

Overview

Hydrogen has the highest energy content per unit of weight of any known element. It is also the lightest element. As a result, it is characterized by low volume energy density, meaning that a given volume of hydrogen contains a small amount of energy. This presents significant challenges to storing the large quantities of hydrogen that will be necessary in the hydrogen energy economy.

A critical challenge for transportation applications is balancing the need for a conventional driving range (>480 km) with the vehicular constraints of weight, volume, efficiency, safety, and the cost of on-board hydrogen storage systems. A second set of challenges for transportation applications relate to durability over the performance lifetime of on board storage systems.

To overcome the on-board storage challenge, an alternative may be on-board reformation of higher density fuels such as natural gas, gasoline, and methanol. An added benefit of this approach is that it does not require the development of new distribution infrastructure for pure hydrogen. However, on board reformation of higher density fuels results in the emission of carbon dioxide, although in lesser quantities than the traditional use of these fuels.

Hydrogen Storage Today

Today, hydrogen for transportation applications is compressed and stored in high-pressure metal and composite storage tanks. Hydrogen is also stored by cooling it to its liquid form and containing it in super-insulated tanks.

- **High-pressure tanks** can be used to store hydrogen. Today, compressed hydrogen tanks for 5,000 psi (~35 MPa) and 10,000 psi (~70 MPa) have been certified worldwide according to ISO 11439 (Europe), NGV-2 (U.S.), and approved by TUV (Germany) and The High-Pressure Gas Safety Institute of Japan (KHK). However, driving ranges for compressed tanks remain inadequate and the energy consumed to compress the hydrogen reduces the efficiency of this storage media. The weight

and size of the tanks are also an impediment to this application.

- **Liquefied Hydrogen** -- The energy density of hydrogen can be improved by storing hydrogen in a liquid state. However, hydrogen losses become a concern and improved tank insulation is required to minimize losses from hydrogen boil-off. In addition, advances in liquefaction efficiencies are required to reduce the energy required to cool and liquefy hydrogen gas.

Future Storage Technologies

Current research on future storage technology includes:

- **Metal hydride** technology uses metals and metal alloys to adsorb hydrogen under moderate pressure and temperature, creating hydrides. A metal hydride tank contains a granular metal, which adsorbs hydrogen and releases it with the application of heat. The heat may be supplied as excess heat from a fuel cell. Conventional high capacity metal hydrides require high temperatures (300°-350°C) to liberate hydrogen, but sufficient heat is not generally available in fuel cell transportation applications.
- **Chemical hydride** slurries or solutions can be used as a hydrogen carrier or storage medium. The hydrogen in the hydride is released through a reaction with water. Chemical hydride systems are irreversible and require thermal management and regeneration of the carrier to recharge the hydrogen content. An essential feature of the process is recovery and reuse of spent hydride at a centralized processing plant. Research issues include the identification of safe, stable, and pumpable slurries, and the design of the reactor for regeneration of the spent slurry.
- **Carbon nanotubes** are microscopic tubes of carbon, two nanometers (billionths of a meter) across, that store hydrogen in microscopic pores

on the tubes and within the tube structures. Similar to metal hydrides in their mechanism for storing and releasing hydrogen, they hold the potential to store a significant volume of hydrogen. However, the amount of storage and the mechanism through which hydrogen is stored in these materials are not yet well-defined.

Challenges

The principal challenges to improving hydrogen storage technologies relate to increasing their efficiency, size, weight, capacity and, ultimately, their cost. Durability remains an issue, as does the development of unified international codes and safety standards to facilitate safe deployment of commercial technologies.

- **Cost.** The cost of on-board hydrogen storage systems is currently too high, particularly in comparison with conventional storage systems for petroleum fuels. Low-cost materials and components for hydrogen storage systems are needed, as well as low-cost, high-volume manufacturing methods.
- **Weight and Volume.** The weight and volume of hydrogen storage systems are presently too high, resulting in inadequate vehicle range compared to conventional petroleum fueled vehicles. Materials and components are needed to allow compact, lightweight hydrogen storage systems that allow driving ranges similar to those available today for light-duty vehicle platforms.
- **Efficiency.** Energy efficiency is a challenge for all hydrogen storage approaches. The energy required to get hydrogen in and out of storage

is an issue for reversible solid-state materials storage systems. In addition, the energy associated with compression and liquefaction must be factored in when considering compressed and liquid hydrogen storage technologies.

- **Durability.** The durability of some hydrogen storage systems is inadequate. Materials and components are needed that allow hydrogen storage systems with a lifetime in excess of 1,500 refueling cycles.
- **Refueling Time.** Refueling times are currently too long. There is a need to develop hydrogen storage systems with refueling times of less than three minutes, over the lifetime of the system.
- **Codes & Standards.** Applicable codes and standards for hydrogen storage systems and interface technologies, which will facilitate implementation/commercialization and assure safety and public acceptance, have not yet been established. Standardized hardware and operating procedures are required.

IPHE partners are collaborating to reduce the challenges to hydrogen storage technologies and advance toward the hydrogen economy. For more information, please visit www.iphe.net.