HYDROGEN FACT SHEET

The Basics of Hydrogen

H_2

Introduction

From the Greek words "hydro" and "genes" meaning "water" and "generator"

Hydrogen, in vast quantities, has been used as an industrial chemical and rocket propellant for more than 50 years. During that time, a very robust infrastructure developed and hydrogen has been produced, stored, transported, and utilized with an understanding and respect for its physical properties. Hydrogen is the building block of all other elements, consisting of one proton and one electron, and it reacts easily with other elements to form compounds like water (H_2O), "hydro-carbon" fuels (oil, natural gas, coal), and others. The hydrogen economy that many envision as the next major energy transition would employ the diatomic form of the hydrogen molecule "H_2" as an energy carrier and transportation fuel.

Hydrogen's physical properties and characteristics define its suitability as an energy carrier. The same properties and characteristics that make hydrogen an ideal energy carrier and fuel also make it a safety concern. However, industry has demonstrated that hydrogen can be used safely in a wide variety of applications and conditions by employing proper safety controls. In fact, hydrogen is no more or no less dangerous than other fuels. And, in a manner similar to that used for the introduction of other fuels, codes and standards, necessary safety, and handling procedures will be developed and implemented as needed to ensure public safety.

Some Common Properties

Under most conditions, hydrogen is a colorless, odorless, tasteless, and nontoxic gas. Hydrogen undergoes phase change to a liquid state at -423°F (20.26°K or -252.89°C). Hydrogen is the lightest of the elements, with a very low density per unit volume that is approximately 14 times less than air. Hydrogen is very buoyant, as well as highly diffusive in the surrounding air. This allows hydrogen to dissipate rapidly in open areas and migrate through very small spaces. These properties make it difficult to efficiently store hydrogen. It also enables hydrogen atoms to penetrate the molecular structure of some metals (making the metal "brittle"), especially in cases where physical stresses from extreme temperatures or elevated pressures exist, causing a phenomenon known as hydrogen embrittlement.

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Hydrogen Safety Considerations

The safety considerations associated with handling hydrogen include:

FIRE

Fire requires three ingredients: fuel, an oxidizer (i.e., oxygen or other substance capable of supporting combustion), and a source of ignition. Hydrogen can be easily ignited in air by heat, open flames, electrical sparks, and static electricity. Hydrogen flames are invisible to the naked eye.

EXPLOSION

A fire becomes an explosion if the combustion is sufficiently rapid to cause pressure waves. Hydrogen has the highest energy content per unit mass. Its presence (with concentrations of about 4-74%) can result in ignition. Explosions often result when hydrogen is ignited in enclosed spaces.

ASPHYXIATION

Hydrogen leaked into enclosed spaces can dilute the concentration of oxygen in air below levels necessary to support life.

TISSUE DAMAGE

Liquid hydrogen (LH_2) is extremely cold, –423ºF. Contact with the LH_2 or its cold vapors can cause extensive tissue damage.

The combustion properties of hydrogen position it as a capable fuel and energy carrier. Its energy content per unit mass is about three times that of gasoline. Its high heating value, which is defined as the amount of energy released when a fuel is burned completely, is almost three times higher than that of gasoline. Hydrogen ignites across a wide range of concentrations, from about 4 to 74 percent, and only requires a small amount of energy to initiate ignition. When hydrogen reacts with oxygen in either a combustion or electrochemical conversion process to generate energy, the resulting reaction product is water vapor.

Because of hydrogen's properties and characteristics, the immediate dangers associated with hydrogen leaks are fire, explosion, and asphyxiation. Hydrogen, in the presence of air, is easily ignited by sources of heat, open flames, electrical sparks, and static electric discharge. Most hydrogen fires have the flame characteristic of a torch or jet originating at the point of hydrogen discharge. Hydrogen flames burn hot, result in little radiant heat, and are invisible to the naked eye. This can be problematic as the flames are difficult to detect and can be stumbled upon without warning.

The explosive risks of hydrogen are significant. Blast energy from hydrogen explosions are typically less than those resulting from an equivalent energy content from other fuels because of the combined effects of the fuel properties. A fire becomes an explosion if the combustion is sufficiently rapid to cause pressure waves, which in turn produce sound waves. Hydrogen fires in confined spaces often result in explosions, which can cause significant damage.

Hydrogen gas is odorless and nontoxic but may induce suffocation by diluting the concentration of oxygen in air below levels necessary to support life. While the risk of asphyxiation does exist, it is very unlikely. The amount of hydrogen gas necessary to produce oxygen-deficient atmospheres is well within the flammable range; thus fire and explosion are the primary hazards associated with hydrogen and air atmospheres. Liquid hydrogen presents an additional hazard because of its extremely cold temperature.

Hydrogen Safety and the Public's Perception

The perception of "hydrogen" has been incorrectly shaped by vividly haunting images of three well-publicized events, namely the 1937 Hindenburg Airship disaster, the development and proliferation of nuclear weapons, specifically the hydrogen bomb, and the 1986 Space Shuttle Challenger accident.

In the case of the Hindenburg, hydrogen was the buoyancy gas used to provide lift to the airship. It is true that the gas did ignite and burn; it did so quickly, upwardly, and away from the people below.

Hydrogen did not cause the Hindenburg to explode. The explosion was later attributed to a weather-related static electric discharge, which ignited the airship's silver-colored, canvas exterior covering. Forensic research has revealed that the exterior covering was treated with two materials that years after the Hindenburg accident became key ingredients of solid rocket fuel. All the passengers that rode the airship down to the ground survived. Thirty-five of the thirty-seven casualties resulted from people jumping to the ground.

The hydrogen bomb uses hydrogen in the form of Tritium, a hydrogen atom with three neutrons in the nucleus, and the heat and nuclear reactions from the detonation of a nuclear fission bomb, to induce a nuclear fusion reaction. Nuclear fusion is the same process by which the sun generates its energy. These nuclear reactions require enormously high temperatures and pressures, and are in no way similar to the simple chemical reactions associated with hydrogen (H_2) production, storage, distribution, and use.

The Government Commission that investigated the 1986 Challenger accident concluded that the accident was not caused by hydrogen. While the Shuttle did have hydrogen on-board as a fuel for its main rocket engines, the primary cause of the explosion was leaking hot plasma from one of its two solid-fueled booster rockets.

Fuel leak simulation: photo on top shows hydrogen leak and gasoline leak after 3 seconds, respectively. Photo on bottom shows hydrogen leak and gasoline leak after one minute. As can be noted, the hydrogen gas burns off away from the vehicle and much more quickly.

Comparing Hydrogen to other Fuels:

The table below provides a comparison of various fuel properties and characteristics for hydrogen, natural gas, gasoline, and propane.

Table 1. Properties of Hydrogen, Natural Gas, Gasoline, and Propane

	Hydrogen	Natural Gas	Gasoline	Propane
Lower heating value[1]	51,532 BTU/lb	21,300 BTU/lb	18,000–19,000 BTU/lb	19,800 BTU/lb
Density at standard conditions	0.0007 lbs/gal [a]	0.005 lbs/gal [a]	6.0–6.5 lbs/gal [a]	4.22 lbs/gal
Phase at standard conditions	Gas	Gas	Liquid	Liquid
Autoignition temperature in air	1,050–1,080°F	1,004°F	495°F	850–950°F
Volume concentrations for flammability in air	4.1% – 74%	5.3% – 15%	1.4% – 7.6%	2.2% – 9.5%
Diffusion coefficient[2] in air	0.0946 in^2/sec [b]	0.0248 in^2/sec [b]	0.008 in^2/sec [b]	0.017 in^2/sec [c]
Toxicity to humans	Non-toxic, simple asphyxiant	Non-toxic, simple asphyxiant	Poisonous, carcinogenic. Irritant to lungs, stomach and skin	Non-toxic, simple asphyxiant

Sources: *All values are from DOE Alternative Fuels Data Center, except as follows:*

a) *Clean Air Program: Design Guidelines For Bus Transit Systems Using Hydrogen As an Alternative Fuel.* U.S. Department of Transportation. DOT-VNTSC-FTA-98-6, 1998. Table 2.1.

b) *Hydrogen Energy System: A Permanent Solution to Global Problems.* T. Nejat Veziroglu. University of Miami. Coral Gables, FL.

c) *Guidelines on Remediation of Contaminated Sites.* Appendix 5.5, "Physical and Chemical Data."

1. Heating Value is defined as the amount of energy released when a fuel is burned completely in a steady-flow process and the products are returned to the state of the reactants. Higher heating value (HHV) is used when all water formed by combustion is in liquid form. Lower heating value (LHV) is used when all water formed from combustion is in vapor form. Since no vehicles in use, or currently being developed for future use, have power plants capable of condensing the moisture of combustion, the LHV is used for practical comparisons between fuels. (www.taftan.com/thermodynamics/HVALUE.HTM).

2. Describes the rate of diffusion of particles, depending on the particle size, viscosity and temperature (www.dataphysics.de/english/service_gloss.htm)

Interested in Learning More?

U.S. Department of Energy
www.eere.energy.gov/hydrogenandfuelcells

National Hydrogen Association
www.hydrogenassociation.org

U.S. Fuel Cell Council
www.usfcc.com

International Partnership for the Hydrogen Economy (IPHE)
www.iphe.net

Considering Hydrogen as an Energy Carrier and Fuel

In considering hydrogen as an energy carrier and fuel, it is important to compare hydrogen to other fuels. Hydrogen has numerous advantages over other fuels in terms of safety. In some respects, these properties also mean that hydrogen fires can be safer than fires involving conventional fuels. Hydrogen has a very high flame speed and dissipates quickly, so fires, even those involving liquid hydrogen, will burn out rapidly. In addition, other materials near the flame are unlikely to catch fire themselves, reducing the danger of toxic smoke emissions and prolonged burning.

Sources:

For safetygrams:
www.airproducts.com/responsibility/ehs/productsafety/productsafetyinformation/safetygrams.htm

For information on the development of safety, codes, and standards for hydrogen:
www.fuelcellstandards.com and www.hydrogensafety.info

For product safety information:
www.airproducts.com/responsibility/ehs/productsafety/productsafetyinformation

- Compressed Gas Association (CGA) www.cganet.com
- European Industrial Gas Association (EIGA) www.eiga.org
- Japanese Industrial Gas Association (JIGA) www.jiga.gr.jp/english
- American Chemistry Council www.americanchemistry.com

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