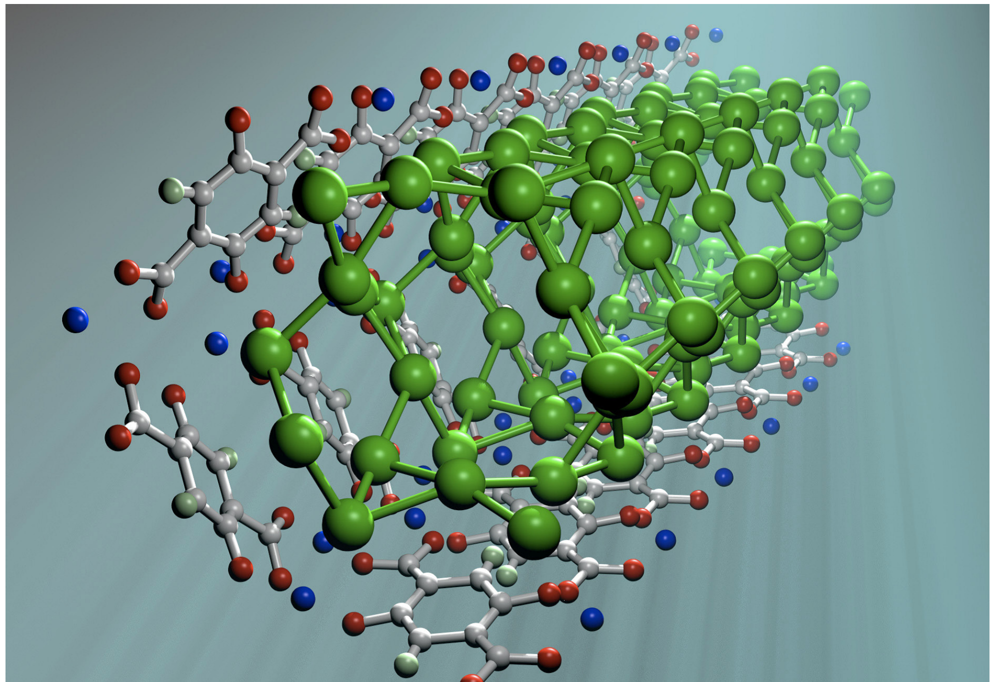
Hydrogen Storage

Developing safe, reliable, compact, and cost-effective hydrogen storage technologies is one of the most technically challenging barriers to the widespread use of hydrogen as a form of energy. To be competitive with conventional vehicles, hydrogen-powered cars must be able to travel more than 300 mi between fills. This is a challenging goal because hydrogen has physical characteristics that make it difficult to store in large quantities without taking up a significant amount of space.



Hydrogen can be stored on the surfaces of solids by adsorption. In adsorption, hydrogen associates with the surface of a material either as hydrogen molecules (H_2) or hydrogen atoms (H). This figure depicts hydrogen adsorption within MOF-74.

Where and How Will Hydrogen be Stored?

Hydrogen storage will be required onboard vehicles and at hydrogen production sites, hydrogen refueling stations, and stationary power sites. Possible approaches to storing hydrogen include:

- Physical storage of compressed hydrogen gas in high pressure tanks (up to 700 bar);
- Physical storage of cryogenic hydrogen (cooled to -253°C, at pressures of 6-350 bar) in insulated tanks; and
- Storage in advanced materials — within the structure or on the surface of certain materials, as well as in the form of chemical compounds that undergo a chemical reaction to release hydrogen.

What Are the Challenges?

Hydrogen has a very high energy content by weight (about three times more than gasoline), but it has a very low energy content by volume (liquid hydrogen is about four times less than gasoline). This makes hydrogen a challenge to store, particularly within the size and weight constraints of a vehicle.

A light-duty fuel cell vehicle will carry approximately 4-10 kg of hydrogen on board (depending on the size and type of the vehicle) to allow a driving range of more than 300 mi, which is generally regarded as the minimum for widespread public acceptance. Drivers must also be able to refuel at a rate comparable to the rate of refueling today's gasoline vehicles.

Using currently available high-pressure tank storage technology, placing a sufficient quantity of hydrogen onboard a vehicle to provide a 300-mile driving range would require a very large tank — larger than the trunk of a typical automobile. Aside from the loss of cargo space, there would also be the added weight of the tank(s), which could reduce fuel economy. Low-cost materials and components for hydrogen storage systems are needed, along with low-cost, high-volume manufacturing methods for those materials and components.

Research Directions

Reducing our dependence on foreign oil for transportation is a key driver for using hydrogen as a form of energy. Hydrogen storage research, therefore, is focused primarily on technologies and systems used onboard a vehicle. Scientists in government, industry, and academia are working to improve the weight, volume, and cost of current hydrogen storage systems, as well as identify and develop new technologies that can achieve similar performance, at a similar cost, as gasoline fuel storage systems.

Compressed gas and liquid hydrogen tanks

Traditional compressed hydrogen gas tanks are much larger and heavier than what is ultimately desired for light-duty vehicles. Researchers are evaluating light-weight, safe, composite materials that can reduce the weight and volume of compressed gas storage systems.

Liquefied hydrogen is denser than gaseous hydrogen and thus it contains more energy in a given volume. Similar sized liquid hydrogen tanks can store more hydrogen than compressed gas tanks, but it takes energy to liquefy hydrogen. However, the tank insulation required to prevent hydrogen loss adds to the weight, volume, and costs of liquid hydrogen tanks. Researchers are also studying a hybrid tank concept that can store high-pressure hydrogen gas under cryogenic conditions (cooled to around -120 to -196°C) — these "cryo-compressed" tanks may allow relatively lighter weight, more compact storage.

Gasoline tanks used in cars and trucks today are considered conformable and take maximum advantage of available vehicle space. Researchers are evaluating concepts for conformable high-pressure hydrogen tanks as an alternative to cylindrical tanks, which do not package well in a vehicle.

Materials-based storage

Hydrogen atoms or molecules bound tightly with other elements in a compound (or potential storage material) may make it possible to store larger quantities of hydrogen in smaller volumes at conditions that are within the practical operational boundaries of a polymer electrolyte membrane (PEM) fuel cell.

Scientists are investigating several different kinds of materials, including metal hydrides, adsorbent materials, and chemical hydrides, in addition to identifying new materials with potential for favorable hydrogen storage attributes.

Hydrogen storage in materials offers great promise, but additional research is required to better understand the mechanism of hydrogen storage in materials under practical operating conditions and to overcome critical challenges related to capacity, the uptake and release of hydrogen (i.e., kinetics), management of heat during refueling, cost, and life cycle impacts.

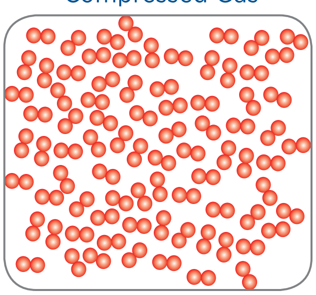
For More Information

More information on the Fuel Cell Technologies Program is available at *http://www.hydrogenandfuelcells.energy.gov*.

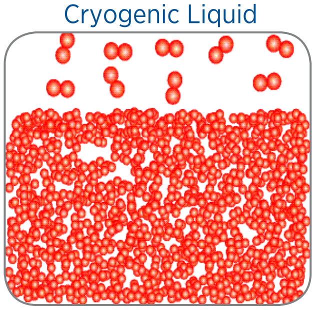
Hydrogen can be stored in different forms

In tanks...

Compressed Gas



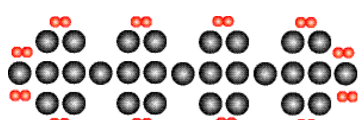
Cryogenic Liquid



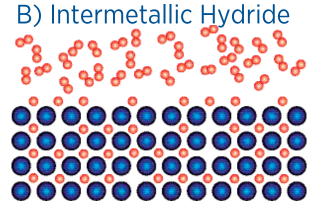
And in materials...

Hydrogen can be stored on the surfaces of solids (by adsorption) or within solids (by absorption). In adsorption (A), hydrogen attaches to the surface of a material either as hydrogen molecules (H_2) or hydrogen atoms (H). In absorption (B), hydrogen molecules dissociate into hydrogen atoms that are incorporated into the solid lattice framework – this method may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and at temperatures close to room temperature. Finally, hydrogen can be strongly bound within molecular structures, as chemical compounds containing hydrogen atoms (C, D). Density increases from A to D.

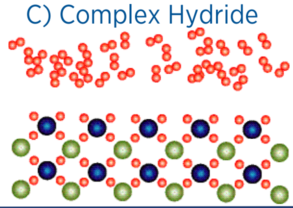
A) Surface Adsorption



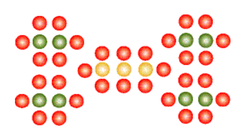
B) Intermetallic Hydride



C) Complex Hydride



D) Chemical Hydride



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