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hydrogen SAFETY

Hydrogen: Similar but Different

For over 40 years, industry has used hydrogen in vast quantities as an industrial chemical and fuel for space exploration. During that time, industry has developed an infrastructure to produce, store, transport and utilize hydrogen safely.

> "Hydrogen safety concerns are not cause for alarm; they simply are different than those we are accustomed to with gasoline or natural gas."
>
> –Air Products and Chemicals, Inc.

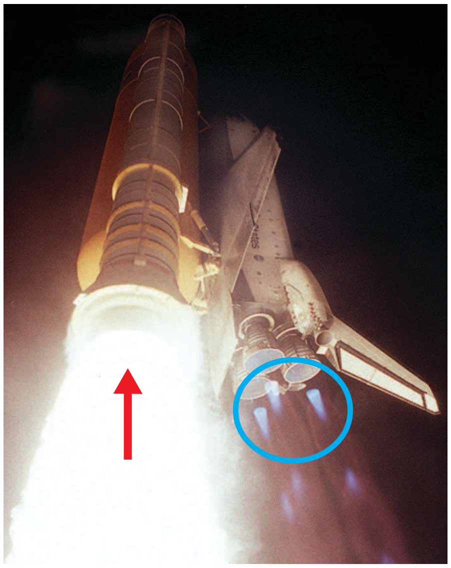
Hydrogen is no more or less dangerous than other flammable fuels, including gasoline and natural gas. In fact, some of hydrogen's differences actually provide safety benefits compared to gasoline or other fuels. However, all flammable fuels must be handled responsibly. Like gasoline and natural gas, hydrogen is flammable and can behave dangerously under specific conditions. Hydrogen can be handled safely when simple guidelines are observed and the user has an understanding of its behavior.

The following lists some of the most notable differences:

Hydrogen is lighter than air and diffuses rapidly. Hydrogen has a rapid diffusivity (3.8 times faster than natural gas), which means that when released, it dilutes quickly into a non-flammable concentration. Hydrogen rises 2 times faster than helium and 6 times faster than natural gas at a speed of almost 45 mph (20m/s). Therefore, unless a roof, a poorly ventilated room or some other structure contains the rising gas, the laws of physics prevent hydrogen from lingering near a leak (or near people using hydrogen-fueled equipment). Simply stated, to become a fire hazard, hydrogen must first be confined – but as the lightest element in the universe, confining hydrogen is very difficult. Industry takes these properties into account when designing structures where hydrogen will be used. The designs help hydrogen escape up and away from the user in case of an unexpected release.

Hydrogen is odorless, colorless and tasteless, so most human senses won't help to detect a leak. However, given hydrogen's tendency to rise quickly, a hydrogen leak indoors would briefly collect on the ceiling and eventually move towards the corners and away from where any nose might detect it. For that and other reasons, industry often uses hydrogen sensors to help detect hydrogen leaks and has maintained a high safety record using them for decades. By comparison, natural gas is also odorless, colorless and tasteless, but industry adds a sulfur-containing odorant, called mercaptan, to make it detectable by people. Currently, all known odorants contaminate fuel cells (a popular application for hydrogen). Researchers are investigating other methods that might be used for hydrogen detection: tracers, new odorant technology, advanced sensors and others.

Hydrogen flames have low radiant heat. Hydrogen combustion primarily produces heat and water. Due to the absence of carbon and the presence of heat-absorbing water vapor created when hydrogen burns, a hydrogen fire has significantly less radiant heat compared to a hydrocarbon fire. Since the flame emits low levels of heat near the flame (the flame itself is just as hot), the risk of secondary fires is lower. This fact has a significant impact for the public and rescue workers.



Hydrocarbon flames (left, red arrow) vs. hydrogen flames (right, blue circle)

Combustion

Like any flammable fuel, hydrogen can combust. But hydrogen's buoyancy, diffusivity and small molecular size make it difficult to contain and create a combustible situation. In order for a hydrogen fire to occur, an adequate concentration of hydrogen, the presence of an ignition source and the right amount of oxidizer (like oxygen) must be present at the same time. Hydrogen has a wide flammability range (4-74% in air) and the energy required to ignite hydrogen (0.02mJ) can

Figure 1: Fuel Comparisons

	Hydrogen	Gasoline Vapor	Natural Gas
Flammability Limits (in air)	4-74%	1.4-7.6%	5.3-15%
Explosion Limits (in air)	18.3-59.0%	1.1-3.3%	5.7-14%
Ignition Energy (mJ)	0.02	0.20	0.29
Flame Temp. in air (°C)	2045	2197	1875
Stoichiometric Mixture (most easily ignited in air)	29%	2%	9%

be very low. However, at low concentrations (below 10%) the energy required to ignite hydrogen is high--similar to the energy required to ignite natural gas and gasoline in their respective flammability ranges--making hydrogen realistically more difficult to ignite near the lower flammability limit. On the other hand, if conditions exist where the hydrogen concentration increased toward the stoichiometric (most easily ignited) mixture of 29% hydrogen (in air), the ignition energy drops to about one fifteenth of that required to ignite natural gas (or one tenth for gasoline). See Figure 1 (page 1) for more comparisons.

Hydrogen car (l), gasoline car (r). Photo from a video that compares fires from an intentionally ignited hydrogen tank release to a small gasoline fuel line leak. At the time of this photo (60 seconds after ignition), the hydrogen flame has begun to subside, while the gasoline fire is intensifying. After 100 seconds, all of the hydrogen was gone and the car's interior was undamaged. (The maximum temperature inside the back window was only 67°F!) The gasoline car continued to burn for several minutes and was completely destroyed. Photo/Text: Dr. Swain, University of Miami.

Hydrogen Economy ≠ Hydrogen Bomb

The hydrogen economy uses the most common type of hydrogen: the isotope, Protium. Hydrogen bomb technology uses a rare hydrogen isotope called Tritium. Both Tritium plus the super-intense heat from the detonation of a nuclear fission bomb are needed to induce the nuclear fusion reaction that makes a hydrogen bomb. Tritium is radioactive and does not occur naturally, but can be made with lithium or a conventional nuclear reactor. This technology bears no resemblance to the simple chemical reactions associated with the Protium hydrogen isotope in hydrogen production, storage, distribution and use in the hydrogen economy.

Explosion

An explosion cannot occur in a tank or any contained location that contains only hydrogen. An oxidizer, such as oxygen must be present in a concentration of at least 10% pure oxygen or 41% air. Hydrogen can be explosive at concentrations of 18.3-59% and although the range is wide, it is important to remember that gasoline can present a more dangerous potential than hydrogen since the potential for explosion occurs with gasoline at much lower concentrations, 1.1-3.3%. Furthermore, there is very little likelihood that hydrogen will explode in open air, due to its tendency to rise quickly. This is the opposite of what we find for heavier gases such as propane or gasoline fumes, which hover near the ground, creating a greater danger for explosion.

Asphyxiation

With the exception of oxygen, any gas can cause asphyxiation. In most scenarios, hydrogen's buoyancy and diffusivity make hydrogen unlikely to be confined where asphyxiation might occur.

Toxicity/poison

Hydrogen is non-toxic and non-poisonous. It will not contaminate groundwater (it's a gas under normal atmospheric conditions), nor will a release of hydrogen contribute to atmospheric pollution. Hydrogen does not create "fumes."

Cryogenic burns

Any cryogenic liquid (hydrogen becomes a liquid below -423°F) can cause severe freeze burns if the liquid comes into contact with the skin. However, to keep hydrogen ultra-cold today, liquid hydrogen containers are double-walled, vacuum-jacketed, super-insulated containers that are designed to vent hydrogen safely in gaseous form if a breach of either the outer or inner wall is detected. This robust construction and redundant safety features dramatically reduce the likelihood for human contact.

"Don't paint your airship with rocket fuel!"

The fire that destroyed the *Hindenburg* in 1937 gave hydrogen a misleading reputation. Hydrogen was used to keep the airship buoyant and was initially blamed for the disaster. An investigation by Addison Bain in the 1990s provided evidence that the airship's fabric envelope was coated with reactive chemicals, similar to solid rocket fuel, and was easily ignitable by an electrical discharge. The Zeppelin Company, builder of the *Hindenburg*, has since confirmed that the flammable, doped outer cover is to be blamed for the fire. For more information, view a short video at: www.HydrogenAssociation.org.

Hydrogen Codes and Standards

Codes and standards help dictate safe building and installation practices. Today, hydrogen components must follow strict guidelines and undergo third party testing for safety and structural integrity. For more information on hydrogen safety, codes and standards, please visit the following websites:

www.HydrogenSafety.info
www.fuelcellstandards.com
www.eere.energy.gov/hydrogenandfuelcells/codes.

Summary

Industry has developed new safety designs and equipment because hydrogen's properties and behavior are different than the fuels we use now. Hydrogen will make us re-think operating practices already in place for gaseous and liquid fuels. Education of those differences is the key enabler to making hydrogen a consumer-handled fuel that we use safely and responsibly.