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Current Hydrogen Storage Difficulties and Possible Solutions

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Abstract. Using hydrogen as an energy source is becoming increasingly popular around the globe. Compared to other traditional energy sources, hydrogen can be effectively produced and utilized. However, the technology of hydrogen storage is difficult and constrains hydrogen power to be applied globally on a large scale. Hydrogen can be stored in the liquid phase, chemically kept and retained in either a covalent or an ionic compound, in gas cylinders, on materials with a large specific surface area, and in oxidation of reactive metals in water. However, each of the above-mentioned hydrogen storage methods has its own flaws and their technical difficulties. Aquifers, exhausted natural gas and oil reserves, and salt caverns are all examples of ways and methods to physically store hydrogen underground. These places are often places where large-scale hydrogen storage takes place. If the issue could be resolved, and the challenge of hydrogen storage be overcome, it would be a huge improvement to the entire humanity as hydrogen is a very promising future energy source.

1 Introduction

Coal, petroleum, nuclear biomass, solar thermal energy, natural gas, nuclear energy, and geothermal energy can produce fossil fuels and serve as some of the major energy sources predominantly used by governments and companies to produce electricity that is used by the public. However, there are limitations to all the current energy sources. For example, fossil fuels from coal, natural gas, and petroleum are extremely toxic to the environment. Emissions can cause serious health issues. 65 percent of the extra mortality rate is one of the serious effects that are caused by air pollution. In addition, emissions related to fossil fuels are responsible for 70% of the global cooling brought on by anthropogenic aerosols [1]. Renewable energies like solar energy and wind energy are highly dependent on the surrounding and their supply fluctuates. Hydrogen appears to be a more reliable source of energy. There are various ways to produce hydrogen. In the past, hydrogen was produced from sources like partial oxidation of hydrocarbons, coal gasification, and steam reforming of natural gas. These are all very conventional and traditional energy sources and have many limitations. For example, one disadvantage of these methods is that they emit a great amount of greenhouse gases like carbon monoxide, carbon dioxide, and methane into the atmosphere. Hydrogen can also be created using sustainable energy sources including hydropower, wind, and solar photovoltaic power for direct conversion. Both small-scale and large-scale electrolysis are viable, and the end product is pure [2]. It does not emit any carbon dioxide if the power source is renewable energy. Compared to other conventional energy sources, hydrogen is a lot greener and would produce less greenhouse gas into the atmosphere. Hydrogen's development and its wide application to the public have been confined because of various technical difficulties pertaining to its storage technique. This paper intends to investigate some of the current ways to store hydrogen and their limitations, and also address ways that might resolve the issues.

2 Storage

Traditionally, hydrogen could be stocked and kept in six ways (Figure 1). Hydrogen in the liquid phase is capable of being retained in cryogenic tanks. A host metal's interstitial sites can absorb hydrogens. Covalent and ionic substances both allow for the chemical bonding of hydrogens. It can be stored in high-pressure gas cylinders (Figure 2). Absorbed hydrogen can be stored on materials with a large specific surface area. Another way to store hydrogen is to store it in the oxidation of reactive metals like Lithium, Sodium, Magnesium, Aluminum, and Zinc in water [3]. Each storage method utilizes and employs different techniques to achieve the purpose of storing hydrogen. Yet each one of the conventional storage methods all has its own specific flaws, disadvantages, and limitations pertaining to various issues.

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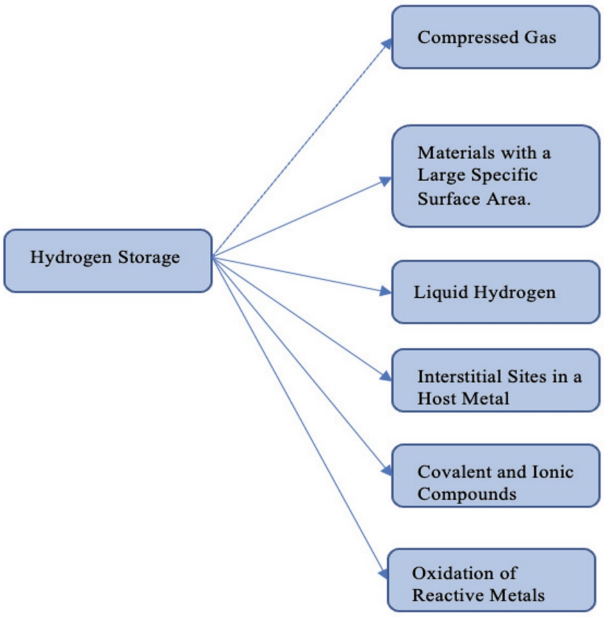

Fig. 1. Different Methods of Storing Hydrogen Traditionally (Picture credit: Original)

Because hydrogen has a boiling point of -252.8 °C (or 20.35 K) at one atmosphere of pressure, storage of hydrogen as a liquid in cryogenic tanks needs cryogenic temperatures [4]. Cryogenic temperature is characterized as being between -150 °C and -273 °C, which is the absolute zero. LH_2, the liquid phase of hydrogen, is highly volatile. Therefore, cryogenic tanks can address this issue perfectly. Due to gasoline evaporation after prolonged parking, evaporative losses that add up over short everyday drives, and evaporative losses after shorter periods of inactivity, cryogenic tanks can reduce the likelihood of becoming lost. Cryogenic tanks also have other potential safety benefits, such as dramatically reduced theoretical H_2 burst energy at low temperatures [5].

Solid metal-hydrogen compounds are the principal end product of the reactions that occur when hydrogens that are stored by being absorbed on interstitial sites in a host metal interact with metals, intermetallic compounds, and alloys. In particular, at high temperatures, hydrogen combines with other transition metals and their alloys to generate hydrides. They are also known as interstitial hydrides because they have a conventional metal-like lattice structure with hydrogen atoms in the interstices. The atoms of hydrogen can either fit into a tetrahedral, an octahedral, or a combination of the two types of holes in the metal lattice in this sort of structure; this also has the limiting composition of MH, MH_3, or MH_2. Depending on the metal, the hydrogen has a partial negative charge. Furthermore, the host lattice's incredibly high volumetric density of hydrogen atoms is another one of the metallic hydrides' most intriguing characteristics. $BaReH_9$ has a hydrogen-to-metal ratio of 4.5. However, this case is rare. Most often, the metallic hydrides can only absorb hydrogen up to a metal-to-hydrogen ratio of 2 (H/M=2), which is still significant enough [6]. Therefore, it is acceptable to say that metal hydrides are excellent for safely and compactly storing huge volumes of hydrogen.

Lithium, Magnesium, Boron, and Aluminum are just a few examples of group one, two, or three light elements that can form bonds with hydrogens that are chemically stored in covalent and ionic compounds. Since hydrogen atoms typically weigh little and fit two to a metal atom, this way to stock and keep hydrogen is efficient. The transformation of the metals to a covalent molecule and to an ionic molecule upon hydron absorption is the primary distinction between these complicated hydrides and the aforementioned metallic hydrides. At complex hydrides, hydrogen can be frequently found located at a tetrahedron's corners. with aluminum or boron in its center. The complicated hydrides are a brand-new hydrogen storage substance that is both fascinating and difficult [6].

At a specific temperature, hydrogen density rises as storage pressure rises. By increasing pressure, larger storage densities can be achieved when storing high-pressure gaseous hydrogen [7]. Pressure vessels come in four different varieties. However, they can also be polymorph or toroidal. The most typical shape for pressure vessels is a cylinder. Metal pressure vessels are under Type I. Pressure vessels that are named Type II have a substantial copper liner hoop that is covered with a fiber resin composite in the cylindrical portion. A carbon fiber-wrapped plastic or metal linin that is inserted in a polymer matrix makes up the total composite materials-based pressure vessels, referred to as composite overwrapped pressure vessel (COPV), an acronym for composite overwrapped pressure vessels. The COPV is named as type III when the liner adds to the mechanical opposition by greater than five percent. The COPV is type IV otherwise. The range of 25 MPa to 30 MPa is the most typical working pressure. 35 MP-70 MPa COPV were developed and approved for usage with hydrogen energy more recently [8].

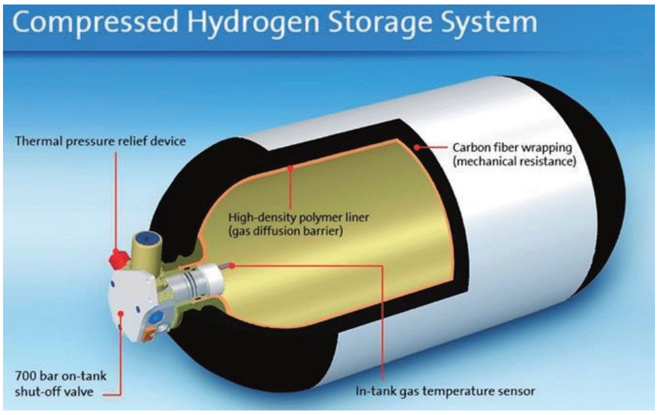

Fig. 2. A General Fuel Cell Car that contains a 700 Bar Tank [9].
Source link: https://leehamnews.com/2022/03/25/bjorns-corner-sustainable-air-transport-part-12-hydrogen-storage/

Hydrogen that has been absorbed can be retained on substances with large specific surface areas. Physisorption often only occurs at low temperatures because of the very weak forces that interact between the adsorbate and adsorbent. Since there is no energy barrier, the molecule approaching the surface cannot effectively enter the physisorption process. As a result, the process is not triggered, and physical adsorption is characterized by quick kinetics. At least in situations where cooling is not an issue, as high specific surface area materials seem to hold great promise pertaining to the storage and depot of hydrogen. Carbon nanostructures that have been activated and improved and exhibit a high micropore density make excellent candidates for hydrogen adsorption [10].

Last but not least, the oxidation of reactive metals can store hydrogen. This process converts sodium into sodium hydroxide. Sodium hydroxide may eventually be extracted and converted back into metallic sodium in a solar furnace, even if the process is not immediately reversible. Two sodium atoms and two water molecules combine to form one hydrogen molecule. The water molecule that is produced when the hydrogen molecule burns is capable to be recyclable to produce new hydrogen gas. But the oxidation of the two sodium atoms requires the inclusion of the second water molecule [6].

3 Limitations and Challenges

However, all of the six current methods discussed above have limitations. Hydrogen has a density of 0.09 kg/NA m^3 when it is a hydrogen gas: this is an extremely low density. It also has a boiling point of 20.2 K at its gaseous state, this is a low boiling point. However, the density of hydrogen in its liquid state is very high at roughly 70.9 kg/NA m^3, which is nearly 800 times more than hydrogen in its regular gaseous state. These characteristics together make hydrogen storage quite challenging [3].

A liquid level sensor must be integrated into a cryogenic pressure vessel for subcritical LH_2 storage, and the process of storage presents two-phase issues of comparable size to those in a standard liquid hydrogen storage system (evaporation at overheated tank walls, two-phase stratification, thermo-acoustic oscillations, protracted and unproductive warm refueling, etc.). This limits the pressure supply to a few atmospheres while still requiring subcritical LH_2 to be stored at low pressures [5]. In addition, turning hydrogen into its liquid phase can request as much as 40 percent of its actual, authentic energy content, which again reiterates the fact that liquid hydrogen stored in a cryogenic vessel is not a very effective way to store hydrogen [6].

Transition metals make up every reversible metal hydride that operates at standard temperature and pressure. Exploring the characteristics of the light metal hydrides is still difficult because hydrogen's gravimetric density is constrained to less than three of its mass percent [6].

The main difficulty in producing metal in a solar furnace with chemically bonded hydrogen is the controllability and reversibility of the heat reduction process. Zinc has been used to successfully demonstrate the procedure. Scientists have theorized this process with zinc. ZnO (s) dissociates into Zn (g) and O_2 around 2,300 K in the first endothermic stage, which uses concentrated solar radiation as the process heat source. At 700 K, liquid zinc is hydrolyzed to produce H_2 and solid ZnO, the latter of which separates and is then recycled back to the first step in the second non-solar exothermic process. Furthermore, since the majority of complex hydrides do not exist as intermetallic complexes when the hydrogen is withdrawn, although stability, sorption kinetics, and reversibility are hardly acquired and rarely studied [6].

Between 5% and 20% of the lower heating value is needed to compress hydrogen up to 35 MPa and 70 MPa. Additionally, compressed hydrogen is frequently kept at room temperature while liquid hydrogen must be kept in vacuum-insulated tanks to maintain a standard temperature of 253 ˚C [7]. The storage option is determined by the final application, which demands a compromise between technical performance and economics. As mentioned above, in bulk storage inefficient metallic type I cylinders (storing only approximately 1 weight percent of hydrogen), hydrogen is stored at pressures between 20 and 30 MPa for industrial purposes. This is substantially below the targets set for hydrogen energy applications [8]. Neither one of the four types of vessels will fully satisfy. Safety issues pertaining to gaseous hydrogen storage are also concerning. Some of the potential risks of high-pressure gaseous hydrogen include hydrogen embrittlement, commonly referred to by the abbreviation HE, vessel explosion, gas leakage, temperature rise during fast filling [7].

Similarly, absorbed hydrogen stored a huge specific surface area of materials and the oxidation of reactive metals like lithium, sodium, magnesium, aluminum, and zinc in water are also having analogous problems that are involved in energy efficiency, safety, cost, etc.

4 Solutions

As a result, more people are turning toward underground storage like aquifers, depleted deposits of natural gas and oil, and salt caverns for large-scale hydrogen storage in the long term because of its high capacity and low cost (Figure 3). Despite the fact that every underground storage location has a different set of characteristics, all underground storage locations have a few common problems. Any underground location chosen for storage must satisfy the fundamental prerequisite of having enough trapping capacity. The features of the stored gas have a big impact on both the capacity for trapping and storage operation success. For instance, CO_2 may be stored in subterranean storage facilities in greater amounts than hydrogen due to its density, compressibility, and solubility [11].

Using aquifers to store hydrogen has specific characteristics. They are porous and permeable structures so that it allows fresh and salt water to pass through their pore spaces within the structure. Aquifers are a viable alternative for subterranean hydrogen storage since they are widespread around the earth. An impermeable layer must be present in order to stop the gas being stored from migrating, and the aquifer itself must have good reservoir properties of the host rock. When hydrogen is poured into an aquifer that is filled with water, the liquid will flow downhill or to the sides because gas and liquid have different densities. In this case, the same volume of hydrogen is added while no liquid is removed, thus increasing the porous media's pressure and modifying the point where liquid and gas meet during the injection. However, a drawback of hydrogen in aquifers is that when it is about to be removed, the liquid and gas can both be created concurrently due to the movement of when the gas and liquid meet together [11].

In massive subsurface salt deposits, salt caverns are primarily cylindrical, man-made holes that are constructed from the surface by carefully injecting water into a well in the salt rock. The salt caverns are a suitable choice for hydrogen storage due to the unique geological circumstances, such as tightness, the advantageous mechanical qualities of salt, and its impedance to chemical processes. The capacity of salt caves is the only constraint. The storage capacity is impacted by the caves' depth. More pressure and compressed gas result from a cavern's greater depth, and vice versa [11]. However, that limitation would not pose many difficulties as salt caverns can be easily made artificially.

Depleted oil and gas reservoirs contain geological formations that are easily recognized, have good caprock tightness and integrity, and already have the essential surface and subsurface infrastructure in place. Depleted gas reserves are well described, and nearly all of the formation's data is available. Additionally, it has been demonstrated that the caprocks of depleted gas reservoirs are tight. Even though the presence of leftover gas in a depleted gas reservoir is seen to be advantageous since it can serve as cushion gas, it can occasionally also be seen as a drawback when it can lower the hydrogen's purity [11].

As of 2021, 75% of underground hydrogen storage in the world is in depleted deposits. In recent years, because of their stability and imperviousness of their walls, salt caverns have seen great interest in storing hydrogen gas owing to their stability [12].

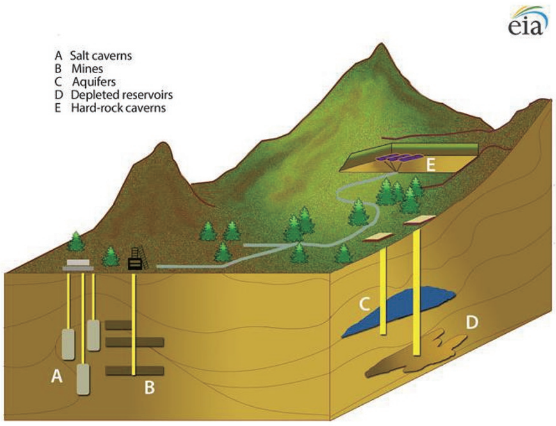

Fig. 3. Types of Underground Natural Gas Storage Facilities [13].

Source link: https://www.eia.gov/naturalgas/storage/basics/

5 Conclusion

In conclusion, this research paper talked about some of the current ways in which hydrogen can be stored, including in the liquid phase, chemically bonded in covalent and ionic compounds, in gas cylinders, on materials with a large specific surface area, and in the oxidation of reactive metals in water. This paper also discussed the corresponding flaws and technical difficulties of each of the current hydrogen storage methods mentioned above, which have imposed tremendous barriers in attempts to apply hydrogen as an energy source on a large scale. As discussed earlier, underground storage is a relatively new way of storing hydrogen and has demonstrated itself to be a promising hydrogen storage method as it could eliminate or circumvent issues that predominantly exist in other traditional and conventional ways to store hydrogen. If more research will be conducted and more effort specifically focused on underground hydrogen will be put in, it is certain that underground hydrogen storage will become the leading way to store hydrogen, and there exists a very positive future prospect to achieve net zero.

References

1. J. Lelievel, K. Klingmüller, A. Pozzer, PNAS, **116** (2019)
2. R. Kothari, D. Buddhi, R.L. Sawhney, Renewable and Sustainable Energy Reviews, **12**, 553-563 (2008)
3. S. Hosseini, B. Butler, International Journal of Green Energy, **17**, 13-37 (2020)
4. Office of Energy Efficiency and Renewable Energy www.energy.gov/eere/fuelcells/hydrogen-storage.
5. S. Aceves, F. Espinosa-Loza, E. Ledesma-Orozco, et al., International Journal of Hydrogen Energy, **35**, 1219-1226 (2010)
6. A. Züttel, Naturwissenschaften, **91**, 157-172 (2004)
7. J. Zheng, X. Liu, P. Xu, et al., International Journal of Hydrogen Energy, **37**, 1048-1057 (2012)
8. H. Barthelemy, M. Weber, F. Barbier, International Journal of Hydrogen Energy, **42**, 7254-7262 (2017)
9. B. Fehrm, Bjorn's Corner: Sustainable Air Transport. Part 12. Hydrogen Storage, Released March 25, 2022, Accessed May 12, 2023 https://leehamnews.com/2022/03/25/bjorns-corner-sustainable-air-transport-part-12-hydrogen-storage/
10. M. Hirscher, B. Panella, Journal of Alloys and Compounds, **404-406**, 399-401 (2005)
11. D. Zivar, S. Kumar, J. Foroozesh, International Journal of Hydrogen Energy, **46**, 23436-23462 (2020)

12. M. Yue, H. Lambert, E. Pahon, et al., Renewable and Sustainable Energy Reviews, **146** (2021)
13. U.S. Energy Information Administration, The Basics of Underground Natural Gas Storage, released November 16, 2005, accessed May 12, 2023, https://www.eia.gov/naturalgas/storage/basics/