

— continue on page 3 —

Concerns about Liquid Hydrogen

Liquid hydrogen is gaining attention as a storage and transport solution for notoriously leak-prone, low-density hydrogen gas. Liquefying hydrogen exacerbates the same cost and efficiency concerns present with hydrogen gas and introduces new problems related to hydrogen losses and safety.

ENERGY CONSUMPTION

Hydrogen gas must be cooled to extremely low temperatures to turn into a liquid, requiring a huge amount of energy to reach and maintain these temperatures. Hydrogen liquefaction is inefficient, and a substantial amount of energy is lost during the process.

HIGH COSTS

It costs around \$2.5–\$3 to liquefy one kilogram of hydrogen. If the hydrogen is produced through electrolysis using renewable energy, the total cost could reach \$10 per kilogram of liquid hydrogen.

STORAGE AND TRANSPORTATION

Storage and transport of liquid hydrogen requires specialized equipment and materials that can both withstand cryogenic temperatures and prevent the cracks and fractures caused by hydrogen. These materials and equipment are costly.

LOSSES DUE TO EVAPORATION

About 1-5 percent of stored liquid hydrogen evaporates and turns back into gas every day. This hydrogen is typically vented out of the storage tank or truck. Evaporation is inevitable due to heat from the environment, movement, and molecular changes in the hydrogen itself.

GLOBAL WARMING IMPACT

Hydrogen is an indirect greenhouse gas that will greatly contribute to global warming if it enters the atmosphere. Storing and transporting liquid hydrogen results in the purposeful release of evaporated hydrogen gas and exacerbates this issue.

SAFETY CONCERNS

The extremely low temperatures needed to maintain liquid hydrogen can introduce risks of frostbite, suffocation, hypothermia, and asphyxiation for workers if there is a leakage.

vessel. This evaporation and venting are inevitable as stored liquid hydrogen is exposed to heat from a variety of sources:

- **Heat transfer:** The stored liquid hydrogen will be exposed to some heat from the surrounding environment. No insulation can fully protect from this, though there are specifics related to materials, design, and size of the storage compartment that can help to reduce heat transfer and the subsequent evaporation (source).
- **Sloshing:** During transportation, heat is generated through the movement of liquid hydrogen in the tank, resulting in evaporation (source).
- **Flashing:** When liquid hydrogen is transferred from a high-pressure transportation tank to a lower- pressure storage tank, some hydrogen undergoes evaporation. During these transfers, 10–20 percent of the hydrogen may be lost (source).
- **Hydrogen conversion:** In its gaseous state, hydrogen exists in two different forms. These two types of hydrogen molecules are exactly the same except for the direction in which the molecule's two protons spin. When hydrogen is cooled down to a liquid, the percentage of each of these types of hydrogen, called spin isomers, changes and one spin isomer converts to another. This conversion is exothermic, meaning that it gives off heat, resulting in a constant cycle of evaporation. During liquefaction, this conversion is catalyzed to reduce evaporation, extending the time that liquid hydrogen can be stored but not fully mitigating the issue (source 1, source 2).

This inescapable evaporation is not just an issue for efficiency and the economic viability of liquid hydrogen production. Because hydrogen itself is an indirect greenhouse gas, releasing it into the atmosphere contributes to climate change. Some of the evaporated hydrogen can be captured and burned, but this is not a universal practice. See CEG's Hydrogen's Global Warming Impacts factsheet for more information on the greenhouse gas effect of hydrogen.

Liquid hydrogen heightens safety concerns

Due to its chemical properties, transporting, storing, and handling hydrogen is more dangerous compared to other fuels. It has a wider flammability range, a lower auto-ignition temperature, and can create cracks and fractures in steel and iron materials, a phenomenon called hydrogen embrittlement. Liquid hydrogen exacerbates some of these existing issues and introduces new ones.

- The extremely low temperature needed to maintain hydrogen as a liquid comes with added safety concerns. These cryogenic temperatures introduce risks like frostbite, suffocation, hypothermia, and asphyxiation to workers during a leakage incident (source).
- Extremely low temperatures decrease the ability of certain materials to withstand damage. This can compound with hydrogen embrittlement and increase the risk of a crack or rupture (source 1, source 2).
- An accidental leak or release of liquid hydrogen could result in a variety of ignition events (source). Liquid hydrogen disperses less quickly compared to gaseous hydrogen, so it is more prone to combine with air to form a flammable mixture, potentially leading to an explosion (source).

Hydrogen, in both liquid and gaseous states, has limited climate beneficial uses

Liquefying hydrogen for higher density transport and storage relies on the assumption that gaseous hydrogen is a useful and efficient energy source. Producing, transporting, and using gaseous hydrogen is not only costly and inefficient, it can also increase emissions and delay climate action. Using even more energy to liquefy hydrogen plus losing a significant percentage of it through evaporation further compounds the inadequacies of hydrogen as a source of energy storage and generation. Liquid hydrogen is currently being used as rocket fuel and to cool superconductors, but expanding its use cases to hydrogen storage, aviation, and maritime shipping, as is proposed by industry, is not likely to yield beneficial results.

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To learn more about other harms associated with hydrogen's production and use, visit www.cleanegroup.org/initiatives/hydrogen.